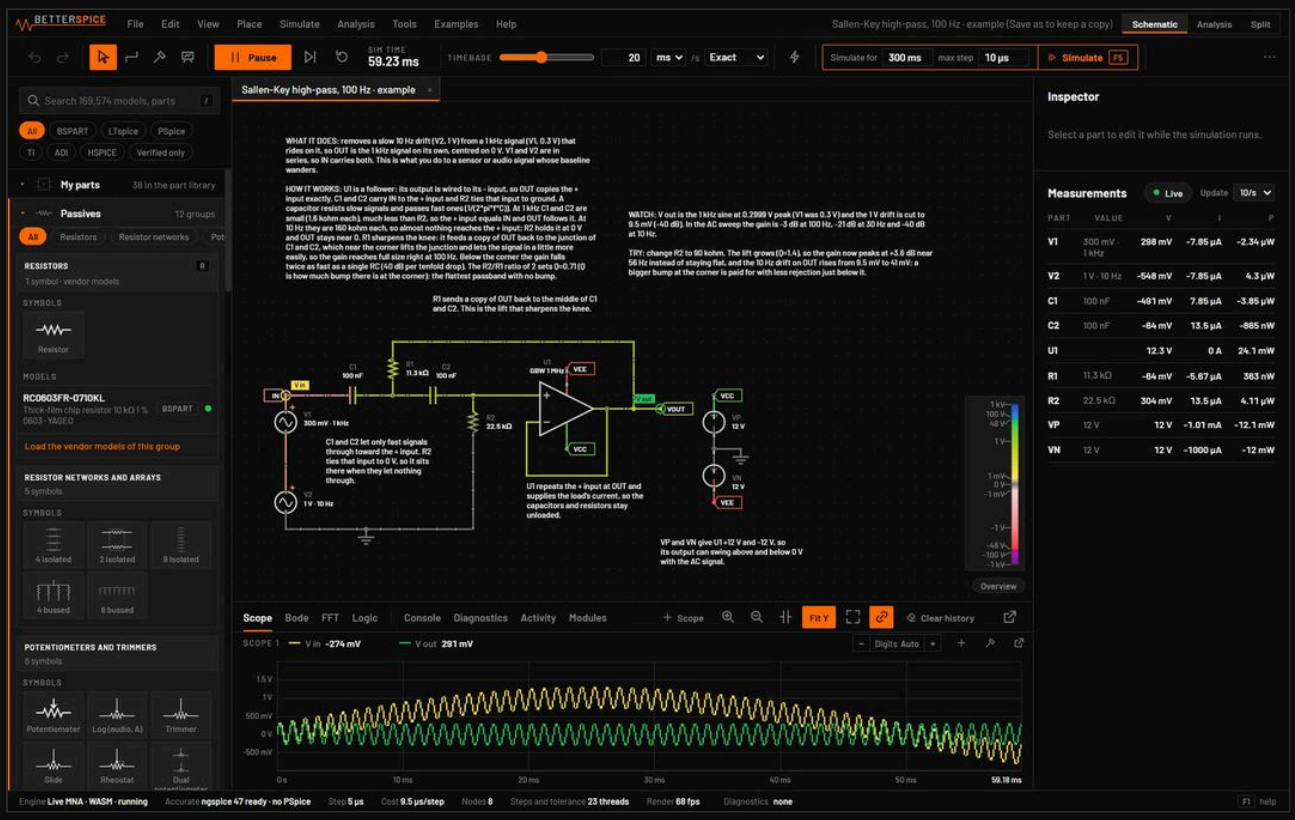
BETTERSPICE

LIVE CIRCUIT SIMULATOR



User manual

Version 0.8.1 · 17 November 2026

Windows desktop app and browser

Start here

Pick the line that sounds like you. Each one is a link.

NEW TO BETTERSPICE

I want to see it work

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SOMETHING IS WRONG

It stopped, reads 0 V or looks wrong

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CURIOUS

I want to understand why

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→ **When to trust which result**, p. 34
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Search

Press Ctrl + F in your PDF viewer. The **glossary**, p. 108 and the **task index**, p. 41 list the words other simulators use too.

Read the signs

Labels on screen are in **bold**. Keys look like Ctrl + S. Menu paths look like **File** › **Save as**. What you type looks like **4k7**.

Ask the app

? lists every shortcut. Ctrl + K finds any command or part. E opens 715 example circuits that run as they open.

Quick start

Open a filter that's already built, change one value while it runs, and read its frequency response. You need BetterSPICE installed (**Install and start**, p. 9) and nothing else.

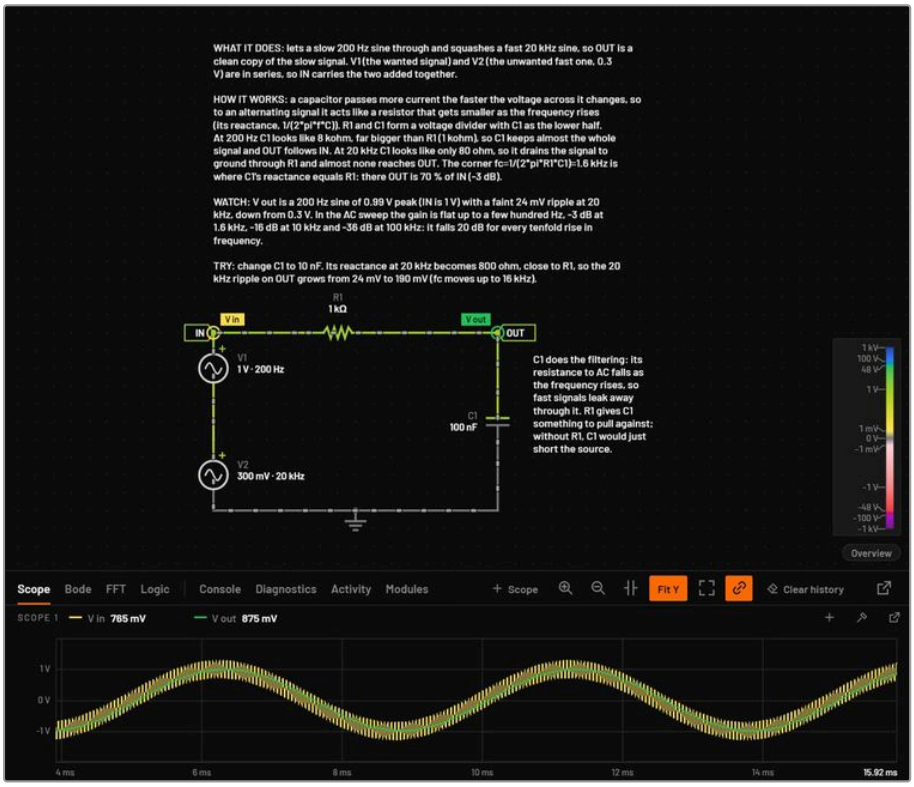


Figure 1 The example **RC low-pass, 1.6 kHz** running: the circuit on the canvas, V in and V out on the scope below it. The library is to the left of the canvas and the inspector to the right.

Open a running circuit

1 Start BetterSPICE from the Start menu.

YOU SHOULD SEE A demonstration circuit opens, named **Rectifier and LDO · example**. The wires are coloured and dots move along them: the circuit is already running.

2 Press E.

YOU SHOULD SEE The example browser opens.

3 Type **rc low**, select **RC low-pass, 1.6 kHz** and press Enter.

YOU SHOULD SEE A new tab named **RC low-pass, 1.6 kHz · example** opens. The scope at the bottom shows two traces: **V in**, a 200 Hz sine with a fast 20 kHz ripple on it, and **V out**, the same slow sine with almost none of the ripple.

IF YOU SEE **paused in the status bar,** press Ctrl + R.

Change a value while it runs

1. Click the capacitor **C1**.

   YOU SHOULD SEE The inspector on the right shows C1 with **Capacitance** 100 nF and a slider under it.

2. Drag the **Capacitance** slider to the right.

   YOU SHOULD SEE V out gets smaller and later, and the last of the ripple disappears. The circuit never stops: the change applies at once.

3. Press Ctrl + Z.

   YOU SHOULD SEE Capacitance is back to 100 nF. The whole drag was one undo step.

Read the frequency response

1. Press F7.

   YOU SHOULD SEE The example already has an AC setup (V1, 1 Hz to 1 MHz), so the sweep runs at once. The window splits: the schematic on top, the Analysis view below with the Bode plot, flat, then falling 20 dB per decade. The strip above the plot reads **–3 dB at 1.59 kHz**, which is 1 / (2π × 1 kΩ × 100 nF).

   IF YOU SEE **the Simulation setup dialog instead,** the circuit has no AC setup yet. Click **Run AC sweep** in it: the setup is saved, and F7 runs it from then on.

2. Press Ctrl + 1.

   YOU SHOULD SEE The schematic fills the window again, still running.

TIP **Where next.** Draw a circuit of your own in Tutorial 1: Draw an RC filter and watch it run, p. 12. Look up a job in the task index, p. 41. If a step didn't work, go to Troubleshooting by symptom, p. 78.

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PART

I

Learn

Install, a guided first circuit in two parts, a vendor model, a part of your own, and how BetterSPICE thinks. Read it in order once.

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01 Install and start

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BetterSPICE installs in one step and opens on a circuit that's already running. ngspice comes with the installer, so you need nothing else for the tutorials.

01.1 Install the desktop app

1 Run **BetterSPICE_<version>_x64-setup.exe**. You don't need administrator rights.

YOU SHOULD SEE The installer finishes without questions. It installs for your user account, adds BetterSPICE to the Start menu, adds the Microsoft WebView2 runtime if Windows lacks it, and registers the file types **.bsc** (circuit), **.bspart** (part) and **.bssym** (symbol).

2 Start BetterSPICE from the Start menu.

YOU SHOULD SEE A bridge rectifier feeding an LDO opens, already running. The status bar at the bottom says **ngspice 47 ready**.

IF YOU SEE **ngspice not found,** the tutorials still work. Only circuits with vendor models need ngspice. **ngspice for vendor models**, p. 675 says where BetterSPICE looks for it.

Double-click any **.bsc** file in Explorer to open it. If BetterSPICE is already open, the file opens in a new tab of the same window. Double-click a **.bspart** or **.bssym** file to add that part or symbol to **My parts**.

01.2 Optional: PSpice for TI

You need this only for Texas Instruments models that Cadence has encrypted. Install the free PSpice for TI from ti.com into its default folder (**C:\Cadence\PSpiceTI**). BetterSPICE finds it and runs those models in it, hidden. **PSpice for encrypted models**, p. 224 explains the limits.

01.3 NixOS

On NixOS, use the Nix package rather than the AppImage. It builds BetterSPICE from source on the system's own WebKitGTK, Mesa and graphics drivers, with ngspice from nixpkgs and the **bspice** command line. The installer's **Linux/NixOS** folder has the flake (the source), a prebuilt copy you can import without building, and a README with the NixOS and home-manager lines.

1. Copy the flake folder to the NixOS computer and add the model library zip to the Nix store once:

```
nix-store --add-fixed sha256 BetterSPICE-0.2.1-Model-
Library.zip
```

2. Run it, or install it into your profile:

```
nix run .#betterspice-full
nix profile install .#betterspice-full
```

YOU SHOULD SEE The BetterSPICE window. The status bar says that ngspice (nixpkgs' **libngspice**) is ready. **betterspice** without **-full** leaves out the model library (about 3 GB).

The AppImage also runs on NixOS through **run-betterspice-nixos.sh** in the same folder (it uses **appimage-run**). If the window stays blank or the start stops with an **EGL_NOT_INITIALIZED** error, check that **hardware.graphics.enable = true** is set, then try **WEBKIT_DISABLE_DMABUF_RENDERER=1** (BetterSPICE's default on Linux) or **=0** in front of the command.

01.4 Updates and patches

BetterSPICE keeps itself up to date from its private releases server. About two seconds after it starts it asks quietly whether there is a newer version, and an **Update** pill with the version number appears in the menu bar when there is. **Help** › **Check for updates** asks at once. To turn the check at the start off, clear **Check at every start** in that dialog.

1. Click the pill.

YOU SHOULD SEE What changed, and how much there is to download. For a small change that is a patch: only the files that changed.

2. Click **Update**.

YOU SHOULD SEE The download and its check. You can keep working: the open app does not change until it starts again.

3 Click **Restart now**.

YOU SHOULD SEE BetterSPICE closes, asking first about unsaved work, and starts again as the new version. A short panel lists what the version brings. It shows once, and **Help** › **What's new** opens it again.

You can also install a patch by hand, with no server and no internet. A patch is one file, **BetterSPICE-<version>-Windows-Patch.exe**. Double-click it: it finds the installed copy, says what will change and asks. **Help** › **Install patch file** takes the same file from inside the app. On Linux it is **sudo ./BetterSPICE-<version>-Linux-deb-Patch**, or **-Arch-Patch** on Arch.

A patch changes the app's own files only: your circuits, settings and parts, and the model library, stay as they are. Every file is checked against the release's signature before anything changes, and if a file can't be replaced, or the PC stops half way, every file is put back. An AppImage is replaced as a whole. A Nix install can't be changed from inside the app: update it from the new flake (see the NixOS README).

01.5 The browser version

The same app runs in a current Chrome or Edge, without ngspice and PSpice. **Desktop or browser**, p. 676 lists every difference.

TIP **Next.** Run the **Quick start**, p. 3, or build your first circuit in **Tutorial 1: Draw an RC filter and watch it run**, p. 12.

02 Tutorial 1: Draw an RC filter and watch it run

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You'll draw an RC low-pass filter, name its nets, set its values and watch it run. It takes about fifteen minutes. At the end the output is a smaller, later copy of the input, and you can change the filter while it runs.



Figure 2.1 What you'll build: a 1 V, 1 kHz sine into a 1 kΩ resistor and a 100 nF capacitor, running, with V IN and V OUT on the scope. The corner frequency is 1 / (2π × 1 kΩ × 100 nF) = 1.59 kHz.

YOU NEED

BetterSPICE running (**Install and start**, p. 9). Nothing else.

YOU WILL LEARN

Placing parts by key, wiring, net labels, typing values, probes, the timebase and sliders.

02.1 Start a new circuit

1 Press Ctrl + N.

YOU SHOULD SEE A new tab named **untitled · not saved** opens with an empty sheet and a start hint. The status bar says **Live MNA · idle**: the live simulation is on, but there's nothing in it yet. If the open tab is already an untouched empty untitled circuit, Ctrl + N reuses it. Otherwise a second new circuit is named **untitled 2**.

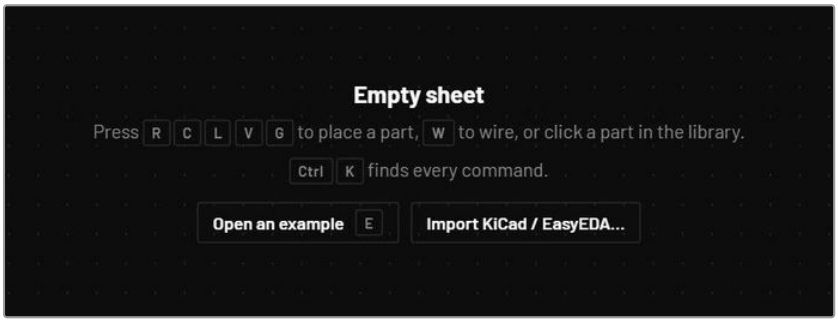


Figure 2.2 A new circuit: an empty sheet with the start hint.

02.2 Place the parts

Each part has a key. The letter is also on its tile in the library on the left.

2 Press A (AC source, a sine).

YOU SHOULD SEE A sine source follows the pointer.

3 Click the left part of the sheet.

YOU SHOULD SEE The source **V1** stays there. Another one follows the pointer, because placing stays on until you stop it.

4 Press R (resistor).

YOU SHOULD SEE The part following the pointer turns into a resistor, lying horizontally: another part's key switches the part you're placing.

5 Click to the right of V1, level with its top pin.

YOU SHOULD SEE **R1** is placed.

6 Press C (capacitor).

YOU SHOULD SEE A capacitor follows the pointer, lying horizontally.

7 Press C again.

YOU SHOULD SEE The capacitor stands upright. While placing, the part's own key (or Space) rotates it.

8 Click to the right of R1.

YOU SHOULD SEE **C1** stands upright, right of R1.

9 Press G (ground) and click under V1. Click again under C1.

10 Press Esc.

YOU SHOULD SEE The pointer is free again: one Esc always leaves a placing tool. The sheet holds V1, R1, C1 and two grounds. Nothing is connected yet, so a red marker such as **E_SINGULAR** can sit on a part: it clears once the circuit is wired.

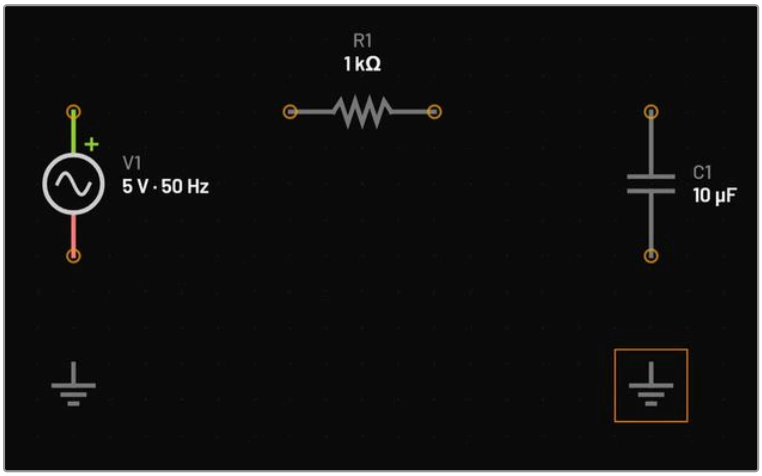


Figure 2.3 The parts placed, not yet wired.

02.3 Wire it

11 Move the pointer onto the top pin of V1.

YOU SHOULD SEE The pointer becomes a crosshair and the hint says *"Drag to draw a wire"*.

12 Press the mouse button, drag to the left pin of R1 and release.

YOU SHOULD SEE A wire joins them.

IF YOU SEE **a wire end in mid-air,** it missed the pin. Drag that end onto the pin, or press Ctrl + Z and drag again.

13 Drag from the right pin of R1 to the top pin of C1.

14 Drag from the bottom pin of V1 to the ground under it, and from the bottom pin of C1 to its ground.

YOU SHOULD SEE As the loop closes, the wires take colour and dots start to move. The circuit was running all along and now has something to run.

CAUTION **Every circuit needs a ground.** Without one, the status bar badge turns red with **E_NO_GROUND** and nothing gets a voltage. Ground is the 0 V reference that every other voltage is measured from. Press G and wire one in.

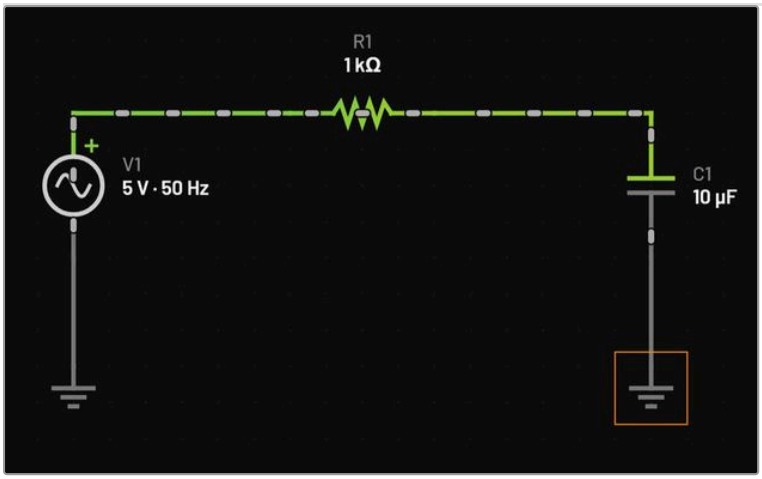


Figure 2.4 Wired: the wires take colour as soon as the loop closes.

02.4 Name the nets

A net is everything connected by wires. Naming the two that matter makes every reading say **IN** and **OUT** instead of a made-up name.

15 Press N (net label) and click the wire between V1 and R1.

YOU SHOULD SEE A box for the name opens.

16 Type **IN** and press Enter.

17 Click the wire between R1 and C1, type **OUT**, press Enter, then press Esc.

YOU SHOULD SEE The labels **IN** and **OUT** sit on the two wires.

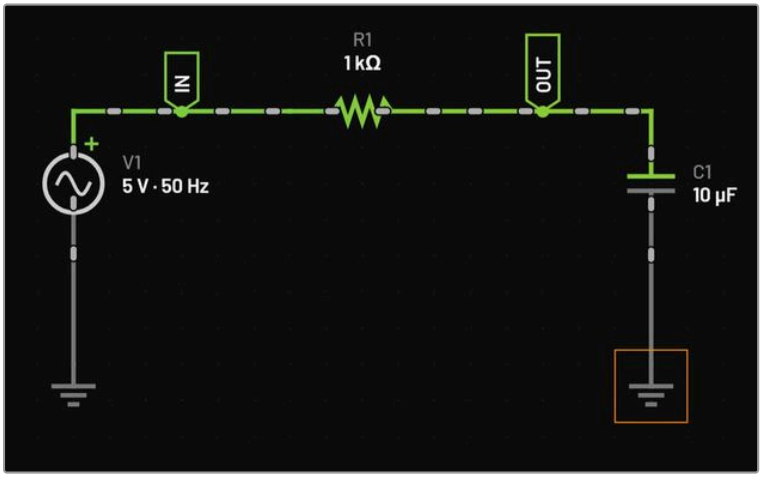


Figure 2.5 The nets named IN and OUT.

02.5 Set the values

18 Click R1.

YOU SHOULD SEE The inspector on the right shows R1. **Resistance** already reads 1 kΩ, the value you need.

19 Click C1. Click the **Capacitance** field, type **100n** and press Enter.

YOU SHOULD SEE The field reads 100 nF. Clicking a field selects its old value, so what you type replaces it.

IF YOU SEE **the field turned red,** the text isn't a number. Type it again: **100n** means 100 nanofarads.

20 Click V1. Type **1** in **Amplitude** and press Enter.

21 Type **1k** in **Frequency** and press Enter.

YOU SHOULD SEE The small preview in the inspector shows a sine. V1 now makes 1 V peak at 1 kHz.

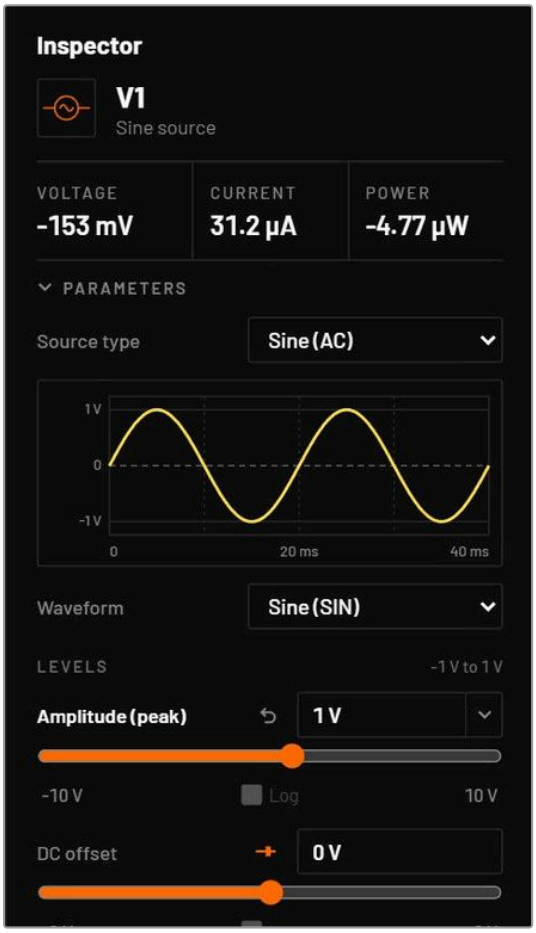


Figure 2.6 The inspector for V1 after the values are set: 1 V, 1 kHz.

02.6 Watch it run

22 Press P (probe) and click the wire that carries the **IN** label, beside the label.

YOU SHOULD SEE The Scope tab at the bottom shows a trace named **V IN**.

23 Click the wire that carries the **OUT** label, then press Esc.

YOU SHOULD SEE A second trace, **V OUT**. Clicking a probed wire again adds nothing: a message says *"V OUT already shows this net"*.

24 In the toolbar, set the timebase to **1m** by pressing 1.

YOU SHOULD SEE The toolbar shows **1 ms/s**: one millisecond of circuit time per real second. One 1 kHz period now takes a second to draw.

25 Read the scope.

YOU SHOULD SEE V OUT peaks at about 0.85 V against 1 V at IN, and its peaks come about 89 µs (32°) after the input's. At 1 kHz the filter, with its corner at 1.59 kHz, has already started to cut. The note below shows the start-up.

26 Click C1 and drag the slider under **Capacitance** to the right.

YOU SHOULD SEE V OUT shrinks and slides later while the circuit keeps running.

27 Press Ctrl + Z.

YOU SHOULD SEE C1 is back to 100 nF.

> **NOTE** **A new circuit starts at rest.** A circuit made with File → New starts at 0 V with every capacitor empty, as if it had just been switched on. C1 charged while you closed the loop, before the probes were on. To watch it, press Ctrl + Shift + Backspace: the simulation restarts at t = 0, and V OUT climbs from 0 V and settles into the steady wave within about 0.5 ms of circuit time. To start from the settled DC state instead, turn off **Simulate** › **Start at rest (power-on)**. Examples and older files start from the DC operating point. Start at rest or from the operating point, p. 181 has the details.

> **CAUTION** **The timebase is not time per division.** In BetterSPICE the timebase is how much circuit time passes per real second. The scope always shows the last 6 real seconds, so at 1 ms/s it spans 6 ms.

IF YOUR SCREEN DOES NOT MATCH

IF YOU SEE	DO THIS
Grey wires, no dots, a red badge with **E_NO_GROUND**	Place a ground (G) and wire it to the bottom of V1 and C1.
paused in the status bar (**Live MNA · WASM · paused**)	Press Ctrl + R.
A trace named after a pin, like **V C1 pin 1**	The probe is on a net with no name. Name the net (N), then probe the label again.
A message that the net is already probed	Probing the same net twice adds nothing. The existing probe is selected and flashes.
A blur on the scope	The timebase is too fast. Press 1.
A wire that doesn't connect	Wires join only at their ends and at pins. Drag from pin to pin, or press W and click both pins.

02.7 What you did

You placed parts with their keys, wired them pin to pin, named the nets, typed values with SI prefixes and watched the result live, changing a part while it ran. Keep this circuit open for **Tutorial 2: Measure it exactly**, p. 19.

03 Tutorial 2: Measure it exactly

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03.2	Measure the delay with cursors	20	03.5	Save	23
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The live simulation shows what a circuit does. To measure it, run it with Simulate. You'll take the filter from Tutorial 1, run a transient, measure the delay with cursors, find the –3 dB point and sweep the resistor. About fifteen minutes.

YOU NEED

The circuit from **Tutorial 1: Draw an RC filter and watch it run**, p. 12, open and running. Or open the example **RC low-pass, 1.6 kHz** (E): it has the same R and C.

YOU WILL LEARN

Simulate (F5), the Analysis view, cursors, the AC sweep, the parameter step and saving.

03.1 Run a transient

1 In the toolbar, click **Simulate for**, type **5m** and press Enter .

YOU SHOULD SEE The field reads 5 ms: the run covers the first 5 ms of the circuit's life.

2 Click **max step**, type **1u** and press Enter .

YOU SHOULD SEE 1 µs: the solver never takes a longer step, so a 1 ms period gets at least 1000 points.

3 Press F5 .

YOU SHOULD SEE The view splits. The schematic stays on top and the Analysis view below shows V IN and V OUT from 0 to 5 ms. V OUT starts at 0 V and settles within about 0.5 ms (five time constants of 100 µs).

IF YOU SEE **a banner that starts *Simulation failed:*,** read the reason in it, press **Dismiss**, and go to **Troubleshooting by symptom**, p. 78.

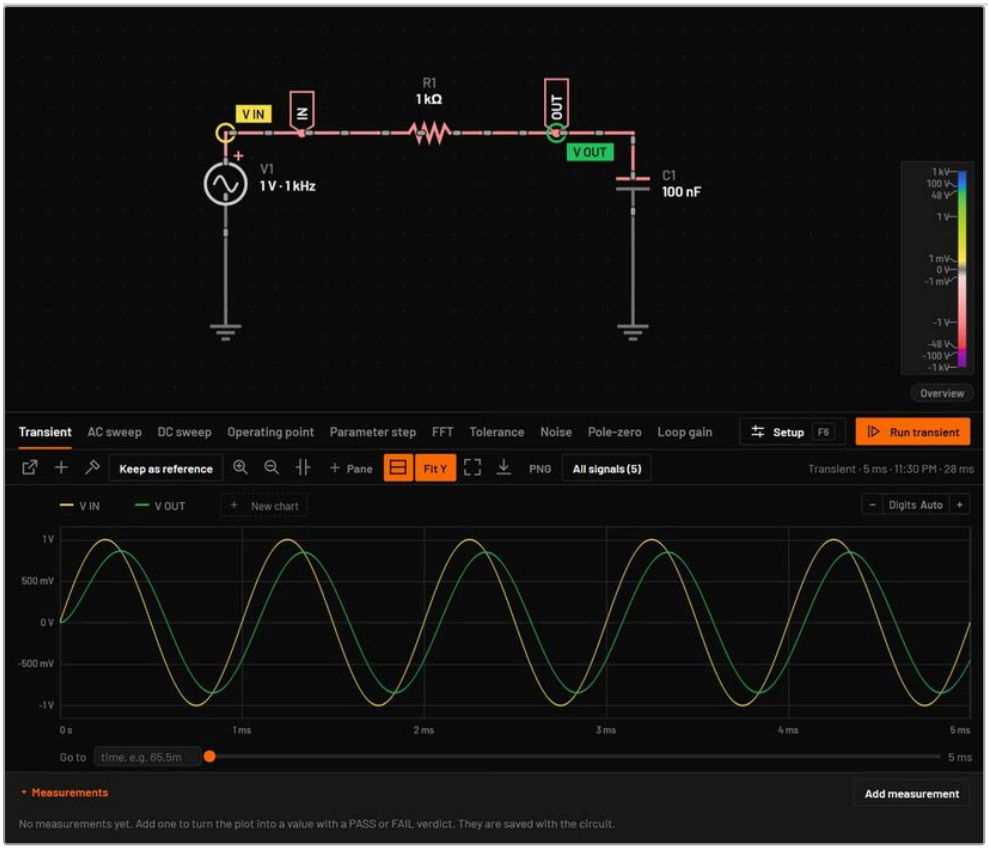


Figure 3.1 Split view after F5: the schematic on top, the transient below.

03.2 Measure the delay with cursors

4 Click **Cursors** in the plot toolbar.

YOU SHOULD SEE Two vertical lines, A (solid) and B (dashed), and a readout on the right.

5 Drag cursor A onto a peak of V IN, for example the one at 4.25 ms.

6 Drag cursor B onto the next peak of V OUT.

YOU SHOULD SEE The readout gives Δ of about 89 µs, and V OUT at B of about 0.85 V.



Figure 3.2 Cursors A and B on a peak of V IN and the next peak of V OUT.

03.3 Find the corner frequency

7 Press F7.

YOU SHOULD SEE **Simulation setup** opens on the **AC sweep** tab, because this circuit has no AC setup yet. **Input source** is already V1, from 1 Hz to 1 MHz. The header says *"F7 runs it from now on · F6 opens this setup"*.

8 Click **Run AC sweep**.

YOU SHOULD SEE A Bode plot: gain flat at 0 dB, then falling 20 dB per decade, and phase going from 0° to −90°. The strip above it reads **−3 dB at 1.59 kHz**. The window stays split. The setup is saved in the circuit, so the next F7 runs the sweep at once.

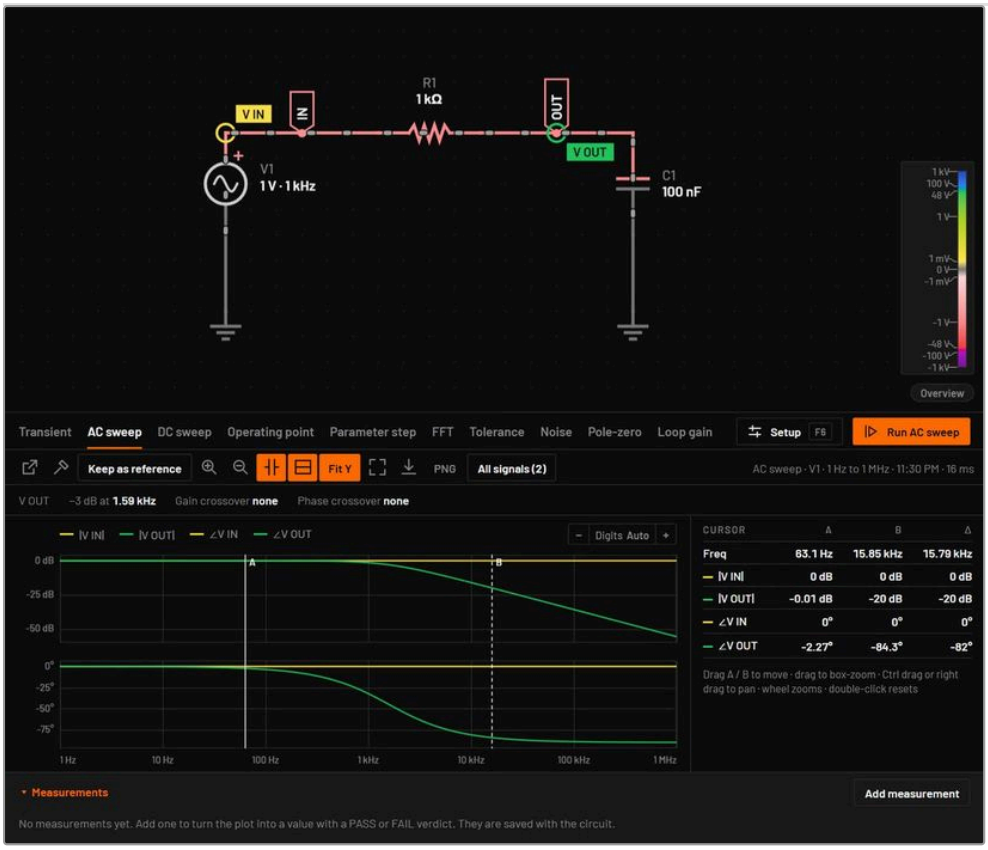


Figure 3.3 The AC sweep. The strip above the plot reads –3 dB at 1.59 kHz.

03.4 Sweep the resistor

9 Press Shift + F7.

YOU SHOULD SEE The **Parameter step** tab opens, as the circuit has no step setup yet. **Parameter** is already **R1.r**, the resistance of R1.

10 In **Values**, type **500, 1k, 2k, 4k**.

11 In **Analysis to repeat**, choose **AC sweep**.

12 Click **Run parameter step**.

YOU SHOULD SEE Four Bode curves named **V OUT · R1.r = 500** and so on. Their corners are at about 3.18 kHz, 1.59 kHz, 796 Hz and 398 Hz: double R, half the frequency.

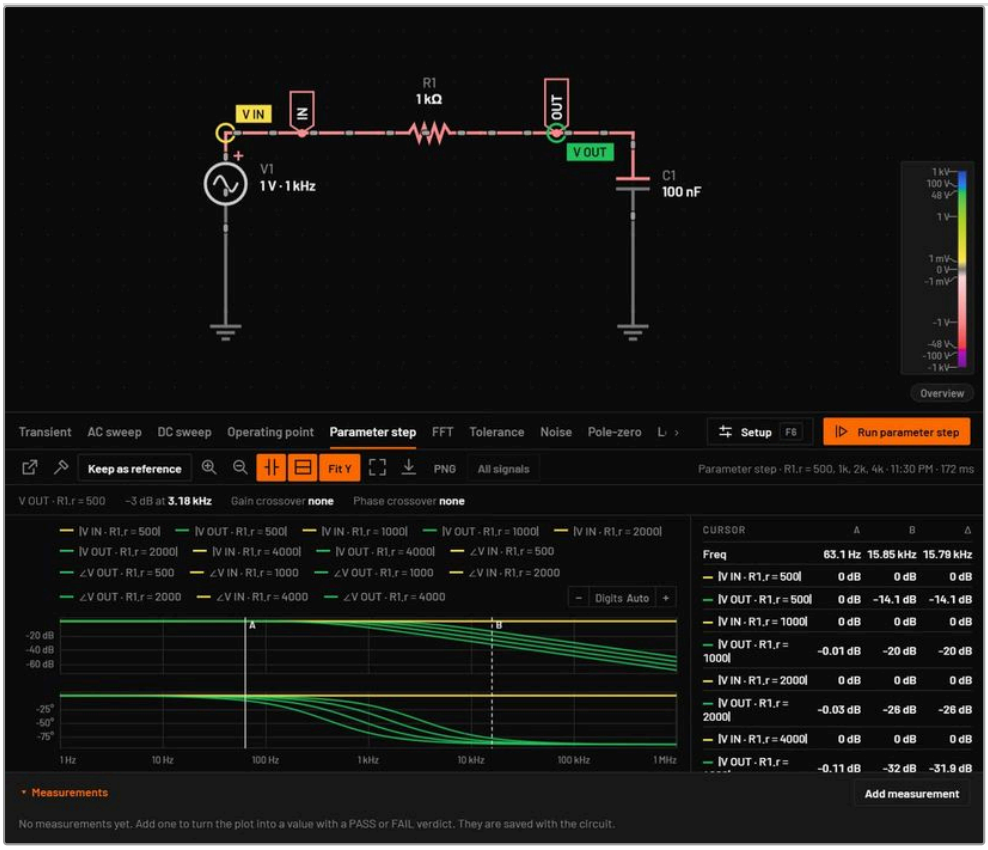


Figure 3.4 The parameter step: one Bode curve per value of R1.

03.5 Save

13 Press Ctrl + S.

YOU SHOULD SEE A Save dialog opens. The browser version asks for the name in the window, then downloads the file.

14 Type **rc-lowpass** and press Enter.

YOU SHOULD SEE The tab is named **rc-lowpass.bsc** and its unsaved dot is gone. The file keeps the parts, wires, probes and every analysis setting you used.

IF YOUR SCREEN DOES NOT MATCH

IF YOU SEE	DO THIS
A plot with no traces and *No probes*	Probe IN and OUT first (Tutorial 1), or hold Alt and click a net in the schematic above the plot. A plain click only selects.
The cursors are missing	Click **Cursors** in the toolbar of the plot, not in the dock.
A −3 dB point far from 1.59 kHz	Check R1 (1 kΩ) and C1 (100 nF) in the inspector, then press Ctrl + F5 to run the sweep again.
Only one curve after the parameter step	Separate the values with commas: **500, 1k, 2k, 4k**.

03.6 What you did

You measured the filter three ways: a transient in time, an AC sweep in frequency, and a parameter step across four resistor values. **How BetterSPICE thinks**, p. 32 explains why BetterSPICE has both the live simulation and Simulate, and **Simulate and measure**, p. 52 has a page for each kind of measurement.

04 Tutorial 3: A regulator with a vendor model

04.1 Open the regulator 25
04.2 Give the op-amp a vendor model 25
04.3 Run it with the vendor's model 26
04.4 What you did 27

Real chips come with the manufacturer's own SPICE model. You'll open a ready-made linear regulator, give its op-amp a Texas Instruments model, and run that model in ngspice with Simulate. About ten minutes. Desktop app only.

YOU NEED
The desktop app with **ngspice 47 ready** in the status bar.

YOU WILL LEARN
Assigning a vendor model, what the live simulation does with it, and how to read the output and its ripple from a Simulate run.

04.1 Open the regulator

1 Press E, type **op-amp series**, select **Op-amp series regulator (LM317 principle)** and press Enter.

YOU SHOULD SEE A 12 V supply with 1 V of 100 Hz ripple feeds transistor Q1. Op-amp U1 compares the divided output (FB) with a 1.25 V reference and holds V out at 5 V. The scope shows V in, V out and V FB.

04.2 Give the op-amp a vendor model

2 Double-click U1.

YOU SHOULD SEE The model dialog opens on the **Library** tab, listing op-amp models.

3 Type **lm358** in the search box.

YOU SHOULD SEE LM358 rows from several libraries. The first, marked **BSPART**, is a BetterSPICE part file. The others are vendor SPICE models.

4 Click the row **LM358 · Subcircuit · 5 pins · Texas Instruments**, format **SPICE**.

YOU SHOULD SEE The preview on the right shows the maker, the pins and the **Live view** line: the live simulation uses a model fitted to TI's, and Simulate runs TI's file itself.

5 Click **Assign LM358**.

YOU SHOULD SEE A message says *"LM358 assigned to U1"*. The inspector header for U1 now names LM358.

IF YOU SEE **a warning that the pins don't match,** choose another LM358 row with five pins, or place the LM358 from the library instead.

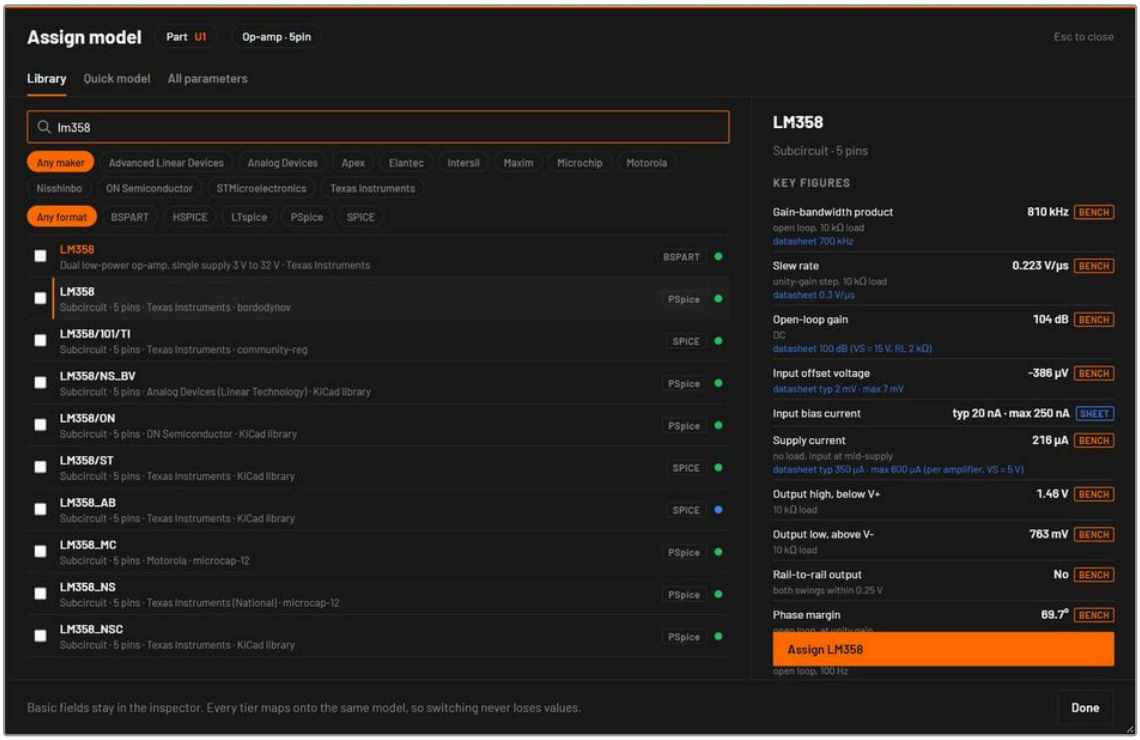


Figure 4.1 The model dialog with the TI LM358 subcircuit selected. The preview shows its pins and the Live view line.

04.3 Run it with the vendor's model

6 Press F5.

YOU SHOULD SEE The progress line says **in ngspice (vendor models)**. After a few seconds the Analysis view shows the three probes over 100 ms.

7 Read V out.

YOU SHOULD SEE V out sits at 5.00 V from the first instant, because a transient starts from the DC operating point, while V in swings between 11 V and 13 V.

8 Drag a box around V out to zoom in on it.

YOU SHOULD SEE A ripple of about 0.26 mV peak to peak at 100 Hz, against 2 V peak to peak at the input: the loop gain of the op-amp removes about 78 dB of it.

NOTE **Live and Simulate differ here.** The live simulation runs a model fitted to the LM358, and its ripple is far smaller, about a microvolt: the fit doesn't carry the finite power-supply rejection of TI's model. The Simulate result comes from TI's own file. **When to trust which result**, p. 34 says which to use for what.

TIP **See the start-up.** Press F6, set **Start from initial conditions** to **Yes: start from the ic values**, and run again. The run then starts from 0 V and shows the output rising.

IF YOUR SCREEN DOES NOT MATCH

IF YOU SEE	DO THIS
ngspice not found, and a banner with **E_NGSPICE_MISSING**	Reinstall BetterSPICE, or point **BSPICE_NGSPICE** to **ngspice.dll** (**Environment variables and files**, p. 673).
"timestep too small" in the banner	The model stalled at a rail. **Settings saved in the circuit**, p. 223 shows the **abstol=1e-9** option that cures it.
The run takes a long time	Vendor models are slower than built-in parts. The progress bar shows how far it has got. **Cancel** stops it.

04.4 What you did

You replaced a generic op-amp with a manufacturer's model, and BetterSPICE chose ngspice to run it without being asked. The same steps work for regulators, references and current-sense amplifiers: **Choose the model a part uses**, p. 64.

05 Tutorial 4: Make a part with the Part Wizard

05.1 Choose the template 28
05.2 Fill in what the datasheet says 29
05.3 Try the part 30
05.4 What you did 31

When a part has no model, make one from its datasheet. You'll turn the AP2112K-3.3 LDO regulator into a BetterSPICE part with the Part Wizard, then place it and watch it regulate. About fifteen minutes, with the datasheet open beside you.

YOU NEED
The AP2112 datasheet (Diodes Incorporated). Any LDO datasheet works the same way.

YOU WILL LEARN
Templates, min / typ / max values with page numbers, pin mapping, and My parts.

05.1 Choose the template

1. Press Ctrl + Shift + N.

   YOU SHOULD SEE **New part** opens on step 1, **Part type**, with the part types grouped by family.

2. Type **ldo** and click the tile **LDO regulator IC**.

   YOU SHOULD SEE The header reads **Type Power · LDO regulator IC**, the step bar unlocks, and the right side starts showing the file being written.

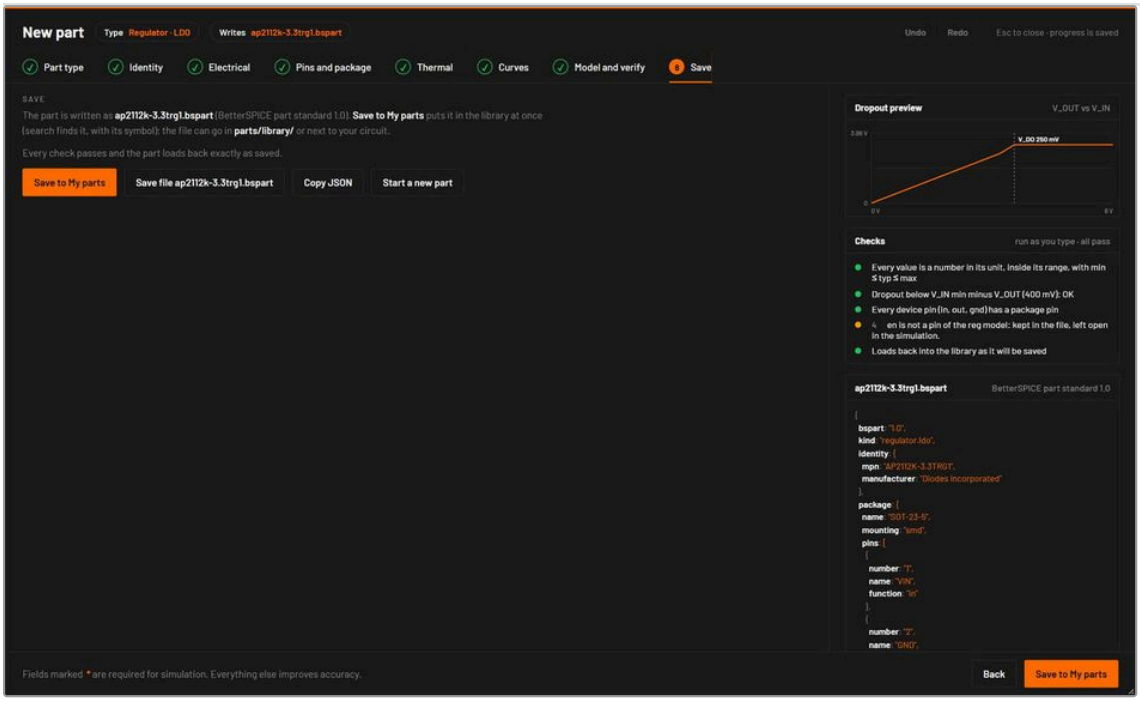


Figure 5.1 Step 1, Part type, after typing ldo: the LDO templates.

05.2 Fill in what the datasheet says

3. Click **Next**. In **Part number (MPN)**, type **AP2112K-3.3TRG1**. In **Manufacturer**, type **Diodes Incorporated**.

4. Click **Next**. In the **Output voltage** row, type **3.234**, **3.3** and **3.366** under Min, Typ and Max, and **4** as the page.

   YOU SHOULD SEE The **Checks** card turns the output voltage check green.

5. In **Dropout voltage**, type **250m** under Typ and **400m** under Max, page **4**.

6. Click **Next**. In **Common package**, pick **SOT-23-5**: the pin table gets five rows. Name them 1 VIN, 2 GND, 3 EN, 4 NC, 5 VOUT and click **Auto-assign functions**. Set EN to **other**.

   YOU SHOULD SEE The device pin chips read *in* → *1*, *gnd* → *2*, *out* → *5*. The simulation uses IN, GND and OUT. EN is kept in the file for the drawing and the datasheet. (The variant **en5** on step 2 has an EN pin in the model too.)

7. Click **Skip optional** until step 7 and press **Run the test circuit**, then go on to step 8, **Save**. Click **Save to My parts**.

   YOU SHOULD SEE A message: *Saved AP2112K-3.3TRG1 to My parts*, with a **Place now** button.

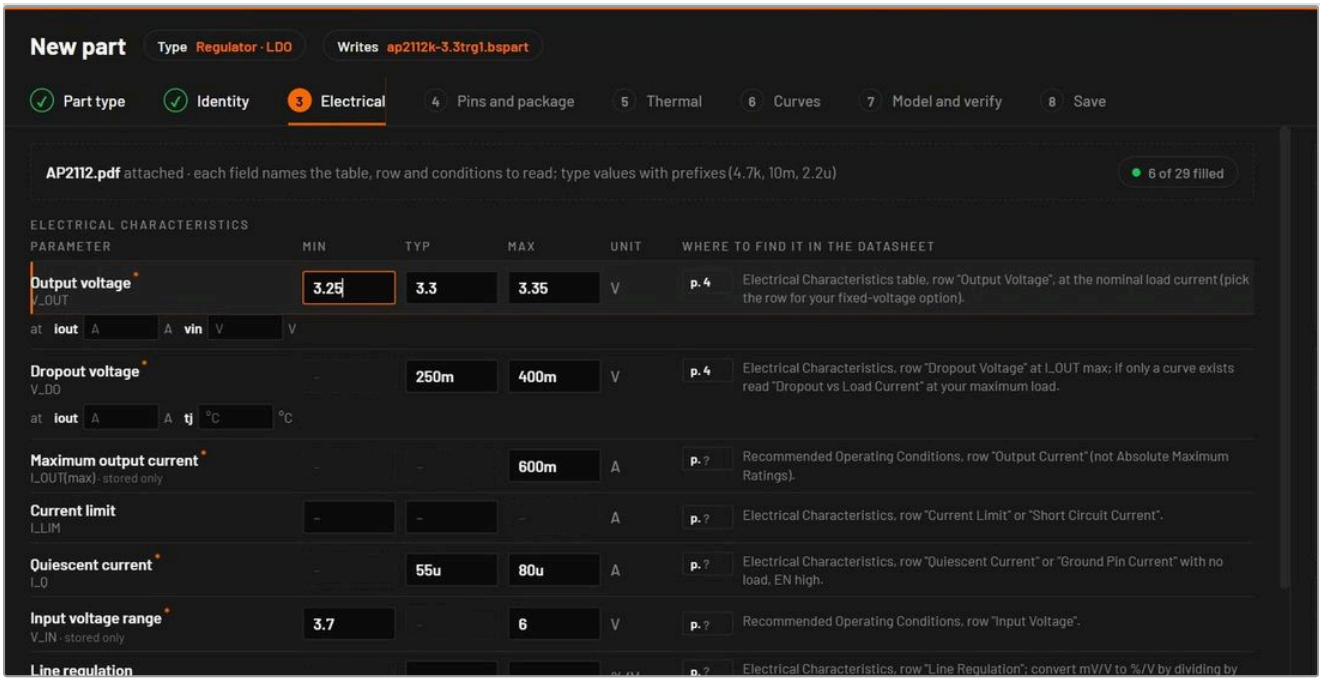


Figure 5.2 Step 3, Electrical: Min, Typ and Max, the unit, and the page of the datasheet each value came from.

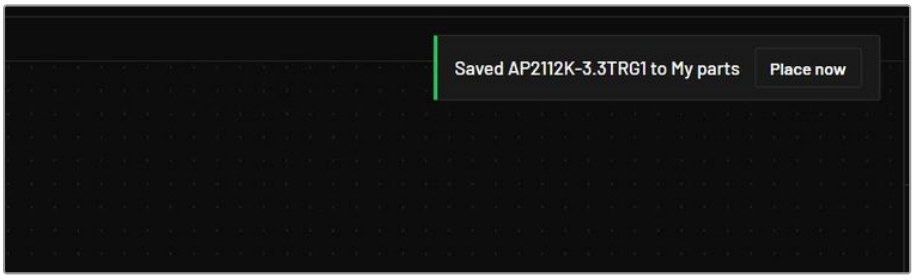


Figure 5.3 Saved to My parts: the message offers Place now.

05.3 Try the part

8 Open a new circuit (Ctrl + N). In the library, open **My parts** and click **AP2112K-3.3TRG1**, then click the sheet.

9 Place a DC source (V) of **5** V on its input, a **33** Ω resistor (R) from its output to ground, and a ground on its GND pin.

10 Hold the pointer over the output wire.

YOU SHOULD SEE 3.30 V: the typical value you typed. The load draws 100 mA.

11 Select the source and type **3.4**, then **3.3**, in its voltage field.

YOU SHOULD SEE At 3.4 V in, the output still reads 3.30 V. At 3.3 V in it falls to 3.25 V: the input has come within the dropout. At 100 mA the dropout is only about 50 mV. The 250 mV you typed is at the full 600 mA.

IF YOUR SCREEN DOES NOT MATCH

IF YOU SEE	DO THIS
A red check, *No package pin is mapped to IN, GND, OUT*	Go back to step 4 and give each of those functions a package pin.
The part is missing from My parts	Step 8 has two buttons. **Save to My parts** adds it to the library. **Save** only writes a file.
The output reads 0 V	Check that the GND pin is wired to ground and the source is on IN, not OUT.

05.4 What you did

You made a part file (**.bspart**) with real datasheet limits, and BetterSPICE built its live model from the typical values. **Part Wizard**, p. 420 describes every step and check, and **Part templates reference**, p. 606 lists every template.

06 How BetterSPICE thinks

06.1 Two ways to run a circuit 32
06.2 How a run starts 32
06.3 From drawing to answer 33
06.4 Nets and ground 33
06.5 Parts, models and where a value comes from 33
06.6 Exact and approximate 34
06.7 When to trust which result 34
06.8 If you know SPICE 35
06.9 Desktop and browser 35

BetterSPICE runs every circuit in two ways. The live simulation shows what it does while you draw. Simulate measures it, with the manufacturers' own models where a part has one. **Live shows. Simulate measures.**

06.1 Two ways to run a circuit

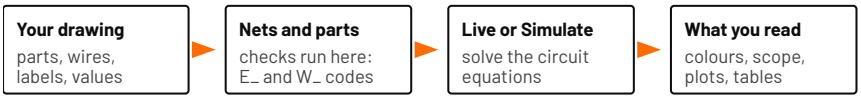
	WHEN IT RUNS	USE IT TO
Live simulation	Always, from the moment a circuit opens. Ctrl + R pauses it.	See the circuit work while you edit. Built-in parts and discrete vendor models (diodes, transistors) use the same equations as ngspice. Vendor chips such as op-amps use a model fitted to the vendor's.
Simulate	When you press F5, or run an analysis from the **Analysis** menu.	Measure: transient, AC sweep, DC sweep, operating point, parameter step, FFT. Circuits with vendor chips run the vendor's own model files in ngspice, or in PSpice for TI when Cadence encrypted the model. Both run hidden.

You never choose the engine. A Simulate run of built-in parts uses the BetterSPICE engine. A circuit with a vendor model file goes to ngspice, and one with an encrypted file goes to PSpice for TI. **Which engine runs**, p. 214 has the full rule.

06.2 How a run starts

The live simulation of a circuit made with **File** › **New** starts **at rest**: every node at 0 V, every capacitor empty, as at power-on. A first RC filter then charges where you can see it. Examples and files saved before this option start from the DC operating point, the settled state, so a regulator opens already regulating. **Simulate** › **Start at rest (power-on)** switches the circuit between the two and restarts it from t = 0. Simulate always starts from the operating point, unless the circuit asks for initial conditions (**Settings saved in the circuit**, p. 223).

06.3 From drawing to answer



Flow Every change to the drawing goes through the same path, many times a second for the live simulation.

Before the circuit is solved, BetterSPICE checks it for a ground, a path from every net to ground, and sources that short themselves. A problem becomes a diagnostic: a code, a sentence that names the part and the net, and the fix. **E_** codes stop the run. **W_** codes are warnings and it keeps running. There are 78 codes, all in **Diagnostics and what they mean**, p. 86.

06.4 Nets and ground

A net is a set of pins joined by wires, labels or flags. Every pin on a net has the same voltage. Two labels with the same name are one net even with no wire between them. A wire that only crosses another doesn't connect to it.

Ground (key G) is net **0**, the 0 V reference. Every voltage BetterSPICE shows is measured from it, so every circuit needs one, and every net needs a DC path to it. A net that only connects through capacitors has nothing to set its voltage (**E_FLOATING_NET**).

A side that must not share that ground, such as a transformer secondary or the output of an optocoupler, gets an isolated ground: a ground symbol with its own name, like **ISO1**. All grounds with that name are one ground domain. Its side is referenced to net 0 only through a 1 GΩ, 10 pF isolation barrier, the way a real isolation barrier leaks. The barrier belongs to the domain: change it on any symbol of the domain and it changes for all of them.

06.5 Parts, models and where a value comes from

A part is what you place: R1, Q3, U2. Its model says how it behaves. A new part simulates with built-in typical values, and the inspector says **Generic (no vendor model)**. Assigning a model from the library replaces them.

VALUE COMES FROM	WHEN	EXAMPLE
Built-in typical value	A part placed from a key or a tile, with no model.	A new NPN has bf = 100.
Vendor model card	A discrete model (.model D, NPN, NMOS and so on) from the library. The live simulation uses the same equations as ngspice.	A 2N3904 takes bf, is and vaf from the vendor file.
Fitted from the vendor model	A vendor subcircuit, such as an op-amp. The live simulation uses a behavioural model fitted by running the vendor's. Simulate runs the vendor file itself.	TLV9062: gain-bandwidth and slew rate measured from TI's model.
Quick model	Datasheet numbers you typed in the Quick model tab.	Vth = 2 V and Rds(on) = 20 mΩ become vto and kp.
Part file (.bspart)	A part made with the Part Wizard. The live model uses the typical value, or the middle of min and max.	An LDO with V_OUT 3.234, 3.3, 3.366 V.
You	Typed in the inspector, on the canvas, with a slider, or set by an AI agent.	

06.6 Exact and approximate

Every device type is in one of two classes. Exact devices use the same equations as ngspice and are compared with it signal by signal. Approximate devices are behavioural models measured against a reference. The class is in every device table in Part VI and in the report.

CLASS	DEVICES	HOW IT'S CHECKED
Exact	Resistor, capacitor, inductor, sources, switch, diode, BJT, MOSFET level 1, JFET, controlled sources, transformer	The same netlist runs in BetterSPICE and ngspice-47, and every signal is compared within a tolerance (**Verification**, p. 678).
Approximate	Power blocks, controller ICs, op-amp macromodels, sensors	Compared with the vendor model or a transistor-level reference. The report gives the error.

06.7 When to trust which result

YOUR QUESTION	USE
Does the circuit work, and how does it react when I change it?	The live simulation.
What exactly is the ripple, the overshoot or the settling time?	Simulate (F5) with a small **max step**.
Does an op-amp clip, and how close does it get to its rails?	Simulate with the vendor model. The live simulation uses a fitted model.
What are the gain and phase margins?	The AC sweep (F7).
Does it still work across component tolerances?	A parameter step over the minimum, typical and maximum values.

CAUTION **Vendor models have limits too.** A vendor macromodel is a model, not the part. The TI TLV9062 model cannot drive its output below about 50 mV from the negative rail, while the datasheet allows 20 mV. Check results that depend on the edge of a model against the datasheet.

06.8 If you know SPICE

- You never choose an engine. The live view always runs the BetterSPICE engine, and Simulate picks BetterSPICE, ngspice or PSpice for TI from the models in the circuit.
- Probes and every analysis setting are saved in the circuit file.
- In input fields, **M** and **Meg** both mean mega. In a netlist or vendor file, and on the **bspice** command line, **M** means milli. Type **1Meg** to be safe everywhere.
- The timebase is circuit time per real second, not time per division.
- Vendor **.lib** and **.subckt** files from TI, ADI, LTspice, PSpice and HSPICE run in ngspice, converted where needed (**Dialects and conversion**, p. 405).
- Hierarchical sheets are flattened before the solve. **uic**, the integration method and **.options** can be stored in the circuit (**Settings saved in the circuit**, p. 223).

06.9 Desktop and browser

The Windows desktop app has everything in this manual. The browser version has the editor, the live simulation, the analyses in the BetterSPICE engine, the library, the Part Wizard and the symbol editor, but no ngspice or PSpice runs, no native file dialogs and no recent files (**Desktop or browser**, p. 676).

07 A tour of the window

One window holds everything. There's no settings dialog: what you change is remembered.



Figure 7.1 The BetterSPICE window with a circuit running. The numbers match the table below.

	AREA	WHAT IT'S FOR
1	**Menu bar**	File, Edit, View, Place, Simulate, Analysis, Tools, Examples, Help. On the right: the **Follow AI** switch, the circuit name with **saved**, **edited**, **not saved** or **example (Save as to keep a copy)**, and the view switch.
2	**Toolbar**	File, undo, drawing tools, **Run** / **Pause**, Step, Reset, the circuit time, the timebase and the current dots.
3	**Simulate group**	**Simulate for** (stop time), **max step** and the **Simulate** button (F5).
4	**View switch**	Schematic, Analysis or Split.
5	**Library**	Search, source filters, My parts and the part families with their symbols and models.
6	**Canvas**	The schematic. While it runs, wire colour is voltage and moving dots are current. Hold the pointer over anything for its readings.
7	**Inspector**	The selected part: live readings, model, parameters with sliders.

	AREA	WHAT IT'S FOR
8	**Measurements**	Every part with its value, voltage, current and power, live.
9	**Dock**	The Scope, Bode, FFT, Logic, Console, Diagnostics and Activity tabs.
10	**Status bar**	The live engine and whether it's running or paused, the timestep, the diagnostics badge and a hint for the active tool.

07.1 Signs of state

YOU SEE	IT MEANS
running or **paused** after the engine name in the status bar	The live simulation is on, or paused (Ctrl + R). Nothing is drawn on the canvas for these two states.
A red **Halted · *code*** pill on the canvas and a red **Halted** button in the toolbar	The live simulation stopped on an error. Click either to open Diagnostics. This is the only state that's also shown on the canvas.
A number on the status bar's Diagnostics badge	Red when there's an error, amber when there are only warnings. Click it, or press Alt + 6.
Live MNA · WASM · running in the status bar	The fast live engine. **Live MNA · JS** is the slower fallback for when the fast engine cannot load. **idle** instead of running: the sheet is empty.
ngspice 47 ready	Simulate can run vendor models (desktop).
A dot on a tab	Unsaved changes. BetterSPICE autosaves them for recovery anyway.
example after a tab name	An example you opened. It's not your file: Save as keeps a copy.
A violet **AI · *name***	An AI agent is working in this circuit (**Working with an AI agent**, p. 591).

Every area is described in detail in **The window in detail**, p. 115.

08 The guided tours

08.1	Start a tour	38	08.4	The Quick intro	39
08.2	What a step looks like	38	08.5	The Full tour	39
08.3	Your own work is not touched	38			

BetterSPICE teaches itself on a practice circuit. The **Quick intro** takes about two minutes; the **Full tour** goes through every part of the app, a chapter at a time. Both ask you to do the thing, with your own mouse and keys.

08.1 Start a tour

The first time BetterSPICE opens on a computer, a welcome card offers both. It shows once. **Not now** closes it and says where the tours are. They are always under **Help**: **Quick intro** and **Full tour**. The command palette (Ctrl+K) finds them too: type **tour**.

08.2 What a step looks like

The window dims and turns gray everywhere except the part the step is about, which stays at full brightness inside a thin orange outline. A card sits beside it, never on top of it, with a pointer to the thing, a title, a sentence or two, **Step N of M** and a progress bar. The spotlight follows the real element when you resize the window or open a pane.

ON THE CARD	WHAT IT DOES
Next and **Back**	Move one step on or back. The first step has no Back. → or Enter is Next and ← is Back, on a step you only read.
Try it steps	Wait for you. The card says **Waiting for you** until the change is really there (a part placed, a wire joining two pins, a probe added, a run started), then **Done** and Next. While it waits, only the highlighted area answers clicks.
Do it for me	Makes the same change itself, so you can see it done. Ctrl+Z takes it back like any edit.
Skip step	Goes on without doing it. Later steps put in what they need themselves, so nothing gets stuck.
Not quite	A short correction when you did something else, for example placed a different part.
Skip tutorial or Esc	Asks **Leave the tour?**. Esc first closes a menu, a dialog or a tool you have open, then asks.

08.3 Your own work is not touched

- The tour works in its own tab, **Practice circuit**. Your circuits stay in their tabs, with their unsaved edits, undo history, selection and view, exactly as

they were.

- The practice circuit is never saved, never autosaved and never counted as unsaved changes, so closing the window in the middle of a tour asks nothing and leaves nothing behind.
- What the tour changes in the window (the view, hidden panes, the dock tab, run or pause, the timebase, the library search) is put back when it ends.

08.4 The Quick intro

Eight steps: find parts in the library, place a resistor (R), wire it in, close the loop, add a probe (P), run it and read the scope (Ctrl+R, 1 to 4), change a value while it runs, and where to come back to.

08.5 The Full tour

Eleven chapters, listed when you start it. Pick any chapter; the list ticks the ones you finished and **Continue** takes you back to the step you left, even after you close the app.

CHAPTER	COVERS
1 The window	Menus, toolbar, library, sheet, inspector, dock, the command palette.
2 Drawing and editing	Place, move, rotate, name nets, undo, copy and delete.
3 Parts and the library	Search, vendor filters, My parts, the Part Wizard, family keys.
4 Models	Vendor models, the **≠ datasheet** note, Assign model, Edit a copy of a model, Quick model.
5 Live simulation and the inspector	Pause and step, the timebase, changing a part while it runs, colours and current dots.
6 Probes, scopes and the dock	Probes, trace chips, a second scope, the Bode and FFT tabs.
7 Simulate and analysis	F5 transient, F7 AC sweep, the other analyses, the Analysis view.
8 Sheets, subcircuits and modules	Create a module, open it, the pin window, the Monitor, back up.
9 Digital, control and MCU	Gates, the logic analyzer, the Console, controllers.
10 Reports, export and import	The report, image and netlist export, KiCad and EasyEDA Pro import.
11 Examples, AI agents and help	The examples, working with an AI agent, the shortcut list, Help.

PART

II

How do I…?

One page per job, titled by the goal. Each says what you need first, gives the steps, what you should see, what to do if it doesn't work, and where to read more.

09	Task index	41
10	Draw and edit	44
11	Simulate and measure	52
12	Build parts and choose models	64
13	Bring work in and out	69
14	Design with the calculators	73

09 Task index

Find your goal, in your own words. The grey words are what other people call the same thing, so a search for "Bode" or "bias point" lands here too.

I WANT TO ...	PAGE
Add a datasheet graph to a part (curve, digitize, paste a table, datasheet graph, R_DS(on) vs temperature, fit the model)	66
Build the inside of a subcircuit myself (edit subcircuit, blank IC, make a block, sub-sheet tab, X1, subckt)	50
Change the colours or the theme	119
Check a calculator design in the simulator (verify in simulation, calculator check, pass fail limits, advanced calculator)	74
Check a circuit across component tolerances (tolerance, worst case, min typ max, corner, Monte Carlo, yield, spread, histogram)	58
Check a power supply: start-up, load step and ripple (ripple, load transient, soft start, overshoot, settling time, regulator, buck converter, LDO)	57
Choose an op-amp for a gain stage (op-amp selection, opamp picker, offset budget, find an op amp)	75
Choose the model a part uses (assign model, vendor model, SPICE model, change model, model card)	64
Compare a run with an earlier one (reference, before and after, compare runs, keep a trace, difference)	60
Design a buck or boost stage and pick its inductor (smps, switching regulator, inductor selection, power stage, dc-dc converter)	74
Draw or edit a symbol (symbol editor, custom symbol, pinout, IC box, bssym)	67
Export a netlist for another simulator (netlist, ngspice, cir, LTspice, SPICE export)	71
Find a part or a vendor model in the library (search parts, find a model, part number, MPN, component library)	49
Find out why every voltage is 0 V	78
Find the DC operating point of every net (bias point, quiescent point, DC voltages, node voltages, OP)	56
Find the frequency response and the phase margin (Bode plot, AC analysis, gain margin, stability, -3 dB, bandwidth, cutoff frequency, loop gain)	55
Fix a run that will not converge (did not converge, E_NEWTON, E_SINGULAR, E_TIMESTEP, halted, convergence, Gear)	61
Get a model from datasheet numbers (Quick model, fit a model, datasheet values, no model available)	64
Go back in time in a paused run (scrub, playhead, replay, history, go to a time)	62
Hand a task to an AI agent and check what it did (Claude, AI, MCP, agent, automate design)	72
Import a KiCad or EasyEDA Pro design (KiCad, EasyEDA, import schematic, kicad_sch, epro)	69
Keep sides isolated with their own grounds (isolated ground, floating ground, galvanic isolation, optocoupler, transformer, ISO1, secondary side, second ground, ground domain)	45
Know which result to trust	34

I WANT TO ...	PAGE
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10 Draw and edit

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10.1 Place, rotate and wire parts

Put parts on the sheet, turn them the right way and connect them.

BEFORE YOU START An open circuit. Ctrl + N starts a new one.

1. Press the part's key, for example R for a resistor, or click its tile in the library.

   YOU SHOULD SEE The part follows the pointer.

2. Press the same key again, or Space, to rotate it 90°. Ctrl + E mirrors it. Another part's key switches to that part.

3. Click to drop it. Click again to drop another of the same part.

4. Press Esc once to stop placing.

5. Move the pointer onto a pin until it becomes a crosshair, drag to another pin and release.

   YOU SHOULD SEE A wire joins the two pins. Each click of the Wire tool (W) places a corner instead.

RESULT The parts are connected and the live simulation runs them at once: wires take colour as soon as a loop closes.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A second copy of the part when you meant to stop	Press Esc after the last drop, or Ctrl + Z to remove the extra one.
A wire end in mid-air	It missed the pin. Drag the end onto the pin: the pointer is a crosshair when it's on one.
Two wires cross but don't connect	Wires connect only at ends and pins. End one wire on the other: a junction dot appears.

SEE ALSO **Placing parts**, p. 139 (every place key), **Wires**, p. 140, **Keyboard shortcuts by task**, p. 101.

10.2 Name nets and use ground and power flags

Give nets names, so readings and probes say OUT and VCC, and join nets without drawing wires.

1. Press N (net label) and click a wire.
2. Type the name, for example **OUT**, and press Enter. Names can't contain spaces: use an underscore.
3. For a supply, press Shift+G (power flag), click the wire and type **VCC**. Every flag and label named VCC is one net.
4. Press G for ground: the 0 V reference, net **0**. Every circuit needs one.

RESULT Holding the pointer over a wire shows its name and voltage. Probes on it are named after it, like **V OUT**.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
"Type a name or press Esc."	An empty name is refused. Type one, or press Esc.
Two labels with the same name didn't join	Net labels join only on the same sheet. Use a global label (Shift+N) across sheets.

SEE ALSO **Labels, flags and ground**, p. 141, **Nets and ground**, p. 33.

10.3 Keep sides isolated with their own grounds

Draw circuits whose sides don't share the main ground, such as the secondary of a transformer or the output of an optocoupler, and tie them together only through the isolating part.

BEFORE YOU START A circuit with a main ground (G).

1. Press G, then Tab until the ghost under the pointer is named **ISO1**. Or open **Sources** in the library and take **Isolated ground** (the open triangle). Click it onto the 0 V wire of the isolated side.

   YOU SHOULD SEE A message names the domain, for example *Isolated ground ISO1 (new domain)*, and the name is under the triangle.

2. Place more grounds of the same name on that side as needed. Grounds with the same name are one net, like labels.
3. For another isolated side, press Tab again while placing, until the name is a new one such as **ISO2**. (**Start a new ground domain**, p. 47 has the other ways.)
4. Join the sides only through the isolating part: a transformer (**Devices: passives**, p. 265), an optocoupler or a digital isolator.
5. To read a voltage on an isolated side, press P and click its net. The probe is against that side's own ground and says so, for example **V OUT (ISO2)**. **Shift+click** reads against the main ground instead and is named **V OUT (vs GND)**.

6 To change the isolation, select any ground of the side and edit **Isolation resistance** or **Isolation capacitance** in the inspector.

YOU SHOULD SEE Every ground of that domain follows, in one undo step. The main ground has no isolation fields, only its name.

RESULT Each isolated side is its own net family, tied to the main ground only through its isolation barrier: **Isolation resistance** (1 GΩ) in parallel with **Isolation capacitance** (10 pF). The values belong to the domain, not to one symbol. Hold the pointer over an isolated ground: *Isolated ground · ISO1*, with *V vs GND* (the float across the barrier) and *I barrier*. The example **Isolated grounds: transformer and optocoupler** has two such sides.

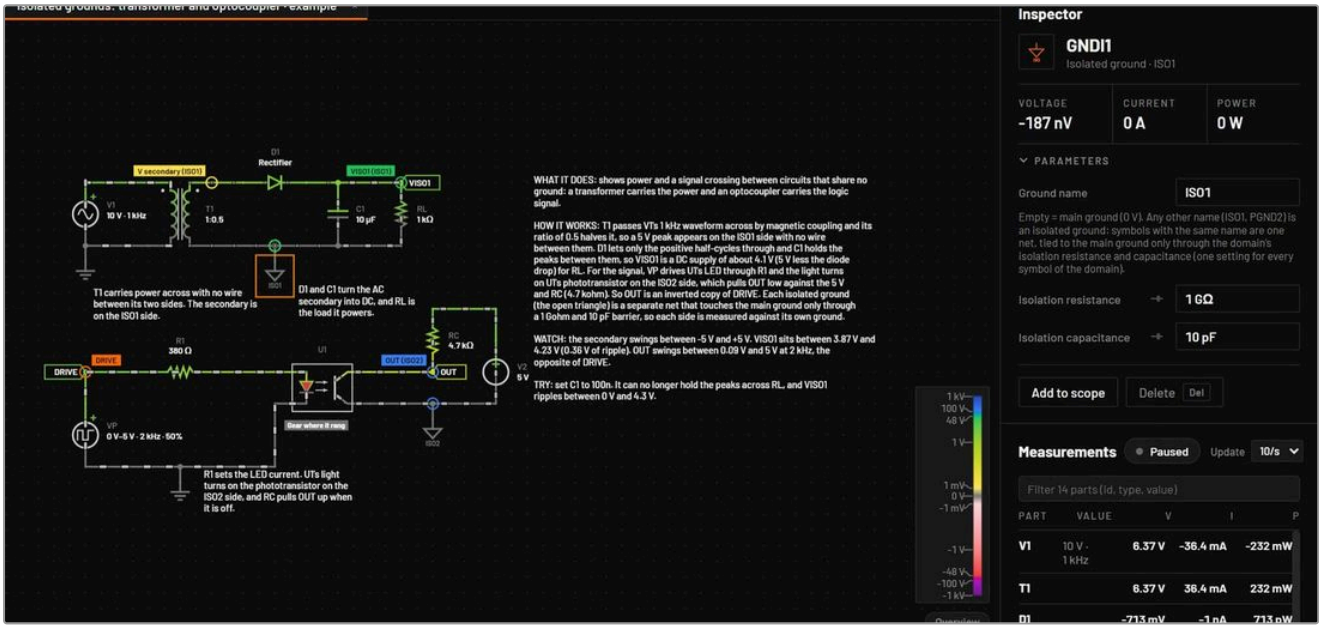


Figure 1 Two isolated grounds, ISO1 and ISO2 (open triangles), next to the main ground. T1 and U1 are the only links between the sides. The probe names end in the ground they are measured against, such as *(ISO1)*. The inspector shows the selected ground's name and its isolation barrier.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
W_ISO_TIED: *"Isolated ground ISO1 is joined to the main ground, so it is not isolated."* and the canvas tag **ISO1 tied to GND** (amber)	A wire, label or main ground symbol sits on the isolated side. Click **Show the tie** in Diagnostics to select the joining wires and labels and remove them. Or click **Make it the main ground** if the two are meant to be one. Two isolated domains joined into one offer **Name them all ISO1**.
E_NO_GROUND: *"The circuit has only isolated grounds (ISO1) and no main ground."*	Isolated grounds are measured from the main ground. Place one ground (G) with no name.
E_SINGULAR on a net of an isolated side	Its isolation is too perfect for the solver at that step. Raise **Isolation capacitance** or lower **Isolation resistance** of that side's ground.
A probe reads a few volts too high or low on an isolated side	It was made with **Shift+click**, which measures against GND. Make it again with the probe tool and a plain click.

SEE ALSO **Labels, flags and ground**, p. 141, **Nets and ground**, p. 33, **Adding probes**, p. 195.

10.4 Start a new ground domain

Give a part of the circuit its own isolated ground, rename a domain, or turn an isolated ground back into the main ground.

BEFORE YOU START A circuit with a main ground. Isolated sides need one.

1. Press G.

   YOU SHOULD SEE A ground follows the pointer.

2. While the ground follows the pointer, press Tab until the ghost shows the name you want.

   YOU SHOULD SEE The ghost steps main ground, then each isolated domain on the sheet (ISO1, ISO2...), then a new free domain (**ISO*n***). A message names the choice. Another Tab returns to the main ground.

3. Click the 0 V wire of the new side.

4. To start a domain from a ground that's already placed, right-click it and choose **Start a new ground domain (ISO3)**. That ground becomes the first symbol of the next free domain.

5. To rename a domain, right-click any of its grounds and choose **Rename domain ISO1...**, type the new name and press Enter.

   YOU SHOULD SEE Every ground symbol, power flag, global label and net label of that name on the sheet takes the new name, in one undo step.

6. To turn an isolated side back into the main ground, right-click one of its grounds and choose **Make it the main ground**.

   YOU SHOULD SEE The side joins net 0, and the **ISO1 tied to GND** tag and its warning go away. One undo brings the isolation back.

RESULT Every ground with the same name is one domain, with its own isolation resistance and capacitance. The inspector's **Ground name** field does the same job by hand: empty, GND or 0 is the main ground, any other name is a domain.

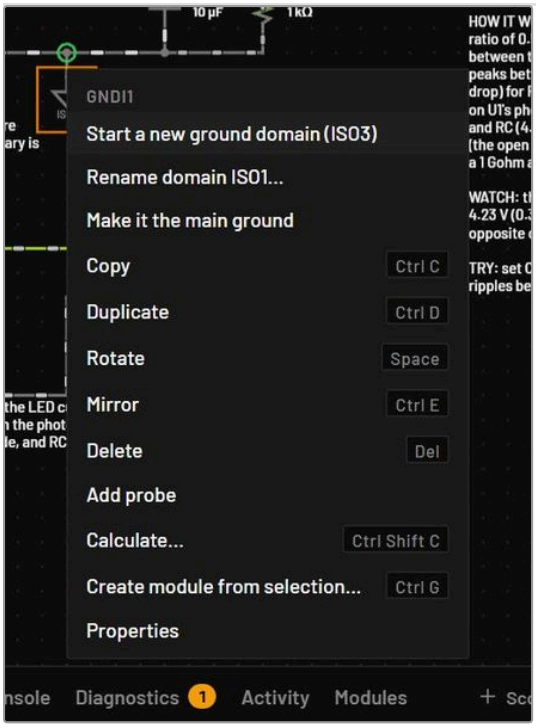


Figure 2 The right-click menu of an isolated ground: start a new domain, rename this one, or make it the main ground.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
Pressing G again turned the ground instead of changing it	While placing, a part's own key rotates it. Use Tab to change the domain.
The new name is refused	Names can't contain spaces, and GND and 0 mean the main ground: use **Make it the main ground**.

SEE ALSO **Keep sides isolated with their own grounds**, p. 45, **Labels, flags and ground**, p. 141.

10.5 Select, move, copy and undo

Change the drawing without breaking connections.

1. Click a part, or drag a box on empty canvas. Left to right selects what is fully inside, right to left also what it touches.
2. Drag the selection to move it. Wires stretch to stay connected. The arrow keys nudge by one grid step, with Shift by five.
3. Press Ctrl + D to duplicate, or Ctrl + C and Ctrl + V to paste at the pointer.

   YOU SHOULD SEE Copies get the next free designators: R1 becomes R4 if R1 to R3 exist.
4. Press Ctrl + Z to undo and Ctrl + Y to redo. Each tab keeps 300 steps.

RESULT Every edit, including a whole slider drag and an AI agent's edits, is one undo step.

SEE ALSO **Selecting**, p. 143, **Editing**, p. 143.

10.6 Find a part or a vendor model in the library

Find a part by its number, maker or function and place it with its model.

1. Press / to jump to the library search.
2. Type a part number, maker or function, for example **IRLZ44** or **logic level mosfet**. Every word must match. A value and a kind, such as **10k resistor**, offers a generic part with that value first.

   YOU SHOULD SEE Results in sections: **My parts**, **Symbols**, **Examples** and **Models**. Exact part numbers come first, one row per part number with **+N other models**.
3. Optional: click a source chip such as **TI** or **Verified only** to narrow the list.
4. Press **Down** to highlight a row and **Enter** to place it, or click a row, or drag it onto the canvas. Click the sheet to drop it.

   YOU SHOULD SEE The part is placed with its model, its pin map and its live values.

RESULT Simulate runs the vendor's own file for that part. A green status dot means it runs in ngspice as it is.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
No results	The card shows near matches and **Clear filters**. Try a function search such as **Ido 3.3**.
A message that the model was replaced	The model fails in every engine. A working model of the same part was placed instead.

SEE ALSO **The library and model search**, p. 155, **The model catalogue**, p. 401.

10.7 Type exact values and tune them with sliders

Set a part's value exactly, or sweep it by hand while the circuit runs.

1. Click the part. The inspector shows its main parameters. Select several parts of one type to set them all at once.
2. Click a field (its value is selected), type the value with an SI prefix, for example **4k7**, **100n** or **1Meg**, and press **Enter**.

   YOU SHOULD SEE The value applies at once and keeps the circuit running.
3. To step to a neighbour, press **Up** or **Down** in the field, or **PageUp** and **PageDown** for the next standard value. The chevron at the right of the field lists the standard values.

4 To tune, drag the slider under the field, or drag the field's label sideways. The whole drag is one undo step.

5 Optional: set the slider's **Min**, **Max** and **Log** under it for a useful range. A field with no slider has a small slider button beside its label.

RESULT The value is saved with the part. Double-clicking a value label on the canvas edits it in place too.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A red line under the field	The text isn't a value the part can take. **1,5** (comma decimal), **1.2.3**, **12/3**, junk after the number such as **4k7x**, zero for a resistance and a negative delay are refused with a reason, and the old value stays.
A value a million times off	In fields, **M** is mega. Write **1Meg** for mega and **1m** for milli to be safe.

SEE ALSO Typing numbers, p. 171, Sliders, p. 174.

10.8 Organise a big circuit with sheets and buses

Put a block of the circuit inside a box with ports, so the top sheet stays readable.

1 Select the parts, wires and labels of the block.

2 Press Ctrl+G. In the **Create module** dialog type a name, for example **HPF**, check the pin names and directions, and press Enter.

YOU SHOULD SEE One box replaces the selection, with a pin for every net that crossed its edge, inputs on the left and outputs on the right. Esc instead cancels and changes nothing.

3 Wire the box like a part, or join modules with net labels: a label on a pin, and the same label elsewhere on the sheet.

4 Double-click the box to open it. Backspace with nothing selected goes back up. Double-click a pin to see its pin window (Alt+8).

5 To add a pin later, use the pin window, or inside the module put a **Sheet port** (Alt+P) or a net label of the pin's name on the net.

RESULT The circuit simulates exactly as before. Parts inside are named with a prefix, like **S1/R3**. Direction is only a label for drawing, sorting and monitoring.

SEE ALSO Hierarchical sheets and buses, p. 148.

10.9 Build the inside of a subcircuit myself

Place a box with pins and draw what is inside it, without a vendor model.

1 Press X and place a **Subcircuit / IC**. Wire the circuit around it to its pins.

2 Double-click it, or right-click it and choose **Edit subcircuit**.

YOU SHOULD SEE The box becomes a sheet and opens in its own tab, ↳ **X1**, with one port for every pin.

3 Draw the circuit between the ports, as on any sheet.

4 Click the circuit's tab to go back to the top level, and ↳ **X1** to go back in. The × on the ↳ tab closes only that tab.

RESULT The circuit runs with what you drew inside. One undo brings the plain box back.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A double-click opens the model dialog	The part has a vendor model. Only a blank Subcircuit / IC can be edited this way.

SEE ALSO **Editing a subcircuit**, p. 151.

11 Simulate and measure

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11.1 Watch a circuit run, slow it down or pause it

See a fast signal move at a speed you can follow.

1. Press Ctrl + R to run or pause the live simulation.
2. Choose a speed: 1 1 ms/s, 2 10 ms/s, 3 100 ms/s, 4 real time. Or type a timebase in the toolbar, such as **20u**.

   YOU SHOULD SEE The scope always shows the last 6 real seconds, so at 1 ms/s it spans 6 ms of circuit time.
3. Paused, press . to advance one timestep.
4. Press Ctrl + Shift + Backspace to restart at t = 0, from the circuit's start state (a new circuit: capacitors empty).

RESULT A 1 kHz signal at 1 ms/s draws one period per second. Use 1 for switching converters, 2 for mains and audio, 3 for RC charging, 4 for thermal and battery circuits.

SEE ALSO Timebase and speed, p. 181.

11.2 Start a circuit from rest or from the operating point

Choose whether the live simulation shows the start-up, a capacitor charging from empty, or begins already settled.

BEFORE YOU START An open circuit with a capacitor or an inductor in it.

1 Open the **Simulate** menu and look at **Start at rest (power-on)**.

YOU SHOULD SEE A tick means the circuit starts at rest: 0 V everywhere, capacitors empty. A circuit made with File → New is ticked. Examples and older files aren't.

2 Choose it to change the tick.

YOU SHOULD SEE The simulation restarts at t = 0. At rest, a first RC charges on the scope. Unticked, the same circuit sits at its DC operating point from the first instant. A message says which one you got.

3 To start one part somewhere else, select the capacitor or inductor and click **All N parameters**. Type a value in **Initial voltage** (capacitor) or **Initial current** (inductor).

YOU SHOULD SEE The circuit starts with that value instead.

4 Press Ctrl + Shift + Backspace any time to start again the same way.

RESULT The choice is saved in the circuit file. It changes the live simulation only. Simulate (F5) starts from the operating point unless the circuit asks for initial conditions.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A capacitor shows 0 in **Initial voltage** but starts charged	Without an initial value a part starts from the operating point when the circuit doesn't start at rest. The field shows 0 until you set one.
After setting one initial value every other capacitor also starts at 0	Setting any initial value, even 0, makes the whole start use initial conditions, as **uic** does in SPICE.

SEE ALSO **Start at rest or from the operating point**, p. 181, **Settings saved in the circuit**, p. 223, **How a run starts**, p. 32.

11.3 Probe a signal and read it on the scope

Plot a voltage or a current live, and keep it for every analysis and the report.

1 Press P (probe tool).

2 Click a wire for the net voltage (not the label itself), near a pin for that pin's voltage, or the body of a two-pin part for its current.

YOU SHOULD SEE A trace named like **V OUT** or **I R1** appears on the scope, with its latest value in the header.

3 Press Esc to stop probing.

4 Hold the pointer over the plot to read every trace at that instant.

RESULT Probes are saved in the circuit. Simulate and the analyses plot them, and the report includes them. On an isolated side the probe is against that side's own ground and says so, **V OUT (ISO2)**. **Shift+click** reads against GND, **V OUT (vs GND)**.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A probe named after a pin, like **V C1 pin 1**	The net has no name. Label it (N) and probe the label.
"... already shows this net" and nothing new on the scope	That net or current is already probed. Its probe is selected and flashes on the canvas.

SEE ALSO **Adding probes**, p. 195, **The scope menu**, p. 202.

11.4 Measure time, amplitude and frequency with cursors and stats

Read a time difference, a level or a frequency off a plot.

1. Click **Cursors** in the dock header, or in the Analysis view's toolbar.

   YOU SHOULD SEE Lines A (solid) and B (dashed), with a readout.

2. Drag A and B to the two points.

   YOU SHOULD SEE The readout gives the time at each, Δ, 1/Δ in hertz, and each trace's value at A and B.

3. For levels, right-click the scope and choose **Show stats**.

   YOU SHOULD SEE Max, Min, Avg, RMS, P-P, Freq and Duty for each trace over the visible window.

4. For a steady picture of a periodic signal, choose **Rising edge** under Trigger in the same menu.

RESULT The same cursors work in the scope, the Bode and FFT tabs and the Analysis view.

SEE ALSO **Cursors**, p. 204, **The tools**, p. 252.

11.5 Run a transient with Simulate

Get a result you can measure, from t = 0 to a stop time, with vendor models where the circuit has them.

BEFORE YOU START Probes on the signals you want (P).

1. In the toolbar, set **Simulate for** (the stop time), for example **5m**.
2. Set **max step**, for example **1u**. Use a tenth of the fastest edge you care about.
3. Press F5.

   YOU SHOULD SEE The view splits: the schematic on top, the Analysis view below. The Simulate button shows the percentage and **Cancel** while it runs.

4. Hold Alt and click a net or a two-pin part on the schematic to add its trace. A plain click only selects.

RESULT Signals against time, ready for cursors, Export CSV and PNG. BetterSPICE chose the engine: the progress line says when it used ngspice or PSpice.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A red banner *Simulation failed:*	Read the reason and press **Dismiss**. **Models and the library**, p. 82 lists the usual ones.
Edges look rounded	Lower **max step** and run again.

SEE ALSO **Simulate (F5) and its engines**, p. 213, **Transient**, p. 228.

11.6 Find the frequency response and the phase margin

Plot gain and phase against frequency and read the –3 dB point and the margins.

1. Press F7.

   YOU SHOULD SEE The first time, Simulation setup opens on the **AC sweep** tab. Once the circuit has an AC setup, F7 runs it at once and F6 opens the setup.

2. Check **Input source**: the source that gets the 1 V small-signal stimulus. Its pick button lets you click the source on the schematic instead.
3. Set the range, for example **1** Hz to **1Meg** Hz, and **Points per decade**.
4. Click **Run AC sweep**, which also saves the setup.

   YOU SHOULD SEE A Bode plot of every probe. The strip above it gives the –3 dB frequencies and, for a loop, the gain crossover, the phase margin, the phase crossover and the gain margin.

RESULT A phase margin under 45° and a gain margin under 6 dB show in amber. The Bode tab in the dock keeps the last sweep.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
No margins in the strip	Margins need a loop gain that crosses 0 dB. Probe the loop, not the closed-loop output.
Unknown source	Choose one of the circuit's sources. The message lists them.

SEE ALSO **AC sweep**, p. 230, **Tutorial 2: Measure it exactly**, p. 19.

11.7 Sweep a part value and compare the curves

Run the same analysis for several values of one parameter, overlaid.

1. Press Shift + F7. The first time it opens the setup on the **Parameter step** tab. Later it runs the saved step.
2. In **Parameter**, type the part and key, for example **R1.r** or **C1.c**. The keys are in the device tables.

3. In **Values**, type up to 12 values separated by commas, for example **500, 1k, 2k, 4k**.
4. Choose the analysis in **Analysis to repeat**: **Transient**, **AC sweep** or **DC sweep**.
5. Click **Run parameter step**.

YOU SHOULD SEE One curve per value, named like **V OUT · R1.r = 2k**.

RESULT Each run uses the setup on its own tab. In the browser the values run in parallel.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
"X has no value "key", its values: ..."	Use one of the keys the message lists.

SEE ALSO Parameter step, p. 235.

11.8 Plot a transfer curve with a DC sweep

Sweep one source slowly and plot the steady result at each value.

1. Press F8. The first time it opens the setup on the **DC sweep** tab. Later it runs the saved sweep.
2. Choose the **Swept source**: a DC voltage or current source.
3. Set **Start value**, **Stop value** and **Increment**, for example **0**, **2**, **5m**. The defaults are 0 to twice the source's value in about 500 steps.
4. Click **Run DC sweep**.

YOU SHOULD SEE The probes against the source value.

RESULT For a diode in series with 100 Ω the current stays near zero until about 0.6 V, then rises steeply.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A battery can't be swept	Use a DC voltage or current source.

SEE ALSO DC sweep, p. 232.

11.9 Find the DC operating point of every net

Get a table of every net voltage and every part current at DC.

1. Press F9.

YOU SHOULD SEE A table: probes first, then **V(net)** for every net, then **I(part)** and, for runs in the BetterSPICE engine, **P(part)**.

2. Type in the filter box to find a row.
3. Click **Export CSV** to keep it.

RESULT Nets are named after their labels, so label them. A value that's only solver residue, such as a femtovolt on a net that's really at 0 V, reads 0. Hold the pointer over it for the exact value. **Copy as table** keeps the raw numbers.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
W_GMIN_SHUNT	Some net has no real DC path. Give it one.
W_DC_CYCLE	The circuit oscillates and has no DC point. Use a transient.

SEE ALSO Operating point, p. 233.

11.10 See the spectrum and distortion of a signal

Turn a waveform into a spectrum and compare the harmonics with the fundamental.

BEFORE YOU START A probe on the signal, and a Transient stop time long enough for many periods.

1. Press Shift + F8. The first time it opens the setup on the **FFT** tab. Later it runs the saved FFT.
2. Choose the **Signal** (a probe) and a **Window**: **Blackman** for distortion, **Rectangular (none)** for signals periodic in the window.
3. Set **Use data from** past the start-up, for example **10m**.
4. Click **Run FFT**.

YOU SHOULD SEE The spectrum in dB. The harmonics sit below the fundamental by the distortion.

RESULT For a quick look while it runs, choose **FFT** on a trace in the scope menu: the FFT tab shows it live.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
Asks for a longer stop time	Fewer than 16 samples were left. Lengthen the Transient stop time.

SEE ALSO FFT, p. 241, FFT tab, p. 205.

11.11 Check a power supply: start-up, load step and ripple

Measure how a supply starts, how it answers a load change and how much ripple it leaves.

BEFORE YOU START A supply circuit. The examples in **Linear regulators** and **Switching converters** are ready to use. **LDO load-transient response** already has a load step.

1. Probe the output and the input (P).

2. For a load step, place a current source (I) from the output to ground. In the inspector, change its **Source type** to a pulse and set the two load currents.
3. Set **Simulate for** past the start-up and the step, and **max step** to a tenth of the switching period, for example **50n** for 1 MHz.
4. Press F5.

   YOU SHOULD SEE The output rising with its soft start, then the dip and recovery at the load step.
5. Zoom to the end of the run, turn on **Cursors**, and read the ripple peak to peak.

RESULT Start-up time, the dip and its recovery, and the steady ripple, from one run. The report (Ctrl + Shift + G) also lists the ripple over the last 20 % of each probe.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
Ripple far smaller than expected	Lower **max step**: a large step smooths the switching edges.
The run is very slow	Shorten **Simulate for**, or set **Start saving at** to skip the start-up.

SEE ALSO Tutorial 3: A regulator with a vendor model, p. 25, Transient, p. 228, Generate report, p. 583.

11.12 Check a circuit across component tolerances

See how far a result moves when the parts are off their nominal values, and how many builds would still meet the specification.

BEFORE YOU START A circuit with a measurement that has limits, for example the -3 dB frequency of a filter between 1.5 kHz and 1.7 kHz (Set a pass or fail limit on a result, p. 59). A resistor counts as 1 %, a capacitor as 10 % and an inductor as 20 % until you set a tolerance.

1. Select a part and set **Tolerance** in the inspector, for example 5 for a capacitor. Under **All parameters** choose **Tolerance distribution**: Gauss, or Uniform.
2. Press Shift + F9. The first time it opens the setup on the **Tolerance** tab.
3. Choose the **Analysis to repeat**, for example AC sweep. Choose **Monte Carlo** and **Runs** 200, or **Worst case**.
4. Click **Run tolerance**.

   YOU SHOULD SEE All runs drawn over each other with the nominal run on top, then a histogram of each measurement, the yield and a bar per part.
5. Type the lowest and highest allowed value under the histogram.

   YOU SHOULD SEE The share of runs inside shows at once as the yield.

6 Read **Which parts matter**. Tighten the part with the longest bar first.

RESULT The spread of the result with its mean, sigma, minimum and maximum, and the yield. The same seed gives the same runs, here and in **bspice**. **Export CSV** writes one row per run.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
No yield is shown	Measurements without limits cannot fail. Type the limits under the histogram, or set them in the measurement.
The yield is lower than expected	A run the engine could not solve counts as a failure. Open the table to see how many.
Worst case gives a mean and sigma that look odd	Worst case runs corners, not a random sample. Read its minimum and maximum.

SEE ALSO **Tolerance**, p. 237, **Measurements**, p. 253, **Parameter step**, p. 235 for one part at a time.

11.13 Set a pass or fail limit on a result

Name a result of a run, such as a rise time or a -3 dB frequency, and have the app judge it against limits.

BEFORE YOU START A circuit with a result on screen, for example an AC sweep of a filter.

1 Run the analysis. Under the plot, the **Measurements** panel opens.

2 Click **Add measurement**.

3 Choose what to measure, for example the -3 dB frequency, and the signal, for example **V out**.

4 Type the lowest and highest allowed value, for example **1.5k** and **1.7k**, and click **Add**.

YOU SHOULD SEE A row with the value and **PASS** or **FAIL**.

RESULT The measurement is saved in the circuit and evaluated after every run. In a parameter step it is shown for every value. In a tolerance analysis it is judged in every run, which gives the yield.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
FAIL and a reason	A limit on a value that cannot be measured counts as a FAIL and the row says why. For a rise time, start the window before the edge and end it after the output has settled.
The measurement is not listed after another analysis	The panel lists the measurements that fit the analysis on screen. Run the kind of analysis the measurement reads.

SEE ALSO **Measurements**, p. 253.

11.14 Compare a run with an earlier one

Keep results on screen and see how a change moves the next one.

1. Run a transient, DC sweep or AC sweep.
2. Click **Keep as reference** in the Analysis toolbar.
3. Change the circuit, for example a capacitor value, and run the same analysis again.

   YOU SHOULD SEE The kept traces are drawn dashed behind the new ones.
4. Hold the pointer over the plot.

   YOU SHOULD SEE The readout shows the difference of each trace to the reference.
5. Keep more runs the same way (up to five, each in its own colour). Click a run's chip to hide or show it.
6. Click the × on a chip to delete that run when you are done.

RESULT The kept runs are not saved with the circuit. Only runs of the same kind are drawn against them.

SEE ALSO Keep as reference, p. 254.

11.15 See where the power goes in a circuit

Watch the power move through the circuit and read the input, the output and the losses.

BEFORE YOU START A running circuit with a load. A resistor named RL, RLOAD or LOAD, an LED, a lamp or a motor counts as the load.

1. Press Alt + E, or click the lightning bolt in the toolbar.

   YOU SHOULD SEE Bands lie on the wires that carry power. Parts that give power have an orange outline. Parts that make heat get an orange wash.
2. Read the ledger in the corner: **Input**, **Output**, **Losses**, **Efficiency** and **Energy held**.
3. Click a row of the ledger to select that part.
4. Switch between **Average** and **Instant** to see the ripple.

RESULT The **Residual** is zero when every pin current is accounted for. The panel says *Does not balance* in red when it is not.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
Not measurable at this timebase	A switching circuit has edges faster than the engine's steps. Use a slower timebase or **Instant**.
No efficiency	The circuit has no part the app takes as the load. Click **Load** on the resistor's row.

SEE ALSO **Energy view**, p. 184.

11.16 Fix a run that will not converge

Get a run past a Newton or time step failure and keep the fix.

1. Run the circuit. The engine retries by itself and keeps the first setting that works.

   YOU SHOULD SEE A **W_CONVERGENCE_AIDS** row in Diagnostics (Alt + 6) says which setting worked and names the part at fault where it can.

2. Read the sentence in the row. It often names the cause: a switch that flips in no voltage range, a source edge of zero time, an ideal source on a gate.

3. To run that way from the start, click **Fix convergence** in the row.

   YOU SHOULD SEE The setup now holds the method, maximum step or gmin. Ctrl+Z takes it back.

4. Better, fix the cause the row names.

RESULT A run that converges the first time is never touched. If the doctor finds nothing that works, the run stops with the error and the part with the largest update.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
The row has no button	The setting cannot be saved in the setup. Follow the sentence in the row.

SEE ALSO **Convergence doctor**, p. 222,
Red Halted, a red badge, or a diagnostic code, p. 79.

11.17 Measure voltage and current at one point

Read the voltage and the current of one place, on the scope and in a tag on the schematic.

1. Press P and click a pin of a two-pin part, or the wire between two part pins.

2. Select the probe. In the inspector, set **Measures** to **Both**.

   YOU SHOULD SEE The scope gets two traces: volts on the left axis, amps on the right.

3. Set **Tag** to show the voltage and the current on the canvas, for example **OUT 4.98 V 1.21 A**.

RESULT The Analysis view plots the same two quantities. The current is the current into the part's first pin.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
Current is not offered	On a net where several pins meet there is no single current path, so only voltage is offered. Probe a pin of a two-pin part instead.

SEE ALSO **A probe for voltage, current or both**, p. 196.

11.18 Zoom a paused trace to fit the screen

Look at a small detail of a paused run with the vertical axis fitted to it.

1. Press Ctrl + R to pause.
2. Zoom the time axis on the scope with the wheel or by dragging a box.

   YOU SHOULD SEE The vertical axis fits the traces in view, as in the Analysis view.
3. To keep the axis of the whole record instead, click **Fit Y** in the dock header, or turn off **Scale, Fit Y to the zoomed view when paused** in the scope menu.

RESULT The choice is remembered. While the run is going the scale works as before.

SEE ALSO **The scope**, p. 198.

11.19 Look at digital signals on the logic analyzer

See gates, counters and buses as high and low lines with their values.

1. Press Alt + 4.

   YOU SHOULD SEE The Logic tab lists the digital outputs of gates, flip-flops, counters and control blocks.
2. To add an analog net, right-click its wire and choose **Add to logic analyzer...**. Give the threshold in volts (1.65 for 3.3 V CMOS).
3. Set **Trigger** to **Normal**, choose the signal and **Rising edge**. **Single** waits for the next edge after you arm it, then pauses with the window held on that edge.
4. Click one edge and **Shift-click** another.

   YOU SHOULD SEE Δt and 1/Δt at the top right.

RESULT The picture locks on each trigger. Double-click the plot to follow the live time again.

SEE ALSO **Logic analyzer**, p. 207, **Digital logic**, p. 364.

11.20 Go back in time in a paused run

Pause the live simulation and look at any instant since the start of the run.

1. Press Ctrl + R to pause.

   YOU SHOULD SEE A **Go to** bar appears under the scopes. Paused, the scopes hold the whole run.

2. Type a time in the box, for example **65.5m**, and press Enter, or drag the slider.

   YOU SHOULD SEE An orange playhead on every scope, with the value of each trace at that time.

3. Zoom one scope with the wheel: linked scopes follow and centre on the playhead.

4. Press Ctrl + R to run again. The playhead goes away.

RESULT A very long run keeps all of it at a coarser spacing, so a short early spike can look thinner than it did live.

SEE ALSO **Scrubbing a paused run**, p. 201.

12 Build parts and choose models

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12.1 Choose the model a part uses

Give a placed part a manufacturer's model, so Simulate runs the real part.

1. Double-click the part, or select it and press Ctrl + M.

   YOU SHOULD SEE The model dialog on the **Library** tab, listing models that fit this kind of part.

2. Type the part number in the search box. Filter by maker or format with the chips.

3. Click a row to see its maker, pins, status and the **Live view** line on the right.

4. Click **Assign**.

   YOU SHOULD SEE A message confirms it. The inspector header names the model.

RESULT Assign is one undo step. It sets the model, the pin map and the live values, and the file Simulate loads.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
"its N pins (...) do not match this op-amp"	Place the model from the library instead, so it brings its own pins.
"encrypted: Simulate cannot run it"	Choose another model of the part, or install PSpice for TI if it's a TI model.

SEE ALSO **Library tab**, p. 409, **Tutorial 3: A regulator with a vendor model**, p. 25.

12.2 Get a model from datasheet numbers

Build a working model from a few datasheet numbers when the library has none. Resistors and capacitors need none: type their value.

1. Select the part and press Ctrl + Shift + M.

   YOU SHOULD SEE The Quick model tab: datasheet fields on the left, fitted parameters on the right.

2. Type the values from the datasheet, for example for a MOSFET V_GS(th) **1.8**, R_DS(on) **8m** at V_GS **4.5**.

   YOU SHOULD SEE The fitted parameters update as you type.

3. Click **Apply**.
4. Optional: click **Save as .bspart** to keep it as a part file.

RESULT The part now behaves as the datasheet says at the test point. A part that had a vendor model is renamed *model* (fitted) and no longer loads the vendor file.

SEE ALSO **Quick model tab**, p. 415.

12.3 Run a program on a microcontroller

Write a short program for a microcontroller and watch its pins drive the circuit around it.

BEFORE YOU START A circuit with a supply, and an LED with a resistor to wire to the chip.

1. Place the generic MCU (type **microcontroller** in the library search) and wire VDD and GND.
2. Select it, click **Code** in the inspector and pick a **Template...**, for example **Blink**.

   YOU SHOULD SEE The chip grows a pin for every **pin** and **bus** line.

3. Wire the new pins to the circuit and press Ctrl + R. Edit the program in the code box and click away to apply it.
4. Open Diagnostics (Alt + 6) if the status line under the code shows a warning, and add what it says: a pull-up, a series resistor.

RESULT The program runs in simulated time and drives the pins like real ones. Probe a pin to see it on the scope.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A red line in the code box	The status line says what to write instead, for example a unit after **wait**.
W_MCU_PIN or **W_MCU_BUS**	A floating input, an overloaded pin or a missing I²C pull-up. **Warnings you may see**, p. 389 lists each fix.

SEE ALSO **Programming the MCU**, p. 373, **Templates and examples**, p. 392.

12.4 Make a part from a datasheet

Turn a datasheet into a part file with min, typ and max values, pins and an optional symbol and SPICE model.

1. Press Ctrl + Shift + N and choose a template, for example **Power · LDO regulator IC**. Or type a part number in step 1, for example **TL431**: when the library knows it, a line says *TL431 is a Voltage reference in the library*, and **Start from it** fills the template, the part number, the maker and the description.
2. Type the part number and the manufacturer (already filled if you started from a part number).
3. Fill in the electrical values with their datasheet pages. Fields marked * are required for simulation.
4. Pick the package (SOT-23-5, SOIC-8, ...), name the pins as the datasheet does and click **Auto-assign functions**, then check each device pin has a package pin. Optionally draw a symbol, import a KiCad one or pick one from My parts.
5. On step 7, press **Run the test circuit** to compare the model with your values, and attach the vendor SPICE file if there's one.
6. On step 8, click **Save to My parts**.

   YOU SHOULD SEE The part appears in My parts at the top of the library.

RESULT A **.bspart** file. The live model uses the typical values. Progress is saved as you type, so you can close the wizard and come back.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A red check in **Checks**	Click it to jump to its step. The field itself says what is wrong.
Save to My parts is greyed	A check still fails. **Download draft** saves the file as it is.
Change a saved part	Press **Edit part** on it in My parts.

SEE ALSO Tutorial 4: Make a part with the Part Wizard, p. 28, Part Wizard, p. 420, Part templates reference, p. 606.

12.5 Add a datasheet graph to a part

Put a graph from a datasheet into a part file, and fit the model to it where the model can use it.

BEFORE YOU START The Part Wizard open on step 6, **Curves**.

1. Find the editor for the graph, for example **Output capacitance vs drain voltage**.
2. If the datasheet has a table, copy two columns and press Ctrl + V on the grid.

   YOU SHOULD SEE The rows appear in the grid with the units converted.
3. If you only have the graph, paste a screenshot (Win + Shift + S, then Ctrl + V) or drop the image file on the area, and click **Digitize an image**.

4. Click two known ticks on the x axis and type their values, say whether the axis is linear or logarithmic, then do the same for y.
5. Click along the curve, or pick the curve's colour and press **Trace the colour**. Remove strays with **Undo last**, then press **Use N points**.
6. Press **Fit to the model**, check the dashed curve and the error, and press **Apply to the model**.

RESULT The curve is saved with the part and marked *read by eye* if you digitized it. The fitted parameters appear on step 7.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A unit error under the grid	The unit does not fit the axis. Type the value in the unit the axis shows, or let the header carry it.
A warning that the model is far from the points	The model's equation does not describe this part well, for example a square law against a power MOSFET at high current. Keep the curve and leave the fit out.

SEE ALSO Step 6: Curves, p. 427.

12.6 Draw or edit a symbol

Draw a schematic symbol with the pins where you want them.

1. Press Ctrl + Alt + B, or **Edit symbol** on a row in My parts.
2. To begin from an existing symbol, use the **Start from** card: type a name and pick a library symbol, or click **Import .kicad_sym...** to read a KiCad symbol library (the other symbols of the file are offered in the same search as *kicad: NAME*). Its body, pins and drawing are copied in, in one undo step. Or start empty:
3. In **Pin list**, type one pin per line as **number name function**, for example **1 VIN in**.
4. Click **Auto-place pins**.

   YOU SHOULD SEE The pins laid out as an IC box: supplies on top, grounds at the bottom, inputs left, outputs right.
5. Fix anything the **Audit** card lists. Saving is off while it shows errors.
6. Click **Save to My parts**.

RESULT A **.bssym** file in My parts, or the symbol inside the part you were editing.

SEE ALSO Symbol editor and My parts, p. 433.

12.7 Run a model that is encrypted

Simulate a Texas Instruments model that only PSpice can read.

BEFORE YOU START The desktop app and PSpice for TI, installed free from ti.com.

1. Place or assign the model. Its library row says *"Cadence-encrypted, verified in PSpice"*.
2. Probe at most four signals: PSpice for TI keeps no more.
3. Close any PSpice window of your own.
4. Press F5.

YOU SHOULD SEE The progress line says **in PSpice (encrypted vendor models)**. The result appears like any other run.

RESULT The whole circuit ran in PSpice, hidden. The live simulation uses parameters fitted in PSpice, so it's approximate.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A message that names PSpice for TI	It's not installed, or **BSPICE_PSPICE** points elsewhere.
E_MODEL: needs PSpice for some parts and ngspice for others	Replace the parts on one side.

SEE ALSO **PSpice for encrypted models**, p. 224.

12.8 Replace a model that does not run

Get a working model for a part whose model fails.

1. Read the diagnostic (Alt + 6). It names the part and the file.
2. Double-click the part and search its part number.
3. Choose a row with a green or amber dot, from another library if needed, and click **Assign**.
4. If nothing fits, build one with Quick model (Ctrl + Shift + M).

RESULT Models that fail in every engine aren't in the library at all. Where a working model of the same part exists, placing the broken one places that instead, with a message.

SEE ALSO **Retired models**, p. 406, **Models and the library**, p. 82.

13 Bring work in and out

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13.1 Import a KiCad or EasyEDA Pro design

Open a schematic from another tool as a circuit that runs.

BEFORE YOU START For a hierarchical KiCad design, a zip of the whole project folder.

1. Press Ctrl + I and choose the file: **.kicad_sch**, **.kicad_pro**, a project **.zip**, **.epro** or **.eprj**. You can also drop the file on the window.

   YOU SHOULD SEE *"Importing <file>..."* while it runs, then a new tab and the **Import report**.

2. Read **Not recognised** in the report: parts placed as boxes. Click a row to select and zoom to its part.

3. Click **Assign model...** on each IC that matters. **File** › **Import report...** reopens the report later.

4. If the report added no supply, place a DC source on the supply net.

5. Press Ctrl + R if the circuit is paused.

   YOU SHOULD SEE The board runs. Hold the pointer over a net to read its voltage.

RESULT Every net keeps the same pins as in the source. The report says how many it checked.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
"No supply in the imported circuit: add a DC source"	Place a DC source on the supply net.
E_IMPORT_FORMAT	KiCad 5 files aren't read. Save the design in KiCad 6 or later.

SEE ALSO Importing KiCad and EasyEDA Pro, p. 577.

13.2 Save a picture, a plot or the data

Get the schematic, a plot or the numbers into a document or a spreadsheet.

1. For the schematic, press Ctrl + Shift + P. Choose **SVG** for documents or **PNG** for slides, and **Light (print)** colours. **Copy PNG** puts the picture on the clipboard for a chat or a slide.
2. For a plot, click **PNG** in the Analysis view's toolbar.
3. For data, click **Export CSV** in the Analysis view, or right-click a scope and choose **Export CSV**.

RESULT Files named after the circuit, such as **rc-filter.svg**, **transient.csv** or **scope1.csv**.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
"Nothing to export: the sheet is empty."	Open the circuit you meant, or draw something first.
"Nothing to export: run an analysis first."	Run the analysis, then export.

SEE ALSO Export and reports, p. 581.

13.3 Write a report

Make one file that shows the circuit, every analysis you ran and whether it passes.

BEFORE YOU START A circuit you have run. The report covers the analyses run in this session.

1. Press Ctrl + Shift + G.

   YOU SHOULD SEE A dialog with one tick box per section.
2. Tick the sections you want. Tick **Run what is missing** to run analyses you have not run yet.
3. Press **Generate**.

   YOU SHOULD SEE A panel at the bottom shows the step, the runs and the time. Desktop: then a Save dialog for **name-report.html**. Browser: the file downloads.
4. Open the file in a browser and print it to PDF if you need one.

RESULT One HTML file with the fonts inside. The summary lists every named measurement with PASS or FAIL and four verdicts. Further sections hold the parts against their ratings, each analysis, the tolerance results, the spectrum, the diagnostics and the netlist.

SEE ALSO Generate report, p. 583.

13.4 Send a circuit to someone who has no BetterSPICE

Let someone open your circuit and watch it run in a browser, with nothing to install.

1. Choose **File** › **Share link...**.

   YOU SHOULD SEE The dialog shows the link, its length and the viewer address.

2. Click **Copy link** and paste the link into your message.

3. If the dialog says the link is too long or too big, choose **File** › **Export interactive HTML...** instead and attach the file.

RESULT The circuit travels inside the link, after the **#**, and nothing is uploaded. The other person sees it running with the scope, the sliders and the inspector.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
The dialog offers no link	The viewer address is still the placeholder. Type your viewer address in the dialog, or use Export interactive HTML.
A part runs as a generic device in the viewer	The viewer has no vendor model library. Open the circuit in the desktop app once, so it stores the live equivalent in the file.

SEE ALSO Share link and interactive HTML, p. 587, The browser viewer, p. 589.

13.5 Export a netlist for another simulator

Write the circuit as a SPICE netlist that ngspice runs.

1. Press Ctrl + Alt + N.

   YOU SHOULD SEE A message says where the **.cir** file went and how many symbol-only parts were left out.

2. Run it with **bspice ngspice file.cir**, or in ngspice.

RESULT Hierarchical sheets are flattened and every model parameter is written out. Behavioural parts that ngspice has no equivalent for become comments.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
E_EXPORT	The message gives the first problems and their fixes. The rest are in Diagnostics.

SEE ALSO Export SPICE netlist, p. 582, Files and formats, p. 572.

13.6 Run simulations from a script

Check and simulate circuits without the window, for scripts and build servers.

1. Open a terminal in the install folder, or add it to your path.

2. Check a folder of circuits: **bspice validate examples**.

3. Run an analysis to CSV: **bspice tran rc.bsc —stop 10m —max-step 10u —out run.csv**.

4 Use the exit code: 0 success, 1 diagnostics with errors, 2 a usage error.

RESULT The same engine and the same files as the app. Vendor-model runs need the app, or **export-spice** and **ngspice**.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
Unknown option	The message lists the options that command knows.
A value a thousand million times off	On the command line **1M** is milli. Write **1meg**.

SEE ALSO **The command line (bspice)**, p. 596.

13.7 Hand a task to an AI agent and check what it did

Let an AI agent edit and simulate the circuit you have open, while you watch.

BEFORE YOU START Claude Code (or another MCP client) set up with the **bspice mcp** server (**Setting up Claude Code**, p. 591).

1 Open the circuit in the desktop app.

2 Ask the agent, for example *"Add a 10 µF output capacitor and show me the ripple."*

YOU SHOULD SEE A bar at the top of the canvas names the agent and what it's doing. Its cursor moves to each part it touches.

3 Press Esc or **Take over** at any time to stop it.

4 Open **Activity** (Alt + 7) to read every edit and run it made.

5 Press Ctrl + Z to undo any of its edits.

RESULT Parts it changed carry an **AI · *name*** badge in the inspector. Parts and symbols it creates go to My parts.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
AI agents cannot connect	Set **BSPICE_PORT** to a free port for both the app and the agent.

SEE ALSO **Working with an AI agent**, p. 591.

14 Design with the calculators

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14.1 Size a part with a calculator and place it

Work a value out with one of the 17 calculators and put it into the circuit.

BEFORE YOU START An open circuit. To fill the calculator from parts, select them first.

1. Press Ctrl + Shift + C and type what you want, for example **led** or **divider**, then Enter.

   YOU SHOULD SEE The calculator window opens on it. With parts selected, the calculators that fit them are listed first, with their values filled in.

2. Type the values you know. Press **SOLVE** above the value you want worked out.

   YOU SHOULD SEE That field reads SOLVED and shows the result. The tiles, warnings and plot follow every change.

3. Read the amber warnings: each says what is off and what to change.

4. Press the orange place button, such as **Place and run AC analysis**, or **Apply to the selected ...** to write the value into the parts you selected.

RESULT The circuit is placed at a free spot with its source and probes, and its analysis runs. One Ctrl + Z takes it all away again.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
Apply to the selected ... is missing or greyed	It needs the right parts selected: two resistors for the divider, an inductor and a capacitor for LC.
Names changed to V2 or OUT2	The circuit already used those names. The measurements follow the new names.
The values are not the ones you typed last time	Values are kept while the app runs. **Reset to the defaults** starts over.

SEE ALSO The calculator window, p. 441, and each calculator's own chapter.

14.2 Check a calculator design in the simulator

Run the design a calculator gives in the simulator, with the calculator's numbers as the pass limits.

1. In the calculator, press **Advanced** beside its title.

   YOU SHOULD SEE The Advanced view: tabs with green, amber or red dots, the inputs on the left, the cards on the right.

2. Fix what the red and amber checks say, then open the last tab, **Verify in simulation**.

   YOU SHOULD SEE A table of each check, the calculator's value, the analysis that checks it and its limit.

3. Press the place-and-run button, such as **Place circuit and run AC** or **Run corners**.

RESULT The circuit is placed and run, and the Measurements list marks each check **PASS** or **FAIL**, with **All pass** in its header when every one passes.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
A row says *not simulated*	The engine has no model for it (light output, board heat, antennas). The row says why.
A measurement fails	Read its value against its limits in the Measurements list, then the Verify table's method column: it names what the simulator does differently.

SEE ALSO Placing the circuit and checking it, p. 449.

14.3 Design a buck or boost stage and pick its inductor

Size a switching stage over its input range and choose a real inductor and regulator from the library.

1. Open the buck and boost stage (type **buck**) and press **Advanced**. Choose Buck or Boost, the rectifier and the control.

2. Type the input range, the output, the load, the switching frequency and the ripple target.

   YOU SHOULD SEE L needed, the three peak currents (full load, current limit, start-up), the efficiency and the warnings.

3. Open the **Inductor** tab and press **From library**.

   YOU SHOULD SEE The inductors that fit the L window, each with the whole design worked out, the best first.

4. Select a row and press **Use this part**. For the controller, press **Regulator from library** in Controller limits.

5. Open **Verify in simulation** and press **Run three corners**.

RESULT The stage runs at Vin min, nominal and max with the part's own saturation curve, and twelve measurements pass against the calculator.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
No inductor passes	Widen the L window or the size filters, or tick **Parts with no Isat in the catalog**.
On-time at Vin max is ... under the ... minimum	Lower the switching frequency to the value the warning gives.

SEE ALSO Buck and boost stage, p. 515.

14.4 Choose an op-amp for a gain stage

Find the op-amps of the library that meet a gain stage's swing, speed, stability and DC error.

1. Open the op-amp gain (type **op amp**), press **Advanced**, and set the stage, gain, rails, signal and load.
2. Press **Op-amp from library**.

   YOU SHOULD SEE The filters are set from the design. Every op-amp in them is worked out, the best 30 get the full circuit analysis, and the table lists them by worst-case DC error.
3. Select a row to see where each of its figures comes from, then press **Use this part**.
4. Type the datasheet maximum for any figure the model lacks (the notes name them), then open **Verify in simulation** and press **Place with** the part.

RESULT The stage runs with the part's vendor model, and its gain is checked against the calculator.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
The part you want is not in the 30	Narrow the filters (GBW, slew, vendor, input type): the 30 are the best of what passes them.
A DC error far over the limit after Use this part	The model has no offset and 3 mV stands in for it. Type the datasheet Vos max.

SEE ALSO The op-amp picker, p. 503.

14.5 Size a PCB trace and check it in the circuit

Find the trace width for a current, then put the trace into a wire of your circuit with its hot resistance.

1. Open Trace current and width (type **trace**) and press **Advanced**. Type the current, the rise allowed, the copper and the length.

   YOU SHOULD SEE **Width to draw**, sized on the thinnest copper and the narrowest etch.

2. Close the window, click the wire the current flows in, and open the calculator again.

3. Open **Verify in simulation** and press **Insert in wire and run**.

RESULT R_TRACE sits in the wire at the trace temperature, the live view runs, and two measurements check the current and the drop against the calculator.

IF IT DOES NOT WORK

IF YOU SEE	DO THIS
Insert in wire and run is greyed	Select a straight horizontal or vertical wire at least 4 grid units long (8 for a via).
Both measurements fail	The wire carries more than the design current. Raise the current in the calculator.

SEE ALSO **Trace current and width**, p. 540, **Via current and parasitics**, p. 547, **Wire gauge and fusing**, p. 559.

PART

III

Fix a problem

Something stopped, reads 0 V or looks wrong. Find what you see on the screen, then the cause and the fix. Every diagnostic code is here too.

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15 Troubleshooting by symptom

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Find the line that matches what you see. Messages are quoted as the app shows them, so you can search this page for the words on your screen.

15.1 Nothing happens, or every reading is 0 V

First check. First look at the status bar: **Live MNA · WASM · running**, **· paused** or **· halted**.
Only a halt is also shown on the canvas.

WHAT YOU SEE	WHY	WHAT TO DO
Every voltage reads 0 V and the status bar says **paused**	The live simulation is paused.	Press Ctrl + R. The colours and readings start to move.
Every voltage reads 0 V and the status bar says **running**	The circuit has no source, or the source isn't wired in.	Place a source (V for DC, A for a sine) and wire both of its pins.
A wire ends in a pair of net labels instead of a line	Every route between its two ends would have run through another pin.	Nothing is wrong: the labels join the two ends. Move a part to make room and draw the wire again if you want a line.
Wires stay grey after you drew them	The wire ends aren't on pins, so nothing is connected.	Wires join only at their ends and at pins. Drag from pin to pin, or use the Wire tool (W) and click the pins.
An empty sheet with a start hint, and **idle** in the status bar	There's nothing to run yet.	Place parts, or click **Open an example** or **Import** in the hint. The live simulation starts on the parts by itself.
The scope shows one line, *"No probes yet. Select a part and press Add to scope, drag a trace name here, or"*, and a **Probe tool (P)** button	Nothing is probed.	Click **Probe tool (P)**, or press P and click a net, or select a part and click **Add to scope** (**Probe a signal and read it on the scope**, p. 53).
The scope shows a blur or a solid band	The window holds hundreds of cycles of the signal.	Zoom the scope in with the wheel while it runs: it samples faster and shows each cycle. Or press 1 (1 ms/s) or 2, or type a slower timebase in the toolbar.
An analysis key (F7, F8, Shift + F7 …) opens the setup instead of running	The circuit has no saved setup for that analysis yet.	Click **Run** in the setup. It's saved, and the key runs the analysis from then on. F6 opens the setup again.
In Split view, clicking the schematic selects a part instead of adding a trace	A plain click edits, as in the Schematic view.	Hold Alt and click the net or part to add its trace.

WHAT YOU SEE	WHY	WHAT TO DO
Esc didn't close the dialog	In a dialog field, the first Esc cancels that field's edit.	Press Esc again.
A key does nothing	A text field, a slider or a dialog has the focus.	Ctrl combinations and F-keys work everywhere. For a single-letter key, press Esc or click the canvas first. A focused slider keeps its arrow keys, a tick box its Space.
Probing a net adds nothing: *"... already shows this net"*	The net or current is already probed.	Nothing to fix. The existing probe is selected and flashes.

15.2 Red Halted, a red badge, or a diagnostic code

First check. First press Alt + 6: the Diagnostics tab names the part, the net and the fix. Click the row to zoom to it.

WHAT YOU SEE	WHY	WHAT TO DO
Red **Halted** button and **Halted · *code*** pill	The live simulation can't continue.	Click the button. Fix what the diagnostic says. The simulation restarts by itself.
E_NO_GROUND: *"The circuit has no ground."*	No 0 V reference.	Click **Add ground** in the Diagnostics row, or place a ground (G) and wire it to the 0 V side of the circuit.
E_FLOATING_NET: *"Net ... has no DC path to ground."*	A net joins only through capacitors or open gates, so nothing sets its voltage.	Click **Add 1 GΩ to ground** in the Diagnostics row, or add a resistor from the net to ground yourself, or connect the net. The badge clears.
W_ISO_TIED: *"Isolated ground ISO1 is joined to the main ground"*, and an amber tag **ISO1 tied to GND** on the canvas	A wire, label or main ground symbol sits on the isolated side, so the two grounds are one net.	Click **Show the tie** in the Diagnostics row to select the joining wires and labels, then delete them. Or click **Make it the main ground** if the two sides are meant to be one.
E_VSRC_LOOP	Two voltage sources, or a source and an inductor, in parallel.	Add a small series resistance (1 mΩ), or give the inductor a small **dcr**.
E_VSRC_SHORT: *"V1 is shorted"*	A wire joins both pins of a source.	Delete that wire.
E_NEWTON or **E_TIMESTEP** (didn't converge)	The solver could not find a solution at that instant, often at a hard switching edge.	The message names the part. Add series resistance, slow the edges of sources, or lower **max step**. In Simulate, try the Gear method (**Transient**, p. 228).
E_PARAM: *"R1 parameter r = 0 is out of range"*	A value outside what the part accepts.	Type a value inside the range the message gives. For a link, use a wire, not 0 Ω.
W_PARAM: *"V2: rise ... + width ... + fall ... is longer than the period ..."*	A pulse source whose edges and width don't fit in its period, so each pulse is cut off when the next period starts.	Do what the message says: make the width at most period − rise − fall, or the period at least their sum (**Pulse source**, p. 276).
A red line under a field, *"abc" is not a value: try 4k7, 10u, 1meg*, and a message *"... kept ..."*	The text isn't a number the part can take: not a number, zero for a resistance, or a negative delay.	Type a plain number or an SI prefix: **4k7**, **100n**, **1Meg**. A comma decimal (**1,5**) is refused. The line says what the field needs.

WHAT YOU SEE	WHY	WHAT TO DO
W_NO_MODEL: *"X3 has no model: assign one."*	An IC box or vendor part with no model.	Double-click the part and choose a model (**Choose the model a part uses**, p. 64). A blank Subcircuit / IC can instead be built: double-click it (**Editing a subcircuit**, p. 151).
W_MCU_PIN: *"U1 pin BTN floats ... so it reads random values"*	An MCU input that nothing drives rests at half the supply.	Write **pin BTN in pullup** in the code, or wire a 10 kΩ resistor to VDD or GND (**GPIO: outputs and inputs**, p. 381).
W_MCU_PIN: *"pin LED sources 40 mA (an MCU pin is rated about 25 mA)"*	The pin drives more than its limit, or two outputs are joined.	Add a series resistor (330 Ω for an LED) or drive the load through a transistor.
W_MCU_BUS: *"SDA ... has no pull-up resistor, so the transfer fails"*, and **OLED.ack** is 0	I²C lines are open-drain and go high only through pull-ups.	Add 2.2 kΩ to 10 kΩ from SDA and from SCL to VDD (**I²C**, p. 385).
W_MCU_BUS: *"no target answered (NACK)"*	The 7-bit address is wrong, or the target isn't powered or not wired.	Check the address in the datasheet (0x3C for an SSD1306), the target's supply and the wiring.
W_UART: *"framing error on RXD (the stop bit is low)..."*, and the text from the MCU is missing or wrong in the Console	A USB-UART bridge received a frame at another baud rate than its own, so the byte is dropped, or its RXD is wired to something that's not a UART signal.	Set the bridge's **baud** to the rate in the MCU's **bus ... uart** line, and wire the bridge's RXD to the MCU's TX (**Chips and displays**, p. 359).
The Console has no input bar, or text typed there goes nowhere, or an error line follows the → *text* line	The bar belongs to a USB-UART bridge. Without a bridge in the circuit there's nothing to send through. Text also needs the live simulation to have started, with the bridge powered above 2.5 V.	Place a **chip** of variant **usb_uart**, wire its TXD to the MCU's RX and its RXD to the MCU's TX, power its VCC, and press Play (**Console**, p. 210).
An MCU line is marked red in the code box, and the chip doesn't run	The program has a mistake, **E_SCRIPT**.	Read the status line under the code: it names the line and says what to write, for example **wait 10ms** instead of **wait 10** (**Errors in the code**, p. 379).
The MCU has no pin I declared	The code has an error above that line, or the name is a supply pin, or the program is the old script API (**fn step()**).	Fix the error shown under the code. Declare I/O pins with other names than VDD and GND.
A small open dot on a pin, **E_UNCONNECTED_PIN**	A pin with nothing on it, shown 1.5 s after your last edit. It's a warning.	Wire the pin, or leave it if it's meant to be open. **Wire it** and **Delete** in the Diagnostics row do it in one step.

15.3 The result looks wrong

First check. First ask which result you're reading: the live simulation or a Simulate run (**When to trust which result**, p. 34).

WHAT YOU SEE	WHY	WHAT TO DO
Live and Simulate disagree on an op-amp or regulator	The live simulation runs a model fitted to the vendor's. Simulate runs the vendor file.	Trust Simulate for numbers at the edges (clipping, rails, start-up).

WHAT YOU SEE	WHY	WHAT TO DO
An op-amp output stops short of the rail	The vendor model limits the swing, sometimes more than the datasheet.	Check against the datasheet. A model isn't the part.
Ripple or overshoot looks smooth or too small in Simulate	**max step** is too large for the fastest edge.	Set **max step** to a tenth of the shortest rise time and run again.
A capacitor starts charged, or a run skips the start-up	A part sets **ic**, or the circuit sets **uic**.	Check the Transient tab and the circuit settings (**Settings saved in the circuit**, p. 223).
The live simulation starts with every capacitor empty, but I expected the settled state	A circuit made with File → New starts at rest.	Untick **Simulate** › **Start at rest (power-on)** (**Start a circuit from rest or from the operating point**, p. 52). Examples and older files start settled.
An example shows the output settled from the first instant, with no start-up	Examples start from the DC operating point.	Tick **Simulate** › **Start at rest (power-on)** to see the power-on.
A probe on an isolated side reads a different voltage from the parts beside it: *"... (vs GND)"*	It was made with Shift+click, which measures against the main ground, so it includes the float of the isolated side.	Remove it and probe again with a plain click (*"... (ISO2)"*, against that side's ground).
A reading shows **0** and its tooltip gives a tiny number such as *–2.3 fV (solver residue)*	A value below a billionth of the circuit's own scale is solver noise and is shown as 0.	Nothing. The exact value is in the tooltip, and CSV and Copy keep the raw numbers.
An analysis tab says *No FFT result yet* (or another analysis name) with a **Run** button	Each analysis tab keeps its own result and this one hasn't been run.	Click **Run**. The other tabs keep their results.
A chip **Circuit edited since this run** above the result	Parts or wires changed after the run, so the plot may no longer match the circuit.	Run the analysis again (Ctrl + F5).
A warning that Simulate ran again from 0 V	ngspice found no DC operating point, common for some vendor op-amp models.	Nothing. The run starts from power-up, with every capacitor discharged.
The plot says a trace could not be read: *"this run has no signal for it"*	The signal isn't in this result, for example the AC current of a part that has none.	Probe a nearby net or part instead.
The Bode plot has no margins in the strip	The output trace never crosses 0 dB or –180°.	Margins exist only for a loop gain. Probe the loop, not the closed-loop output.
The FFT shows nothing, or asks for a longer stop time	**Use data from** is past the end of the transient.	Make the Transient stop time longer, or **Use data from** smaller (**FFT**, p. 241).
Run is greyed and *"Must be earlier than the stop time..."* under **Start saving at**	Nothing would be kept.	Set **Start saving at** below the stop time.
A DC sweep note: *"All signals skipped... only the probes were kept"*	The sweep was too long to keep every signal.	Probe the signals you need before the run.

15.4 Slow, stuck or busy

First check. First look at the Simulate button: while a run is going it shows the percentage, the seconds and **Cancel**.

WHAT YOU SEE	WHY	WHAT TO DO
The status bar says **Live MNA · JS**	A part isn't in the fast WebAssembly engine, so the whole live simulation runs in JavaScript.	Nothing is wrong. The results are the same, only slower. A diagnostic names the part.
A long run seems stuck	It's still running. Vendor models are slow: twenty of them can take 30 seconds.	Watch the progress bar. **Cancel** stops the run.
"A simulation is already running (N s, P %). Press Cancel to stop it, then Simulate again."	You pressed F5 during a run.	Wait, or press **Cancel** first.
"This run uses the built-in engine and cannot be cancelled; it stops by itself when it reaches the stop time."	Browser version: its engine runs to the end.	Wait, or shorten **Simulate for** next time.
"The circuit changed while the transient ran; its result was discarded."	You edited the circuit during a run.	Run it again after the edit.
The live simulation runs slower than the timebase	The computer can't keep up, so circuit time slows down rather than becoming inaccurate.	Use a slower timebase, or close pop-out windows.

15.5 Models and the library

First check. First look at the status dot of the model row: green runs as it is, amber after conversion, red has a stand-in.

WHAT YOU SEE	WHY	WHAT TO DO
ngspice not found in the status bar, or **E_NGSPICE_MISSING**	**ngspice.dll** isn't where BetterSPICE looks.	Reinstall, or set **BSPICE_NGSPICE** to its folder (**ngspice for vendor models**, p. 675).
A banner: *"Simulation failed:"* and a reason	The run failed: usually a missing model file, ngspice missing, or no convergence. For ngspice failures the banner gives a short summary (*"ngspice stopped at 2.158 ms: timestep too small near Q1"*, *"singular matrix at …"*, *"no DC operating point"*, *"could not find model …"*) with the likely cause and what to try. The part ngspice names is mapped back to your part.	Do what **Try** says. **Show full log** opens ngspice's own log, one line per line, with **Copy log**. The diagnostic code is in Diagnostics.

WHAT YOU SEE	WHY	WHAT TO DO
"timestep too small" with a TI op-amp model	The model's output clamps switch abruptly when the op-amp comes out of saturation (for example when a regulator leaves dropout).	Simulate already re-runs it once with convergence aids (warning **W_CONVERGENCE_AIDS**). If that fails too, lower the maximum step and set Gear in **Simulate** › **Setup**, and check that the op-amp's supply is within its rating.
An op-amp output is a solid band in Simulate, or a regulator loses regulation at a high input, while the live view is clean	The assigned model is a comparator, not an op-amp (TLV902x, TLV18xx, LMV393 …): in a linear loop it switches on and off. Some TI comparator models float their output to mid-supply above the supply rating.	Assign an op-amp model. Keep the supply of the part within its rating.
A run with an encrypted TI model stops	Another PSpice run is going.	Close your own PSpice and run again (**Run a model that is encrypted**, p. 67).
A **Needs PSpice** badge on a model row (**Needs PSpice · not found**, dashed)	The model is encrypted by Cadence. Only PSpice can run it. *not found*: PSpice isn't on this computer, so the fitted behavioural model is used (approximate).	Hover the badge for the steps. Windows: PSpice for TI. Linux: Wine + PSpice for TI. macOS: not available.
The status bar says **no PSpice** after **Accurate**	PSpice wasn't found (on Linux: Wine, or PSpice in its prefix, is missing). Everything else works.	Hover it for the steps, install, and restart BetterSPICE. It says **PSpice found** once it's there.
A message that a model was replaced when you placed it	The model fails in every engine, and a working model of the same part stands in.	Nothing. The stand-in is the same part from another library.
A model you knew isn't in the library	It can't run in any engine and was retired.	Look in **library/broken/index.csv** for the reason, and choose another library's model of the part (**Retired models**, p. 406).
"its N pins (…) do not match this op-amp: Simulate may wire it wrongly"	The model has another pin order from the symbol.	Place the model from the library instead, so it brings its own pins.
"No compatible model … Use the Quick model tab"	Nothing in the catalogue fits this kind of part.	Build one from the datasheet (**Get a model from datasheet numbers**, p. 64).

15.6 Files, import, agents and install

First check. First look at the message at the bottom of the window. It names the file and the reason.

WHAT YOU SEE	WHY	WHAT TO DO
A circuit dropped on the window opens as **… · not saved**	A dropped file opens as an unsaved copy, without its path.	Use **File** › **Open** (Ctrl+O) or double-click the file in Explorer to keep working on the file itself.
Ctrl+S on an example or an import asks for a name	They have no file of their own yet. A tab marked **example** isn't your file.	Choose a folder and a name. Later saves go there without asking. In the browser the name is asked for in the window, and Esc keeps the circuit unsaved.

WHAT YOU SEE	WHY	WHAT TO DO
Help › User manual (PDF) is missing	BetterSPICE didn't find **BetterSPICE-User-Manual.pdf** next to the app or in the repository, or the browser's server doesn't serve it. The user guide (**Help › User guide**, F1) is part of the app and is always there.	Put the PDF in **docs\manual** next to **betterspice.exe**.
I can't find a tab	Many tabs are open and the strip scrolls.	Click the down-arrow button at the right end of the tab strip for the list, or use the ‹ › arrows.
E_FILE: a file can't be opened or saved	Missing, read-only, a folder, over 64 MB, or not UTF-8 JSON.	The message names the file and the reason.
"Recovered N unsaved circuits from <date>. Save to keep it."	The app closed with unsaved work. Autosave kept a copy.	Save each recovered tab (Ctrl+S).
An imported board reads 0 V everywhere: *"No supply in the imported circuit: add a DC source"*	No source in the import, or ICs without models.	Add a DC source on the supply net, and assign models to the ICs that matter (**Import a KiCad or EasyEDA Pro design**, p. 69).
A hierarchical KiCad design imports without its sub-sheets	A single **.kicad_sch** can't bring its sub-sheet files.	Zip the project folder and import the zip.
AI agents cannot connect	The control port could not open, usually because another program uses it.	Set **BSPICE_PORT** to a free port for both the app and the agent (**Working with an AI agent**, p. 591).
An agent reports *"this ran headless on files, NOT in the BetterSPICE window"*	The agent didn't reach the running app, so it edited the file on disk.	Check the port and the token, then ask again (**Hand a task to an AI agent and check what it did**, p. 72).
The window opens off screen or squeezed	Window and pane sizes from a larger monitor.	**View** › **Reset pane sizes**. Sizes saved on another monitor are fitted to this one.
A pane shows **... stopped after an error** and a **Reload panel** button	The library, inspector, Measurements, Analysis view or scope dock met an error while drawing itself. Only that pane stops: the rest of the window, the canvas and the live simulation keep working, and the Console panel (Alt+5) has the line *"The ... panel stopped after an error: ..."*.	Press **Reload panel**: the pane starts afresh. If it stops again with the same circuit, save it and report it with the Console line (**Reporting a problem**, p. 85).

WHAT YOU SEE	WHY	WHAT TO DO
A notice **Some keys do not reach BetterSPICE** (or **A key does not reach BetterSPICE**)	Another program on the PC claims those keys for the whole PC, for example a graphics driver's recording keys, which can take Ctrl + Shift + C, Ctrl + Shift + S, Ctrl + Shift + G, Ctrl + Shift + M and Ctrl + Alt + L. Windows then gives the key to that program, never to BetterSPICE. The desktop app on Windows checks its keys shortly after start and names the commands that cannot get theirs. The notice waits while a dialog or menu is open.	Press **Keyboard shortcuts** in the notice: each taken key is marked there with *"Taken by another program on this PC"*. Pick another key for the command (a key you pick is checked at once), or free the key in the other program. **Don't show again** hides the notice for that set of keys. A key taken later is still announced. The command still runs from its menu.

15.7 Reporting a problem

1. Save the circuit (Ctrl + S). The file is plain JSON and holds everything needed to reproduce a result.
2. Write down what you pressed, what you expected and what you saw.
3. Copy the text of any diagnostic, banner or message.
4. Attach **%APPDATA%\BetterSPICE\betterspice.log**.
   Help › **About BetterSPICE** shows that folder.

16 Diagnostics and what they mean

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16.4 Every code, A to Z 89

BetterSPICE checks the circuit before every solve and while it runs. A problem becomes a diagnostic: a code, a sentence that names the part and the net, and the fix.

E_ codes are errors: the run stops. **W_** codes are warnings: it keeps running. Numbers in messages use engineering units, such as 4.7 kΩ or 1.5 µs.

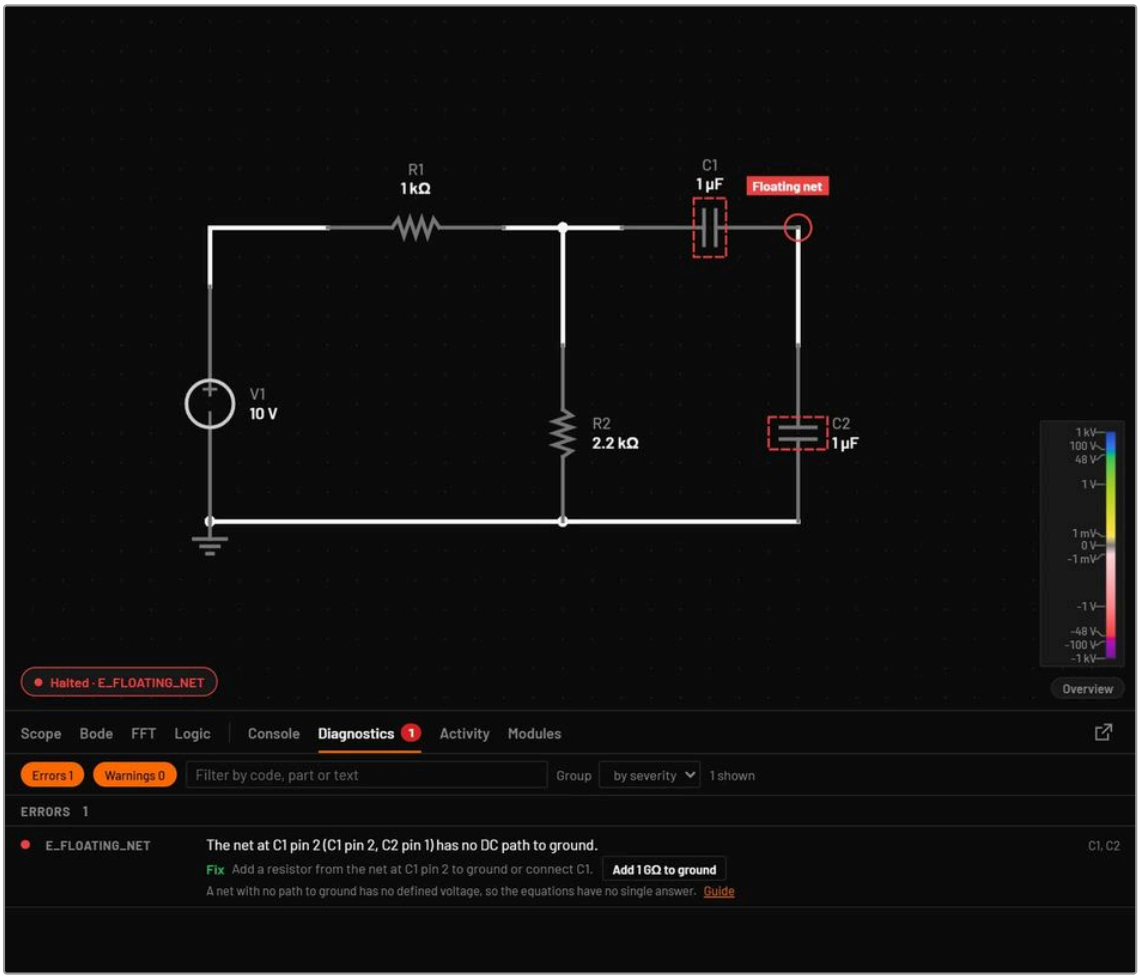


Figure 16.1 C2 leaves the middle net with no DC path to ground. The diagnostic names the net, the parts and the fix, with a quick-fix button.

16.1 Where diagnostics appear

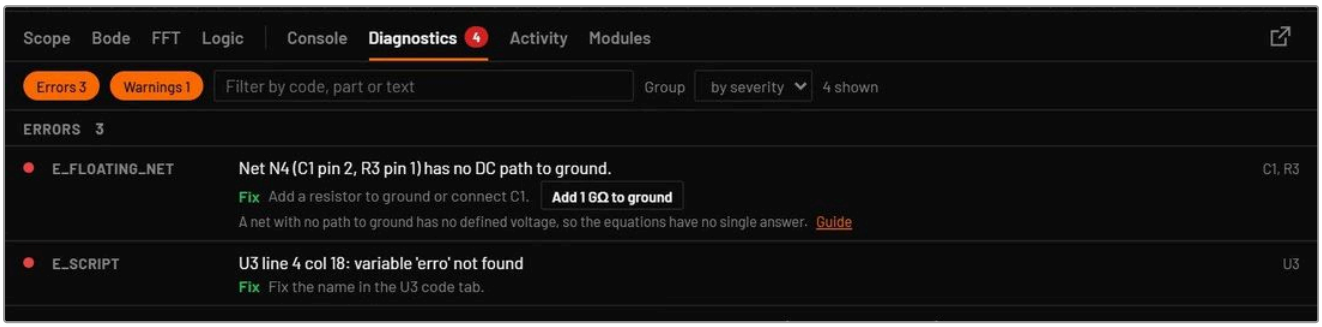


Figure 16.2 The Diagnostics tab: errors and warnings as chips, a filter box, Group, and a row with its fix, a quick-fix button and a Guide link.

- The **Diagnostics** tab (Alt + 6): one row per diagnostic with a red or amber dot, the code, the message, **Fix** with the advice, and the parts. Run-time problems add the circuit time.
- The status bar badge: the number of errors (red) and warnings (amber). The badge is red only when there's an error. Open pins are counted once your edits have paused for 1.5 s.
- Markers and tags on the canvas: a red or amber badge at the place of the problem, and short tags in words such as *ISO1 tied to GND* or *Floating net*. Hold the pointer over a marker for the text.
- The red **Halted** button and pill, which open the tab.
- A message at the bottom of the window for the most important ones, such as files that can't be opened.

The tab groups the rows by severity or by part (**Group**), hides errors or warnings with the two chips, and filters by code, part or text. Each row gives a one-line reason for its code and a **Guide** link. Long lists draw 100 rows at a time per group with a **Show more** button.

Click a row or a marker to ring the parts, select the first one and zoom to it. The rows can also be reached with Tab; Enter picks one. Some rows have quick-fix buttons, each one undo step: **Add ground** for **E_NO_GROUND**, **Add 1 GΩ to ground** for **E_FLOATING_NET** (placed in the first free direction from the net, so it never cuts a wire), **Wire it** or **Delete** for **E_UNCONNECTED_PIN**, and **Show the tie** and **Make it the main ground** for **W_ISO_TIED**. With no problems the tab says *"No problems. The circuit passed every pre-solve check."* Diagnostics from a failed analysis clear when a later run succeeds.

TRY IT

Find a floating net

1. Place a DC source, a resistor and a capacitor in series to ground, and a second capacitor from the middle to ground.
2. Look at the status bar.
3. Click the badge, then **Add 1 GΩ to ground** in the row.

YOU SHOULD SEE The badge turns red with **E_FLOATING_NET**. Clicking it rings the net and both capacitors. The quick fix adds the resistor and the badge clears.

16.2 The codes you meet most

CODE	WHAT IT MEANS	WHAT TO DO
E_NO_GROUND	The circuit has no ground.	Place a ground symbol on the 0 V net.
E_FLOATING_NET	Net N (pins…) has no DC path to ground.	Add a resistor from the net to ground, or connect the capacitor or gate that isolates it.
E_VSRC_LOOP	V1 and L1 form a loop of voltage sources and inductors, the current around it is undefined.	Add a series resistor, or give the inductor a small dcr.
E_NEWTON	Newton iteration did not converge at t = T, largest update in D2 …	Check that part's values and connections, add a series resistor, or lower the maximum timestep.
E_TIMESTEP	The time step fell below the minimum at t = T, Newton fails at … Or: time advances only … per step.	Add a gate resistor, slow source edges, raise the maximum step or shorten the run.
E_PARAM	R1 parameter r = 0 is out of range, allowed > 0. Or: is not a number. Also wrong PWL points, unknown power block kinds, bad filter coefficients, LUT tables, state machines, wire sizes, unknown variants, min-max order, unknown logic families.	Set the value inside the range given in the message.
W_NO_MODEL	X3 has no model: assign one. A Subcircuit / IC or vendor part with no model. Every chip variant has a model (the generic chip is an IC box that only loads its supply, without this warning).	Double-click the part and choose a model, or, for a blank Subcircuit / IC or a generic chip, choose **Edit subcircuit** and draw the inside.
E_UNCONNECTED_PIN	R1 pin 2 is not connected to anything. A warning, drawn as a small open dot 1.5 s after the last edit. **validate** also reports a net label that looks like a slip (VCX beside VCC, the same name in another case) and a part none of whose pins reaches anything.	Wire the pin or delete the part. The Diagnostics row has **Wire it** and **Delete**. Correct a mistyped label.
E_NGSPICE_MISSING	ngspice is not installed or not found.	Reinstall, or set **BSPICE_NGSPICE**.
W_NO_SOURCE	Nothing drives the imported circuit.	Place a DC source on the supply net.

16.3 Rejected edits

An edit that would break the circuit, for example a value that's not a number, is refused. It raises **E_OP** and a message *"Edit rejected (user): ..."*. A file that can't be opened or saved raises **E_FILE** with the reason.

16.4 Every code, A to Z

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
E_DESKTOP	Files, editing and the app	A failure reported by the desktop app's backend that came without a code, quoted as it was said.	See the message. It names the file or the command.
E_ENGINE	Files, editing and the app	The WebAssembly engine failed to load, the JavaScript engine runs instead. It runs every part type, more slowly.	Restart the app.
E_EXPORT	Files, editing and the app	The netlist export failed for a part.	The message gives the fix.
E_FILE	Files, editing and the app	A file does not exist, cannot be read or written, is a folder, is too large, or is read-only. Also an output that is the circuit itself (**export-spice x.bsc -o x.bsc**), and an MCP save over a file another session changed.	The message names the file and the reason. Write the output to another file, or open the circuit again with **open_circuit**.
E_FLOATING_NET	Circuit structure	Net N (pins...) has no DC path to ground.	Add a resistor from the net to ground, or connect the capacitor or gate that isolates it.
E_FORMAT	Files, editing and the app	An operating point asked for as CSV.	Use JSON for an operating point.
E_IMPORT_CHECK	Import	Connectivity differs from the source.	Check those parts by hand.
E_IMPORT_FORMAT	Import	Not a file the importer reads, a KiCad 5 schematic, or an archive without a schematic.	Export from KiCad 6 or later, or from EasyEDA Pro.
E_IMPORT_MISSING	Import	A sub-sheet or symbol is missing.	Import the project zip.
E_IMPORT_PARSE	Import	A syntax error at line and column.	Open and save the file in KiCad again.
E_INTERNAL	Files, editing and the app	An internal error.	Report it with the circuit file.
E_ISRC_OPEN	Circuit structure	I1 has no DC path for its current.	Add a resistor from the net to ground or across the source.

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
E_MEMORY	Simulate with vendor models	Simulation stopped at the memory limit: the run heads for more points than the limit holds (80 % of the free memory, or **—max-memory**, **maxMemory**, **BSPICE_MAX_MEMORY**). It names the points, the signals and the memory need. On the command line and MCP the run is refused before it starts, in the app a vendor run stops on its way.	Shorten the stop time, raise the maximum step in Setup (F6), or choose **Keep less and run again**: the probed signals keep every step and the other signals are left out. On the command line **—probes** does the same, or raise **—max-memory**.
E_MODEL (encrypted)	Simulate with vendor models	The model is encrypted for a simulator that cannot run here.	Choose an unencrypted model of the same part.
E_MODEL (files)	Simulate with vendor models	The model file was not found, is not installed, has no definition of that name, or a pin map points past its pins. **validate** reports a missing file too, naming the file and where it looked.	Choose the model again in Assign model, or set its file path.
E_MODEL (ngspice run)	Simulate with vendor models	*"ngspice (accurate mode) failed: …"* with ngspice's own lines. When a vendor model trips one of ngspice's internal consistency checks, the run stops here (**bspice** says *"ngspice stopped on an internal check: …"*). Before 0.8.1 such a check opened a **Microsoft Visual C++ Runtime Library: Assertion failed!** box with Abort, Retry and Ignore and held the run until someone clicked. Since 0.8.1 no box opens.	Check the vendor model named in the message, try a smaller maximum step or another solver setting in the Simulation setup, or simulate without that model.
E_MODEL (pins)	Circuit structure	U1 (opamp) has 4 pins, this type needs 3, 5, 7 or 8.	Place the part again from the library.
E_MODEL (PSpice)	Simulate with vendor models	PSpice is busy, or reported an error.	Close your own PSpice, or fix the named part.
E_MODEL (sheets)	Parameters and models	A sheet refers to a file that is not loaded, cannot be read, or nests more than 16 levels.	Put the file next to the parent, or remove the recursion.
E_MODEL (Simulate only)	Parameters and models	X3 (vendor model …) is accurate-only: it runs in Simulate, and the live simulation leaves its pins open. A warning.	Press Simulate, or give it a behavioural equivalent.
E_MODEL (two simulators)	Simulate with vendor models	The circuit needs PSpice for some parts and ngspice for others.	Replace one side.
E_MODEL (type)	Circuit structure	X1 has type t, which the engine does not support.	Replace it with a supported part.
E_NEWTON	Running	Newton iteration did not converge at t = T, largest update in D2 …	Check that part's values and connections, add a series resistor, or lower the maximum timestep.
E_NGSPICE	Simulate with vendor models	ngspice failed. Its message is quoted.	Fix the circuit as the message says.

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
E_NGSPICE_MISSING	Simulate with vendor models	ngspice is not installed or not found.	Reinstall, or set **BSPICE_NGSPICE**.
E_NO_GROUND	Circuit structure	The circuit has no ground.	Place a ground symbol on the 0 V net.
E_NUMERIC	Running	The voltage of a net or the current of a pin is not a finite number.	Look for parameters near 10^{308} or 10^{-308}.
E_OP	Files, editing and the app	Edit rejected (user): …	Check the value and try again.
E_PARAM	Parameters and models	R1 parameter r = 0 is out of range, allowed > 0. Or: is not a number. Also wrong PWL points, unknown power block kinds, bad filter coefficients, LUT tables, state machines, wire sizes, unknown variants, min-max order, unknown logic families.	Set the value inside the range given in the message.
E_PARAM (analyses)	Running	Transient stop time, AC source and range, DC sweep source and step problems, too many points, and Simulation cancelled.	The message names the setting.
E_PARAM (id)	Circuit structure	Two parts have the id R1.	Rename one of them.
E_PARSE	Parameters and models	The circuit file is not valid .bsc JSON at line L, column C. Also: *Unsupported .bsc version: "bsc" is 1.5, expected 1*, or a part with no id or a repeated id.	Fix the JSON there. Set **"bsc": 1** (1.0 is read as 1).
E_PART	Files, editing and the app	A part file problem.	Fix the named field.
E_PART_TODO	Files, editing and the app	A part file field still marked TODO.	Fill in the field.
E_PSPICE_MISSING (Diagnostics)	Simulate with vendor models	The same, as a warning row: the fitted model was used for the named parts.	The row's fix gives the steps for your system, as above.
E_PSPICE_MISSING (Simulate)	Simulate with vendor models	Parts with models encrypted by Cadence need PSpice, and PSpice isn't on this computer. The run note names the parts and says their fitted behavioural models were used instead (approximate).	Windows: install PSpice for TI at **C:\Cadence\PSpiceTI** (or set **BSPICE_PSPICE**). Linux: install Wine, then PSpice for TI with **wine** into its prefix (or set **BSPICE_PSPICE** and **BSPICE_WINE**), and restart. macOS: not available.
E_RENDER	Files, editing and the app	A picture could not be made.	The message gives the reason.
E_REPORT	Files, editing and the app	A report could not be made.	The message gives the reason.
E_SCRIPT	Control blocks and microcontrollers	U3 line 4 col 18: the Rhai message. Or: the code has no step function. Or: step() exceeded 100 000 operations. For an MCU program: *U1 line 3 col 3: FAN is a pwm pin; write FAN = 0.5 for 50 % duty, wait 10 needs a unit, y has no value*.	Fix the code at the line and column. The message says what to write.

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
E_SCRIPT (warning)	Control blocks and microcontrollers	An output or input channel that does not exist, or an unknown adc_config trigger.	Use a channel the block has.
E_SINGULAR	Running	The circuit equations are singular at net N: its voltage is not determined. When the net is connected but the resistances span about 30 decades, the message says so: the net is not floating, the matrix is badly conditioned.	Connect the net to ground through a resistor or a source, or bring the extreme resistances closer together.
E_TIMEOUT	Simulate with vendor models	The run stopped after **—timeout** (the MCP **timeout**), vendor runs in ngspice included. **bspice ngspice** stops after 600 s unless told otherwise.	Give a longer time in seconds, **s**, **min** or **h** (**5min**, **2h**). A bare **m** is refused, because in SPICE values it means milli.
E_TIMESTEP	Running	The time step fell below the minimum at t = T, Newton fails at … Or: time advances only … per step.	Add a gate resistor, slow source edges, raise the maximum step or shorten the run.
E_UNCONNECTED_PIN	Circuit structure	R1 pin 2 is not connected to anything. A warning, drawn as a small open dot 1.5 s after the last edit. **validate** also reports a net label that looks like a slip (VCX beside VCC, the same name in another case) and a part none of whose pins reaches anything.	Wire the pin or delete the part. The Diagnostics row has **Wire it** and **Delete**. Correct a mistyped label.
E_VSRC_LOOP	Circuit structure	V1 and L1 form a loop of voltage sources and inductors, the current around it is undefined.	Add a series resistor, or give the inductor a small dcr.
E_VSRC_SHORT	Circuit structure	V1 is shorted: both pins are on one net.	Remove the wire across it.
W_CONVERGENCE_AIDS	Simulate with vendor models	The convergence doctor: the first try stopped (**E_NEWTON**, **E_SINGULAR** or **E_TIMESTEP**, or in ngspice *timestep too small* or no DC operating point), so the run was repeated with other settings, and the first one that worked was kept. The warning says in plain words which setting worked, names the part at fault where it can, and gives a sentence on how to run that way from the start. Built-in engine: a patient DC solve, a larger gmin (1 nS, then 100 nS), Gear-2 integration, a ten times smaller maximum step. Simulate with vendor models: Gear integration, a tenth of the maximum step and more iterations, or 1 TΩ shunts for an operating point. As an error: the retry stopped too.	Nothing if the result looks right. When the row has a **Fix convergence** button, it writes the method, maximum step or gmin into the Simulate setup as one undo step. See **Convergence doctor**, p. 222.

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
W_CONVERT	Simulate with vendor models	U1: the model name ran with the BetterSPICE conversion (the rule that applied): ngspice cannot run the card as written. A note, drawn on the canvas as a small grey tag, not a warning box.	Nothing to do. **docs/MODELS.md** lists what the converter rewrites, and **Dialects and conversion**, p. 405 explains the amber status dot.
W_DC_CYCLE	Running	Parts keep switching at the DC operating point: the circuit is an oscillator.	Use a transient.
W_DIODE_ACROSS_SOURCE	Ratings and stress	D1 sits straight across V1: nothing limits its forward current, which reaches 40 A. A diode or LED with both pins on the two pins of a DC source, above 5 A (1 A for an LED). It needs no rating.	Put a resistor in series with the diode, or move it so it does not touch both pins of the source.
W_EQUIV_STALE	Parameters and models	U1 has a live-view equivalent that the catalog has since refitted (or one the catalog no longer lists). The live view still runs the stored one. A warning, once per circuit.	Simulate is not affected, it runs the vendor model. To take the current equivalent, open the part's Assign model dialog and assign the same model again. To keep the stored one, ignore the warning.
W_EVENT	Device warnings	F1 blew at 1.20 A (I^2t 1.80 A^2s), or: F1 tripped at … for a breaker. Reported by a device in the JavaScript live engine, with that device's own words, once, at the moment it happens.	Replace the part (a blown fuse stays open until you do), or reduce the current.
W_FLOATING_NET	Circuit structure	The same, for a net named like GND or SHIELD, or held only by connectors: it is held at 0 V by gmin.	Usually harmless. Connect it if it matters.
W_FUSE_BLOWN	Device warnings	F1 blew at t = T (I = …, I^2t = …).	Click the fuse to replace it, or raise irated.
W_GMIN_SHUNT	Running	The operating point needed a small conductance from every net to ground, like ngspice rshunt. The JavaScript fallback keeps this solution too, as the main engine does.	Give open nets a real DC path.
W_IMPORT_APPROX	Import	A match with low confidence.	Check the part in the Import report.
W_IMPORT_MODEL	Import	A model file named in the project was not found.	Assign a model from the library.
W_IMPORT_NET	Import	A net was joined or a supply added.	The Import report lists each.
W_IMPORT_PIN	Import	A pin was adjusted to match the device.	Check the pin map in the Import report.
W_IMPORT_UNMATCHED	Import	A part placed as a box.	Assign a model.
W_IMPORT_VALUE	Import	A value could not be read as written.	Set the value in the inspector.
W_ISO_TIED	Circuit structure	Isolated ground ISO1 is joined to the main ground, so it is not isolated. Or: isolated grounds ISO1 and ISO2 are joined into one net. The canvas tag reads *ISO1 tied to GND*.	Click **Show the tie** to select the joining wires and labels and remove them. Or click **Make it the main ground** (**Name them all ISO1** for two joined domains).

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
W_LATCH_BOTH	Device warnings	Both coils of a latching relay are energised, it does not move.	Drive one coil at a time.
W_LATCH_MARGIN	Device warnings	A latching relay switched on a pulse shorter than its minimum.	Lengthen the pulse.
W_LEAKAGE_NODE	Circuit structure	Net N (M1 pin d, C1 pin 1) has a conductance of under 100 pS to every other node at the operating point, so its voltage is set by leakage only. A warning after the operating point (also the one before a transient) for a net, or a group of nets, whose small-signal DC conductance to everything else is below 10 GOhm: a hold capacitor behind an off MOSFET, the middle of two back-to-back zeners, an off H-bridge output. Only gmin (1e-12 S) and junction leakage set it, so its value is not a result, and another simulator may give another one.	Add the real leakage (for example 1 GOhm from the net to ground or to the supply) if the value matters.
W_LIVE_GENERIC	Simulate with vendor models	U1 (vendor model …) runs in the live view as a generic gate or as a fitted equivalent: default thresholds and timing, or a fit to the model's curve; Simulate runs the vendor model. A warning, shown beside the model.	Press Simulate for the vendor model itself, or set the part's equivalent parameters from its datasheet.
W_LIVE_SETUP	Simulate with vendor models	The Simulation setup asks for Gear or another gmin, and the live view steps with the trapezoidal rule and gmin 1 pS. A note.	Nothing to do. Simulate uses the setup.
W_MCU_BUS	Control blocks and microcontrollers	U1 bus OLED: SDA has no pull-up resistor, so the transfer fails. Or: no target answered (NACK). Or: a UART framing error. Or: chip select CS floats while the MCU is in reset. Or: nobody acknowledged the CAN frame.	Add 2.2 to 10 kΩ pull-ups on SDA and SCL, check the address and the wiring, use the same baud rate on both UARTs, add a 10 kΩ pull-up on CS, add a second CAN node and 120 Ω terminations.
W_MCU_PIN	Control blocks and microcontrollers	U1 pin BTN floats: it sits at 1.1 V, between the logic levels, so it reads random values. Or: pin LED sources 40 mA (a pin is rated about 25 mA). Or: pin X drives high but sits at 0.2 V, shorted or fights another output.	Give an input a pull (**pin BTN in pullup**). Add a series resistor, or drive the load through a transistor. Never join two outputs.
W_MODEL_RETIRED	Parameters and models	U1: retired: OPA2189 (opamp, TI) was retired from the model catalog: the reason. The live view keeps the values saved in the circuit; Simulate cannot load the model. A warning on the part, drawn on the canvas as *Retired model*.	Open the part and pick another model in Assign model. The reason says why this one does not run (**Retired models**, p. 406). A source checkout lists every retired entry and what was tried in **library/broken/index.csv**; an install does not carry that file.
W_NETS_JOINED	Circuit structure	A wire you drew joined the nets VIN and VOUT into one net. A warning shown after you draw the wire.	Undo the wire if it was a slip. Wires you draw go exactly where you draw them, so the warning is the only sign that two named nets are now one.

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
W_NGSPICE	Simulate with vendor models	A warning from ngspice, quoted.	Read it. It usually names the model or the option.
W_NO_MODEL	Parameters and models	X3 has no model: assign one. A Subcircuit / IC or vendor part with no model. Every chip variant has a model (the generic chip is an IC box that only loads its supply, without this warning).	Double-click the part and choose a model, or, for a blank Subcircuit / IC or a generic chip, choose **Edit subcircuit** and draw the inside.
W_NO_SOURCE	Import	Nothing drives the imported circuit.	Place a DC source on the supply net.
W_OVER_CURRENT	Ratings and stress	L1 carries 3.4 A, over its 2 A current rating. Also a diode's forward current and a transistor's maximum current. The value is a peak.	Use a part rated above the current, or add series resistance.
W_OVER_POWER	Ratings and stress	R3 dissipates 1.2 W, over its 250 mW power rating. Also a potentiometer, a Zener diode or a transistor against its maximum power. In a transient the power is the average over 1 % of the run, so a spike shorter than that does not count.	Use a part rated for more power, or lower the voltage or current. A part with no rating is never warned about.
W_OVER_VOLTAGE	Ratings and stress	C1 sees 28 V, over its 25 V voltage rating. Also a polarised capacitor driven backwards, a diode's reverse voltage and a transistor's maximum voltage. The value is a peak.	Use a part rated above the voltage, or lower it. Turn a polarised capacitor around.
W_PARAM	Parameters and models	V2: rise 1 µs + width 9 µs + fall 1 µs = 11 µs is longer than the period 10 µs; each pulse is cut off … Or: a PWL source whose Repeat from time is not before its last point, so the points play once. Or: an op-amp whose **gain**, **gbw** and **slew** do not fit together: held to its slew spec, the input stage would saturate so early that the output could never pass 5 V (a gain of 100 with a gbw of 100 MHz and the default slew). The engine lets the output reach the supply, so the part slews faster than its slew spec. Or: a diode with a depletion capacitance whose **vj** falls below zero at its **temp** (a Schottky-like 0.35 V at 147 °C); the engine keeps the potential at 10 mV and warns, where ngspice returns NaN and stops. Each value is valid alone, but together they do not do what was written.	Follow the fix in the message: for a pulse, *"Make V2 width at most 8 µs (period − rise − fall), or the period at least 11 µs"*. For a PWL source, set **Repeat from** to a time before the last point, or untick **Repeat the points**. For a diode, raise **vj** or lower **temp**. For an op-amp, raise **slew** (gain × slew ÷ (2π × gbw) is the largest output swing) or the gain.
W_PART	Files, editing and the app	A part file warning, such as a value outside its usual range.	Check the named field.

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
W_PART_SHORTED	Circuit structure	R1 has both pins on net N: a wire runs across it, so it does nothing. A warning for a resistor, capacitor, diode or LED whose two pins are on one net other than ground (a part dropped on a wire, or a wire drawn over it); a voltage source in that spot is E_VSRC_SHORT.	Remove the wire across the part or move one of its pins.
W_PSPICE	Simulate with vendor models	A warning from PSpice, quoted.	Read it.
W_PSPICE_TRACES	Simulate with vendor models	PSpice for TI keeps at most 4 traces per run.	Probe the signals you need.
W_RATING	Device warnings	K1 contact current 12 A exceeds imax = 10 A. Also coil voltage, motor stall, battery cut-off, power, energy and voltage ratings.	Reduce the stress or choose a part with a higher rating.
W_SAVE_PROBES	Simulate with vendor models	A long run kept only the probed signals.	Click a net to add its trace, or shorten the run.
W_SUPPLY	Device warnings	U1 supply is 1.2 V, below its minimum 2 V.	Power the part within its range.
W_SYMBOL_ONLY	Parameters and models	A part the engine has no model for is left unconnected and the rest runs.	Replace it with a simulated part, or keep it for the drawing.
W_TIMING	Device warnings	U1: a write arrived while the display controller was busy, so it was ignored. A warning for a part driven faster than its datasheet timing allows (an HD44780 write while its busy flag is set, instruction times 37 µs, clear and home 1.52 ms).	Wait for the busy flag to clear, or lengthen the delay between writes in the program.
W_TRAP_GEAR	Simulate with vendor models	Trapezoidal ringing detected at 9.97 ns (first in D1): switched to Gear for 4 steps. It happened 4772 times: 16695 Gear steps in all, 2.3 % of the steps. A note, tagged *Gear where it rang*, not a warning: the engine saw a stiff node reverse at every step and damped it by itself.	Nothing to do. To run Gear throughout, set the Integration method to Gear in **Simulate** › **Setup** (F6).

CODE	GROUP	MESSAGE AND CAUSE	WHAT TO DO
W_TRAP_RINGING	Simulate with vendor models	V(SW) changes direction at each of 138 time points in a row (4.2 µs to 7.9 µs, 5.1 V peak to peak): every second point is high and the next one low, an alternation with a period of two time steps (92 ns). That is **numerical oscillation from the trapezoidal integration rule, not ringing in the real circuit**: the rule does not damp a fast, stiff node (a hard-switched MOSFET or diode), and the period of the oscillation is set by the time step, not by any L or C of the circuit. ngspice's trapezoidal rule oscillates the same way. It spoils the trace and the peak values read at that node, not the averages of the signals (in the 39 example circuits that raise it, the time mean of every signal moved by under 0.2 % of its range in 35, and by 0.35 % to 6.5 % in the other 4: two free-running oscillators, a flyback and a kickback clamp). In Simulate with ngspice the run was repeated with Gear integration.	Set the Integration method to Gear or Backward Euler in **Simulate** › **Setup** (F6); the built-in engine runs both as backward Euler. To tell it from real ringing, run once with Gear or Backward Euler: a numerical oscillation is gone, a real ring is still there, only damped. A damped method can also stop a real oscillator from starting (the joule-thief example does not oscillate in Backward Euler), so check that the circuit still does what it did. A real ring that the steps resolve is smooth over several points per cycle and is never flagged. Lowering the maximum step changes the oscillation only when that step sets the point spacing (the solver's own error control often does). A real ring as fast as the warning (a stray L and C ringing at a few steps per cycle) looks the same at a coarse step: set the maximum step to a tenth of its period to see it. Adding damping to the circuit is not the fix.
W_UART	Control blocks and microcontrollers	UB: framing error on RXD (the stop bit is low): the sender's baud rate differs from 9600 baud, or RXD is not a UART signal. Or: more than 4096 bytes are waiting to be sent; the rest were dropped.	Set the USB-UART bridge's **baud** to the sender's rate, and check that RXD is wired to a TX pin. Send less text at a time, or raise the baud rate.

PART

IV

Quick reference

The one-sheet card, every keyboard shortcut grouped by task, and a glossary of the words this manual uses.

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17 Quick reference card

Print this page and the next on one sheet. Every line is in the chapters that follow, and the keys are read from the app's own list.

Place

R	Resistor
C	Capacitor
L	Inductor
D	Diode
Q	NPN transistor
M	N-channel MOSFET
U	Op-amp
V	DC voltage source
A	Sine source
G	Ground
W	Wire
N	Net label
P	Probe
Shift + P	Meter probe (shows its value)
Esc	Stop placing (once), then clear the selection

Edit

Ctrl + Z	Undo
Ctrl + Y	Redo
Space	Rotate (also while placing and while dragging a part; Shift turns the other way; so does the part's own key)
Ctrl + E	Mirror
Del	Delete
Ctrl + D	Duplicate
Ctrl + C	Copy
Ctrl + V	Paste
Ctrl + M	Assign model
Ctrl + G	Make a sheet from the selection

Run the live simulation

Ctrl + R	Run / Pause
.	Step one timestep
Ctrl + Shift + Backspace	Reset to t = 0
1	1 ms per second
2	10 ms per second
3	100 ms per second
4	Real time

Simulate and analyse

F5	Simulate (transient)
F6	Simulation setup
F7	AC sweep
Shift + F7	Parameter step
F8	DC sweep
F9	Operating point
Shift + F8	FFT
Ctrl + F5	Run the last analysis again

View and find

Ctrl + 1	Schematic
Ctrl + 2	Analysis view
Ctrl + 3	Split
F	Zoom to fit
/	Search the library
Ctrl + K	Command palette
E	Examples
Alt + 1	Scope tab
Alt + 6	Diagnostics tab
Ctrl + B	Hide library
Ctrl + J	Hide dock
Ctrl + F6	Next pane
?	Every shortcut

Files and tabs

Ctrl + N	New circuit
Ctrl + O	Open
Ctrl + S	Save
Ctrl + W	Close tab
Ctrl + Tab	Next tab
Ctrl + I	Import KiCad or EasyEDA Pro
Ctrl + Shift + G	Report

Mouse

Drag from a pin	Draw a wire
Double-click a part	Assign model
Double-click a value	Edit it in place
Right-click	Part or net menu
Wheel	Zoom at the pointer
Middle-drag	Pan
Right-click empty canvas	Paste here, place, fit
Drag a library tile	Place it where you drop

Typing numbers

TYPE	MEANS
4k7, **4.7k**	4 700
100n	100×10^{-9}
2u2, **2.2µ**	2.2×10^{-6}
10m	0.01 (milli)
1Meg, **1M**	1 000 000 in fields
1R5	1.5
10 kΩ, **5V**	units are ignored
Up / Down	next value (Shift: finer, Ctrl: a decade)
PageUp / PageDown	next standard value (E12, E6, rails)

On the command line and in netlists **1M** is milli. Write **1Meg** everywhere.

Files

FILE	HOLDS
.bsc	A circuit, with probes and settings
.bspart	A part from a datasheet
.bssym	A schematic symbol
.cir	An exported ngspice netlist

Signs on screen

YOU SEE	MEANS
running / **paused** (status bar)	Live simulation on or paused. Ctrl + R.
idle	Empty sheet: nothing to run
Red **Halted**	Stopped on an error. Click it.
Live MNA · WASM	Fast live engine
Live MNA · JS	Slower fallback, same results
ngspice 47 ready	Vendor models can run
Red badge	An error: Alt + 6
Amber badge	Warnings only
example on a tab	Not your file: Save as

Voltage colours

New look (the default on a fresh install): one voltage scale from 1 mV to 1 kV, pale yellow to green at 48 V and blue past 50 V, red to purple for negative, and current dots that grow with the current. Classic look: positive green, negative red, zero grey, current dots yellow, and Ctrl + Shift + K switches to orange and blue. **View** › **Live look** picks the look.

MCU code

pin LED out, **pin BTN in pullup**, **bus I i2c SDA SCL**. **loop**, **every 1ms**, **when BTN falls**, **wait 10ms**. **pin LO complement HI dead 200ns**. I²C needs pull-ups.
Programming the MCU, p. 373.

Which result to trust

Live shows. Simulate (F5) measures, with vendor models in ngspice or PSpice for TI.

Codes you meet most

CODE	FIX
E_NO_GROUND	Place a ground symbol on the 0 V net.
E_FLOATING_NET	Add a resistor from the net to ground, or connect the capacitor or gate that isolates it.
E_VSRC_LOOP	Add a series resistor, or give the inductor a small dcr.
E_NEWTON	Check that part's values and connections, add a series resistor, or lower the maximum timestep.
E_TIMESTEP	Add a gate resistor, slow source edges, raise the maximum step or shorten the run.
E_PARAM	Set the value inside the range given in the message.
W_NO_MODEL	Double-click the part and choose a model, or, for a blank Subcircuit / IC or a generic chip, choose **Edit subcircuit** and draw the inside.
E_NGSPICE_MISSING	Reinstall, or set **BSPICE_NGSPICE**.

When stuck

Troubleshooting by symptom, p. 78.
Diagnostics and what they mean, p. 86.
Task index, p. 41.

18 Keyboard shortcuts by task

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Every key the app knows, grouped by what you're doing. The list is read from **docs/HOTKEYS.md**, which the app generates. ? shows the same list in the app, and there every key can be changed: press **Edit** on a row, then press the new keys. Esc cancels, Backspace clears the key, and a **Reset** button on a changed row (and **Reset all to defaults** at the bottom) puts the defaults back. A key that another command already holds is named, and you choose **Replace** or **Cancel**. Esc, F1 and Ctrl + Shift + R cannot be taken. Menus, the palette, the toolbar tips and the hints in the status bar show your keys. The tables below list the defaults.

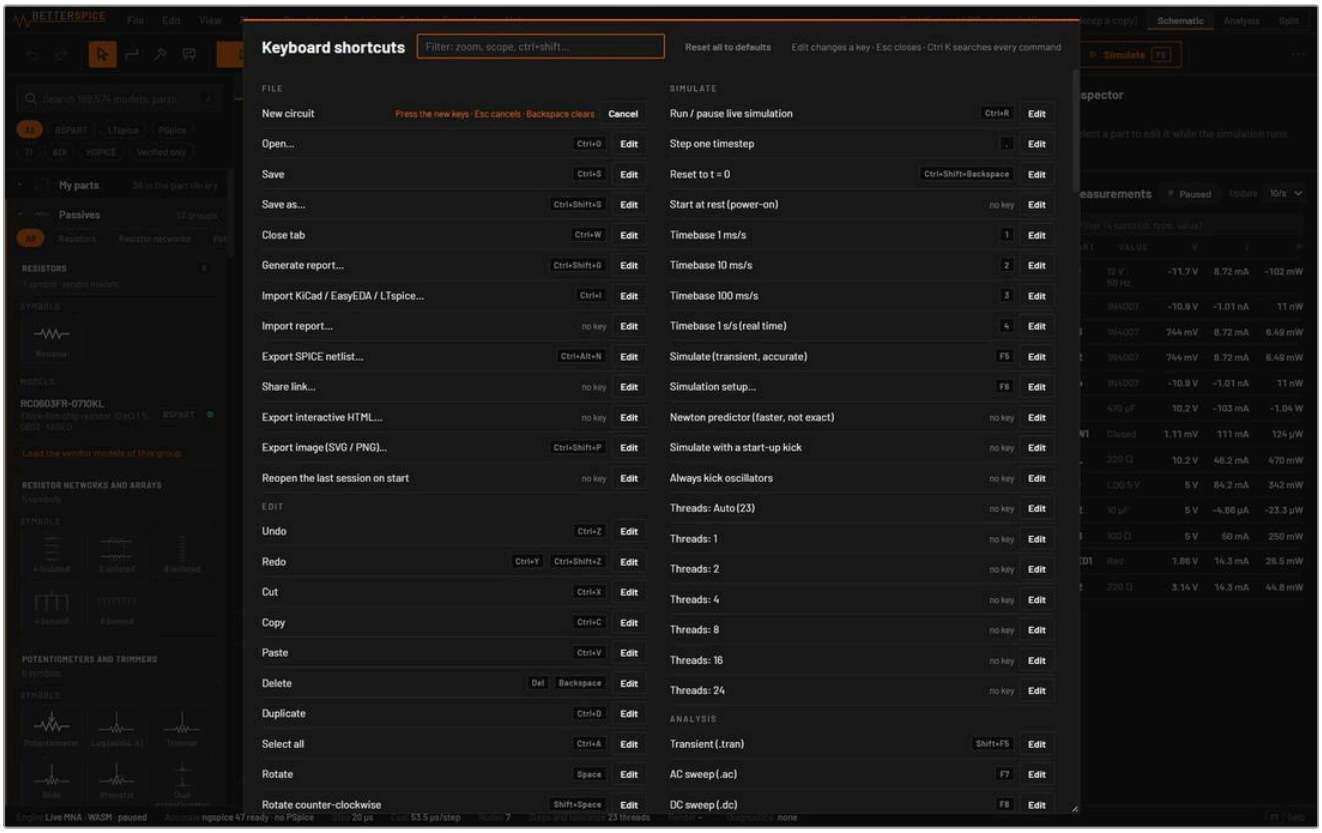


Figure 18.1 The shortcuts list with a row waiting for its new key.

Editor keys act on the schematic canvas. Shell keys work everywhere outside text fields. While you type in a field, only Ctrl combinations, F-keys and Esc reach the app. While a dialog or menu is open, only Esc and Ctrl + K do. Keys are matched by letter, so they work on any keyboard layout. In the browser version on a Mac, Cmd works wherever this manual says Ctrl.

18.1 Place parts and draw

KEY	ACTION	WHERE IT WORKS
A	AC (sine) source	editor
B	Power block	editor
C	Capacitor	editor
D	Diode	editor
Esc	Select tool	editor
G	Ground	editor
I	Current source	editor
J	JFET	editor
K	Relay	editor
L	Inductor	editor
M	N-channel MOSFET	editor
N	Net label	editor
P	Probe	editor
Q	NPN transistor	editor
R	Resistor	editor
S	Switch	editor
Shift + D	LED	editor
Shift + E	Bus entry	editor
Shift + F	Fuse	editor
Shift + G	Power flag	editor
Shift + K	Latching relay	editor
Shift + L	Line	editor
Shift + M	P-channel MOSFET	editor
Shift + N	Global label	editor
Shift + P	Meter probe (shows its value on the schematic)	editor
Shift + Q	PNP transistor	editor
Shift + R	Rectangle	editor
Shift + W	Bus	editor
T	Text	editor

KEY	ACTION	WHERE IT WORKS
U	Op-amp	editor
V	DC voltage source	editor
W	Wire	editor
X	Subcircuit / IC	editor
Alt + A	Pulse source	shell
Alt + C	Circle	shell
Alt + G	Gates and inverters	shell
Alt + L	Classic 74xx / 4000 packages	shell
Alt + M	DC motors, fans, vibration motors	shell
Alt + P	Sheet port	shell
Alt + T	Transformers	shell
H	Headers, terminals and board connectors	shell
Shift + H	Test points	shell
Shift + O	Optocouplers	shell
Shift + Y	Oscillator modules (XO, TCXO, VCXO, MEMS)	shell
Shift + Z	Magnetic and Hall sensors	shell
Y	Crystals	shell
Z	Generic analog sensor	shell

18.2 Select and edit

KEY	ACTION	WHERE IT WORKS
Backspace	Delete	editor
Ctrl + A	Select all	editor
Ctrl + C	Copy	editor
Ctrl + D	Duplicate	editor
Ctrl + E	Mirror	editor
Ctrl + Shift + Z	Redo	editor
Ctrl + V	Paste	editor
Ctrl + X	Cut	editor
Ctrl + Y	Redo	editor
Ctrl + Z	Undo	editor
Del	Delete	editor
Shift + Space	Rotate counter-clockwise	editor
Space	Rotate	editor
Arrow keys	Nudge selection 1 grid (Shift: 5)	editor · selection
Ctrl + G	Create module from selection…	shell

KEY	ACTION	WHERE IT WORKS
Ctrl + M	Assign model…	shell
Ctrl + Shift + M	Quick model from datasheet…	shell

18.3 Run the live simulation

KEY	ACTION	WHERE IT WORKS
.	Step one timestep	editor
Ctrl + R	Run / pause live simulation	editor
1	Timebase 1 ms/s	shell
2	Timebase 10 ms/s	shell
3	Timebase 100 ms/s	shell
4	Timebase 1 s/s (real time)	shell
Ctrl + Shift + Backspace	Reset to t = 0	shell

18.4 Simulate and analyse

KEY	ACTION	WHERE IT WORKS
Ctrl + F5	Run last analysis again	shell
Ctrl + Shift + W	Show results (Analysis view)	shell
F5	Simulate (transient, accurate)	shell
F6	Simulation setup…	shell
F7	AC sweep (.ac)	shell
F8	DC sweep (.dc)	shell
F9	Operating point (.op)	shell
Shift + F5	Transient (.tran)	shell
Shift + F7	Parameter step (.step)	shell
Shift + F8	FFT	shell
Shift + F9	Tolerance (Monte Carlo, worst case)	shell

18.5 View, panes and windows

KEY	ACTION	WHERE IT WORKS
F	Zoom to fit	editor
[	Current dots slower	shell
]	Current dots faster	shell
Alt + 1	Scope	shell
Alt + 2	Bode plot	shell

KEY	ACTION	WHERE IT WORKS
Alt + 3	FFT	shell
Alt + 4	Logic analyzer	shell
Alt + 5	Console	shell
Alt + 6	Diagnostics	shell
Alt + 7	Activity	shell
Alt + 8	Modules	shell
Alt + E	Energy view	shell
Ctrl + -	Zoom out	shell
Ctrl + =	Zoom in	shell
Ctrl + 1	Schematic view	shell
Ctrl + 2	Analysis view	shell
Ctrl + 3	Split view	shell
Ctrl + B	Hide library	shell
Ctrl + F6	Next pane (library, canvas, inspector, dock)	shell
Ctrl + J	Hide dock (scope and panels)	shell
Ctrl + K	Command palette	shell
Ctrl + Shift + B	Hide inspector and measurements	shell
Ctrl + Shift + F	Follow AI	shell
Ctrl + Shift + F6	Previous pane	shell
Ctrl + Shift + K	Orange and blue voltage colours (off: green and red)	shell
Ctrl + Shift + L	Next theme (Dark, Graphite, Gray, Light)	shell
Ctrl + Shift + Tab	Previous tab	shell
Ctrl + Tab	Next tab	shell
F10	Open the menu bar	shell
Shift +]	Fit current dot speed to selection	shell

18.6 Files

KEY	ACTION	WHERE IT WORKS
Ctrl + O	Open...	editor
Ctrl + S	Save	editor
Ctrl + Shift + S	Save as...	editor
Ctrl + Alt + N	Export SPICE netlist...	shell
Ctrl + I	Import KiCad / EasyEDA / LTspice...	shell
Ctrl + N	New circuit	shell
Ctrl + Shift + G	Generate report...	shell
Ctrl + Shift + P	Export image (SVG / PNG)...	shell

KEY	ACTION	WHERE IT WORKS
Ctrl + W	Close tab	shell

18.7 Tools, examples and help

KEY	ACTION	WHERE IT WORKS
?	Keyboard shortcuts	shell
/	Search models and parts	shell
Ctrl + Alt + B	Symbol editor...	shell
Ctrl + Alt + H	About BetterSPICE	shell
Ctrl + Alt + L	Clear activity log	shell
Ctrl + Alt + M	My parts (library)	shell
Ctrl + Shift + C	Calculators...	shell
Ctrl + Shift + N	Part Wizard...	shell
E	Browse examples...	shell
F1	User guide	shell

18.8 Dialogs and the editor

KEY	ACTION	WHERE IT WORKS
Esc	Close dialog / menu, take over from the AI	dialog
Ctrl + E	Rotate / mirror the part being placed (Shift+Space: counter-clockwise)	editor · placing
Same part key	Rotate the part being placed (another part key switches to that part)	editor · placing
Space	Rotate / mirror the part being placed (Shift+Space: counter-clockwise)	editor · placing
Tab	Next ground domain: main, ISO1, ..., a new one	editor · placing a ground

18.9 Mouse on the canvas

GESTURE	RESULT
Double-click net label	Rename net
Double-click part	Assign model
Double-click power flag, global label or sheet port	Rename it
Double-click probe tag	Name the probe
Double-click sheet	Open sheet
Double-click text note	Edit the text in place (Enter new line, Ctrl+Enter or click away to finish, Esc cancels)
Double-click value label	Edit value

GESTURE	RESULT
Drag from a pin	Draw a wire
Hold Space + drag	Pan (a tap that panned does not rotate)
Middle	Pan
pinch	Zoom at cursor
right drag, two-finger scroll	Pan
Right-click part	Context menu
Wheel	Zoom at cursor
Shift+click	Probe against GND (on an isolated side the probe reads against its own ground)
Alt+click	Add the net or part current as a trace to the plot
Click	Select. **Shift** or **Ctrl** toggles in the selection.
Drag on empty canvas	Box select. Left to right: fully inside. Right to left: touching.
Drag a part	Move the selection.
Hold Space and drag	Pan. Space on its own rotates.
Click a switch	Toggle it while running.

18.10 Mouse in plots

GESTURE	RESULT
Hold the pointer over a plot	Read every trace.
Drag	Box zoom.
Wheel	Zoom in time.
Ctrl-drag, Shift-drag, right-drag or middle-drag	Pan.
Double-click	Reset the zoom.
Drag a cursor line	Move cursor A or B.

18.11 Mouse in the logic analyzer

GESTURE	RESULT
Click	Cursor A.
Shift-click	Cursor B.
Wheel	Zoom.
Drag	Pan.
Double-click	Follow live again.

19 Glossary

The words this manual uses with a set meaning. Each entry ends with where it's explained.

AC sweep
A small-signal analysis that plots gain and phase against frequency around the DC operating point. Key F7. p. 230

Activity
The dock tab that logs every edit and run, by you or an AI agent. Alt + 7. p. 212

Advanced view
The full design view of a calculator: corners, tolerance and temperature, checks with their margin, the parts to order, plots over the range, library pickers and Verify in simulation. Beside it is the Simple view. p. 445

AI agent
A program such as Claude Code that edits and simulates the open circuit through the bspice MCP server. p. 591

Analysis view
The area that shows the result of the analysis tab you have open (each tab keeps its own last result): plots, cursors, the operating point table. Ctrl + 2. p. 250

Approximate
The class of behavioural device models, measured against a vendor model or a reference circuit. p. 34

Badge
A small count on the status bar's Diagnostics item: red for errors, amber when there are only warnings. p. 37

BetterSPICE engine
The built-in solver that Simulate uses for circuits without vendor model files. In the browser it runs as WebAssembly. p. 214

Bode plot
Gain in dB and phase in degrees against frequency on a log axis: the result of an AC sweep. p. 230

Bus
A thick line that stands for a group of signals. The member wires carry the connections. p. 154

Calculator
One of 17 design calculators (filter, LED resistor, via, trace impedance, dB and more) that can place a checked circuit. Ctrl + Shift + C. p. 441

Catalogue
The searchable set of vendor models inside the library, each run in a test circuit before it was listed. p. 401

Class
Exact or approximate: how closely a device type matches ngspice, shown in every device table. p. 34

Command palette
A search box over every command, part and model. Ctrl + K. p. 136

Complementary PWM
Two PWM outputs that are never high together, with a dead time between them: **pin LO complement HI dead 200ns** in the MCU language. p. 383

Console
The dock tab that shows what programs print and what a USB-UART bridge receives, with an input bar to send text through the bridge. Alt + 5. p. 210

Convergence
The solver finding a consistent set of voltages at an instant. When it cannot, you get E_NEWTON or E_TIMESTEP. p. 79

CCVS, CCCS
Current-controlled voltage source (H) and current source (F). The current they sense goes through their own **s+ / s-** port, wired in series with the branch. p. 282

Convergence doctor
The retry the engine makes by itself when a run does not converge. It keeps the first setting that works and reports it as W_CONVERGENCE_AIDS. p. 222

Current dots
Moving dots on wires whose speed shows the current. Display only. p. 184

Cursor
One of two vertical lines, A and B, that read values and the time between them on a plot. p. 204

Decoder
A lane of the Logic tab that reads a channel as UART, I2C, SPI, CAN, 1-Wire, PWM or Manchester and lists the frames. Saved in the circuit. p. 209

DC operating point
The steady DC state of the circuit: every net voltage and part current. Key F9. p. 233

DC sweep
An analysis that steps one source slowly and plots the steady result. Key F8. p. 232

Diagnostic
A coded report of a problem: severity, code, a message naming the part and net, and the fix. p. 86

Digitizer
The Part Wizard tool that reads points off an image of a datasheet graph from two clicked ticks on each axis. p. 427

Document tab
The tab above the canvas for each open circuit. Untitled circuits are numbered, examples say example, and the list at the right end of the strip shows them all. p. 117

Dead time
The gap between one PWM output turning off and its complement turning on, so a half bridge never shorts. **dead 200ns**. p. 383

Dock
The tabbed area under the canvas: Scope, Bode, FFT, Logic, Console, Diagnostics, Activity. p. 36

Energy view
The canvas mode that draws bands of power on the wires and a ledger of input, output and losses. Alt + E. p. 184

Fit Y
The scope button that fits the vertical axis to the traces in view when a run is paused and zoomed. p. 198

Full screen (calculators)
The calculator window over the whole app window, with every section of an Advanced view at once. F11. p. 448

Generic (no vendor model)
What the inspector shows for a part with no model: it simulates with built-in typical values. p. 33

E_ code
An error diagnostic. The run stops until you fix it. p. 86

Encrypted model
A vendor model that Cadence encrypted, so only PSpice can read it. Mostly Texas Instruments parts. p. 224

Exact
The class of devices that use the same equations as ngspice and are compared with it signal by signal. p. 34

FFT
A spectrum computed from a waveform. The FFT analysis uses a transient. The FFT tab shows a live trace. p. 241

Fitted model
A behavioural model whose parameters were measured by running a vendor model. The live simulation uses it for vendor chips. p. 419

Floating net
A net with no DC path to ground, for example between two capacitors. E_FLOATING_NET. p. 79

Follow AI
The switch that makes your view follow what an AI agent touches. Ctrl + Shift + F. p. 592

Gear
Gear-2, a second order integration method that damps ringing in stiff circuits. Chosen on the Transient tab. p. 228

Global label
A net name that joins nets on every sheet. Shift + N. p. 141

gmin
A tiny conductance to ground the solver adds when a DC point is hard to find. p. 233

Ground
Net 0, the 0 V reference every voltage is measured from. Every circuit needs one. G. p. 33

Halted
The state of the live simulation after an error it cannot get past. Click the red Halted button. p. 191

Hierarchical sheet
A block of the circuit inside a box with ports, opened by double-click. p. 148

ic
A part parameter that sets the initial voltage of a capacitor or current of an inductor at t = 0. The inspector calls it Initial voltage or Initial current. p. 265

Inspector
The pane on the right that shows and edits the selected part. p. 164

Ground domain
All grounds with the same name, such as ISO1: one net with its own isolation values. The main ground is the domain with no name. p. 47

Isolated ground
A ground with its own name (ISO1): a separate 0 V for a transformer secondary or an optocoupler output, tied to the main ground only through 1 GΩ and 10 pF, which belong to its domain. p. 33

Key figures
The numbers that matter for a vendor model (gain-bandwidth, slew rate, dropout and so on), each marked bench, measured, fit, card or sheet. p. 412

Library
The left pane: every placeable part type and every model, in families. p. 155

Library picker
The part of a calculator that ranks real parts of the model library for the design: inductors and regulators for the buck and boost stage, op-amps for the op-amp gain stage. p. 449

Live engine
The solver behind the live simulation: Live MNA · WASM, or · JS as a fallback. p. 179

Live simulation
The simulation that runs all the time while you draw, colouring wires and moving dots. p. 179

Loop gain
The gain a small signal picks up on one trip around a feedback loop. The Loop gain tab opens the loop at a break point and reports the crossover, phase margin and gain margin. p. 247

Margins strip
The line above an AC result with the –3 dB points, crossovers and phase and gain margins. p. 230

max step
The largest timestep a Simulate run can take. The Transient tab calls it Maximum timestep. Empty means Auto, a step chosen from the circuit. p. 217

MCP
Model Context Protocol: how AI agents connect to BetterSPICE through bspice mcp. p. 591

MCU program
The code of a microcontroller, written in a small language of pins, buses and blocks (**loop**, **every**, **when**). Edited on the Code tab. p. 373

Measurement
A named result of a run, such as a rise time or a -3 dB frequency, with optional limits that give PASS or FAIL. p. 253

Meter probe
A probe that shows its live value in its tag on the schematic. Shift + P. p. 193

MNA
Modified nodal analysis: the method both engines use to write the circuit equations. p. 179

Model
The description of how a part behaves that an engine simulates. p. 408

Model card
A one-line SPICE model (.model) for a diode, transistor or JFET. p. 419

Monte Carlo
A tolerance analysis that draws every part value at random inside its tolerance and repeats the run. p. 237

My parts
Your own parts and symbols, at the top of the library. p. 438

Noise analysis
An analysis of the noise at an output over a frequency sweep: the density, the share of each part and the totals. The Noise tab. p. 243

Net
A set of pins joined by wires, labels or flags, all at one voltage. p. 33

Net label
A name on a wire. Labels with the same name on a sheet are one net. N. p. 141

Newton iteration
The repeated solving the engines do at each instant until the voltages agree. p. 179

ngspice
The open-source SPICE simulator that Simulate uses for vendor model files. Ships with the desktop app. p. 223

Not comparable
A part ngspice cannot simulate (the MCU, ctrl scripts, behavioural blocks). verify checks it against a closed form or a datasheet window instead, and never counts it as a failure. p. 678

Overstress warning
W_OVER_POWER, W_OVER_VOLTAGE, W_OVER_CURRENT or W_DIODE_ACROSS_SOURCE: a part runs over its rating. p. 222

Pole-zero analysis
An analysis that finds the poles and zeros of a transfer function at the operating point. The Pole-zero tab. p. 246

Parameter step
An analysis repeated once per value of one parameter, curves overlaid. Shift + F7. p. 235

Part
What you place on the sheet, such as R1 or U2. p. 33

Part file
A .bspart file: a real part with datasheet values, pins and an optional model. p. 575

Part Wizard
The eight-step dialog that makes a part file from a datasheet. Ctrl + Shift + N. p. 420

Pill
A state label at the bottom left of the canvas. It shows only Halted. Running and paused are in the status bar. p. 37

Power flag
A named supply symbol such as VCC that joins every flag of that name. Shift + G. p. 141

Probe
A measurement point you place and save: a net voltage, a pin voltage or a part current. P. p. 195

PSpice for TI
Texas Instruments' free PSpice, which Simulate runs hidden for encrypted models. p. 224

Pull-up
A resistor from a line to the supply, so it rests high. I²C lines and an open-drain output need one. An MCU input can use its own with **pullup**. p. 385

Quick model
A model fitted to a few datasheet numbers. Ctrl + Shift + M. p. 415

Readout digits
How many significant digits the readouts of the Analysis view and the scopes show, 3 to 9 or Auto: the Digits control beside the trace values. p. 261

Reference (kept run)
A result kept with Keep as reference, drawn dashed behind later runs of the same kind. p. 254

Scope
The live plot of your probes in the dock, like an oscilloscope. p. 198

Sense port
The s+ and s- pins of a CCVS or CCCS: a 0 V branch (an ideal ammeter) whose current controls the source. p. 282

Share link
A web address that holds the whole circuit after the #, so whoever opens it sees the circuit running in the viewer. p. 587

Sheet port
A connection inside a hierarchical sheet to a pin of its symbol in the parent. Alt + P. p. 153

Sheet tab
The ↳ tab of a sheet you opened, after its circuit's tab. It's the same document, not a file. p. 151

SI prefix
A letter that scales a number: f, p, n, u (µ), m, k, Meg, G, T. p. 171

Simple view
The quick view of a calculator: the main values, one set of results and a plot. Beside it is the Advanced view. p. 445

Simulate
The command (F5) that runs a transient you can measure, with vendor models where there are any. Also the analyses. p. 213

Split view
The schematic on top and the Analysis view below. A plain click edits, Alt+click adds a trace. Ctrl + 3. p. 118

Standard value
A value from a preferred series, such as E12 for resistors. PageUp and PageDown step through them in a number field. p. 171

Start at rest
Starting the live simulation at 0 V with every capacitor empty, as at power-on. New circuits start this way. Examples start from the operating point. Simulate › Start at rest (power-on). p. 181

Status bar
The line at the bottom: the live engine and whether it's running or paused, timestep, diagnostics badge and a hint. p. 116

Subcircuit
A SPICE model built from other elements (.subckt), as vendors ship for op-amps and regulators. A blank Subcircuit / IC can also be built by hand: double-click it and it becomes a sheet. p. 151

Symbol
The drawing of a part on the schematic, with its pins. Stored in .bssym files. p. 433

Timebase
How much circuit time the live simulation covers per real second. Not time per division. p. 181

Timestep
The length of one solver step. The live engine uses a fixed one, Simulate an adaptive one up to max step. p. 181

Tolerance analysis
Many runs with part values changed inside their tolerances, as Monte Carlo or worst case. It gives the spread, the yield and which parts matter. p. 237

Transient
An analysis through time from t = 0 to the stop time. Simulate (F5) runs one. p. 228

uic
Use initial conditions: start a transient from the ic values instead of the DC operating point. p. 223

USB-UART bridge
A **chip** of variant **usb_uart** (CH340C). Its UART side sends and receives 8N1 bytes, and its USB side is the Console. p. 359

Vendor model
A model file from a part's manufacturer, such as TI or ADI, run in ngspice or PSpice. p. 401

Verify in simulation
The last tab of every calculator's Advanced view: it places the design's circuit and runs it, with the calculator's numbers as the measurement limits. p. 449

Viewer
The browser build that runs a circuit without the desktop app. It opens share links and interactive HTML files. p. 589

W_ code
A warning diagnostic. The run continues. p. 86

Worst case
A tolerance analysis that sets every part to its low or high end and runs the corners. p. 237

Yield
The share of tolerance runs whose measurement falls inside the allowed limits. p. 237

Reference

Every window, part, field, file and command

Everything from here on describes the app as it is, one window or one kind of part at a time. Look things up here. To learn the app, go back to Part I. To get a job done, use Part II. When something is wrong, use Part III.

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PART

V

The app in detail

Every window, menu, pane, tool and analysis field, in the order they appear on screen.

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20 The window in detail

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Every part of the window in detail. **A tour of the window**, p. 36 has the map with the ten numbered areas.

20.1 The toolbar in detail



Figure 20.1 The toolbar. Run / Pause is orange while the live simulation runs. The Simulate group is on the right.

GROUP	CONTROLS
File	New, Open, Save, Import
Undo	Undo, Redo
Clipboard	Cut, Copy, Paste
Transform	Rotate, Mirror, Delete
Zoom	Zoom in, Zoom out, Zoom to fit
Draw	Select tool, Wire, Bus, Ground, Power flag, Probe. The active tool is highlighted.
Nets	Net label, Global label, Sheet port, Bus entry
Graphics	Text, Line, Rectangle, Circle
Run	**Run / Pause**. When the live engine stops on an error it becomes a red **Halted** button that opens Diagnostics. Then Step, Reset and the simulated time.
Timebase	Simulated time per real second: a slider, a field, a unit list (ps, ns, µs, ms, s) and "/s". Range 1 ps/s to 10 s/s. **Timebase and speed**, p. 181 explains it.
Current	Current dot speed, 0.01x to 100x, and **Fit**. Display only, the simulation doesn't change.
Timestep	The live engine's timestep, read only.
Simulate	**Simulate for** and **max step** are the Transient setup's stop time and maximum timestep. **Simulate F5** runs it. An empty **max step** reads **Auto** with the step, for example **Auto 50 µs**: BetterSPICE picks it from the circuit (**Auto maximum step**, p. 217).
.ac	Shows the AC range, for example **1 Hz–1 MHz**. Click to open the AC setup.

GROUP	CONTROLS
.step	Shows the stepped parameter and the number of values, for example **R1.r ×5**. Click to open the step setup.

When the window is narrow, the groups that matter least fold into a **More tools** menu first, and they come back as soon as there's room. Then the **Simulate for** and **max step** labels go (the fields keep their tooltips), then the file buttons and the bus, ground and power tools fold. The timebase and current sliders stay until after that: the current slider folds next, and only then does the timebase become a compact **Timebase 10 ms/s** ▾ button (a click opens the full slider, value and unit, and Esc or a click outside closes it). With room again, the timebase slider is the first thing to come back. Select, Wire, Probe and Meter probe never fold, and Undo and Redo fold last.

Number fields in the toolbar show the value with its unit, such as **200 ms**. Click a field to select its value, type **200m**, **0.2** or **1u**, and press Enter. A second click places the caret. Esc cancels. Text that's not a number turns the field red and a message says what was kept, for example *"Simulate for: "abc" is not a value (try 4.7k, 100n, 2.2u), kept 200 ms."*

20.2 The status bar in detail



Figure 20.2 The status bar.

ITEM	SHOWS
Engine	**Live MNA · WASM** for the fast engine, **Live MNA · native** in the desktop app for a circuit of 100 parts or more (the same frames, about 1.4x as fast on a 578-part board), **Live MNA · JS** when the WebAssembly engine could not load and the slower JavaScript fallback runs, then **· running**, **· paused** or **· halted** (after an error). **Live MNA · idle** on an empty sheet. Hold the pointer over it for what the engine does. This is where the run state is shown: the canvas no longer has Running and Paused pills.
Accurate	Desktop: **checking…**, then **ngspice 47 ready** or **ngspice not found**. Browser: **built-in engine**.
Step	The live engine's timestep.
Cost	Microseconds of computer time per simulated step.
Nodes	The number of nets in the circuit.
Render	Frames per second while running, a dash when paused.
Threads	What may run side by side, always shown: **Steps and tolerance 16 threads** is how many threads parameter steps, Monte Carlo runs and the analysis pool may use. After a run it also says what that run used, for example **Last run 1 thread (a transient goes step by step)** or **Last run 5 threads** for a parameter step. Hold the pointer over it for the Threads setting and the reason a single transient uses one core: each time step needs the one before it (**Threads**, p. 216).
Diagnostics	A red badge with the number of errors, an amber badge with the number of warnings, or **none**. The badge is red only when there's an error. Warnings alone are amber. Open pins are counted once your edits have paused for 1.5 s. Click it to open Diagnostics (Alt + 6).
Hint	What the active tool does, for example *"Wire: click to start, click to bend or end · double-click ends · Esc stops"*. With no tool active: *"Ctrl+R run · . step · R C L D place · Ctrl+K everything · E examples"*.

20.3 Canvas overlays

The canvas shows only what needs your attention. The one state pill is the red **Halted · *code*** pill at the bottom left, which opens Diagnostics. Running and paused aren't drawn on the canvas: they are in the status bar and on the toolbar's **Run** / **Pause** button. The engine's description (MNA, Newton iteration, companion models, explained in **How the live engine works**, p. 191) is the tooltip of the status bar's engine item. An AI agent at work adds the presence bar (**Working with an AI agent**, p. 591). Inside a hierarchical sheet a breadcrumb sits at the top left (**Hierarchical sheets and buses**, p. 148). The **Overview** button at the bottom right opens the minimap (**Moving around**, p. 147).

20.4 Tabs

Every open circuit has a tab above the canvas. The tab shows the file name, with a dot when there are unsaved changes, and the full path as its tooltip. The window title follows the active tab: *name* • – BetterSPICE, where the dot marks unsaved changes. What a tab says depends on where the circuit came from:

THE TAB READS	IT IS
rc-lowpass.bsc	A circuit saved in a file.
untitled · not saved, **untitled 2 · not saved**, …	A new circuit that was never saved. Each new one gets the next number, so tabs never share a name. **File** › **New** reuses an untouched empty untitled tab instead of opening another.
RC low-pass, 1.6 kHz · example	An example, named by its title. It's not your file: **File** › **Save as** keeps a copy, and the first Save asks for a name. The menu bar says *example (Save as to keep a copy)* until you do.



Figure 20.3 Five open circuits, three examples and two untitled ones, with the list open from the arrow at the right end.

Double-click the tab of an unsaved circuit or an example to rename the circuit in place (one undo step). With many tabs, ‹ and › arrows appear at the ends of the tab strip and the active tab always scrolls into view. The down-arrow button (▾) at the right end of the strip lists every open circuit with its state and unsaved dot: pick one to switch to it.

Switching tabs keeps each circuit's live simulation as you left it: its traces, scope history, logic recordings, timebase, and whether it was running or paused. A circuit you open fresh always runs. BetterSPICE keeps up to four

background tabs this way. A tab beyond that restarts from t = 0 when you return. The tool goes back to Select on a switch.

TO	DO THIS
Switch tab	**Click** it, or Ctrl + Tab and Ctrl + Shift + Tab.
Close a tab	**Click** its ×, **middle-click** it, or press Ctrl + W. A tab with unsaved changes asks **Save**, **Don't save** or **Cancel** in place.
Open a new tab	New (unless the open tab is an untouched empty circuit), Open, Import, opening an example while you have work open, crash recovery, files opened from Explorer and files dropped on the window all open new tabs.
See every tab	Click the down-arrow button at the right end of the tab strip, or use the ‹ and › arrows.
Rename an unsaved circuit	**Double-click** its tab, type the name and press Enter.

20.5 Views

VIEW	KEY	SHOWS
Schematic	Ctrl + 1	The canvas and the dock.
Analysis	Ctrl + 2	Only the Analysis view: the result of the last analysis.
Split	Ctrl + 3	The schematic on top and the Analysis view below. In Split a plain click selects, drags and wires as in the Schematic view. **Alt+click** a net or a two-pin part adds its trace.

Every way of starting a run shows its result the same way: F5, Ctrl + F5, F9, the analysis keys, and **Run** in the setup. From the Schematic view the window splits, so the schematic stays visible. In Split and Analysis the view stays as it is.

20.6 Resizing panes

View › **Hide library** (Ctrl + B), **View** › **Hide inspector and measurements** (Ctrl + Shift + B) and **View** › **Hide dock** (Ctrl + J) give the canvas more room. They are remembered, and a command that needs a hidden pane (a dock tab key, the library search, My parts) shows it again.

Every pane edge can be dragged: the library width, the inspector width (260 px to 45 % of the window), the Measurements height, the dock height and the split height. Double-click an edge to put that one back. Ctrl + F6 moves the keyboard focus to the next pane (library search, canvas, inspector or dock, skipping hidden panes) and Ctrl + Shift + F6 to the previous one. The pane's name is announced to screen readers. With an edge focused, the arrow keys move it by 16 px, with Shift by 64 px. The sizes are remembered, and sizes saved on a larger monitor are fitted to the window.
View › **Reset pane sizes** puts every pane back.

20.7 Themes and colours

View › **Theme** has four themes. Each changes every colour of the window, the canvas, the scope and the plots, and the layout stays the same. Ctrl + Shift + L moves to the next one.



Figure 20.4 Dark, the default: a near-black ground.



Figure 20.5 Graphite: dark gray, softer than Dark (0.8.2).



Figure 20.6 Gray: light gray with no white, softer than Light (0.8.2).



Figure 20.7 Light: white panels, for printing and bright rooms.

THEME	GROUND AND PANELS	FOR
Dark	#0D0D0D and #1A1A1A, white text	The default.
Graphite	#1E1E1E and #282828, off-white text	Long sessions: less glare than Dark, the same orange and the same voltage colours.
Gray	#E0E0E0 and #EBEBEB, near-black text	A light theme without white. Orange stays the colour of buttons, outlines and selections, and orange text is a darker #A04400 so it reads 4.8:1. The canvas voltage colours are tuned to its gray canvas.
Light	#F5F5F5 and white	Printing and bright rooms.

Every text colour of the four themes is at least 4.5:1 against its background (WCAG AA). In **File** › **Export image**, **Light (print)** and **Dark** draw the plain Light or Dark colours, and **As on screen** draws the theme in use, Graphite or Gray included. A report follows the theme's base, dark or light.

SETTING	KEY	WHAT CHANGES
Theme	**View** › **Theme**, Ctrl + Shift + L for the next	Dark, Graphite, Gray or Light, above.
Live look	View, Live look	**New** (the default) or **Classic**, the look of version 0.3 and earlier. The look you pick is kept (**Live look**, p. 187).
Voltage colours	Ctrl + Shift + K	Classic look only. Default: positive wires green, negative red, zero grey, current dots yellow. Design colours: positive orange, negative blue, zero grey, dots white. The colour saturates at the circuit's voltage range, 10 V by default. In the New look the entry is greyed out, because that look has one scale for every circuit.

The theme, the live look, the voltage colours, the pane sizes, hidden panes, the current dot speed, the view mode, the dock tab, the library filter chips, the open library families and its scroll position are remembered for the next start. There's no separate settings dialog. Open, Save and Export dialogs start in the open file's folder, or the last folder you used.

20.8 Messages

Short messages (toasts) appear at the top right of the canvas, up to three at a time. A coloured rule marks the kind: red for a failure. Some carry one button, such as **Undo** after Clear activity log, or **Place now** after a part is saved to My parts. Click a message to close it. It stays while the pointer is over it. Every message is also listed in Activity as a **notice**, so you can read it again later.

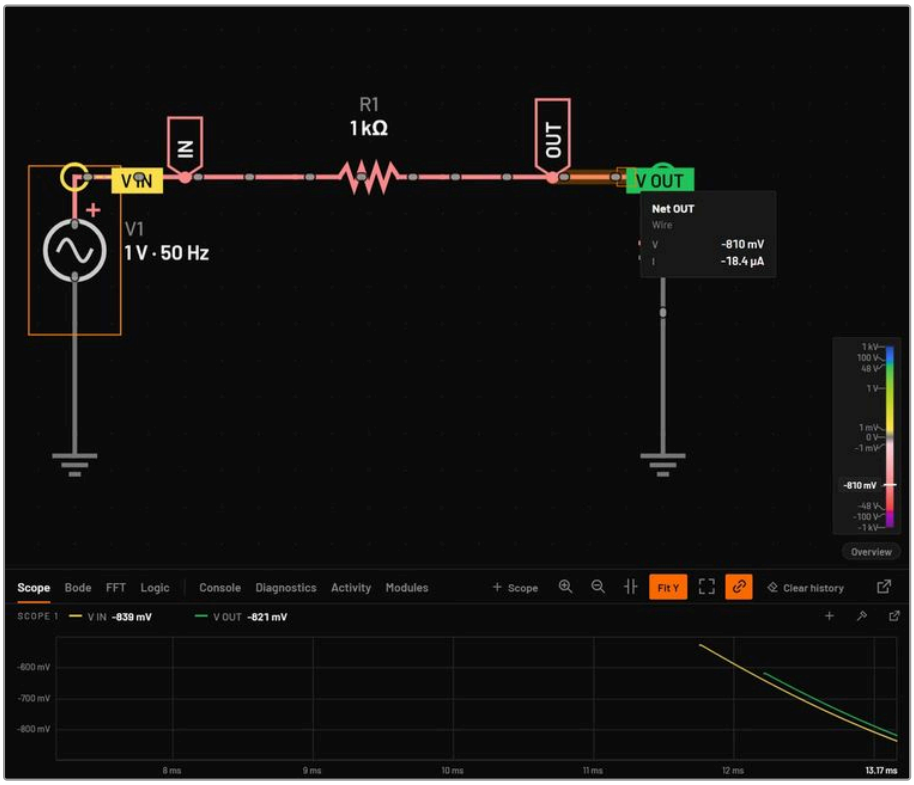


Figure 20.8 A message at the top right of the canvas: probing a net twice adds nothing.

20.9 What's new

A short panel lists what a version brings. It opens by itself once, on the first start after the app's version changed, and it waits for any open dialog to close first. Close it with **Close** or Esc. **Help** › **What's new** opens it at any time. A patch release without notes shows nothing.

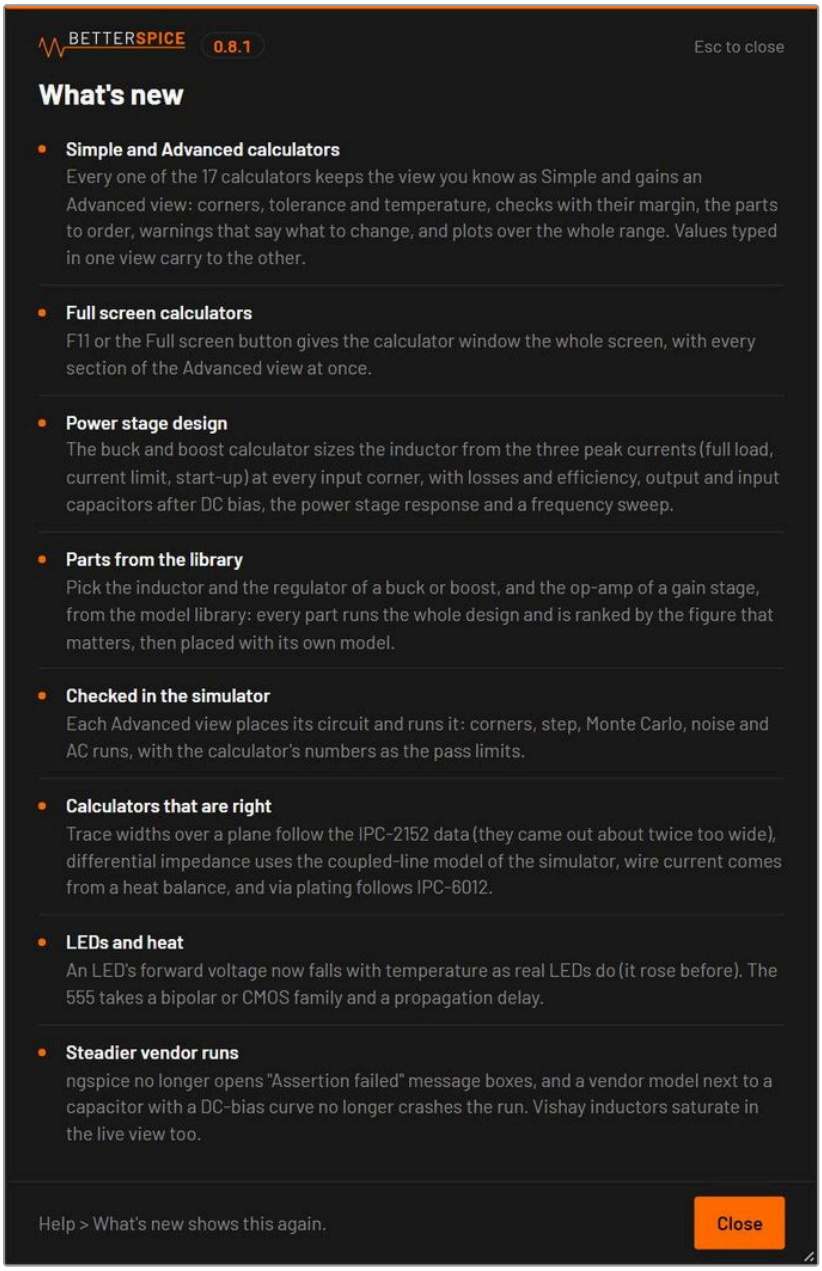


Figure 20.9 The What's new panel for version 0.8.1.

20.10 Pop-out windows

The whole dock, any scope, all scopes together and the Analysis view can each move into their own window, which you can put on a second monitor. They show the same live data, with no copying. Close the window or press **Dock back** to return it. Keys pressed in a pop-out, such as Ctrl+R, reach the main window. Pop-outs close when the app closes.

20.11 Start where you left off

The tabs you had open come back at the next start, in the same order, with the tab you were on in front. Saved files are read again from disk, and a file that is gone is skipped with a note. Examples and unsaved circuits come back from their kept text, still marked unsaved, and a note says so: *"Reopened N unsaved circuit(s) from <time>. Save to keep it."* With nothing to reopen, the app starts with a blank sheet. **File** › **Reopen the last session on start** turns this off, for a blank start every time.

20.12 Autosave and recovery

Every circuit with unsaved changes is copied to the app's storage 1.5 seconds after each change. If the app or the computer stops, the next start reopens those circuits in their own tabs, marked unsaved, with the message *"Recovered N unsaved circuit(s) from <date>. Save to keep it."*

In the desktop app, closing the window with unsaved tabs asks **Save before closing BetterSPICE?** with **Save**, **Don't save** and **Cancel**. Save saves every unsaved tab, asking for a name where there's none.

> CAUTION **Don't save cannot be undone. Don't save** discards your unsaved changes and also deletes the autosave copy, so BetterSPICE cannot recover the circuit at the next start. Choose **Cancel** to go back to your work, or **Save** to keep it.

21 Menus and the command palette

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Every command lives in a menu. The same commands are in the command palette, and most have a key. The tables list each entry as the app shows it, read from the app's own command list.

21.1 Using the menus

- Click a menu title to open it. While one is open, moving the pointer over another title switches to it. Click outside to close.
- Keyboard: F10 opens File. Up and Down move between entries, Left and Right switch menus, Enter runs, Esc closes.
- Each row shows a tick when the setting is on, the label and the first shortcut. Greyed rows can't run now. Running one anyway, from the palette or a key, shows a message saying why, for example *"Select a part first, then assign its model (or double-click the part)."*
- Long menus use two or three columns. A menu that would run off the right edge of the window moves left to fit. Submenus such as **Place** › **Transmission line** and **View** › **Scope tools** open to the side. From the keyboard, F10 and the arrow keys walk the menus, Right or Enter on a row with a ▸ opens its submenu and Left comes back.

21.2 File

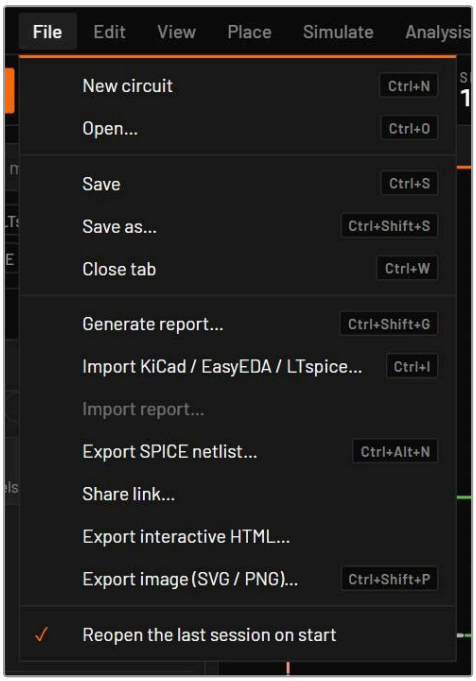


Figure 21.1 The File menu.

COMMAND	SHORTCUT	WHAT IT DOES
Import report...	none	Reopens the Import report of an imported tab. Greyed for other tabs.
New circuit	Ctrl + N	Opens an empty circuit in a new tab, or reuses the open tab when it's an untouched empty untitled circuit. A new circuit starts at rest.
Open...	Ctrl + O	Opens a **.bsc** (or **.json**) circuit in a new tab. A file that's already open is brought to the front.
Save	Ctrl + S	Saves to the circuit's file. A circuit with no file of its own (new, an example, an import) asks for a name first.
Save as...	Ctrl + Shift + S	Saves under a new name or in another folder. The browser asks for the name, then downloads.
Reopen the last session on start	none	Ticked (the default): the tabs of the last session open again at the next start (**Start where you left off**, p. 122). Unticked: a blank sheet every time.
Close tab	Ctrl + W	Closes the tab. With unsaved changes it asks **Save**, **Don't save** or **Cancel** first.
Generate report...	Ctrl + Shift + G	Builds one HTML file with the schematic, parts, results and diagnostics (**Generate report**, p. 583).
Import KiCad / EasyEDA / LTspice...	Ctrl + I	Reads a schematic from another tool into a new tab (**Importing KiCad and EasyEDA Pro**, p. 577).
Export SPICE netlist...	Ctrl + Alt + N	Writes the circuit as an ngspice netlist (**.cir**).
Share link...	none	
Export interactive HTML...	none	
Export image (SVG / PNG)...	Ctrl + Shift + P	Saves or copies a picture of the schematic.
Recent: ***file***	none	Desktop only. The last 8 circuits.

COMMAND	SHORTCUT	WHAT IT DOES
Clear recent files	none	Desktop only. Empties the list. The message offers Undo.

21.3 Edit

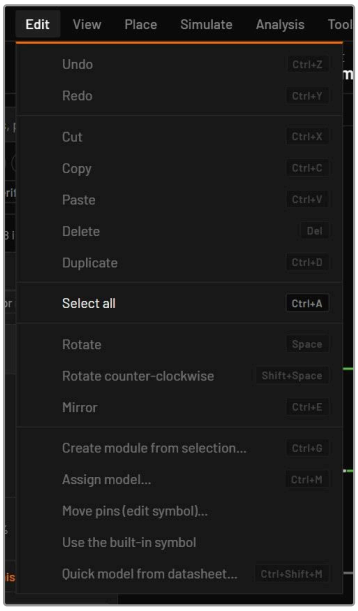


Figure 21.2 The Edit menu.

COMMAND	SHORTCUT	WHAT IT DOES
Undo	Ctrl + Z	Reverses the last edit. 300 steps per tab.
Redo	Ctrl + Y or Ctrl + Shift + Z	Repeats an undone edit.
Cut	Ctrl + X	Copies the selection and deletes it.
Copy	Ctrl + C	Copies the selection, also to the system clipboard as text.
Paste	Ctrl + V	Pastes at the pointer with new designators.
Delete	Del or Backspace	Deletes the selection.
Duplicate	Ctrl + D	Copies and pastes the selection two grid steps away.
Create module from selection...	Ctrl + G	Turns the selection into a module, a hierarchical sheet in a box (**Hierarchical sheets and buses**, p. 148).
Select all	Ctrl + A	Selects everything on the sheet.
Assign model...	Ctrl + M	Opens the model dialog for the selected part.
Move pins (edit symbol)...	none	
Use the built-in symbol	none	
Quick model from datasheet...	Ctrl + Shift + M	Fits a model to datasheet numbers.
Rotate	Space	Rotates the selection 90° clockwise. With Shift, counter-clockwise. Also rotates the part being placed.
Rotate counter-clockwise	Shift + Space	
Mirror	Ctrl + E	Mirrors the selection left to right. Also mirrors the part being placed.

21.4 View

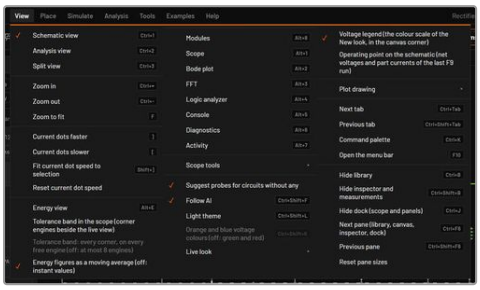


Figure 21.3 The View menu.

COMMAND	SHORTCUT	WHAT IT DOES
Plot drawing: automatic (the graphics card when it is a hardware one, else the processor)	none	The Analysis plot draws on the graphics card where that works, else on the processor. The default (**Plot drawing**, p. 257).
Plot drawing: graphics card (WebGL2)	none	The Analysis plot always draws on the graphics card (WebGL2).
Plot drawing: processor (compatible, slower with many traces)	none	The Analysis plot draws on the processor: compatible, slower with many traces.
Suggest probes for circuits without any	none	Ticked: the empty scope of a circuit with no probes offers a few key nets to probe (**Probe suggestions**, p. 200).
Next tab	Ctrl + Tab	The next tab.
Previous tab	Ctrl + Shift + Tab	The previous tab.
Modules	Alt + 8	
Schematic view	Ctrl + 1	The canvas and the dock.
Analysis view	Ctrl + 2	Only the Analysis view.
Split view	Ctrl + 3	The schematic on top, the Analysis view below.
Zoom in	Ctrl + =	Zooms at the centre.
Zoom out	Ctrl + -	Zooms at the centre.
Zoom to fit	F	Fits the whole circuit in the window, at most 1.3× so a small circuit isn't blown up.
Current dots faster	]	Dot speed ×1.5.
Current dots slower	[	Dot speed ÷1.5.
Fit current dot speed to selection	Shift +]	Sets the dot speed from the selected part's current.
Energy view	Alt + E	

COMMAND	SHORTCUT	WHAT IT DOES
Tolerance band in the scope (corner engines beside the live view)	none	Shades the range each scope trace takes with the parts at the ends of their tolerance, from extra live engines beside the live view. Off by default (**Tolerance band**, p. 186).
Tolerance band: every corner, on every free engine (off: at most 8 engines)	none	The tolerance band from every corner of the toleranced parts, on every free engine. Off: at most 8 engines.
Energy figures as a moving average (off: instant values)	none	
Hide library	Ctrl + B	Hides or shows the library pane. Remembered.
Hide inspector and measurements	Ctrl + Shift + B	Hides or shows the inspector and Measurements. Remembered.
Hide dock (scope and panels)	Ctrl + J	Hides or shows the dock. Remembered.
Next pane (library, canvas, inspector, dock)	Ctrl + F6	Moves the keyboard focus to the next pane: library search, canvas, inspector, dock.
Previous pane	Ctrl + Shift + F6	Moves the focus to the previous pane.
Reset pane sizes	none	Every pane back to its default size.
Reset current dot speed	none	Back to 1×.
Scope	Alt + 1	Opens that dock tab.
Bode plot	Alt + 2	Opens that dock tab.
FFT	Alt + 3	Opens that dock tab.
Logic analyzer	Alt + 4	Opens the logic analyzer.
Console	Alt + 5	Opens the Console tab.
Diagnostics	Alt + 6	Opens the Diagnostics tab.
Activity	Alt + 7	Opens the Activity log.
Follow AI	Ctrl + Shift + F	Your view follows an AI agent while it works.
Theme: Dark (near-black, the default)	none	Near-black, the default.

COMMAND	SHORTCUT	WHAT IT DOES
Theme: Graphite (dark gray, softer than Dark)	none	Dark gray, softer than Dark.
Theme: Gray (light gray, softer than Light)	none	Light gray with no white, softer than Light.
Theme: Light (white panels)	none	White panels, for printing and bright rooms.
Next theme (Dark, Graphite, Gray, Light)	Ctrl + Shift + L	The next theme, in the order Dark, Graphite, Gray, Light.
Orange and blue voltage colours (off: green and red)	Ctrl + Shift + K	Orange and blue wires, or the green and red scale. It belongs to the Classic live look and is greyed out in the New look.
Live look: Classic (voltage colours scaled to the circuit, even dots)	none	The live look of version 0.3 and earlier: wire colours stretched to the circuit, and yellow dots of one size.
Live look: New (one voltage scale from 1 mV to 1 kV, dots sized by current)	none	One absolute voltage scale from 1 mV to 1 kV, and current dots whose size and brightness show the current (**Live look**, p. 187).
Voltage legend (the colour scale of the New look, in the canvas corner)	none	Shows or hides the colour scale of the New look in the corner of the schematic (**Voltage legend**, p. 188).
Operating point on the schematic (net voltages and part currents of the last operating-point run)	none	Writes the last operating point (F9) on the schematic: net voltages and two-pin part currents. They go away when the circuit changes (**Operating point**, p. 233).
Command palette	Ctrl + K	Search and run any command.
Open the menu bar	F10	Opens the File menu for keyboard use.
Add the selected parts to the scope	none	Probes the selected parts.
New scope pane	none	Adds a scope pane.
Scope cursors	none	Cursor lines A and B on the scopes.

COMMAND	SHORTCUT	WHAT IT DOES
Link scope time axes	none	Zoom and pan every scope together.
Scope: reset zoom	none	Every scope back to the full window.

21.5 Place

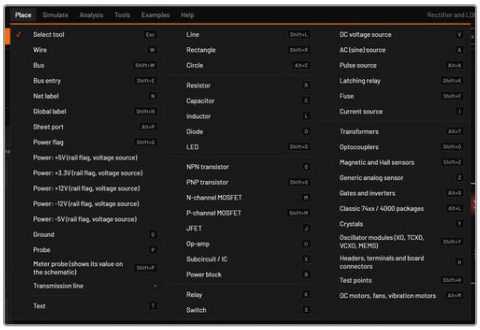


Figure 21.4 The Place menu.

COMMAND	SHORTCUT	WHAT IT DOES
Select tool	Esc	Back to selecting and moving.
Wire	W	Draw wires.
Bus	Shift + W	Draw a bus.
Bus entry	Shift + E	Join a wire to a bus.
Net label	N	Name a net.
Global label	Shift + N	Name a net on every sheet.
Sheet port	Alt + P	A connection out of a hierarchical sheet.
Power flag	Shift + G	A named supply symbol.
Power: +5V (rail flag, voltage source)	none	
Power: +3.3V (rail flag, voltage source)	none	
Power: +12V (rail flag, voltage source)	none	
Power: -12V (rail flag, voltage source)	none	
Power: -5V (rail flag, voltage source)	none	
Ground	G	The 0 V reference.
Probe	P	Probe a voltage or a current.
Meter probe (shows its value on the schematic)	Shift + P	The same, and the probe shows its live value in its tag on the schematic.
Text	T	A note with no electrical meaning.
Line	Shift + L	Drawing only.
Rectangle	Shift + R	Drawing only.
Circle	Alt + C	Drawing only.

COMMAND	SHORTCUT	WHAT IT DOES
Resistor	R	
Capacitor	C	
Inductor	L	
Diode	D	
LED	Shift + D	
NPN transistor	Q	
PNP transistor	Shift + Q	
N-channel MOSFET	M	
P-channel MOSFET	Shift + M	
JFET	J	
Op-amp	U	
Subcircuit / IC	X	A generic IC box for a vendor model, or a box you build the inside of (**Editing a subcircuit**, p. 151).
Power block	B	LDO, buck, boost and more. Also opens the Power family in the library.
Relay	K	
Switch	S	
DC voltage source	V	
AC (sine) source	A	
Pulse source	Alt + A	
Wire (length, gauge): R + L, no ground	none	
Latching relay	Shift + K	
Fuse	Shift + F	
Current source	I	
Transformers	Alt + T	
Optocouplers	Shift + O	
Magnetic and Hall sensors	Shift + Z	
Generic analog sensor	Z	
Gates and inverters	Alt + G	
Classic 74xx / 4000 packages	Alt + L	
Crystals	Y	

COMMAND	SHORTCUT	WHAT IT DOES
Oscillator modules (XO, TCXO, VCXO, MEMS)	Shift + Y	
Headers, terminals and board connectors	H	
Test points	Shift + H	
DC motors, fans, vibration motors	Alt + M	
Transmission line ›	none	Submenu: Ideal line (Z0, delay), PCB trace (microstrip), PCB trace (stripline), PCB coplanar waveguide, Wire over ground, Wire pair, Coax cable, Twisted pair, differential PCB microstrip, differential PCB stripline, differential Twisted pair, differential Wires over ground, differential Ideal pair.

21.6 Simulate

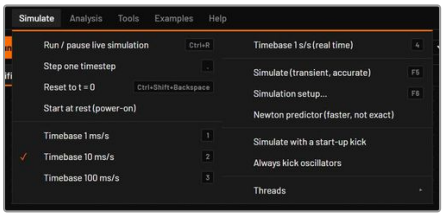


Figure 21.5 The Simulate menu.

COMMAND	SHORTCUT	WHAT IT DOES
Simulate with a start-up kick	none	Runs a transient with a 5 µV pulse on one input of the part with gain, so an oscillator that sits exactly balanced starts (**Start-up kick for oscillators**, p. 219).
Always kick oscillators	none	Ticked: an oscillator that sits balanced always gets the start-up kick. Saved on this computer.
Run / pause live simulation	Ctrl + R	Runs or pauses the live simulation.
Step one timestep	.	Advances the paused simulation by one timestep.
Reset to t = 0	Ctrl + Shift + Backspace	Restarts the live simulation at t = 0.
Start at rest (power-on)	none	Ticked: the live simulation starts from rest (every node 0 V, capacitors empty, as at power-on). Unticked: from the DC operating point. Restarts at t = 0. Saved in the circuit. New circuits are ticked. Examples and older files aren't.

COMMAND	SHORTCUT	WHAT IT DOES
Timebase 1 ms/s	1	Sets the timebase. A message confirms it.
Timebase 10 ms/s	2	Sets the timebase.
Timebase 100 ms/s	3	Sets the timebase.
Timebase 1 s/s (real time)	4	Sets the timebase.
Simulate (transient, accurate)	F5	Runs a transient with Simulate. From the Schematic view the window splits to show the result.
Simulation setup...	F6	Opens the setup with a tab for every analysis.
Newton predictor (faster, not exact)	none	Starts each time step of a Simulate transient from a point extrapolated from the last two steps. Off by default: faster on some smooth analog circuits, not exact (**Newton predictor**, p. 257).
Threads: Auto (23)	none	
Threads: 1	none	
Threads: 2	none	
Threads: 4	none	
Threads: 8	none	
Threads: 16	none	
Threads: 24	none	

21.7 Analysis

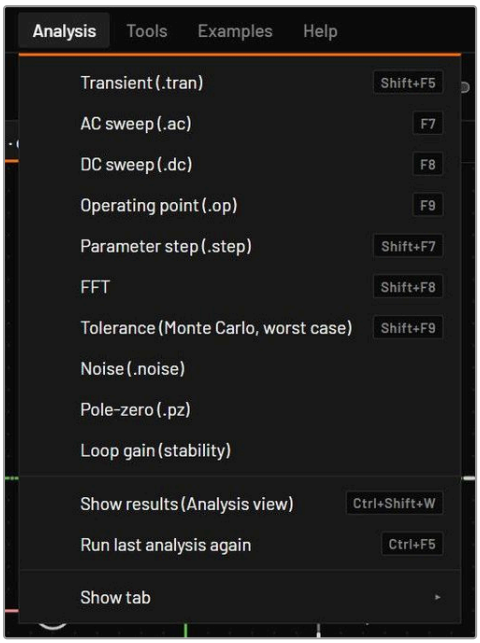


Figure 21.6 The Analysis menu.

COMMAND	SHORTCUT	WHAT IT DOES
Transient (.tran)	Shift + F5	Runs the transient with the setup saved in the circuit. With none yet, opens the Transient tab. Run there saves it.
AC sweep (.ac)	F7	Runs the AC sweep with the saved setup, or opens the AC tab the first time.
DC sweep (.dc)	F8	Runs the DC sweep with the saved setup, or opens the DC tab the first time.
Operating point (.op)	F9	Runs at once and shows the table.
Parameter step (.step)	Shift + F7	Runs the parameter step with the saved setup, or opens the Step tab the first time.
FFT	Shift + F8	Runs the FFT with the saved setup, or opens the FFT tab the first time.
Tolerance (Monte Carlo, worst case)	Shift + F9	
Noise (.noise)	none	Opens the Noise tab: noise density at an output, each part's share and the totals (**Noise**, p. 243).
Pole-zero (.pz)	none	Opens the Pole-zero tab: the poles and zeros of a transfer function (**Pole-zero**, p. 246).
Loop gain (stability)	none	Opens the Loop gain tab: crossover, phase margin and gain margin of a feedback loop (**Loop gain**, p. 247).
Show results (Analysis view)	Ctrl + Shift + W	Switches to the Analysis view (formerly called the waveform viewer).
Run last analysis again	Ctrl + F5	Repeats the last analysis with its setup.

COMMAND	SHORTCUT	WHAT IT DOES
Analysis view: Transient tab	none	
Analysis view: AC sweep tab	none	
Analysis view: DC sweep tab	none	
Analysis view: Operating point tab	none	
Analysis view: Parameter step tab	none	
Analysis view: FFT tab	none	

21.8 Tools

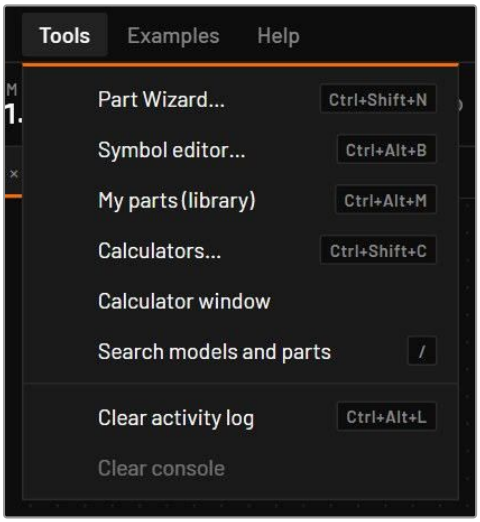


Figure 21.7 The Tools menu.

COMMAND	SHORTCUT	WHAT IT DOES
Part Wizard...	Ctrl + Shift + N	Builds a part file from a datasheet (**Part Wizard**, p. 420).
Symbol editor...	Ctrl + Alt + B	Draws a schematic symbol (**Symbol editor and My parts**, p. 433).
My parts (library)	Ctrl + Alt + M	Opens My parts at the top of the library.
Search models and parts	/	Jumps to the library search box.
Clear activity log	Ctrl + Alt + L	Empties the Activity tab. The message offers Undo.
Clear console	none	Empties the Console tab, which keeps every **log()** and **print** line of every circuit opened in the session. Greyed when it's empty. The message offers Undo.
Calculators...	Ctrl + Shift + C	Opens the calculator picker: type a word and press Enter (**The calculator window**, p. 441).
Calculator window	none	Opens the calculator window with every calculator in a list.

21.9 Examples

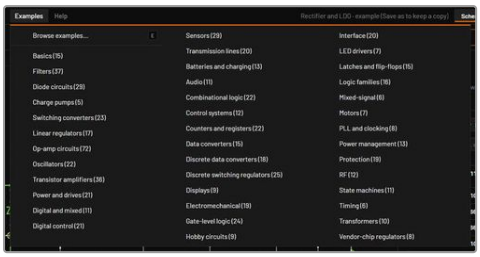


Figure 21.8 The Examples menu.

COMMAND	SHORTCUT	WHAT IT DOES
Browse examples...	E	Opens the example browser.
***Category* (N)**	none	One entry per category. Opens the browser on that category.

21.10 Help

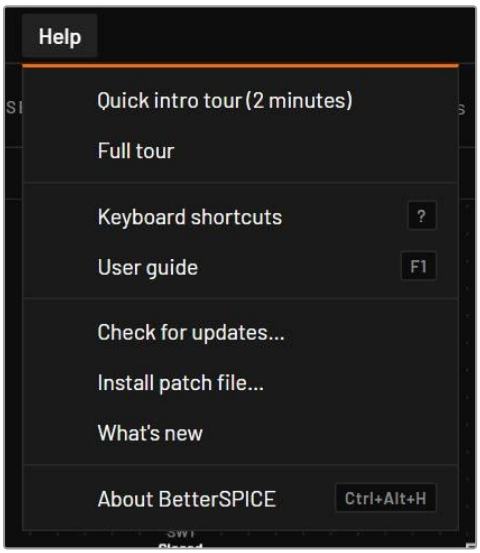


Figure 21.9 The Help menu.

COMMAND	SHORTCUT	WHAT IT DOES
User manual (PDF)	none	Opens this manual (the PDF) in your PDF viewer. Desktop, and a browser whose server has the manual.
What's new	none	Lists what this version brings. It also opens by itself once, on the first start after an update.
Keyboard shortcuts	?	Every shortcut, with a filter box.
Check for updates...	none	Asks the releases server for a newer version. Desktop app.
Install patch file...	none	Installs a patch file, with no server needed. Desktop app.
About BetterSPICE	Ctrl + Alt + H	Version, engines, ngspice, WebView2, the settings folder.
User guide	F1	Opens the user guide, this manual inside the app (The user guide, p. 137). With the pointer over something, it opens at the section that explains it.
Quick intro tour (2 minutes)	none	
Full tour	none	

21.11 Command palette

Ctrl + K opens a search box over every command and every part and model in the library. Type part of a name, for example **exp png** or **tlv9062**. The search matches letters in order, so a few letters are enough, and whole-word matches rank first. Up and Down choose, Enter runs, Esc closes. With nothing typed, it lists the last five commands you ran from it under **Recent**. Rows come in menu order (File, Edit, View ...). Commands that can't run now are listed dimmed, after the ones that can, so the first row is never one you can't use. Enter on one says why, for example *"Select a part first."* or *"Nothing to undo."* Every row shows the command's menu and shortcut, so the palette is also the quickest way to learn the keys.

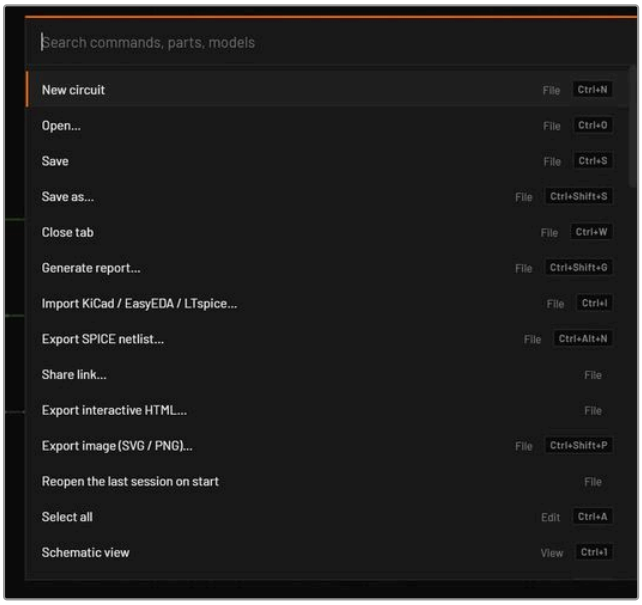


Figure 21.10 The command palette (Ctrl+K).

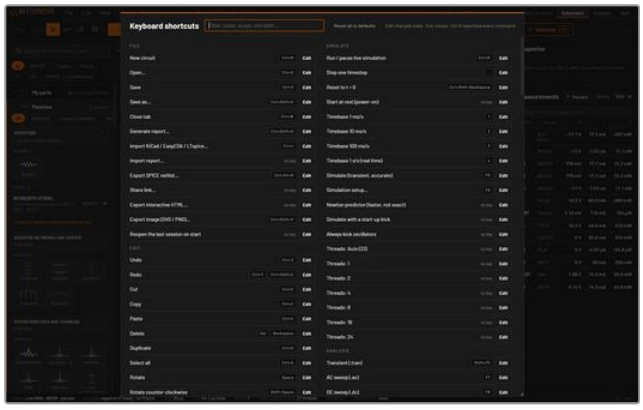


Figure 21.11 Help › Keyboard shortcuts (?), with its filter box.

21.12 Keyboard rules

- Keys are matched by letter, so they work on any keyboard layout. With a non-Latin layout, punctuation keys follow the key position.
- While you type in a text or number field, every shell shortcut with Ctrl or an F-key still works, and the field commits its text first: type a stop time, then press F5. Canvas keys such as Ctrl + Z and Ctrl + C act on the text in the field.
- A focused slider keeps only its arrow, Home, End and Page keys, and a tick box or button only Space and Enter. Every other shortcut works.
- While a dialog or menu is open, only Esc and Ctrl + K reach the app. E opens the examples only when no other dialog is open.
- The symbol editor turns every other key off while it's open, except Esc.
- Esc does the most useful thing first: in a dialog field, give up the edit of that field, then close a dialog, close a menu, take over from an AI agent, leave a placing or drawing tool, and then clear the selection. So typing **999**

into a field and pressing Esc keeps the old value and leaves the dialog open. The next Esc closes it.

21.13 About

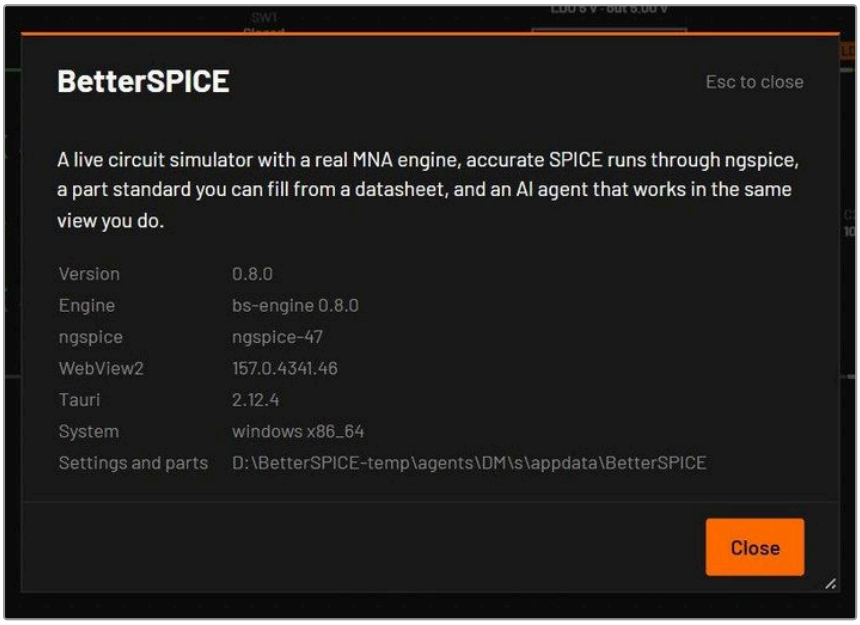


Figure 21.12 Help › About BetterSPICE.

About lists the version, the live engine, the ngspice version, WebView2, Tauri, Windows and the settings folder (**%APPDATA%\BetterSPICE**). The browser version shows the version and engine only.

21.14 The user guide

The user guide is this manual inside the app: the same text, tables and pictures, made from the same source files as the PDF, so the two cannot differ. It is part of the app, so it works offline, in both themes. Open it with **Help** › **User guide**, with the **F1 help** hint at the right end of the status bar, or with F1.

F1 opens the section about the thing under the pointer

- Point at something and press F1. A menu or a menu entry, a toolbar button, a library group or tile, the inspector and its fields, a dock tab, a plot, the status bar, or a dialog and its tabs and steps: the guide opens at the section that explains it. Pointing at **Run** opens **Run, pause, step and reset**, p. 180, and pointing at the **Bode** tab opens **Bode tab**, p. 205.
- On the schematic, a part opens the entry for its type, for example **Resistor** or **MOSFET (N, P)** in **Devices: passives**, p. 265 and **Devices: semiconductors**, p. 287. A wire opens **Wires**, p. 140, a net label, power flag or ground opens **Labels, flags and ground**, p. 141, and a module

box opens **Hierarchical sheets and buses**, p. 148. A diagnostic marker opens its code in the table in **Every code, A to Z**, p. 89.

- With the pointer over nothing in particular, F1 opens the guide where you left it, at the contents the first time.
- From the keyboard, move to a control with Tab and press F1: the guide follows the keyboard focus when you have not moved the pointer since.
- It works while a dialog or menu is open, without closing it: the guide appears in front. In a text or number field, F1 leaves the text and the caret alone, and the field keeps what you typed.
- In a pop-out window (a scope, the dock, the Analysis view), F1 opens the guide in that window.

Using the guide

- The **Contents** button, and the tree beside the text when the panel is wide, list every chapter. Links in the text jump to the section they name, and **Back** and **Forward** (Alt+Left, Alt+Right, or the mouse side buttons) walk your path.
- The search box finds every section that has all the words you type, best first. Enter opens the first. The words are marked in the section you open.
- **Find** (Ctrl+F) searches the section you are reading and steps through the matches with Enter and Shift+Enter. Click a picture to enlarge it, and click it again to shrink it.
- Three buttons choose where the guide is shown: a **floating panel** on the right of the window (the default, wide enough to read beside the circuit, and drag its left edge to resize it), a **Guide tab** in the dock, or its own **pop-out window**. The panel and the tab are remembered. Esc closes the panel.
- **PDF** in the guide's bar, and **Help** › **User manual (PDF)**, open the printable manual where the PDF is installed.

22 Drawing and editing

22.1	Placing parts	139	22.6	Editing	143
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22.3	Labels, flags and ground	141	22.8	Readings under the pointer	146
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Draw on the canvas, the large area in the middle of the window. Parts, wires and labels snap to a grid of 20 px at 100 % zoom. The live simulation keeps running while you draw, so a part starts working the moment its pins connect.

22.1 Placing parts

1. Press the part's key, click its symbol in the library, drag its tile from the library onto the canvas, or choose it from the Place menu.
2. The part follows the pointer as a ghost, hanging from the middle of its pins, in every turn and mirror. While it does, press its own key again or Space to rotate it 90°, and Ctrl + E to mirror it. Another part's key switches the ghost to that part: V, click, R gives a resistor. So does the key of another variant of the same part, for example Shift + D while placing a diode gives an LED.
3. Click to drop it. The tool stays active so you can drop another. A double-click drops one part and opens nothing. One Esc or a right-click stops placing. The next Esc clears the selection.

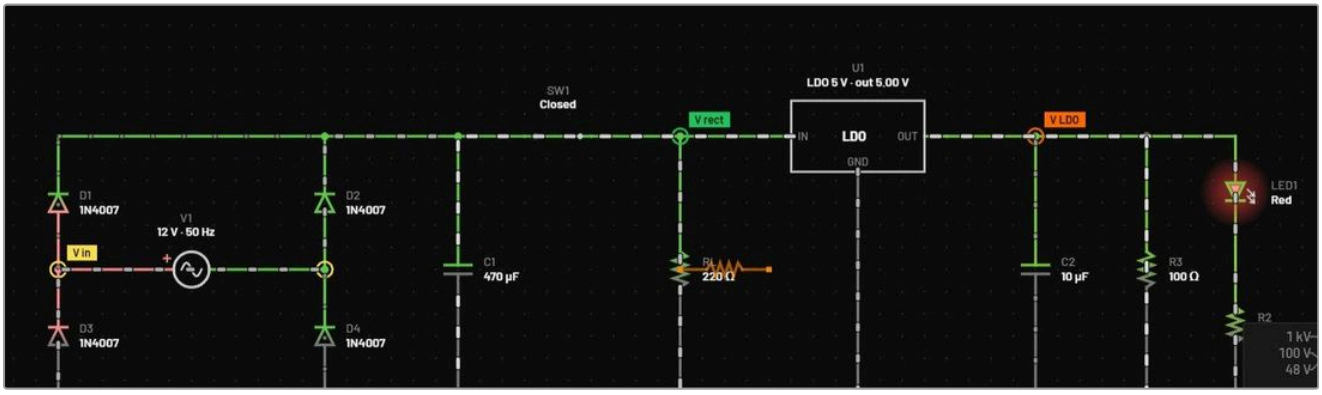


Figure 22.1 Placing a resistor: the part follows the pointer until you click.

KEY	PART	KEY	PART
R	Resistor	Q / Shift + Q	NPN / PNP transistor

KEY	PART	KEY	PART
C	Capacitor	M / Shift+M	N / P-channel MOSFET
L	Inductor	J	JFET
D / Shift+D	Diode / LED	U	Op-amp
V	DC voltage source	A / Alt+A	Sine / pulse source
I	DC current source	B	Power block (LDO, buck, boost and more)
K / Shift+K	Relay / latching relay	S	Switch
X	Subcircuit or IC box	G	Ground
Shift+F	Fuse	Y / Shift+Y	Crystal / oscillator module
H / Shift+H	Header / test point	Alt+G / Alt+L	Logic gates / 74xx packages
Alt+T	Transformers	Shift+O	Optocouplers
Z / Shift+Z	Analog / Hall sensor	Alt+M	DC motors and fans

The keys in the last four rows come from the library's families and are only registered when the key is free and the part exists, so **Help** › **Keyboard shortcuts** shows the exact set in your version.

22.2 Wires

- **Drag from a pin.** Move over a pin or a wire end until the pointer becomes a crosshair and the hint says *"Drag to draw a wire"*, press and drag to another pin, and release. A press on a pin always starts a wire, even where a diagnostic marker sits.
- **Wire tool.** Press W, click a start point, click each corner, and the chain ends by itself when it lands on a pin, a wire end or another wire. Double-click, a right-click or Esc also ends it.
- **Bends.** Each click places a two-segment orthogonal wire. Whether it goes across first or down first follows the direction you moved the mouse first.
- **The wire goes where you draw it.** A wire drawn with the wire tool, or dragged from a pin, is exactly the straight line or the L you chose. It does not detour and it does not tie its ends with net labels. It joins every pin, wire end and flag it touches, and it splits where it crosses a pin or a wire end. Drawing across a part shorts that part, and the part shows **W_PART_SHORTED**. A wire that joins two named nets into one reports **W_NETS_JOINED**.
- **Junctions.** A wire that ends on the middle of another wire connects to it, and a dot is drawn where three or more wires meet. Wires that only cross don't connect.
- **Stretching.** Moving a part drags its wires with it, each wire staying on its own net. This is the one place where a wire still routes around other pins: where every route is blocked, the two ends get a pair of net labels with the net's name instead of a wire through a pin. Dragging the end of an

existing wire does the same. Drag a free wire end, or the end of a selected wire, to lengthen or shorten it.

- **Hitting a wire.** A wire can be clicked within a quarter grid of it, more at high zoom. The wire under the pointer is marked.
- **Open pins.** A pin with nothing on it gets a small open dot 1.5 s after your last edit, so it doesn't flicker while you draw. Hold the pointer over it for the message.

TRY IT

Wire a voltage divider

1. Place a DC source (V), two resistors (R) and a ground (G).
2. Drag from the source's top pin to the first resistor, from the first resistor to the second, and from the second to ground.
3. Drag from the source's bottom pin to the same ground.

YOU SHOULD SEE The wires take colour as soon as the loop closes. Hover the middle wire to read its voltage.

22.3 Labels, flags and ground

KEY	ELEMENT	WHAT IT CONNECTS
N	Net label	Every label with the same name on the same sheet is one net. Click a point and type the name. The tool suggests NET1, NET2 and so on.
Shift + N	Global label	Every global label with the same name is one net on every sheet. The default name is SDA.
Shift + G	Power flag	A named supply symbol, VCC by default. A flag connects to every flag and label with the same name. Styles: bar, arrow, ground, chassis.
Library, Shift + G	Power flag with a voltage	A flag with a voltage is an ideal DC source from its net to the main ground. Place **Rail +5V**, **+3.3V**, **+12V**, **-12V** or **-5V** from the library (Sources, group *Power flags and rails*, found by searching power, rail, 5V, VCC, supply or voltage source), from **Place › Power: +5V**, or press Shift + G and tick **Drives the net with a voltage** in the inspector, then type a voltage (it has a slider like a DC source). The name and the value are separate: a flag named VCC can carry +3.3V, and typing +5V or -3.3V as the name fills the value too. Every flag of one name shares one source. Two voltages on one name is an error that names both flags, and another source on the net is the usual parallel-source error. A flag without a voltage only names the net. A +5V and a -5V flag in one circuit are two sources (the sign is part of the name of the source, **PWR_P5V** and **PWR_N5V**), so a split supply drawn with flags runs.
G	Ground	The 0 V reference, net 0: the main ground. Every circuit needs at least one. While the ground follows the pointer, Tab steps through the main ground, each isolated domain already on the sheet (ISO1, ISO2…) and a new domain.
Library	Isolated ground	The open triangle under **Sources**, or G then Tab: a ground of its own ground domain, named ISO1, ISO2 and so on (**Ground name** in the inspector). Grounds with the same name are one net, kept apart from net 0 except through the isolation resistance (1 GΩ) and capacitance (10 pF), which belong to the domain: set them on any symbol of it and every symbol follows. A ground whose name is cleared, GND or 0 is the main ground again, and the main ground has no isolation fields. Keep sides isolated with their own grounds, p. 45 has the steps.

KEY	ELEMENT	WHAT IT CONNECTS
Alt + P	Sheet port	Inside a hierarchical sheet, a named connection to the sheet symbol in the parent. On the top sheet a message explains that a net label does that job there.

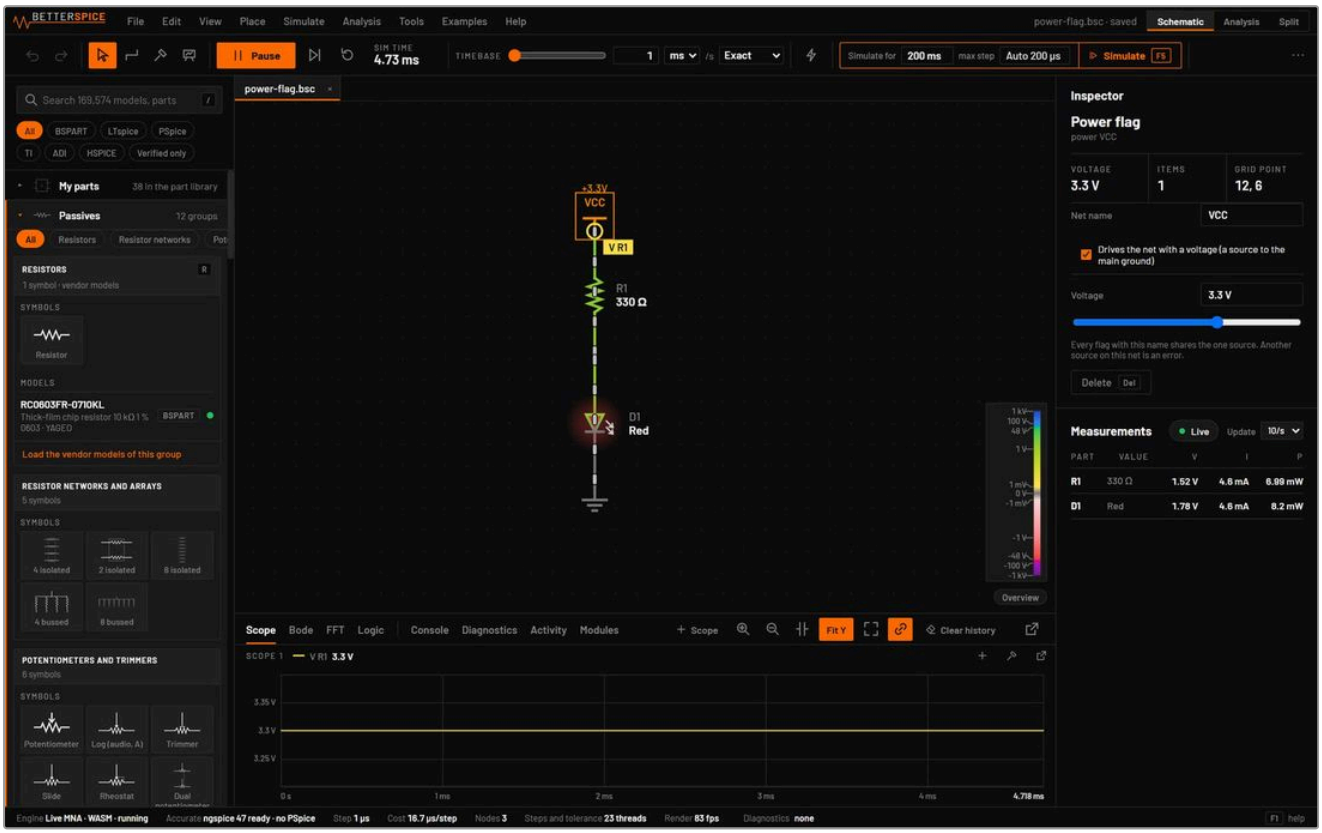


Figure 22.2 A VCC power flag with 3.3 V: the Inspector has the net name, the box Drives the net with a voltage, and the voltage with its slider.

Names can't contain spaces. Use an underscore instead. An empty name is refused with *"Type a name or press Esc."* Double-click a net label to rename that net.

A net label is a flag that points right, left, up or down. Select one or more labels and press R (Shift + R turns the other way), or right-click a label and choose **Rotate label**, or pick the side with the four arrow buttons in the inspector. A side chosen by hand stays when the label is moved or other parts are edited.

22.4 Graphics

Text (T), lines (Shift + L), rectangles (Shift + R) and circles (Alt + C) have no electrical meaning. Use them for notes, titles and boxes around blocks. Drag to draw a line, rectangle or circle.

For text, click where the note goes and type: the note is typed right there on the schematic, in its final size and colour. Enter starts a new line. The bar above it makes the text larger or smaller, bold, or aligned left, centred or

right. Ctrl + Enter, Done or a click elsewhere places it; Esc throws it away. Double-click a note to change it the same way; a note emptied this way is removed. Each edit is one undo step.

22.5 Selecting

ACTION	HOW
Select one item	Click it. Parts, wires, labels, flags, probes, sheets and graphics can all be selected.
Add or remove	Shift-click or Ctrl-click toggles an item in the selection.
Box select	Drag on empty canvas. Left to right (solid box) selects what is fully inside. Right to left (dashed box) also selects what the box touches. Hold Shift or Ctrl to add to the selection.
Select all	Ctrl + A selects everything on the current sheet.
Clear	Click empty canvas, or press Esc.

22.6 Editing

ACTION	HOW
Move	Drag the selection. Wires stretch to stay connected. The arrow keys nudge by one grid step, with Shift by five. A burst of nudges is one undo step.
Rotate / mirror	Space (with Shift, counter-clockwise) / Ctrl + E. Every part turns and mirrors, grounds, test points, connectors and power and rail flags included, alone or in a selection, and keeps its turn when copied. Four turns put a part back exactly.
Delete	Del or Backspace
Copy, cut, paste	Ctrl + C, Ctrl + X, Ctrl + V. Paste puts the middle of the copied group on the grid point under the mouse (the middle of the view when the paste comes from a menu or the toolbar). If that exact spot would put a copied pin, wire end or label on something already there, so the copy would join nets by accident, it goes to the nearest free grid point. Pasted parts get the next free designators, so R1 becomes R4 if R1 to R3 exist.
Duplicate	Ctrl + D puts the copy centred on the mouse when the pointer is on the canvas and not over the selection itself. Otherwise, and from the menu, it pastes a copy two grid steps down and right. Either way the copy is selected. Pasting or duplicating hundreds of parts takes about a second. Four quarter turns of a selection put it back exactly where it was.
Undo / redo	Ctrl + Z / Ctrl + Y. Each tab keeps 300 steps. One slider drag, one typed edit or one drag is one step. Edits made by an AI agent undo the same way.
Edit a value in place	Double-click the value label (4k7, 10u) and type. The hint says *"For example 4.7k, 10u or 2.2e-3 · Enter to apply"*.
Open the model dialog	Double-click the part.
Toggle a switch	Click it while the circuit runs. Push buttons are pressed only while you hold the mouse button. Rotary switches step through their positions. The same click works on a latching relay's test lever, solder jumpers, a touch pad, a PIR motion sensor and an opto-interrupter slot (each flips its live state), and steps an encoder knob by one detent. **Toggle** and **Step one detent** are in the part's right-click menu too.

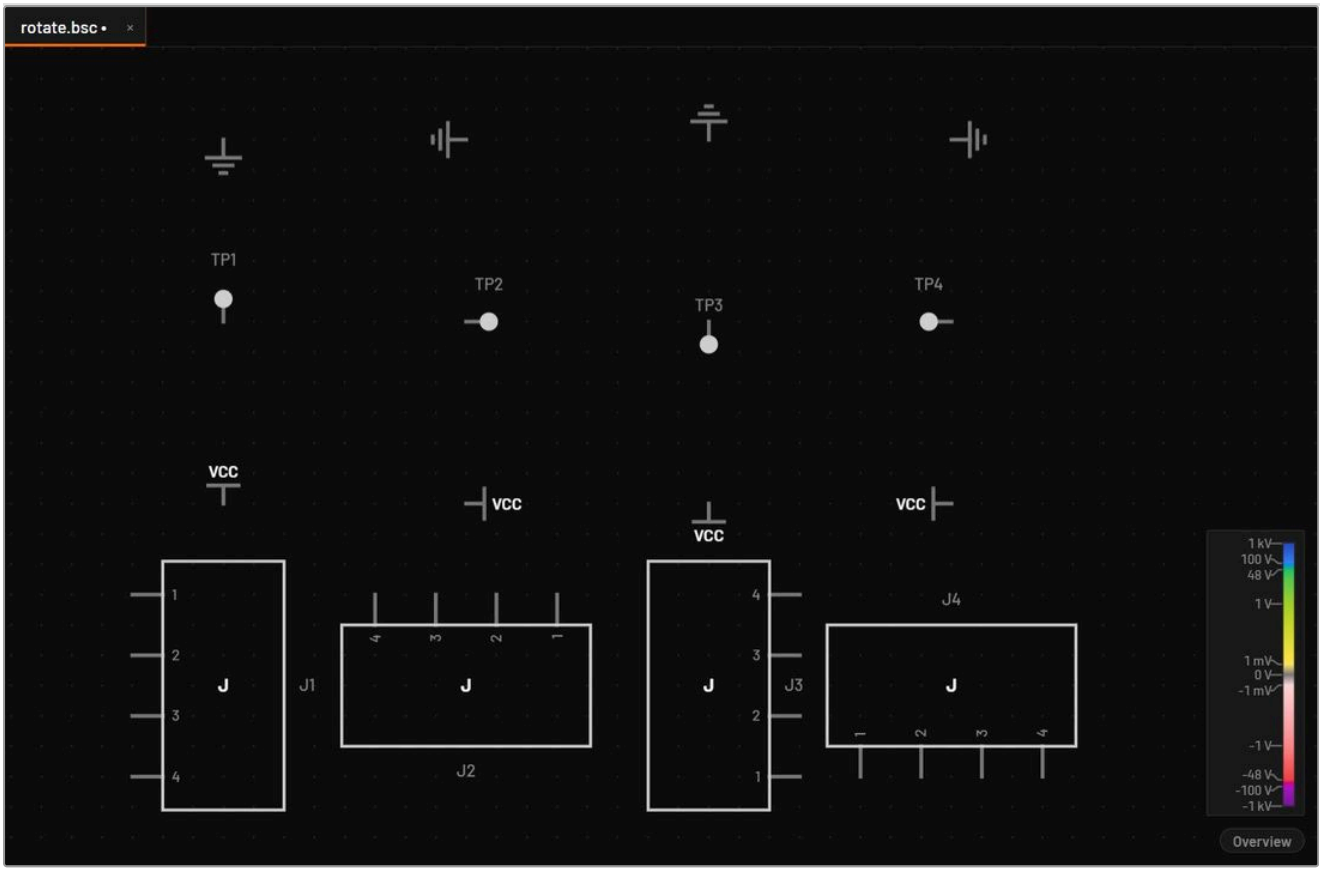


Figure 22.3 Grounds, test points, power flags and connectors, each in its four turns.

Copy also puts the selection on the system clipboard as text, so it can be pasted into another BetterSPICE window. Paste also accepts a whole **.bsc** file's text from the clipboard. Dropping files on the window works too: a **.bsc** or **.json** opens in a new tab (as an unsaved copy, without its path), a **.bspart** or **.bssym** goes to My parts, and a KiCad or EasyEDA Pro file is imported.

22.7 The right-click menus

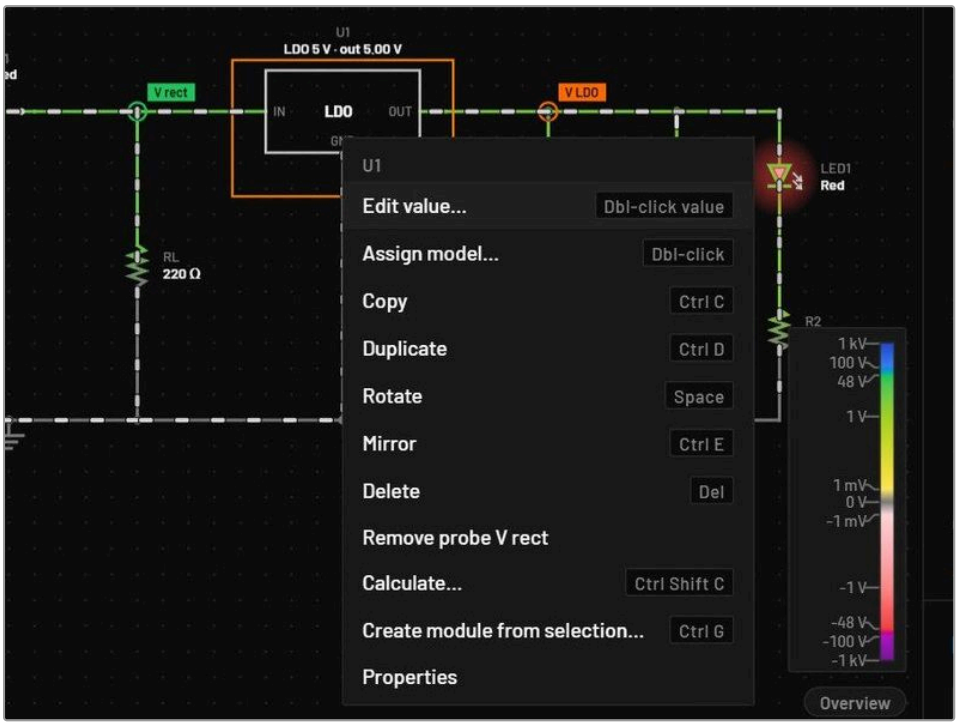


Figure 22.4 Right-click a part.

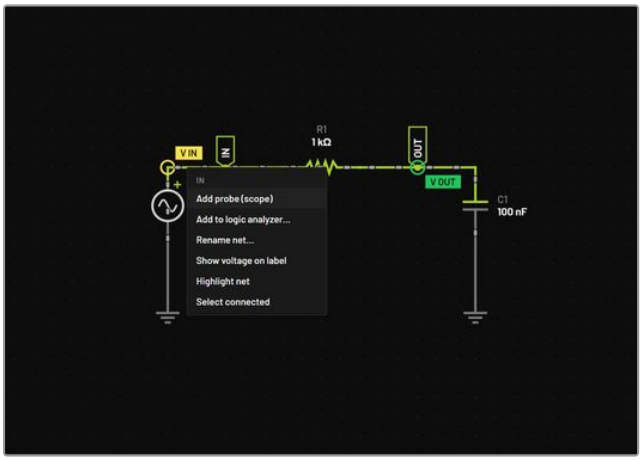


Figure 22.5 Right-click a wire: the net menu.

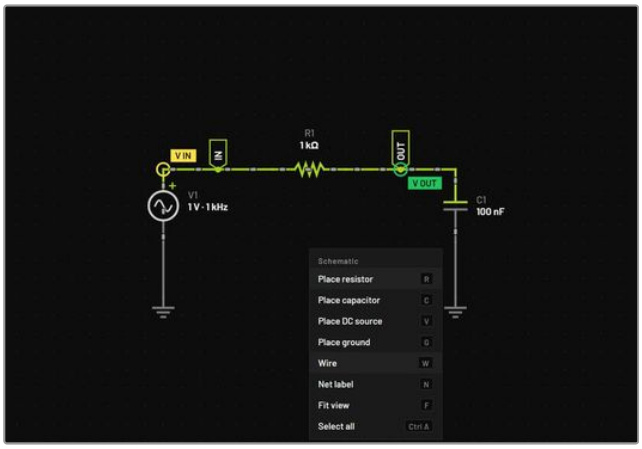


Figure 22.6 Right-click empty canvas.

ON	ENTRIES
A part	**Edit value…** (the inline editor), **Toggle** (switches), **Assign model…** and **Quick model…** (only for types that take one: resistors and capacitors have no Quick model), **Rotate**, **Mirror**, **Copy**, **Duplicate**, **Delete**, **Add probe** (the current through a two-pin part, otherwise the voltage at pin 1) or **Remove probe *label*** when it's probed, **Create module from selection**, **Properties** (jumps to the inspector). On a Subcircuit / IC with no vendor model also **Edit subcircuit**.
A sheet	**Edit subcircuit** (opens the inside in its own tab), **Copy**, **Duplicate**, **Rotate**, **Delete**.
A wire, label or flag	**Rename net…** (renames every label of the net on this sheet) or **Add net label…**, **Highlight net** (for 3 s), **Select connected**, **Add probe (scope)** for the net voltage, and **Add to logic analyzer…**, which asks for the logic threshold in volts (default 1.65, with the hint "5 V CMOS 2.5 · 3.3 V CMOS 1.65 · TTL 1.4").
A ground	On any ground: **Start a new ground domain (ISO3)**, which makes that ground the first symbol of the next free domain. On an isolated ground also **Rename domain ISO1…** (renames every ground symbol, power flag, global and net label of that name on the sheet, in one undo step) and **Make it the main ground**.
Empty canvas	**Paste here**, **Place resistor**, **Place capacitor**, **Place DC source**, **Place ground**, **Wire**, **Net label**, **Fit view**, **Select all**.
Anywhere with a tool active	Cancels the wire in progress, otherwise returns to the Select tool.

22.8 Readings under the pointer

Hold the mouse over anything while the circuit runs.

OVER	SHOWS
A part	Its designator, type and value, and its voltage, current and power. Parts with 3 to 10 pins also list each pin's voltage and current. Controllers show their duty cycle. A reading smaller than a billionth of the circuit's own scale shows as 0, not as solver residue such as 4 fA.
A wire	The net name, its voltage and the current in that wire.
A ground	The main ground: *Main ground* and the current into it. An isolated ground: *Isolated ground · ISO1*, *V vs GND* (how far the isolated side floats from the main ground) and *I barrier* (the current through the isolation barrier).
A label or flag	The net name and voltage.
A sheet symbol	The sheet name and file, and the voltage on each of its ports.
A probe	What it measures and its value. Del removes it.
A diagnostic marker	The code, the message and the fix.

22.9 Moving around

ACTION	HOW
Zoom	Mouse wheel or touchpad pinch, at the cursor. Ctrl and the wheel zooms faster. Ctrl + = and Ctrl + - zoom at the centre. Range 2 % to 500 %.
Pan	Middle-drag, right-drag, two-finger scroll on a touchpad, or hold Space and drag.
Fit	F fits the whole sheet in the window. Opening a circuit fits it too.
Overview	The **Overview** button at the bottom right opens a minimap of the whole sheet with the visible area marked. Click or drag in it to move. It shows the number of parts and the zoom, and opens by itself on sheets with more than 300 parts. **Hide** closes it.

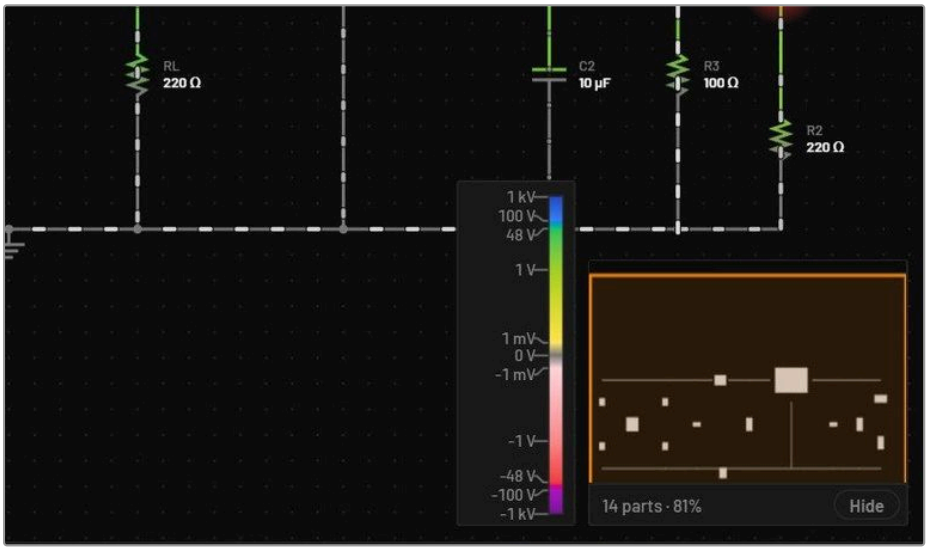


Figure 22.7 The overview minimap, bottom right of the canvas.

At small zoom, parts are drawn as plain boxes and net-label text is left out so large boards stay fast.

23 Hierarchical sheets and buses

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A hierarchical sheet puts part of a circuit inside a box. The box has a port for every net that leaves it. It keeps big schematics readable and lets you reuse a block. Sheets simulate as part of the whole circuit: the engine flattens them automatically.

23.1 Making a sheet from a selection

1. Select the parts, wires and labels that belong together. Drag a box around them.
2. Press Ctrl + G, or right-click a part and choose **Create module from selection...** (Edit menu too).

   YOU SHOULD SEE The **Create module** dialog opens: the module's name, and one row for every net that crosses the selection.
3. Check the rows. Each pin has a name (the net's label when it has one, else the part and pin it touches), a direction and a side. Press Enter, or **Create module**. Esc cancels and changes nothing.

The selection becomes one sheet symbol, named S1, S2 and so on, with a pin for every net that crossed the edge of the selection. The whole change is one undo step and the new symbol is selected. A selection of modules becomes a module of modules.

The box is put where it stands clear: not on another part, wire, name or box, with its pins level with the wires that arrive so they run straight in. When the selection's own place is crowded it takes the nearest clear one (the wires follow); a bus drawn with the selection (its line, entries and label) moves in with it and leaves nothing behind.

23.2 The Create module dialog

PART OF THE DIALOG	WHAT IT DOES
Name	The module's name, drawn above its box. Up to 60 characters.
Pin name	Up to 64 characters; spaces and symbols are fine. Two pins cannot share a name (two nets would join), a name cannot be a vector like **D[0..7]**, a name may hold **/** or **:** (it never joins an inner module's net of a similar path), and it cannot be a name a net label or flag inside the selection uses for another net. **0** and **GND** (any case) are the ground: a pin so called on a net that is not the ground would tie that net to the ground and change the circuit, so the dialog and the pin window refuse it. The dialog says which rule a name breaks and keeps **Create module** disabled until it is fixed.
Direction	**Input**, **Output** or **Both**. It is guessed from the parts: a net driven inside (a source, an IC output pin) is an output; a net read inside (an IC input, a gate or base) or driven only from outside is an input; a net with only passive parts is Both. The line under each row says what the guess rests on, and changes to "direction set by you" when you edit it. Inputs go on the left and outputs on the right by default.
Side	Left, right, top or bottom. A pin that is Both faces the wiring around it.
Required	A net that also touches something outside the selection must be a pin, or the circuit would change; it cannot be left out. Nets wholly inside can be added from **Add a pin for a net inside** and removed again.
Ground	Ground symbols inside tie to the main ground of the whole circuit, so ground is not a pin (the dialog says so).

Direction is a label. It changes how a pin is drawn (a small triangle pointing into the box for an input, out of it for an output, a diamond for Both), how the pin window sorts it and what the monitor watches. It never changes the solved circuit: a pin marked output can still carry current in either direction. A file from before directions has none, which reads as Both and is drawn as before.

Copies are independent. Copy, paste and duplicate (Ctrl+C, Ctrl+V, Ctrl+D) give a module its own copy of the circuit inside: editing one never changes another. A file does not share one definition between boxes. A copy keeps the name with a number added (**Filter 2**, **Filter 3**) and takes the next free id (S2, S3).

23.3 Wiring modules together

A module box is wired like a part. Drag from a pin with the wire tool, or from a part's pin to a module pin; the wires follow when you move the box. A box stays upright (Rotate and Mirror leave its pins where they are, and nothing is disconnected). You can also join modules **without a wire**: put a net label on a pin of one module and a label of the same name on a pin of another module, or on any wire or part on the same sheet. Labels with one name join on one sheet, and the same name inside a module is a different net.

23.4 Tying a pin to a net inside

Inside a module, a pin reaches the circuit in one of two ways, and both mean the same thing: a **sheet port** (Alt + P) of the pin's name on a wire, or a **net label** of the pin's name on a wire. No port is needed. The pin window shows which one a pin has ("Tied by a port", "by a net label", "Not tied inside") and what it reaches. A label inside a module never joins a label of the same name in another module or on the parent sheet unless the name is a pin of that module; a **global label** still joins everywhere, and two copies of a module stay separate circuits.

23.5 The module pin window

1. Click a module, or open it. Then choose **Module pins…** from its right-click menu or the inspector, double-click one of its pins, or press Alt + 8.

   YOU SHOULD SEE The **Modules** tab of the dock shows Inputs, Outputs and Both in separate groups, for the selected module or the one you have open. **Pin to this module** keeps it when the selection moves.

2. Each pin has its name (type, press Enter), direction, side, up and down arrows (order on its side), the net inside it is tied to, what it joins outside, and its live voltage and current.

3. To tie a pin, choose a net by name from **Tie to a net inside…**, or press **Pick on the sheet**, which opens the module and takes one click on a wire or pin inside.

4. To add a pin, type its name at the bottom, choose direction, side and (optionally) the net, and press Enter. To remove one, press its cross: the window says what that cuts, and Ctrl+Z puts it back.

Every change is one undo step and shows on the box at once. Renaming a pin also renames the ports and net labels inside that carry its name, so nothing disconnects. Renaming onto another pin's name is refused. A name too long for the box widens it on the side that has room; when neither side has, the box keeps its size and the drawing shortens the name with an ellipsis (the pin window shows it whole). The pop-out button at the top right opens the window as its own window to keep beside the schematic; **Dock back** returns it. The current shown is the current that flows into the module through the pin.

23.6 Watching inputs against outputs

Put inputs and outputs on a scope (pin window, inspector, or the module's right-click menu) adds a voltage probe on every pin marked Input or Output, grouped and named **S1 IN** and **S1 OUT** (one scope pane each, titled with the group). The probes are saved with the circuit, and renaming a pin keeps its probe. The **Monitor** tab lists every module of the sheet with its input and

output voltages live (or at the scope's playhead while paused, or at the playhead of a Simulate run) and the gain from a chosen input to a chosen output, in V/V and dB. Several modules are watched together.

TRY IT

Pack a filter into a block

1. Open the example **Filters, Active high-pass**.
2. Box-select the op-amp and its two resistors and two capacitors.
3. Press Ctrl + G, type **HPF**, press Enter.

YOU SHOULD SEE One box named HPF replaces the filter, with ports for the input, output and supplies. The scope still shows the same waveforms, because the circuit hasn't changed.

23.7 Editing a subcircuit

The **Subcircuit / IC** part (X) is a box with pins and, until you give it a vendor model, nothing inside. You can build its inside yourself.

1. Place a Subcircuit / IC (X) and wire the things around it to its pins.
2. Double-click it, or right-click it and choose **Edit subcircuit**.

   YOU SHOULD SEE The part becomes a sheet in the same place, with the same name (X1), and the wiring around it is kept. The canvas shows the inside, with one port for every pin, and a new tab ↳ **X1** appears after the circuit's tab.
3. Draw the circuit between the ports.
4. Click the circuit's own tab to go back to the top level. Click ↳ **X1** to go back in.

   YOU SHOULD SEE The circuit simulates with what you drew: the sheet is flattened into the circuit as for any sheet.

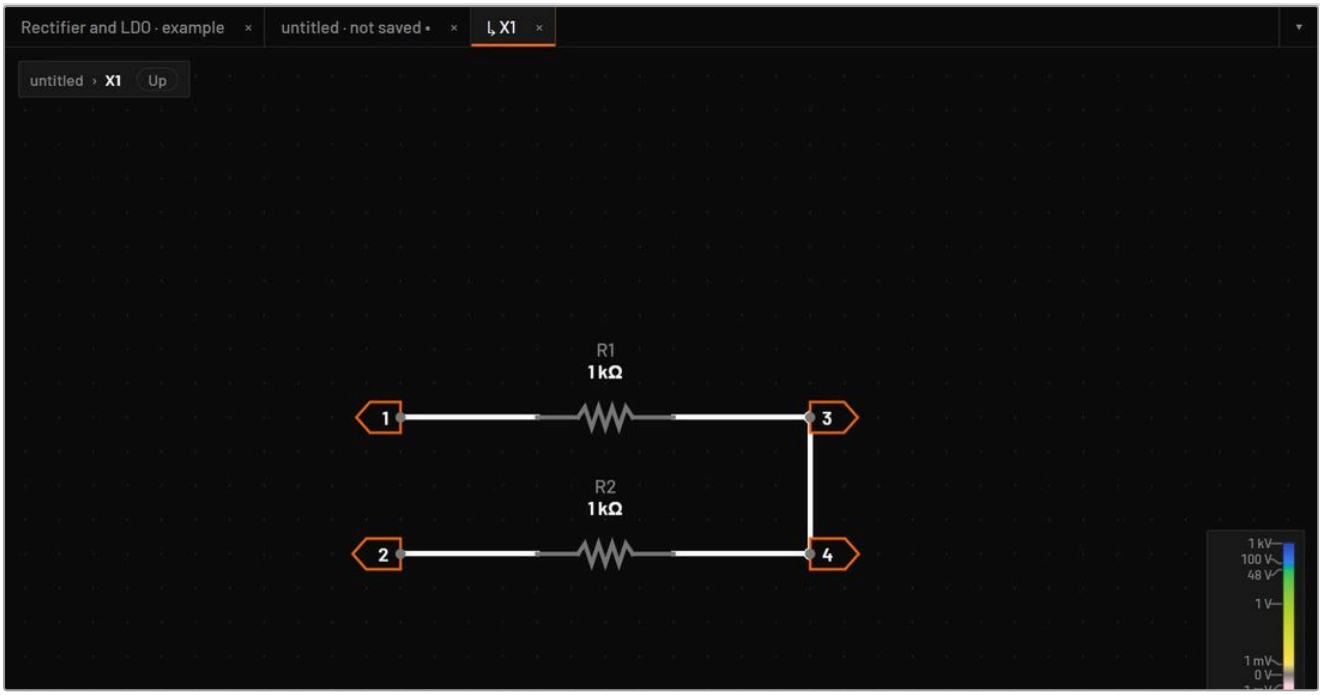


Figure 23.1 The inside of X1: ports 1 and 2 on the left, 3 and 4 on the right, and two 1 kΩ resistors drawn between them. The tab strip shows the circuit's tab and the tab ↳ **X1**.

DETAIL	HOW IT WORKS
Which parts	Only a Subcircuit / IC with no vendor model, no **lib** and no custom symbol. With a vendor model, a double-click still opens the model dialog.
Pins and ports	Every pin becomes a port at the same place on the same side, so the wires keep their connections. Two pins with the same name become **name** and **name_2**. The sheet is named after the part's title, or its id.
Undo	The whole change is one undo step. Undo brings the part back and removes the tab.
The ↳ tab	Every sheet you open shows as a ↳ tab after its circuit's tab, however you opened it. It's the same document: edits go straight into the circuit and are saved, simulated and undone with it. The tab has no file of its own. The **×** or a middle click closes only the tab, and so does Ctrl + W while it's showing.
Existing sheets	Right-clicking any sheet gives the same **Edit subcircuit** and **Module pins...**. The box stays upright.

23.8 Opening and leaving a sheet

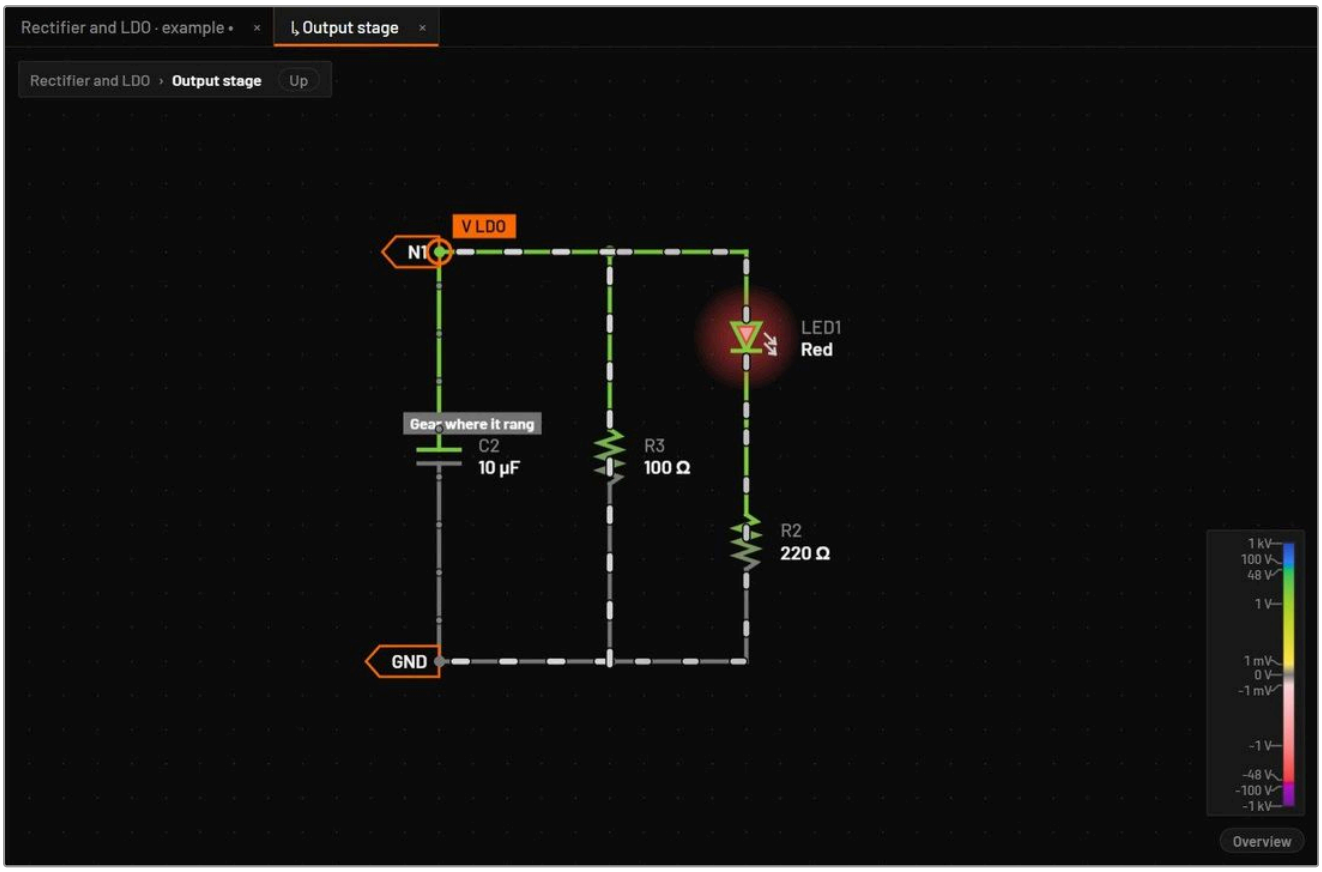


Figure 23.2 Inside a sheet. The breadcrumb at the top left leads back to the parent.

- **Open:** double-click the sheet symbol. The canvas shows the inside of the sheet, and a tab for it appears next to the circuit's tab.
- **Breadcrumb:** the bar at the top left shows **Top › Sheet name**. Click a level to go there.
- **Up:** the Up button, or Backspace with nothing selected, goes up one level.
- **Names inside a sheet:** parts inside a sheet are listed with a prefix, such as **S1/R3**, in Measurements, probes and diagnostics.

23.9 Ports and global labels

Inside a sheet, place a **Sheet port** (Alt + P) on each net that must reach the parent. The sheet symbol grows a matching port. Use a **Global label** (Shift + N) for a net that every sheet shares without wiring, such as a clock or a supply.

23.10 Sheets in files

A sheet is normally stored inside the circuit file. A sheet can also live in its own file next to the circuit, which is how imported KiCad designs keep their sub-sheets. The desktop app reads and writes those files next to the top circuit. If a sheet file can't be read, a message names it.

23.11 Buses

- **Bus** (Shift + W) draws a thick line that stands for a group of signals.
- **Bus entry** (Shift + E) connects one member wire to the bus, one grid step diagonally. R turns the entry through its four directions while placing.
- The member wires carry the connection. Name them with net labels so the same names on both sides of the bus join.

24 The library and model search

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The library is the left pane. It holds every placeable part type and every model in the catalogue, sorted into families such as Passives, Sources, Diodes and thyristors, Transistors, Analog ICs and Power management. An open family shows chips that pick a sub-group, and each sub-group is an outlined block with its **Symbols** (the tiles you place) and its **Models** (the vendor models that belong to it).

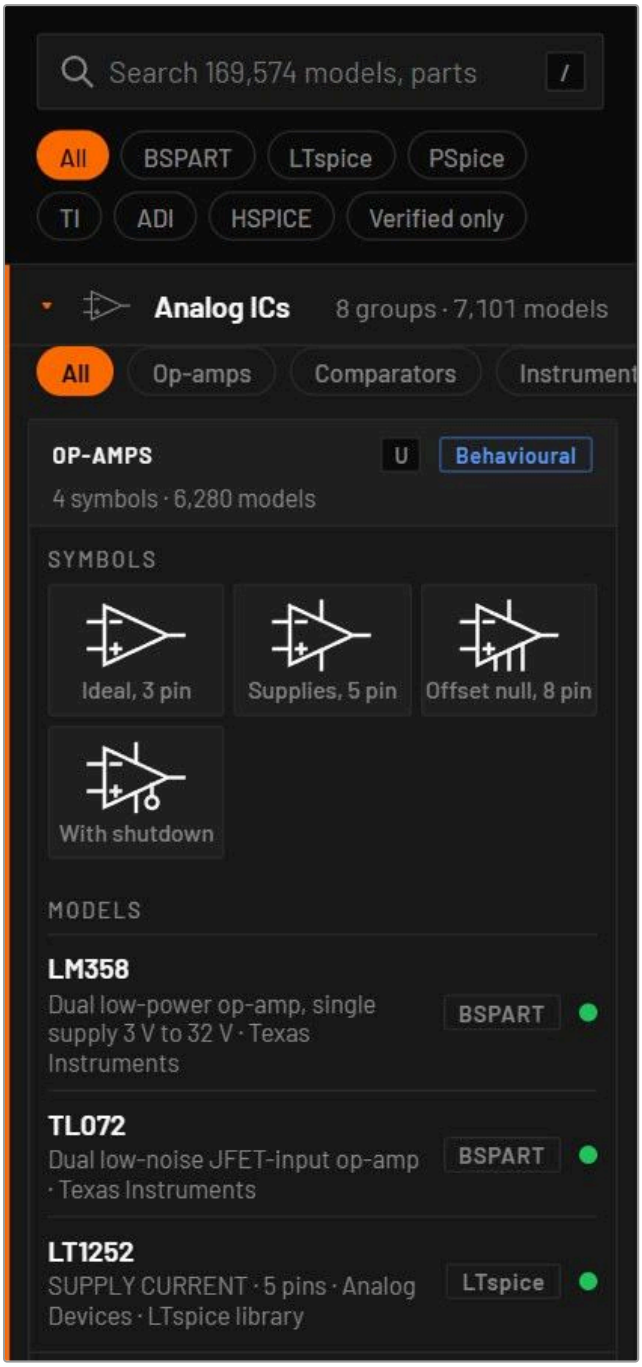


Figure 24.1 An open family: chips at the top, then one outlined block for each sub-group, with its Symbols and its Models.

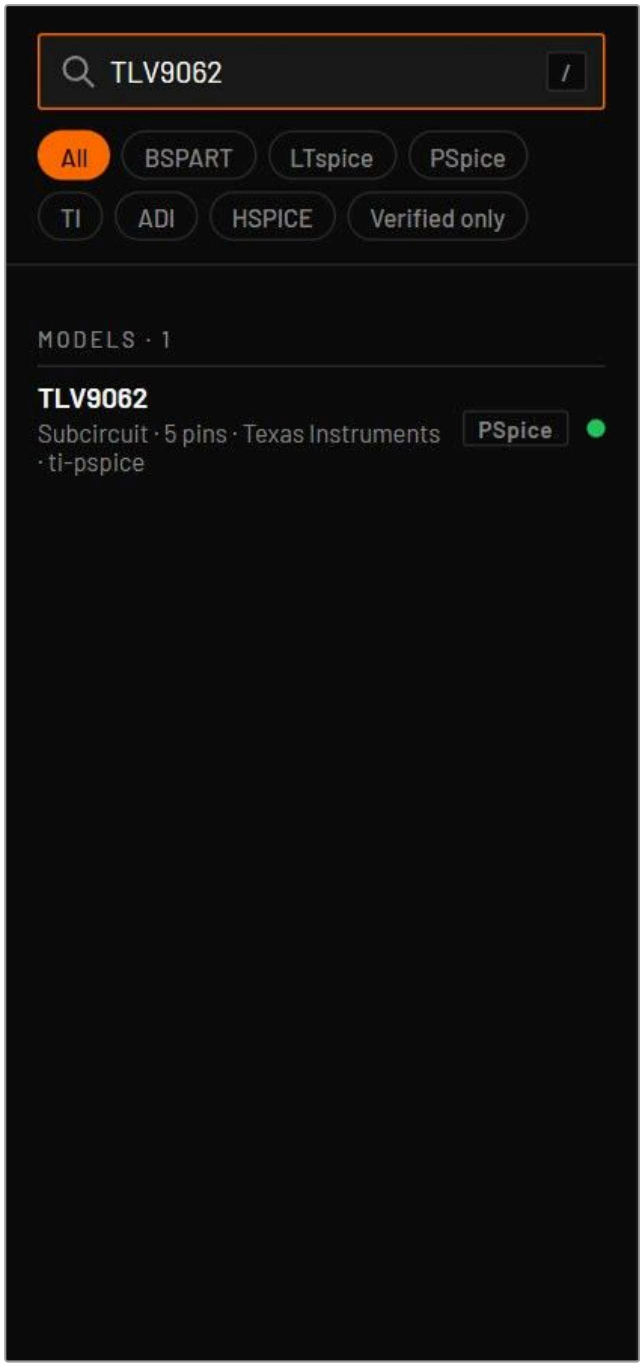


Figure 24.2 Searching TLV9062: the TI model, with pins and maker.

24.1 Searching

- Press / to jump to the search box. Esc clears it. Up and Down highlight a result and Enter places it. Enter with nothing highlighted places the first one.
- Type a value with a kind of part, such as **10k resistor**, **100nF**, **5V source** or **4.7uH**, and the first result is a generic part with that value.

- Type part numbers, makers, functions or descriptions. Every word must match. **IRLZ44**, **logic level mosfet** and **texas instruments comparator** all work.
- Spelling of part numbers is forgiving: **irf 540**, **irf-540** and **IRF540** are the same search, and a part number one or two letters off still finds the part.
- Results are listed in sections: **My parts**, **Symbols** (part types, click to place), **Examples** (click to open) and **Models**. Exact part numbers rank first, then prefixes, then other matches, working models before ones with problems, and BetterSPICE part files first. Symbols rank by their own name (exact, then prefix, then a word, then anywhere) before matches in a group's name, so **isolated** lists **Isolated ground** ahead of the resistor arrays named *4 isolated*. Each part number has one row, from its best source, with **+N other models** to show the rest.
- When models match, only the first two examples are shown, headed *Examples · 2 of 6 · E opens all*, so the models stay in view. With no model match, all matching examples show.
- The catalogue loads in pieces. The first results appear at once and a line says how much is loaded. When the search finds parts, symbols or examples but no model, the models section is one quiet line instead of an empty block.
- When nothing matches, the card shows near matches, how many results there would be without the filters, and buttons to **Clear filters** or **Clear search**. It suggests a function search such as **Ido 3.3** or building a Quick model.

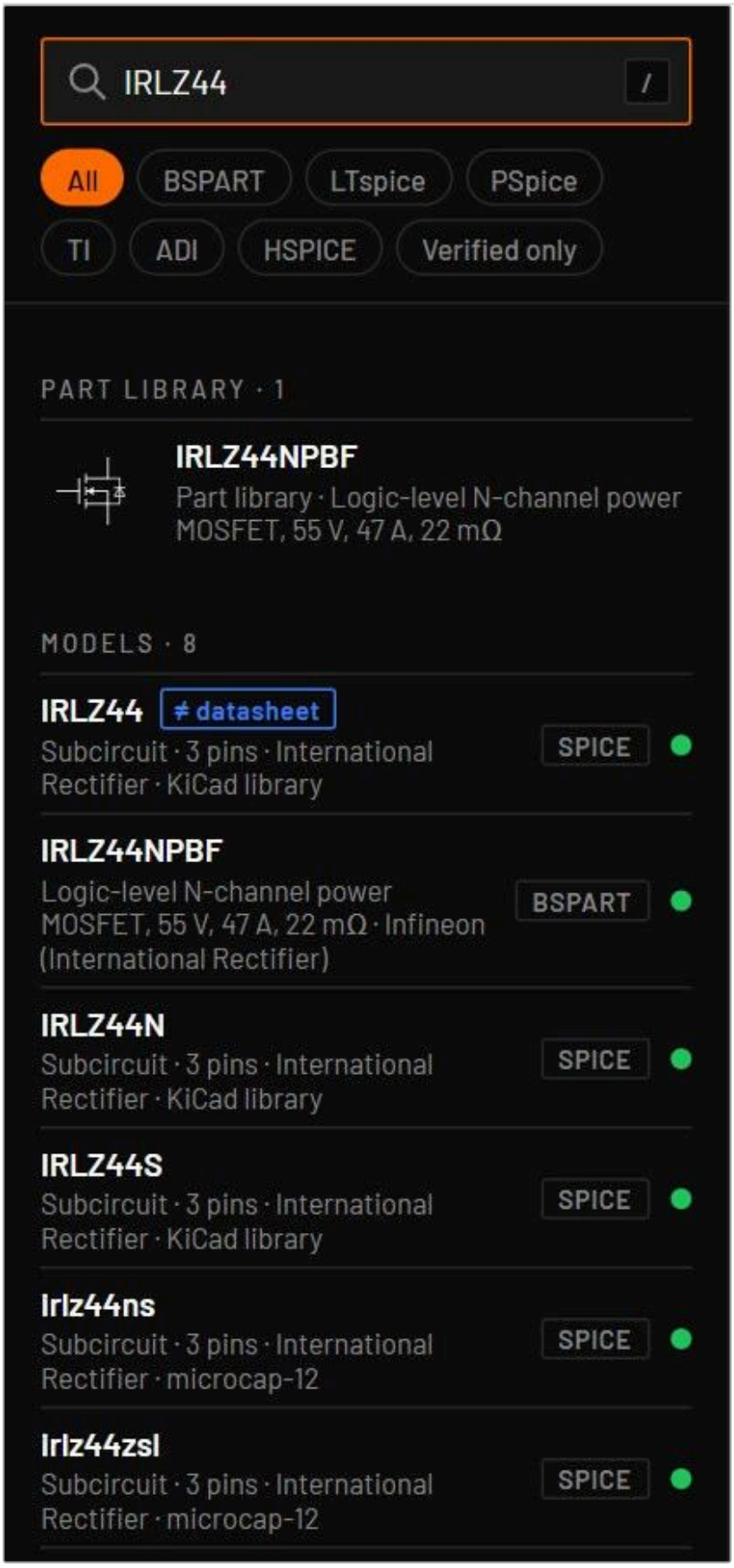


Figure 24.3 Searching IRLZ44: every IRLZ44 model from every library, with its source.

24.2 Source filters

CHIP	SHOWS
All	Everything. Clicking it clears the other chips.
BSPART	BetterSPICE part files: a symbol, a model and the datasheet limits in one file.
LTspice	Models in LTspice syntax.
PSpice	Models in PSpice syntax.
TI	Texas Instruments, including Burr-Brown and National.
ADI	Analog Devices, including Linear Technology and Maxim.
HSPICE	Models in HSPICE syntax.
Verified only	Models that ran in ngspice unchanged or after conversion, with no known issue.

Chips can be combined. They apply to the search results and to the model lists in the tree.

24.3 Families and subcategories

The tree opens with Passives and Sources expanded and remembers which families you opened, and where you scrolled to. A **Recent** family at the top lists the parts you placed last. Tiles and model rows can be dragged onto the canvas. The part drops where you release it. Orange marks only the open family (a 2 px bar, its caret and icon), the chip you picked and the tile under the pointer. Everything else is white, grey and hairlines. An open family has a row of chips: **All**, then one chip for each sub-group, such as Op-amps or Comparators. The mouse wheel scrolls the row sideways. Each sub-group block shows:

ITEM	MEANING
Header	The sub-group's name, the key that places its part where there's one, and how many symbols and models it holds.
Level badge	Shown only when a group isn't exact, so no badge means the device equations are exact (checked against ngspice). **Behavioural**: a fitted behavioural model. **Pass-through**: the vendor model runs as it is. **Placeholder**: drawn and exported, not simulated yet. The tooltip of a badge has this legend.
Symbols zone	Tiles with each symbol style, for example a resistor as a box or a zigzag. Click one to place it. **symbol only** means the engine has no model for it, so it's drawn and exported but left out of the simulation. **planned** means it's not in the editor yet.
Models zone	The group's top three vendor models, and **Show all** for the full list. ← **back** returns to the tree.

24.4 Every model once, and Show all

Every vendor model appears exactly once, under its own sub-group. Kinds that several groups share are split: diodes into rectifier and signal, regulators into LDO and DC/DC, and logic chips by their 74xx or 4000 function (gates, buffers, flip-flops, counters, shift registers, multiplexers,

monostables). Models that the catalogue could not classify go to the group of what they are: capacitor, inductor, ferrite bead, common-mode choke, resistor, transformer, varistor, thermistor, thyristor or crystal. Within a group, verified models come first, then the most common ones.

Show all opens one group on its own. It has a search box for part numbers, makers and words, a pill for each of the top five makers with a **+N** button for the rest, source pills (Verified, Built-in parts, LTspice, PSpice) and a count such as *39 of 6,280*. The list has two sections: verified models, then models that need PSpice, are encrypted or fail. Up, Down and Enter work from both search boxes.

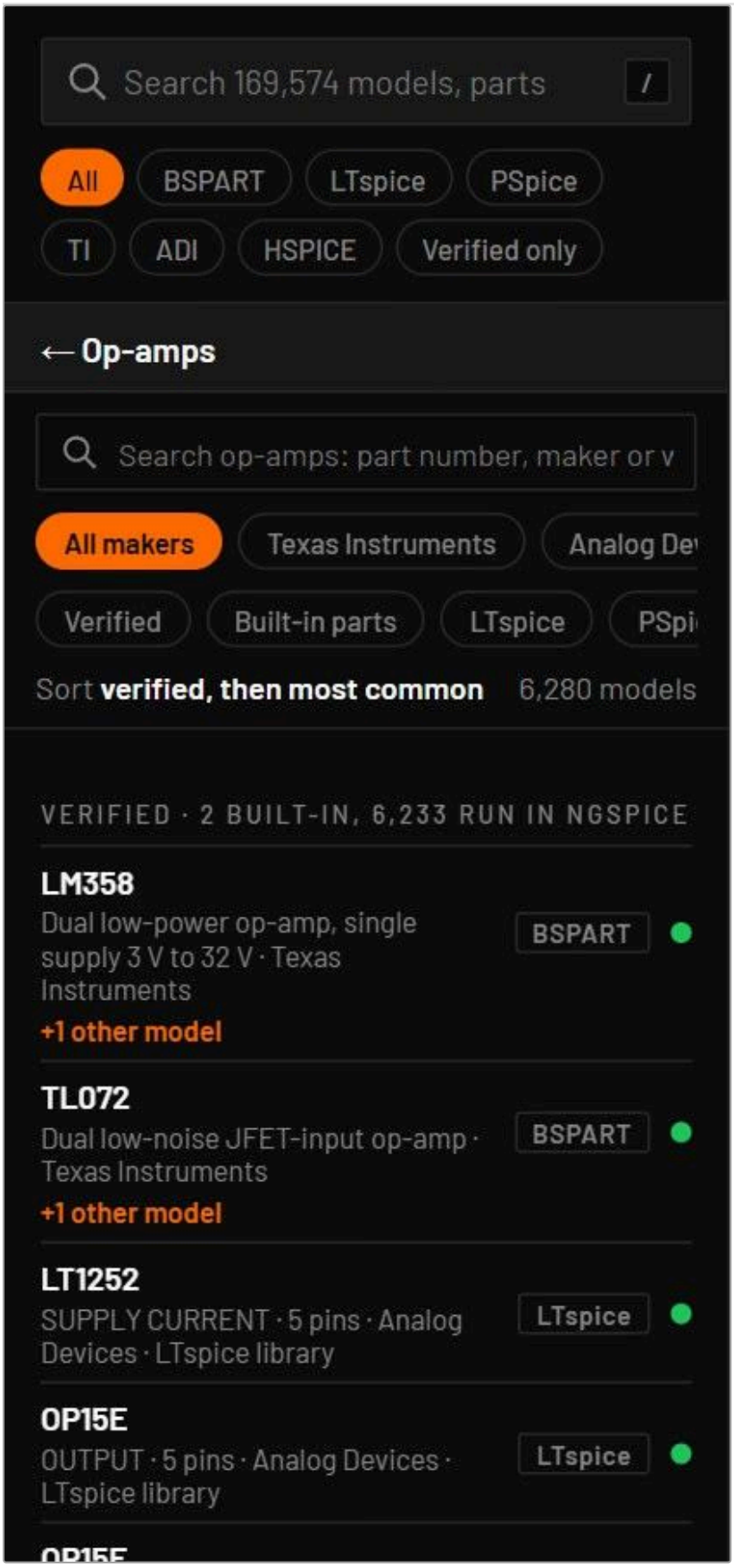


Figure 24.4 Show all for op-amps: its own search, maker and source pills, the count, and the verified models first.

The unsorted vendor models, about 95 000 of them, load only when you ask: when you open a family that needs them, press **Show all** or search. Until then such a family shows how many groups it has, and a group shows a **Load** button. This keeps the app's memory use low at start-up.

24.5 Switch, Relay and Generic IC

There is one **Switch** tile and one **Relay** tile. A Switch has a pill for toggle, push and SPDT, and a Relay one for SPST, SPDT and latching. Click a pill to place that variant, or drag it onto the canvas. **Generic IC** is one tile, a box whose pin names, sides and title you type in the inspector. It takes a vendor subcircuit through **Assign model**, and **Move pins** changes where its pins sit.

24.6 Model rows

Each model row shows the part number, a description, the maker and the origin, a format tag (SPICE, LTspice, PSpice, HSPICE, BSPART) and a status dot.

DOT	TOOLTIP	WHAT SIMULATE DOES
Green	Verified: runs in ngspice unmodified.	Runs the vendor model in ngspice.
Amber	Verified after conversion to ngspice syntax.	Runs the converted model in ngspice.
Green, PSpice	Cadence-encrypted, verified in PSpice.	Runs the vendor model in PSpice for TI (desktop with PSpice installed).
Red with a replacement	Replaced by *X* from *Y*.	Placing it places the working stand-in instead and a message says so.

Models that can't run in any engine are no longer in the catalogue (**Retired models**, p. 406).

24.7 Placing from the library

Click a symbol tile or a model row, then click the canvas. Placing a model from the library sets up everything the part needs to simulate:

- the device type,
- the pin map from the symbol pins to the model pins,
- the parameters the live simulation uses,
- the reference to the vendor file that Simulate loads.

A message appears in three special cases: the model has no live fit, the model is placed as its own IC box with the vendor's pins, or a working stand-in replaces the model.

TRY IT

Place a vendor op-amp

1. Press / and type **tlv9062**.
2. Click the TLV9062 row in Models, then click the canvas.
3. Wire it as a follower and press F5.

YOU SHOULD SEE The live simulation runs the fitted op-amp model. Simulate runs TI's own model in ngspice, and the progress line says so.

24.8 My parts

My parts is the first family. It lists the parts and symbols you made with the Part Wizard and the symbol editor, those an AI agent made, and files you added. Its header has **New symbol...** and **New part...**. Each row has **Edit symbol**, and your own items have **Remove**, which asks **Confirm** first. Below your own parts, **Part library** lists the read-only parts shipped with BetterSPICE. With none of your own, the My parts row reads **N in the part library**. My parts, p. 438 has the details.

25 The inspector, values and sliders

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Select a part to show it in the inspector on the right. Everything in it applies to the running simulation at once.

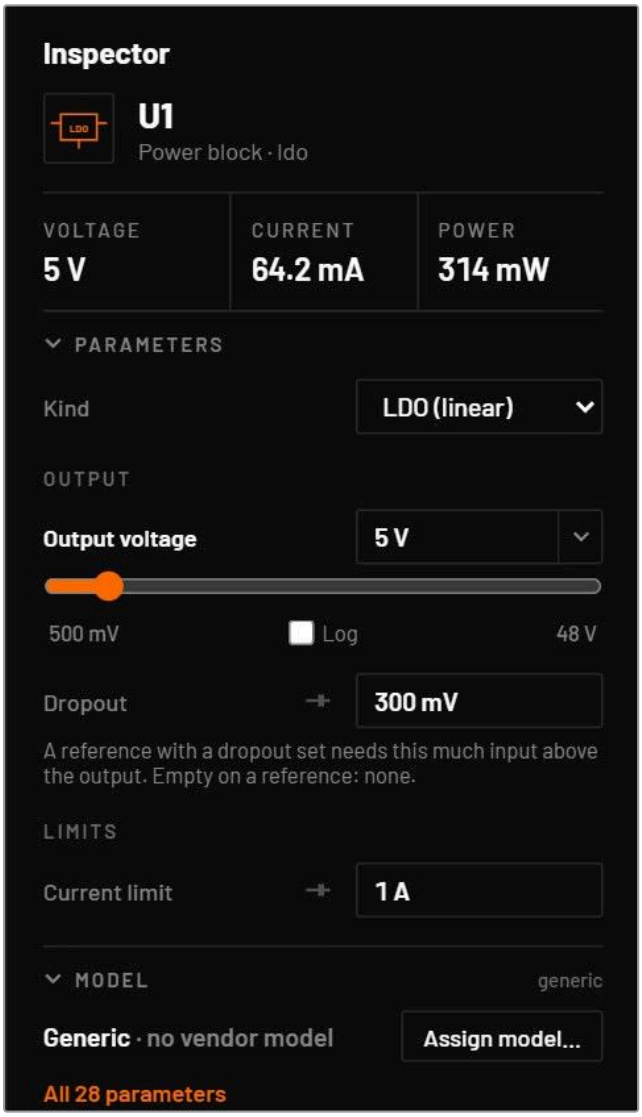


Figure 25.1 A power block in the inspector.

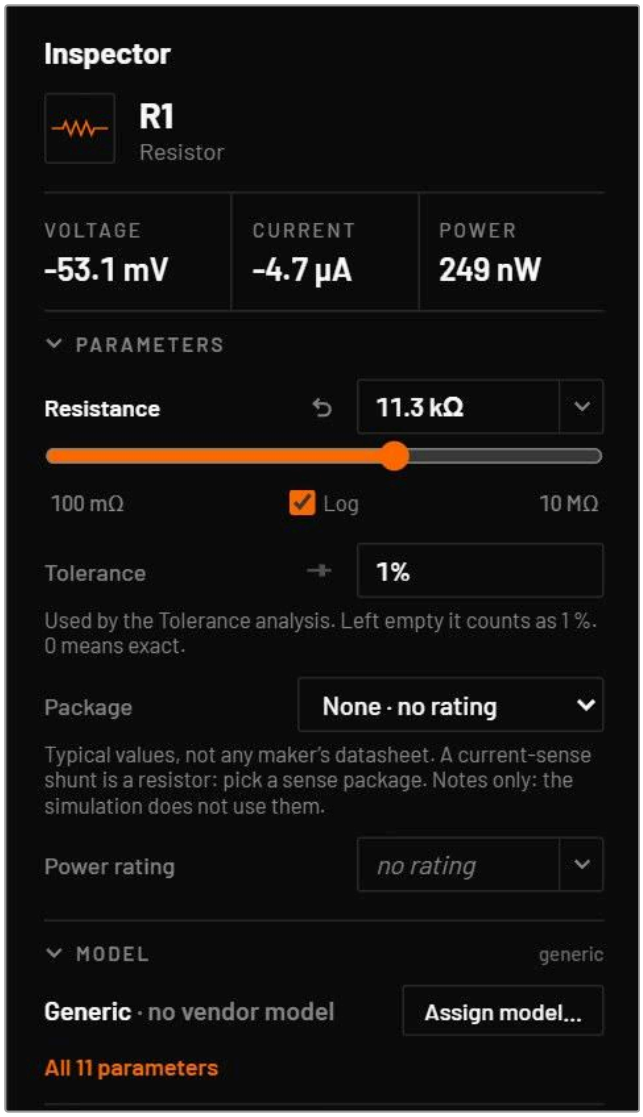


Figure 25.2 A resistor: value and slider.

25.1 Layout

SECTION	WHAT IT SHOWS
Header	The part's symbol, its designator (a long one is cut with an ellipsis, the full id shows on hover) and its type · variant. A violet **AI · *name*** badge marks a part an AI agent edited last. With several parts selected: *"N parts selected, showing R1."*
Readouts	**Voltage**, **Current** and **Power**, live, ten times a second. A dash when paused. A reading below a billionth of the circuit's largest voltage or current reads **0**, so an idle part doesn't show pV or fA. Hold the pointer over it for the exact value. A real small signal of the circuit's own scale still shows.
Source type	For sources: change the kind of source in place (**Changing the source type**, p. 273).
Parameters (folds)	The main parameters of the part, the most useful first, with its label in bold. A slider sits under the main field. Every other number has a small slider button beside its label. A part with four or more fields has headings over them (below). A value that differs from the part's default has a reset button beside its label.
Model (folds)	One line: the model name, or **Generic · no vendor model**, with a note at the right (*generic* or *vendor*). Then **Assign model...**, **Quick model** (for parts that have one) and **All N parameters**.
Live values (folds)	Everything the simulation knows about the part (below), with the run time at the right.
Buttons	**Add to scope** probes the voltage across the part. **Delete**.

Click a section heading to fold it. BetterSPICE remembers which sections you folded, for every part. The inspector fits a narrow pane (260 px) and uses the room when you make it wider.

PART	WHAT IS SPECIAL
Ground	The main ground shows only its **Ground name**. An isolated ground shows its name, the voltage across the barrier, and **Isolation resistance** and **Isolation capacitance**, which apply to every symbol of that domain (**mixed** appears if an old file disagrees).
Capacitor, inductor	Under **All N parameters**: **Initial voltage** (capacitor) and **Initial current** (inductor), where a part starts. Empty means *from the operating point*. See **Start at rest or from the operating point**, p. 181.
Potentiometer	**A → wiper** and **Wiper → B** in ohms, updated as you move the wiper. The wiper position is a plain fraction, 0.75, not 750 m.
Battery	The chemistry, its curve and the charge at the start (**Battery**, p. 283).
PWL source	A table of points, a **Time offset** and a **Repeat the points** check box (**Devices: sources**, p. 273).
CCVS, CCCS	One field (**Transresistance** or **Current gain**) and a note on the **s+ / s–** sense port, which goes in series with the branch to sense. Live value: **Sensed current** (**Devices: sources**, p. 273).
Digital filter, lookup table, state machine	Their coefficients, table and states are edited as tables under the block's fields, with **+** and **×** on each row (**Editing the filter, lookup table and state machine**, p. 305).
USB-UART bridge	Baud, the text to send, its start time, the line ending of the Console input, DTR, RTS and flow control (**Chips and displays**, p. 359).
Parts with a program	A **Code** tab beside **Parameters** for the control block and the microcontroller (**Programming the MCU**, p. 373).
Probe, wire, label	A small card with the voltage, the number of items and the grid point, and **Delete**. A probe also has **Show value on the schematic**, and shows the difference for a differential probe and the current for a current probe.

Select several parts of one type and variant, and the inspector edits them together: a field shows **mixed** where their values differ, and one change is one undo step. Sliders, readouts and Add to scope are hidden then.

Right-click a part and choose **Properties**: the inspector unfolds Parameters and puts the cursor in the main field. For a part with no inspector fields, such as a 555, it opens **All parameters**.

25.2 Curves from a datasheet

Some values are a curve rather than one number: a capacitor's capacitance against DC bias, an inductor's inductance against current, a battery's open-circuit voltage against charge, an LED's I-V curve, a comparator's delay against overdrive, a reference's voltage against temperature and a converter's INL. The curve editor shows the points as a table with a preview plot.

- Type into a cell. SI prefixes and units work, and **Tab** and **Enter** move on. **Enter** in the last value adds a row.
- Use **+** to insert a point after a row and **×** to delete one.
- Paste two columns copied from a spreadsheet or a datasheet table into any cell. The paste replaces the table. A header line is skipped, tabs, commas, semicolons and spaces all separate the columns, and a bad line refuses the whole paste and names the line.
- **Edit as text** takes the whole table as lines. **Clear** removes the curve and the part goes back to its plain value.
- Every change is one undo step. The curves of the main parameters are in the inspector, the others under **All N parameters**. Between points the curve is interpolated linearly (or in log x and log y where the axis is logarithmic) and is flat beyond the ends.

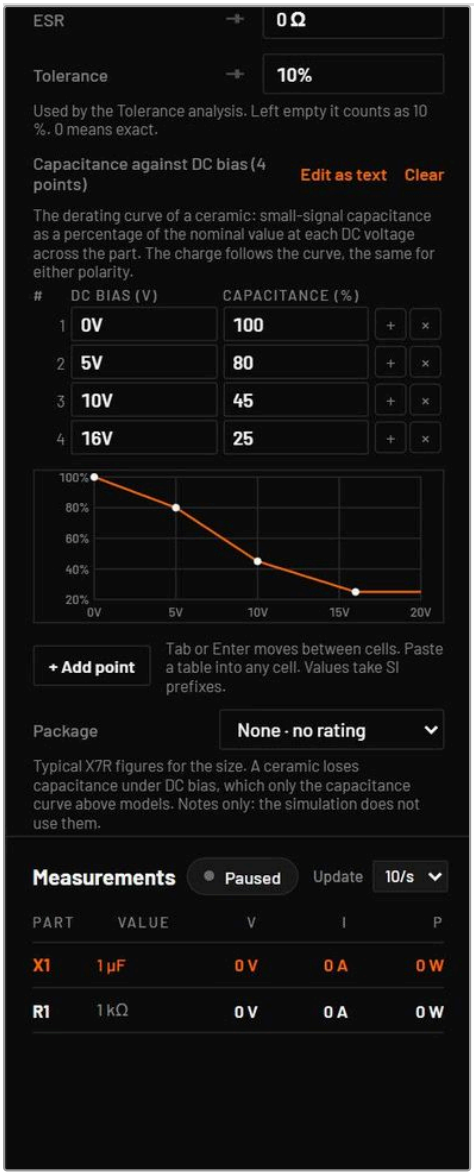


Figure 25.3 The curve editor for the capacitance of a ceramic capacitor against DC bias: a table of points, a preview plot and Edit as text and Clear.

25.3 Datasheet parameters by part family

Many parts have optional datasheet fields. A part that sets none behaves exactly as before, and each field shows its unit and engine default under it.

FAMILY	FIELDS
Resistors, capacitors, inductors	Temperature coefficients (tc1, tc2, temp, tnom), voltage coefficient, parasitic series L and parallel C, capacitor leakage and a DC-bias curve, inductor self-resonance and a saturation curve.
Sources	Damping of a sine source (theta), series resistance of a voltage source, parallel resistance of a current source.

FAMILY	FIELDS
Diodes, LEDs, BJTs, MOSFETs, JFETs, IGBTs	The full SPICE parameter lists, with temperature, flicker noise, and for IGBTs and MOSFETs the gate and tail charges. An LED has a forward-current curve.
Op-amps, comparators, references, regulators	Offset drift, bias current, CMRR and PSRR, rail headroom, a comparator's delay against overdrive, a reference's voltage against temperature, a regulator's soft start, foldback and the output-capacitor loop, and white noise.
Junction self-heating	A thermal resistance (**rth_ja**, or **rth_jc** plus **rth_ca**, in K/W) under **Self-heating** makes a diode, LED, BJT, MOSFET, JFET, IGBT, regulator, op-amp or reference heat with its own power. The operating point and a transient without a thermal capacitance **cth** find the temperature where heat and temperature agree. With **cth** the temperature follows the power with that time constant. **tamb** is the ambient, and the inspector shows the live junction temperature. A part without a thermal resistance is unchanged.
POLY sources	The controlled sources E, G, H and F take a **poly** list of coefficients, as a SPICE POLY source does. One control uses the usual four pins. Two to four controls use the variants *poly2* to *poly4*. The export writes **POLY(n)** lines.
AC magnitude of a source	**ac_mag** (1) and **ac_phase** (0°) set the drive when that source is the one an AC analysis sweeps. Noise, loop gain and pole-zero ignore them on purpose, as ngspice does, because their results are per unit of the source.
Power MOSFET curves	Rds(on) against temperature and gate charge as curves in the curve editor. The model fits its temperature coefficients and capacitances to the points.
Logic and timers	Propagation delays, input thresholds with hysteresis, output levels and input capacitance, and the 555's divider, thresholds, output drop and discharge resistance.

Every key with its unit and default is in **docs/DEVICES.md** and **docs/DEVICES_EXT.md**, and the chapters on devices list the main ones.

Values that act. From 0.8.0 these datasheet values change the simulation as the datasheet says, each checked against ngspice, a closed form or the datasheet:

PART	WHAT THE VALUE DOES
Ceramic capacitor	**dc_bias** and **vrated** lower the capacitance with the DC voltage across it.
Trimmer capacitor	C = **cmin** + **pos** (**cmax** - **cmin**).
Inductor	With **isat** the inductance falls as L / (1 + (i / isat)^2).
CD4000 logic	A chip with supply pins takes its delay, edges and output resistance from its supply, so it slows at 5 V and speeds up at 15 V.
74LS logic	The high level is the datasheet's Vcc - 1.5 V, not the full supply.
Instrumentation and difference amplifier	The offset voltage is added, as on the op-amp.
OTA	The output resistance follows 1 / Iabc, so at Iabc = 0 the output leaks next to nothing, as the LM13700 datasheet says.
LDR	R = min(r_dark, r10 (lux / 10)^-gamma).
CAN and RS-485 drivers	About 2 V differential into 60 Ω and 54 Ω, inside ISO 11898-2 and TIA-485.
Power MOSFET and IGBT	A typed Rds(on) counts. An off IGBT shows its Cres, and the Vce(sat) helper includes the channel drop.

PART	WHAT THE VALUE DOES
Power block	A block placed or imported with a variant and no kind (a buck) runs as that variant, and the Inspector shows its fields.
State machine, dead time, fuse	A fresh state machine with no states sits in one idle state with its outputs low. A dead-time generator starts with outB set by the operating point. No fuse opens at the operating point: an overloaded fuse blows in the transient.
Self-heating with cth	The temperature follows the power at every step, however small the step.
Relay	Operate and release time are the datasheet times (**Relays**, p. 308).

25.4 Groups, reset and nudging

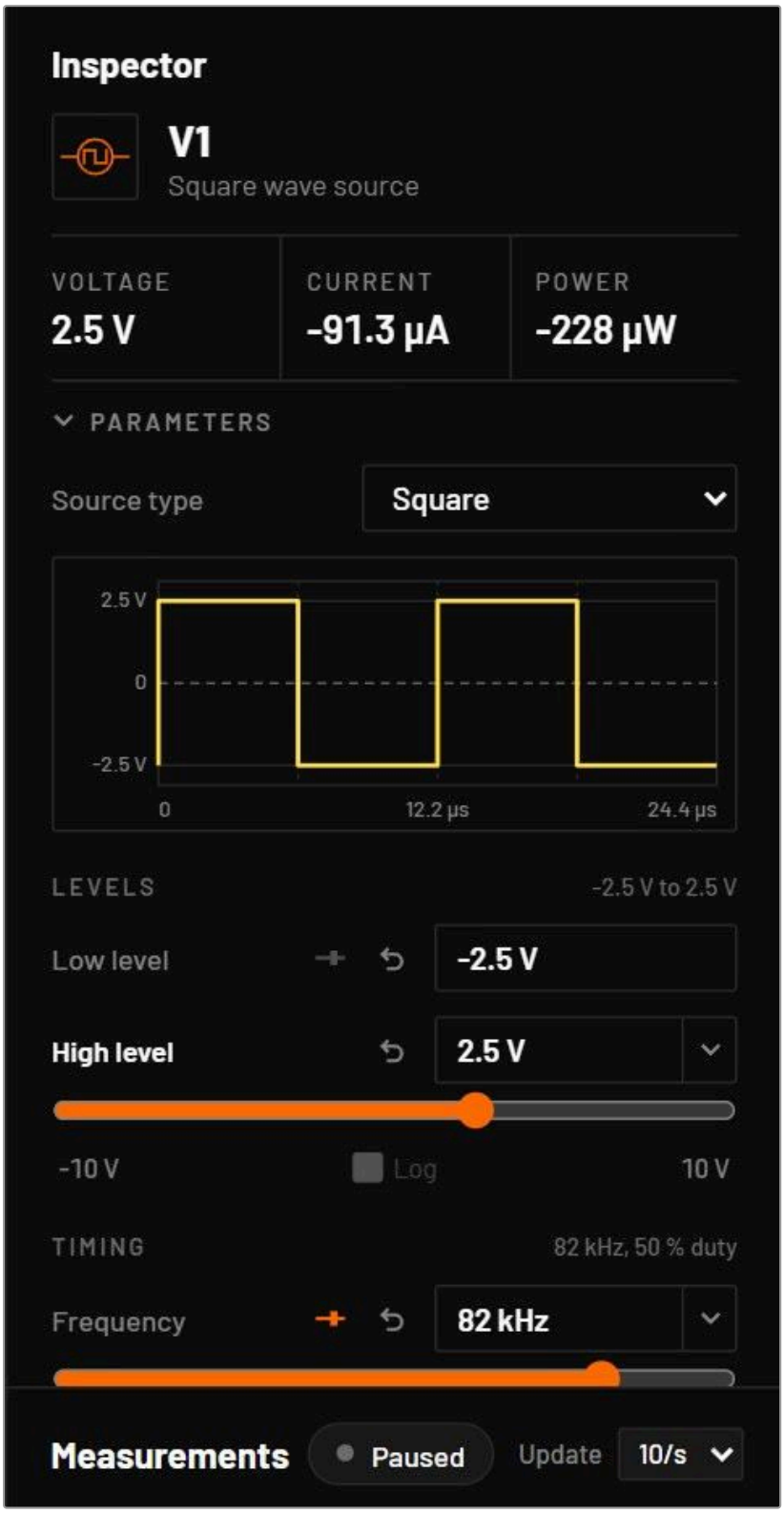


Figure 25.4 A square source with its parameters in groups. Each heading has a short summary, and a changed value has a reset button beside its label.

A part with four or more fields gets headings, so a long list reads in pieces. A source has **Levels**, **Timing** and **Edges**, and each heading shows a summary at its right, such as *0 V to 5 V* or *82 kHz, 81.9 % duty*. An op-amp has **Speed** and **DC**, a regulator **Output** and **Limits**, the PWM generator **Ramp** and **Output**, a controller **Converter**, **Pins** and **Outputs**, and a transformer **Core**, **Saturation**, **Core loss**, **Copper** and **Readouts**. A heading is never empty, and a resistor, a DC source or a diode has none, so they look as before. The main field and its slider stay at the top. Every slider, switch and preset menu is where it was.

A value that differs from the part's default has a small **reset** button beside its label. The default is the value the part is placed with. Click it and the field goes back, as one undo step. With several parts selected it resets all of them in the same step. A part with a vendor model has no reset, because its values belong to the model. **All N parameters** keeps its own reset.

Click into a number field and press Up or Down to move the value to the next step: 81.9 % becomes 82 %. Shift moves ten steps, and Ctrl moves a tenth of a step. The value stays inside the field's limits and never crosses zero. While the field is in use, a line under it shows the keys and the default, for example *Up Down one step · Shift x10 · Ctrl fine · default 1 kHz*. The same keys work in **All N parameters**, without the line.

25.5 Typing numbers

Every number field in BetterSPICE uses one parser.

YOU TYPE	VALUE	RULE
4700, **4.7e3**	4700	Plain numbers and exponents.
4.7k, **4k7**	4700	An SI prefix, which can stand in for the decimal point.
2u2, **2.2u**, **2.2µ**	2.2×10^{-6}	u, U, µ and μ all mean micro.
1R5	1.5	R as the decimal point.
10m	0.01	m is milli.
1M, **1meg**, **1Meg**	1 000 000	M and meg in any case are mega.
100n, **47p**, **1f**	100×10^{-9} …	n, p, f. Also T and G.
10 kΩ, **5V**, **1kHz**	10 000, 5, 1000	Spaces and a trailing unit are ignored.
1,5, **1.2.3**, **12/3**	refused	A comma decimal, two points or arithmetic are errors, never a silent zero.
4k7x, **1meter**	refused	Junk after the number is refused with the field's message. Units after the number (Ω, ohm, F, H, V, A, W, Hz, s, %, °, dB) and the field's own unit are fine.

Values written as text in a file. A circuit file can hold a value as text, as an AI agent or a hand-written file does (**"r": "4k7"**). The simulation reads such text the SPICE way, as ngspice does: **M** and **m** are milli, **meg** is mega, **4k7** reads as 4k and **2.2 k** as 2.2. The schematic label, the inspector, Measurements and the value editor show the value that is simulated, not what the table above would make of the same text, so a part never shows a value it does not run with. Text that is not a number is shown as written. A change made by an agent or by the command line stores a numeric parameter as a number (**10n** is saved as **1e-8**) and refuses text that is no number, with a message that says how to write it.

While you edit, the value is written the short way, **4.7k** or **100n**, with the unit as a muted tag inside the field, so what you see is what you type. Leaving a field you didn't change adds no undo step. A fraction with no unit reads plainly (**0.75**). dB, degrees and percent never take prefixes.

KEY OR GESTURE	IN A NUMBER FIELD
Enter	Applies the value. In a text field (the ground name) too.
Esc	Cancels and puts the old value back.
Tab	Applies, then moves to the next field.
Up / Down	In the inspector and in All N parameters: moves to the next step, 4.7 k to 4.8 k and 81.9 % to 82 %. Shift moves ten steps and Ctrl a tenth of a step. Some fields step linearly (a wiper by 0.01, ADC bits by 1). Other number fields, such as the ones in the toolbar and the setup, step the second significant digit, Shift the third digit and Ctrl a whole decade.
Alt + mouse wheel over a field	The same as Up and Down.
PageUp / PageDown	Jumps to the next or previous standard value.
The small chevron at the right of the field	Opens the list of standard values with the nearest one marked. Up, Down, Home, End, Enter and Esc work in it.
Drag a label sideways	Scrubs the value: 6 pixels per step, Shift for finer steps, held inside the field's limits. The whole drag is one undo step, also with several parts selected.

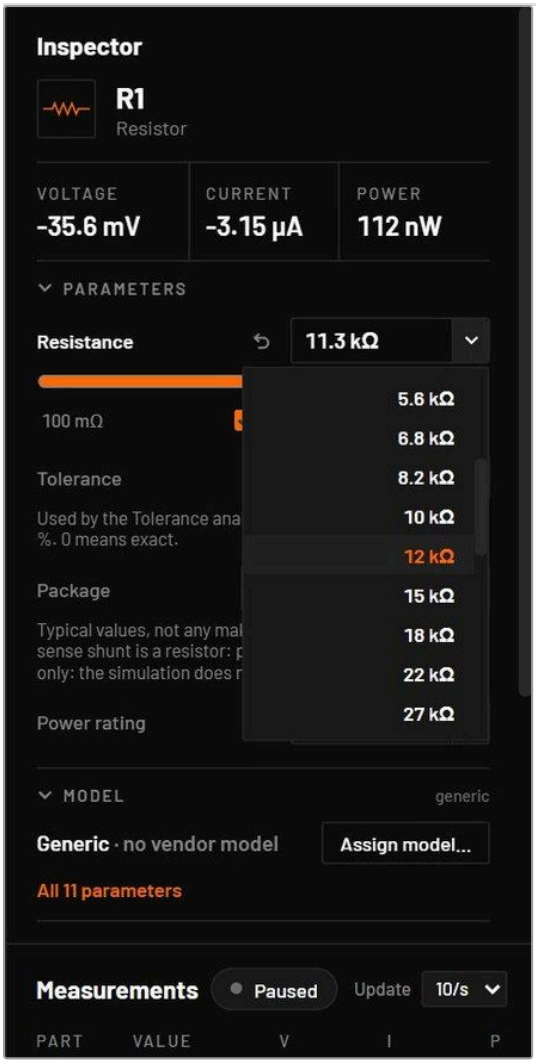


Figure 25.5 The standard values of a resistor: E12 values around the present one, the nearest marked.

FIELD	STANDARD VALUES
Resistance	E12 (1.0, 1.2, 1.5 … 8.2) in each decade.
Capacitance, inductance	E6 over the decade below, the value's own decade and the decade above.
Supply and source voltages	DC source, pulse and square high levels, logic supply, regulator output, reference voltage, battery voltage: the common rails (1.8, 3.3, 5, 12 V …).
Frequency	Sine, function generator, PWM and controller rate.
Others	Battery capacity, fuse trip currents, Zener voltages, op-amp gain-bandwidth and BJT beta.

A value the part can't take is refused as you type, with a red line under the field that says why. The old value stays.

REFUSED	MESSAGE
abc	*"abc" is not a value: try 4k7, 10u, 1meg* (with the field's unit).
Zero or below, for resistance, capacitance, inductance, frequency and period	*must be above zero*
A negative ESR, series resistance, delay, rise or fall time	*cannot be negative*
A wiper outside 0 to 1	Held inside the range.
2.5 for ADC bits or a cell count	*must be a whole number*

A field can also be empty on purpose. An empty field with a grey hint, such as *auto* or *from the operating point*, means the key isn't set and the simulation uses its own rule. Type a number to override it. Clear the field, or type **auto**, to go back. A diode's breakdown voltage takes ∞ or an empty field for no breakdown.

> CAUTION **M is mega here, milli in SPICE files.** In BetterSPICE fields **1M** is one million. In a netlist, a vendor model file and on the **bspice** command line, **M** means milli. Type **1Meg** and you get a million everywhere.

> CAUTION **Mils.** The inspector does not know mil: **10mil** reads as 10 milli, 0.01. Type 0.254 mm as **254u** instead. The circuit file and the command line do accept **10mil** as 254 µm.

25.6 Sliders

The main field of a part has a slider under it, and so does any field you gave a range. For every other number, a small slider button beside its label shows the slider on demand, and BetterSPICE remembers it for that part type and field. On sources the slider sits on the field that matters: pulse and square High, sine Amplitude, generator Frequency, battery charge. Square and pulse sources also show sliders for frequency, duty cycle, rise time and fall time (a pulse source for its period and width), and sine sources for frequency, phase and DC offset. The small slider button beside a label still hides one. Drag it and the running circuit follows, at most once per screen frame. The whole drag is one undo step. Under the slider:

FIELD	VALUES	DEFAULT	WHAT IT DOES
Min	number	see below	The left end of the slider. Negative values are allowed. It reads as quiet text until you hover it.
Max	number	see below	The right end.
Log	on or off	on for wide positive ranges	Equal steps per decade instead of equal steps. Needs Min and Max on the same side of zero.

The range belongs to that part until you delete it. It stays when the slider moves, when you select the part again, through Undo and Redo, in the saved file and in a copy of the part. Setting it is not an undo step, and a new part starts with the default range.

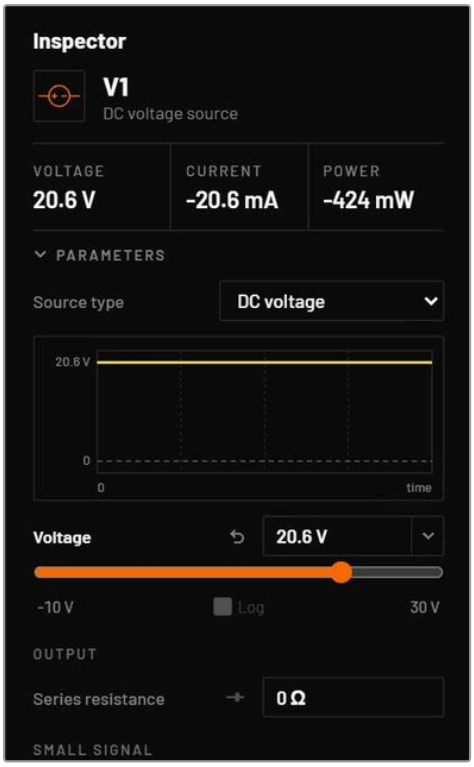


Figure 25.6 A DC source with its Voltage slider set to -10 V … 30 V: the range stays with the part through slider moves, Undo and Redo, saving and copying.

The default range is the parameter's own range where it has one, logarithmic when it spans 100:1 or more. Signed quantities such as volts and amps get a range around zero (a signed value at 0 gets ±10 V), percentages 0 to 1, angles -180° to 180°, and anything else one tenth to ten times the value. A start delay (the sine, square, pulse and function generator **Start delay**, the PWL **Time offset**) is the exception: its slider spans one period of the source, 0 to 1 / frequency, so on a 100 kHz source it runs from 0 to 10 µs instead of 0 to 1 s. The range you set is saved with the part in the circuit file.

TRY IT

Tune an LED resistor with a slider

1. Open **Basics** and an LED example, or place a DC source, a resistor and an LED.
2. Select the resistor. Set Min to **100**, Max to **10k** and tick Log.
3. Drag the slider and watch the LED and the current in the readouts.

YOU SHOULD SEE The LED glows brighter as the resistance falls. The Current readout follows the slider.

While the circuit runs, a dragged slider, and a number scrubbed by its label, moves the value smoothly in run time. The value goes from where it is to the newest value over the time between two mouse events, instead of jumping once per screen frame, and ends exactly where you stopped. A typed value or an arrow-key step applies at once. The tolerance band follows the same ramp.

25.7 Where parameter values come from

Every value a part simulates with has a source. The inspector shows the result, and the model dialog shows the source.

SOURCE	WHEN	EXAMPLE
Built-in typical value	A part placed from a key or a symbol tile, with no model assigned. The inspector says **Generic (no vendor model)**.	A new NPN has bf = 100, is = 10 fA.
Vendor model card	A discrete model (.model D, NPN, PNP, NMOS, PMOS, NJF, PJF) assigned from the library. The live engine uses the same equations as ngspice for that card.	A 2N3904 takes bf, is, vaf and the capacitances from the vendor file.
Fitted from the vendor model	A vendor subcircuit (op-amp, regulator). The live simulation uses a behavioural model whose parameters were fitted by running the vendor model. Simulate runs the vendor file itself.	TLV9062: gbw and slew measured from TI's model.
Fitted from PSpice	A Cadence-encrypted vendor model, measured in PSpice for TI. Approximate in the live simulation. Simulate runs the vendor model itself.	A TI LDO whose model only PSpice can read.
Quick model	You typed datasheet numbers in the Quick model tab and pressed Apply.	Vth = 2 V and Rds(on) = 20 mΩ at 10 V become vto and kp.
Part file (.bspart)	A part made with the Part Wizard. Each value has a minimum, typical and maximum and the datasheet page. The live model uses the typical value, or the middle of min and max.	An LDO with V_OUT min 3.234, typ 3.3, max 3.366 V, page 4.
Imported board	A part read from KiCad or EasyEDA keeps the value printed on the schematic, and the catalogue model of the same name where one is found.	10k on the KiCad symbol becomes r = 10 kΩ.
You	Typed in the inspector, in place on the canvas, with a slider, in the All parameters tab, or by an AI agent.	

The device chapters of Part VI, from **Devices: passives**, p. 265 on, list every parameter of every device with its default, unit, range and source.

25.8 Live values

Under the Voltage, Current and Power readouts, **Live values** lists everything the simulation knows about the selected part, with the run time it shows at the right. Click the heading to fold it, and it stays folded for the next part you select.

- The part's own quantities first. A MOSFET shows Vgs, Vds, Id, Ig, its overdrive (Vgs – Vth, from the model's threshold) and its region: Off, Linear or Saturation (a conducting depletion MOSFET isn't Off). A BJT shows Vbe, Vce, Ic, Ib, Ie, β (Ic / Ib) and its region: Off, Active or Saturation. β is left out when the transistor is off. A diode or LED shows Vf and If, an IGBT Vge, Vce and Ic, and a JFET Vgs, Vds and Id.
- ICs show what matters for them. An op-amp: Vin+ – Vin–, Vout, Iout and the headroom to the rails. A comparator: its output state. A power block: Vin, Vout, Iout, Iin, efficiency and dissipation. A reference: Vout, or Vka and Ika for a shunt.
- Parts from the extended library (sensors, relays, thermal parts, batteries, chargers) show their readouts under names with units, such as *Body temperature (°C)* or *Resistance*. Hold the pointer over one for the raw key.
- Power: the sum of V·I over its pins. Negative means the part delivers power, as a source does.
- The voltage and the current at every pin, named as on the symbol (V d, I g …). A current is positive into the part.

The readouts change 10 times a second. **Update** in the Measurements header sets it to 4, 10 or 30 times a second for Measurements, the inspector and the probe tags, and BetterSPICE remembers the choice. While the simulation is paused, put the scope's playhead on an earlier moment (drag it, or type a time in **Go to**): the inspector, Measurements and the values on the probe tags show that moment, also inside a sheet. Press Run to go back to live values.

25.9 All parameters

The inspector shows the main parameters. **All N parameters** in its Model section opens the **All parameters** tab of the model dialog, which lists every parameter the part's model reads, with the value the simulation uses. **All parameters tab**, p. 417 describes it. A value you haven't set shows the engine's own default for that part, so what you read is what is simulated.

25.10 Measurements

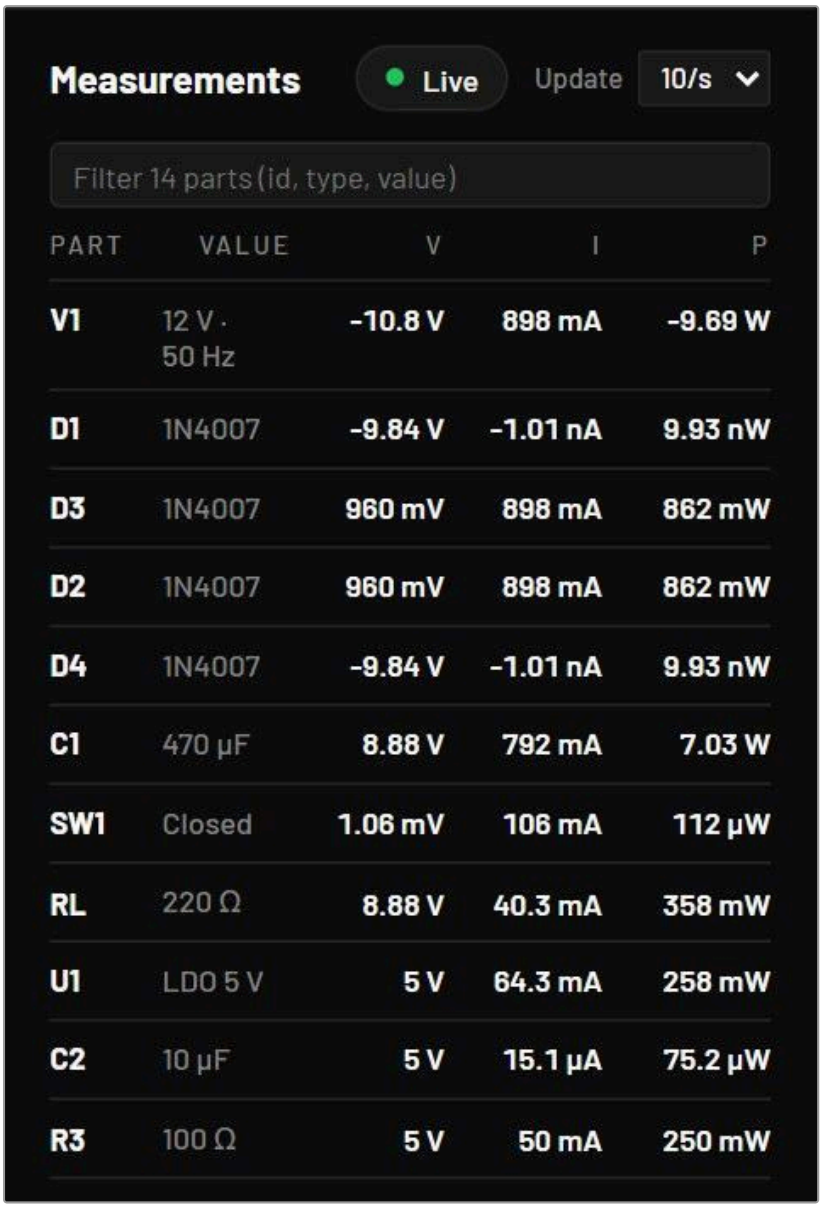


Figure 25.7 The Measurements panel.

The Measurements panel under the inspector lists every part except ground, with its value and its live voltage, current and power. The numbers change 10 times a second, or as set with **Update** in its header (4/s, 10/s or 30/s). While paused, they show the moment under the scope's playhead, so scrubbing the scope scrubs this table too. Parts inside sheets carry the sheet prefix. Click a row to select the part on the canvas. The view pans to it if it's off screen. A filter box narrows the list, and the Part, V, I and P column heads sort it. Long values stay on one line, with the full text on hover. The panel says **Live** or **Paused**, and its top edge can be dragged to make it taller. The list scrolls smoothly even with thousands of parts.

26 Live simulation

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The live simulation starts when a circuit opens and runs while you edit. The status bar says **running** or **paused**. Every frame it solves the circuit's equations for the next stretch of circuit time and redraws the colours, dots and readings.

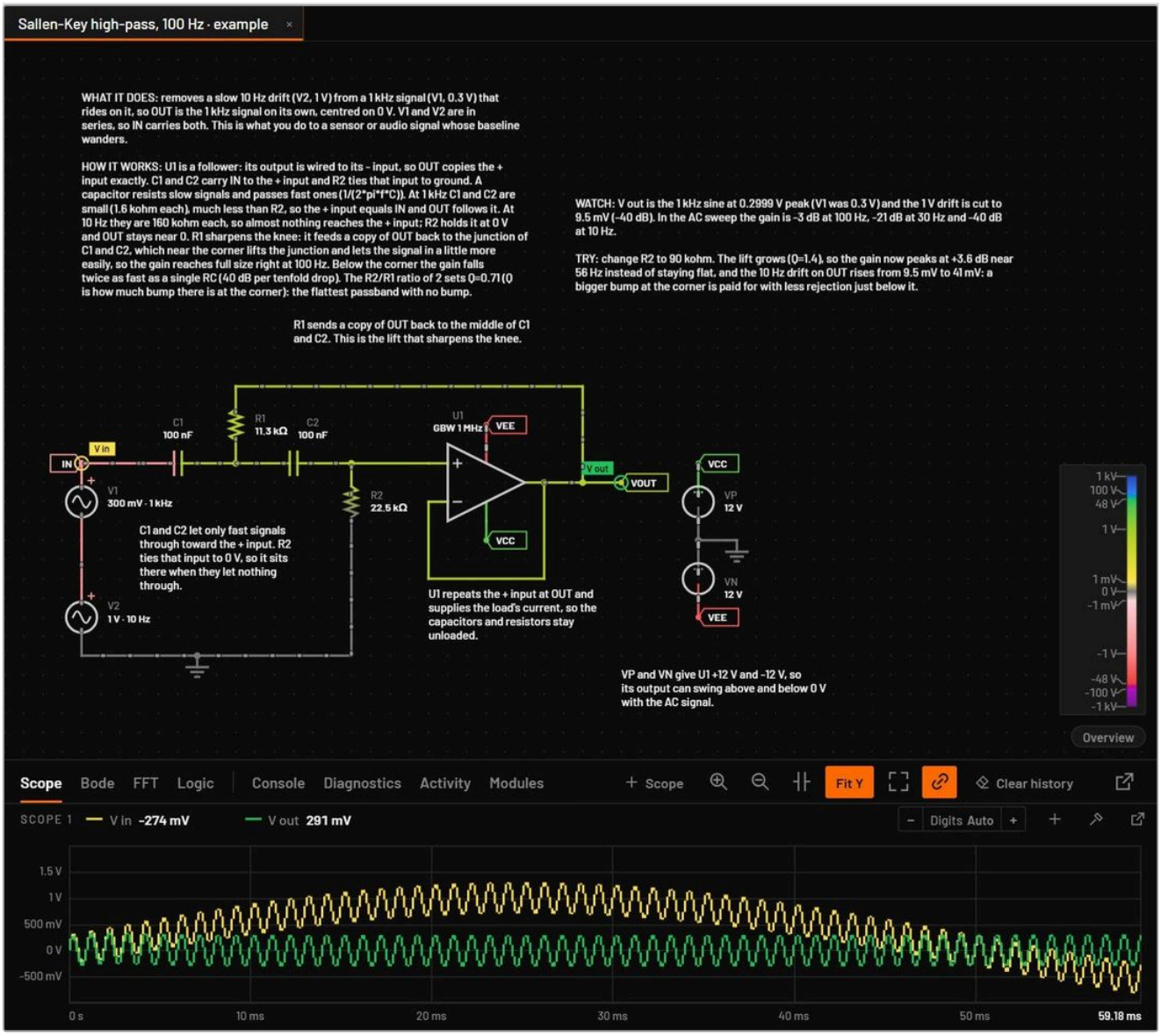


Figure 26.1 An active high-pass filter running. Wire colour is voltage, the dots are current, the scope shows the input and output.

26.1 Run, pause, step and reset

CONTROL	KEY	WHAT IT DOES
Run / Pause	Ctrl + R	Starts or pauses the live simulation (the browser viewer keeps Space for this). Holding Space and dragging pans.
Step	.	Advances by one timestep. Pause first to see one step at a time.
Reset	Ctrl + Shift + Backspace	Restarts at t = 0 from the circuit's start state (below), with counters cleared.
Sim time	toolbar	The simulated time since the last reset, four digits with a prefix.

26.2 Start at rest or from the operating point

The live simulation can start in two ways. **At rest** (power-on): every node at 0 V, capacitors empty, inductors without current. A first RC filter then visibly charges. **From the operating point**: the circuit starts already settled, as if it had been running for a long time, the way a regulator example opens at its output voltage.

CIRCUIT	STARTS
Made with **File** › **New** (or a new tab)	At rest.
An example, or a file saved before this option	From the operating point.
A circuit where a capacitor or inductor has an **Initial voltage** or **Initial current**	From those values, as **ic** does in SPICE. Setting any initial value, even 0, makes the whole live start use initial conditions.

Simulate › **Start at rest (power-on)** shows a tick when the open circuit starts at rest. Choose it to switch, and the simulation restarts from t = 0. The choice is saved in the circuit file. Reset (above) starts again the same way. It applies to the live simulation only: Simulate starts from the operating point unless the circuit asks for initial conditions (Settings saved in the circuit, p. 223).

Initial voltage and **Initial current** are in the part's full parameter list (**All N parameters** in the inspector).

26.3 Timebase and speed

The timebase sets how much simulated time passes per real second. A 50 Hz mains waveform is unreadable at real time on a screen, but at 10 ms per second one cycle takes two real seconds.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Timebase slider	1 to 1000 of the chosen unit, per second	from the circuit, else 10 ms/s	Drags within the chosen unit and snaps to 1, 2 and 5 near each decade. A drag past the right end rolls on into the next unit (1000 ns, then 1.1 µs and on), past the left end into the one before.
Timebase field	a number, or a number with a unit		**20** means 20 of the chosen unit. **20n**, **20 ns**, **1e-8** and **2m** are absolute and switch the unit. Enter applies, Esc cancels.
Unit	ps, ns, µs, ms, s		A new unit lands next to the old value: a unit up starts at 1 of it, a unit down at 1000 of it.
Range	1 ps/s to 10 s/s		Slower than 1 ps/s or faster than 10 s/s is clamped.

KEY	SPEED PRESET	GOOD FOR
1	1/1000: 1 ms per second	Switching converters, PWM, oscillators in the kHz range
2	1/100: 10 ms per second	Mains rectifiers, audio
3	1/10: 100 ms per second	RC charging, slow filters
4	1x: real time	Thermal and battery circuits, relays, motors

The live engine also has a timestep, shown in the toolbar and status bar. It's set per circuit (1 µs for a new circuit) and kept small enough for the circuit's fastest events. When the computer can't keep up, simulated time runs slower than the timebase rather than becoming inaccurate.

The scope shows the last 6 real seconds, so a fast timebase puts many cycles on screen. At 12 ms/s a 13 kHz oscillator fills the window with about 900 cycles, and the scope draws them as a solid band between each trace's lowest and highest value, as an oscilloscope does. Zoom in with the wheel while it runs: like shortening an oscilloscope's time per division, a zoomed view makes the scope sample faster, and each cycle keeps its real shape at any timebase. Zoomed out, the scope keeps only a few points per screen pixel, so a fast timebase doesn't load the computer. Detail is captured only while you're zoomed in: zoom in before you pause to inspect cycles, because data recorded while zoomed out stays coarse. The part of the window older than two zoomed views is dropped and fills in again when you zoom out.

26.4 Live quality

The menu after the timebase unit sets what the live view may give up to keep the timebase. **Simulate** (F5) never changes with it.

SETTING	WHAT THE LIVE VIEW DOES
Exact (the default, every session)	Runs the circuit as drawn, at its own step. When this computer cannot run it at the timebase, the view runs slower. The toolbar shows the real speed in amber, for example *runs at 162 µs/s*, and a banner over the schematic says why, with **Balanced** and **Fast** buttons. A circuit with fast sources or a short **sim.dt** can be far slower than the timebase: a 6 MHz sine needs 20 steps a cycle.
Balanced	Keeps the timebase by raising the live step above the circuit's own, to at most a 200th of the timebase. Edges, ringing and MHz ripple are drawn coarser.
Fast	As Balanced, and every sine source faster than 1000 divided by the timebase (1 MHz at 1 ms/s, 1 kHz at 1 s/s) is held at its average. Each one is named in the banner, tagged *Averaged in live view* on the schematic and listed in Diagnostics.



Figure 26.2 A buck converter at a timebase of 1 s/s in Exact: the toolbar says the real speed in amber, and the banner offers Balanced and Fast.

While Balanced or Fast changes anything, the banner says **Reduced accuracy** and names what is changed, and it offers **Back to Exact**. A switching circuit whose edges set the step (PWM) can still run slower than the timebase in Fast. The banner then says so too.

26.5 Changing the circuit while it runs

- Changing a value, by typing or with a slider, applies at once and keeps the circuit's state. Turn a potentiometer and watch a capacitor charge to the new level. Change a capacitor's value and it keeps its voltage, change an inductor's value and it keeps its current, and a diode's capacitance changes the same way. Before 0.7.0 the node voltage jumped to a different value at the edit. Simulate always starts from the beginning of the run.
- Adding, deleting or rewiring parts also keeps the state of the parts that stay. A relay keeps its contacts as they were.
- A value you set while it runs (typed or picked, not dragged) starts the live step again from first order, as a fresh run would, so the next steps are as accurate as Simulate's. A frequency or period you change becomes that source's step limit at once, and a value that rebuilds the part, such as a capacitor's ESR, keeps the step the timebase and Live quality set. A dragged slider keeps its step.
- Clicking a switch toggles it. Push buttons stay pressed while the mouse button is down.
- An LED glows in proportion to its current: visible from 0.5 mA, with a solid lit body, a pale core and a wide soft halo that is full size at its rated current. Relays, switches and potentiometers draw their state.
- Readings are cleaned of numerical noise. A voltage, current or power below a billionth of the circuit's own scale reads 0 in the inspector, Measurements, the scope legend and the hover card. The exact value is in the tooltip, and exported CSV and copied data keep the raw numbers.

26.6 Several circuits at once

Each open circuit tab keeps its own live simulation. When you switch away, BetterSPICE parks it with its traces, scope history, logic recordings, timebase, diagnostics, and its running or paused state, and picks it up when you come back: a rectifier that was paused at 150 ms is still paused at 150 ms. BetterSPICE keeps up to four background tabs. Beyond that a tab restarts from t = 0. A circuit you open fresh always runs. While the Analysis view fills the whole window, the live view redraws about four times a second instead of sixty to save work. The engine keeps running and the scope keeps every sample.

26.7 Current dots

Dots move along wires and through parts in the direction of conventional current. They are display only. How they look depends on the live look (below). In the New look the dots grow with the current, from a small faint dot at 1 µA to a long bright dash at 20 A, always 28 pixels apart. Their speed is nearly even up to about 1 A (50 pixels a second at 1 µA, 107 at 1 A) and only gets clearly faster for large currents (387 at 10 A). A dot never moves so far in one frame that it seems to run backwards. In the Classic look the dots are yellow, of one size, and their speed follows the square root of the current.

CONTROL	KEY	WHAT IT DOES
Current slider	toolbar	Dot speed from 0.01x to 100x. It snaps to 1x in the middle. Double-click for 1x.
Faster / slower	] / [	x1.5 or /1.5 per press, beyond the slider's range if needed.
Fit	Shift +] or **Fit**	Sets the speed so the largest current in the selection, or in the whole circuit, moves about 150 pixels per second, by the speed rule of the live look in use. Select a part first to study its current.
Reset	View menu	Back to 1x.

If Windows is set to reduce motion, the wires show fixed arrows for the current direction instead of moving dots.

26.8 Energy view

Alt + E, the lightning bolt in the toolbar, or **View** › **Energy view** shows where the power of the running circuit comes from and where it goes. It is off when the app starts and it replaces the current dots while it is on. With it off, the canvas costs what it did before.

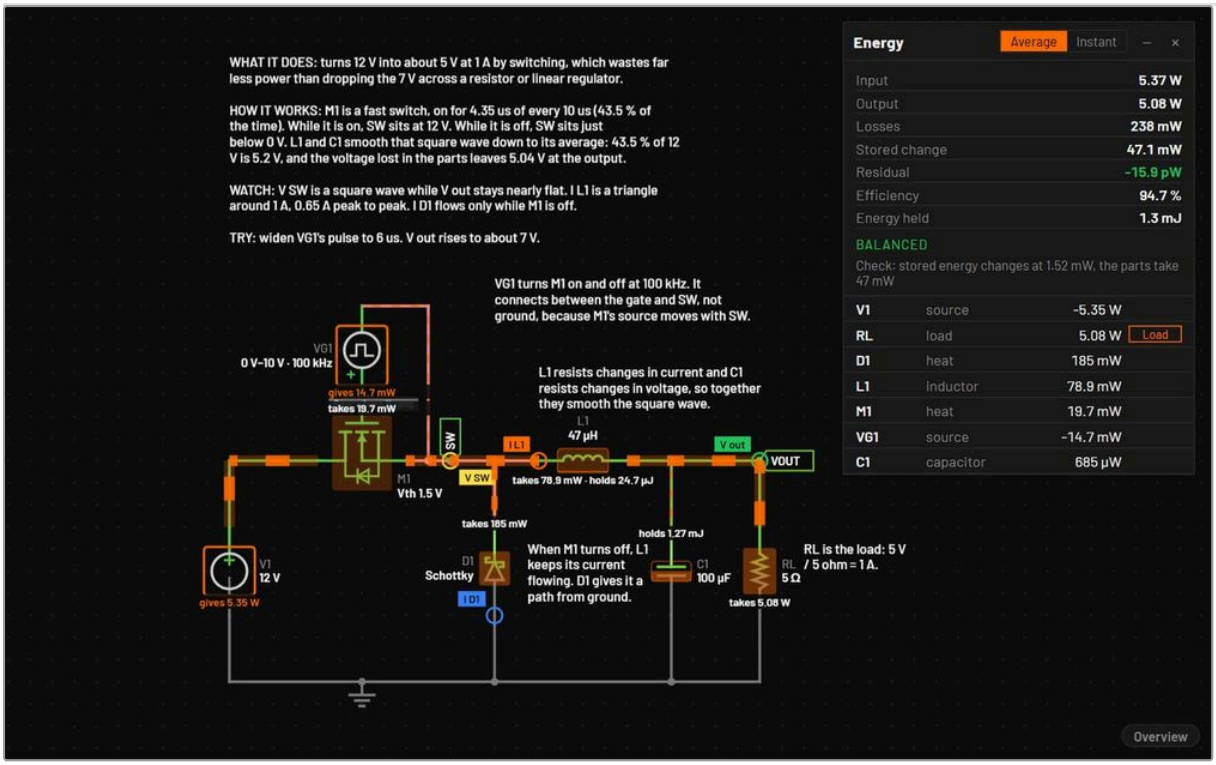


Figure 26.3 The energy view on the 12 V to 5 V buck: bands on the wires that carry power, the parts that give and take it, and the ledger in a corner.

WHAT YOU SEE	WHAT IT MEANS
Flow bands	A band lies on every wire that carries power. Its width grows with the power on a log scale (the thinnest band is a thousandth of the widest). Its dashes move from the end the power comes from to the end it goes to. The power on a wire is its voltage to ground times its current. With reduced motion set, an arrowhead replaces the moving dashes.
Parts that give power	An orange outline and the words *gives 5.8 W*. A part that takes power says *takes*.
Parts that make heat	An orange wash that deepens with the loss.
Capacitors and inductors	A level that rises with the energy held ($\frac{1}{2}CV^2$ or $\frac{1}{2}LI^2$) against the part's own largest value of the last 30 seconds, and the words *holds 26 µJ*.
Ledger	A panel with **Input** (net power of the sources), **Output** (the loads), **Losses** (including capacitor ESR and inductor DCR), **Stored change**, **Efficiency** and **Energy held**. **Residual** is input minus output, losses and stored change. It is zero when every pin current is accounted for, and the panel says *Does not balance* in red when it is not. Click a row to select the part.

- The ledger stands in a corner where it covers no part, label or note. When the circuit leaves no room, it opens folded to its header, which shows the input power and the efficiency. The plus button unfolds it.
- **Average** is a moving average over about half a second of wall time, so a switching circuit reads steadily. **Instant** shows each frame as it is, ripple included.
- The load is an LED, lamp, motor, speaker or buzzer, or a resistor named RL, RLOAD or LOAD. The **Load** button on a resistor's row changes that for the session. A part parameter **load** set to true or false is saved with the circuit. Without a load there is no efficiency.

- A switching circuit can have edges faster than the engine's steps. The moving average then cannot split the loss between the parts. The ledger tests for this, and when a test fails the panel says *Not measurable at this timebase* with the reason and shows no losses or efficiency. A slower timebase or **Instant** still works. The flyback example is such a case.
- The power on a wire is relative to ground. Transformers and chokes show the power they take as stored change, because their stored energy is not modelled.

26.9 Tolerance band

View › **Tolerance band** (also in the scope menu under Display, off by default) shades, around each scope trace, the range it takes with the parts at the ends of their tolerance: resistors 1 %, capacitors 10 % and inductors 20 % unless a part says otherwise. Extra live engines, one per corner and each in its own worker, follow every edit and the timebase and never run ahead of the trace. Every corner runs when they fit (up to 8, or 16 with **every corner**), otherwise the two extremes, and the label in the scope header says which, for example **Band 4 of 4 corners**. The corners are those **bspice app tolerance —mode worst** picks, and the trace itself does not change. The band stays off, with its reason in the label, with Balanced or Fast quality, while the MCU debugger is used, or when the machine has too few free workers or memory.

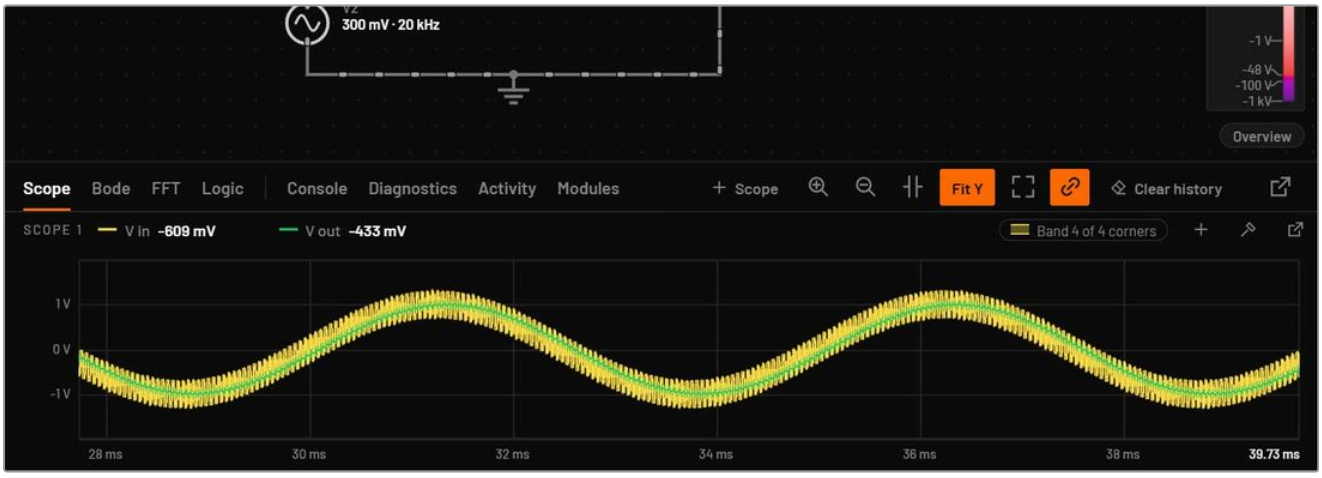


Figure 26.4 The tolerance band on an RC charge and discharge: each trace is shaded over the range its four corners take. The label at the right of the scope header says how many corners run.

26.10 Heavy circuits

In the desktop app a circuit with 100 parts or more runs the live view on the native engine, about 1.4x as fast as WebAssembly on a 578-part board, with the same frames bit for bit. The status bar then reads **Live MNA · native**. Smaller circuits, the browser viewer and a board with the tolerance band on stay on WebAssembly.



Figure 26.5 The status bar of an RC ladder of 151 parts: the live view runs on the native engine.

26.11 Energy view and the scope history

With the run paused, move the scope's playhead back through the history and Energy view shows that moment: its figures and colours follow the playhead, like the wires. Clear the playhead to go back to live.

26.12 Drawing

The schematic is drawn again only when something on it changes (a value, the view, an edit), and the current dots and wire colours draw on the graphics card where it can, with the processor as the fallback.

26.13 Live look

View › **Live look** has two entries, **New** and **Classic**. New is the default, also on a copy that was updated. The look you pick here is remembered.

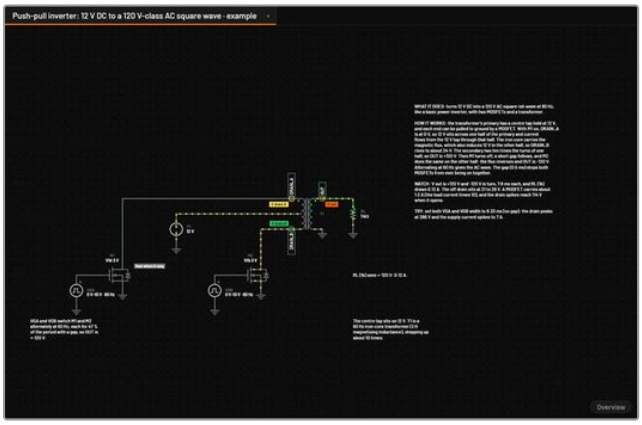


Figure 26.6 The Classic look: colours stretched to this circuit, yellow dots of one size.

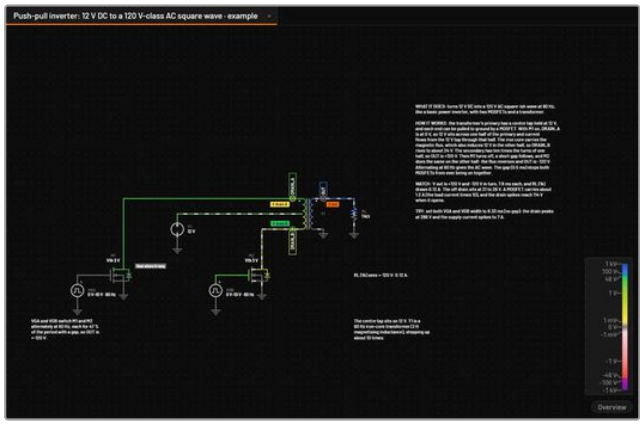


Figure 26.7 The New look: one voltage scale, dots sized by current.

	NEW	CLASSIC
Wire colour	One absolute scale, so the same voltage always has the same colour, in every circuit. A lighter wire always means a smaller voltage.	Stretched to the circuit's voltage range, 10 V unless the circuit file sets another.
Positive voltage	Pale yellow at 1 mV, through lime, to green at 48 V. Then through teal to blue at 100 V, and deeper blue up to 1 kV, so anything past the 50 V safety mark reads at once.	Green, or orange with the orange and blue colours.
Negative voltage	Red only: pale rose, red at -48 V, then crimson and purple at -100 V.	Red, or blue with the orange and blue colours.
Near 0 V	Neutral grey. Noise such as a nanovolt stays grey, and the colour blends in smoothly up to 1 mV.	Neutral grey.
Current dots	Size and brightness show the current (above).	Yellow, of one size.
Colour choice	Ctrl + Shift + K is greyed out and says that voltage colours belong to the Classic look.	Ctrl + Shift + K switches between green and red and orange and blue.

The light theme keeps the same order of colours and keeps them readable on a light background. The New look draws as fast as Classic.

26.14 Voltage legend

In the New look a slim bar in the bottom-right corner of the schematic shows the colour scale: +1 kV at the top, 0 V grey in the middle, -1 kV at the bottom, log in decades, labelled at 1 mV, 1 V, 48 V, 100 V and 1 kV and their negatives. Hold the pointer over a wire, pin or net label and its voltage is marked on the bar with its value. The legend moves left of the sheet overview when that is open and never takes a click. **View** › **Voltage legend** hides it, and the choice is remembered. The Classic look has no legend.

26.15 Hover readouts

POINTER OVER	THE CARD SHOWS
A wire	The name and voltage of the net, and the current in that wire.
A net label, power flag or port	The name and voltage of the net.
A pin	The part and pin, the voltage of the pin, the current into it and the power of the part. A pin is also where a drag draws a wire, and the card says so.
A part	V, I and P of the part, and for a part with more pins the voltage and current of each pin.

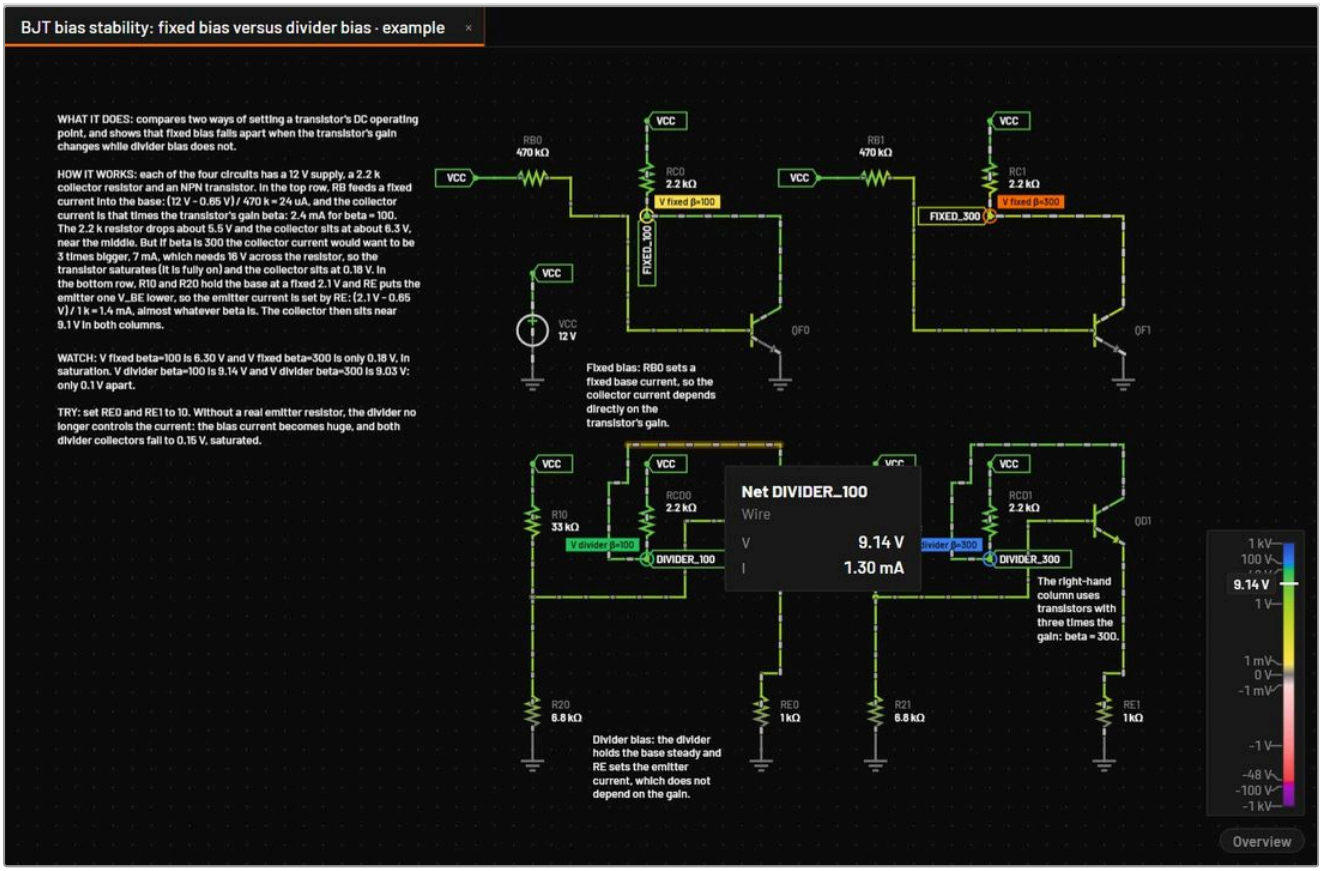


Figure 26.8 The card over a wire: its net, its voltage and the current in it. The legend marks the same voltage.

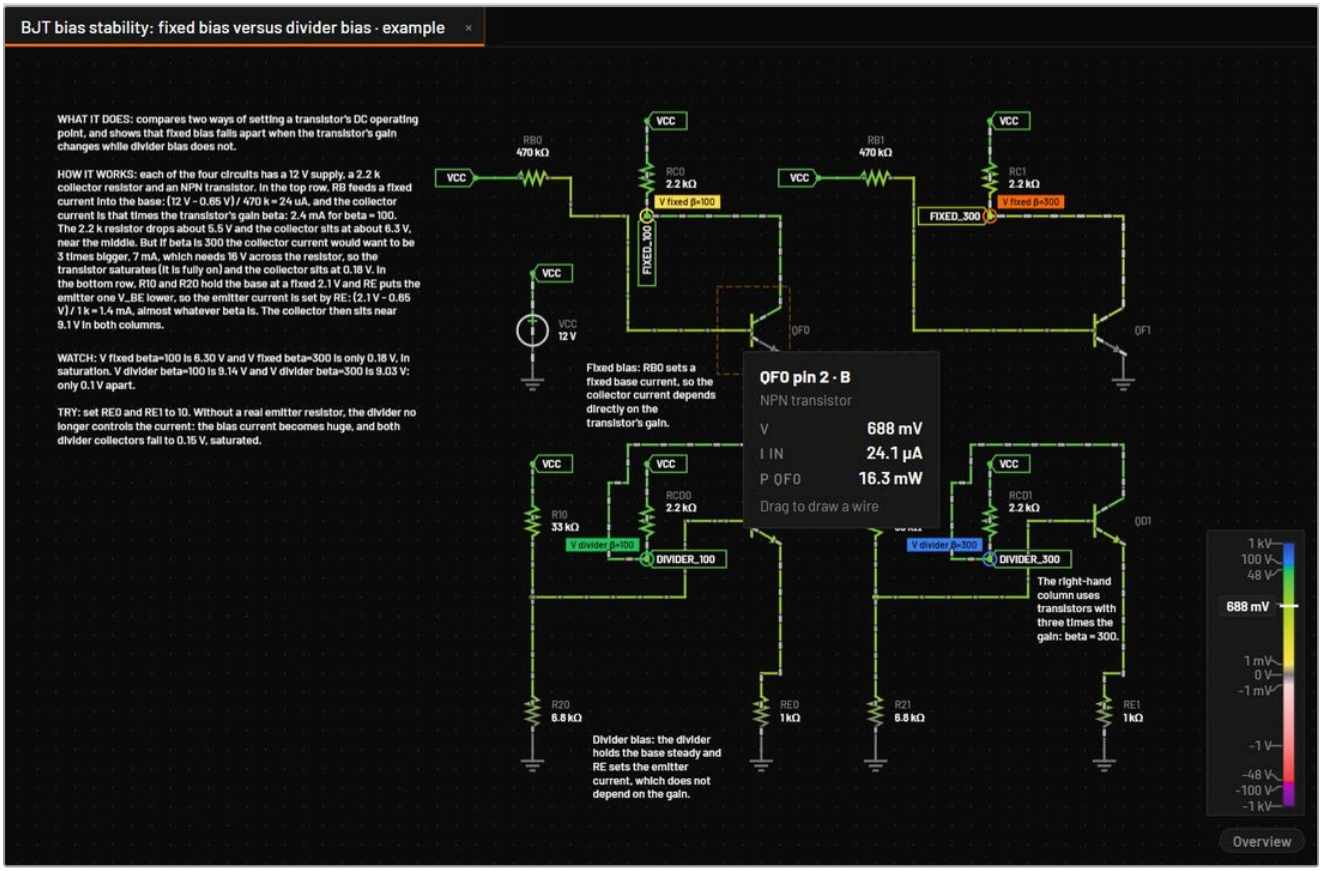


Figure 26.9 The card over a pin: the voltage of the pin, the current into it and the power of the part.

The values are the ones the inspector shows, at its update rate (**Update** in Measurements) while the circuit runs. Paused, they are the paused moment, or the moment under the scope's playhead. The card never takes a click, and it is off while you drag, draw a wire or place a part.

26.16 Voltage colours

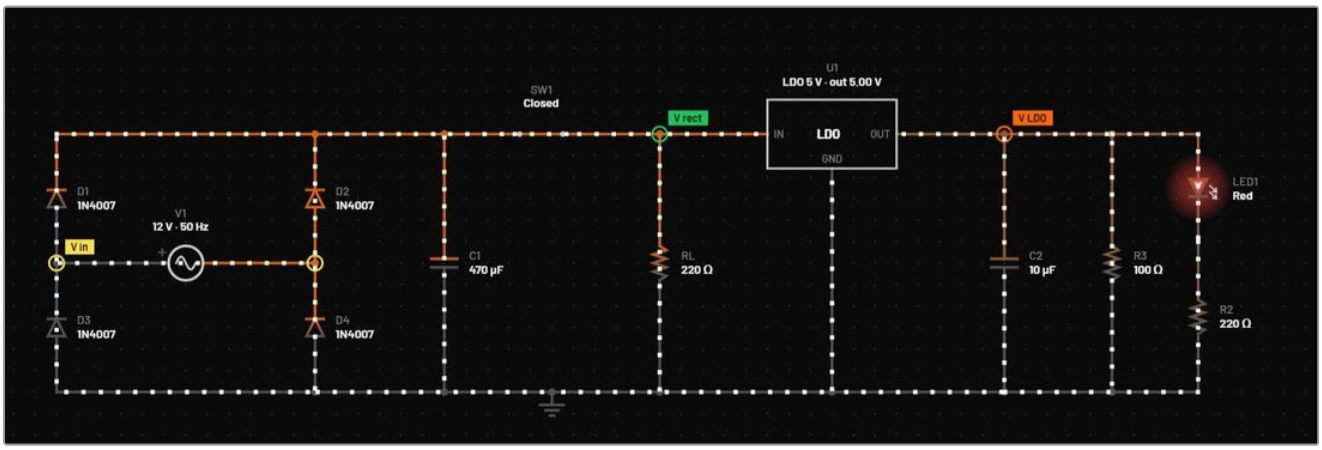


Figure 26.10 Orange and blue voltage colours of the Classic look: orange positive, blue negative.

In the Classic look, wire colour goes from the zero colour at 0 V to the full positive or negative colour at the circuit's voltage range, 10 V unless the circuit file sets another. Ctrl + Shift + K, or **View** › **Orange and blue voltage colours (off: green and red)**, switches between the default green and red scale and the orange and blue scale. In the New look this entry is greyed out, because that look has one scale for every circuit.

26.17 Halted

When the engine can't continue, for example because a node has no DC path to ground, it stops. The Run button turns into a red **Halted** button, the canvas shows **Halted · *code***, and the Diagnostics tab lists the reason with the part, the net and the fix (**Diagnostics and what they mean**, p. 86). Fix the circuit and the simulation starts again.

26.18 Live MNA · JS

What you see: the status bar says **Live MNA · JS** and the live simulation runs slower than usual. **Cause:** the WebAssembly engine could not load (an **E_ENGINE** warning says why), so the live view runs on the JavaScript engine. **Fix:** none is needed, and a restart usually brings the WebAssembly engine back. From 0.8.0 the JavaScript engine runs every part type the main engine has, microcontrollers and their programs, ctrl scripts, logic packages, motors and converters included, on the same device equations. It solves the operating point when the circuit loads, finds switching edges and breakpoints, and sizes its steps by the truncation error, as the main engine does. A part that no engine can simulate is left out of the run with a **W_SYMBOL_ONLY** warning, and the rest of the circuit keeps running.

26.19 How the live engine works

The live engine is a circuit solver, not an animation. It writes the circuit as equations by modified nodal analysis (MNA), turns capacitors and inductors into companion models for each timestep, and solves the nonlinear parts by Newton iteration. It's compiled to WebAssembly so it keeps up with your edits.

It is the engine Simulate uses, and the two agree: the first live step is exactly the first step of Simulate, and at the same step the live view reproduces Simulate bit for bit. The live view always steps with the trapezoidal rule and gmin 1 pS. When the Simulation setup asks for Gear or another gmin, a **W_LIVE_SETUP** note says so, and Simulate uses the setup.

A vendor subcircuit runs in Simulate. In the live view it runs on its fitted stand-in where it has one: the four UC3843 examples run live on the **uc384x** controller with a TL431 and an opto fitted to the vendor models, and are

checked against the vendor models in Simulate. A vendor part with no stand-in, such as TI's averaged PWM models, has its pins open in the live view, and its message says it is accurate-only.

A vendor power inductor runs in the live view as an inductor fitted to its model. For the 1,293 Vishay inductors of the catalogue (IHLP and the other families), the fit also holds the inductance against current that the vendor model gives, measured with a 100 A current ramp and stored as a **lisat** curve (0.8.1). The inductance then falls with current in the live view as it does in Simulate, so a converter that drives one into saturation shows it while you draw. For an IHLP 4.7 µH part the stored curve follows the vendor model within 0.3 % up to three times its 50 % saturation current.

27 Probes, scopes and the dock

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Probes are the signals you want to watch. The scope plots them live, the analyses plot them in the Analysis view, and the report includes them. On the schematic each probe has a tag in its trace colour with its name. A **meter probe** also shows its value in the tag, all the time (10 updates a second, set with **Update** in the Measurements header, and while paused the value at the scope's playhead). Place one with the **Meter probe** tool (Shift + P, the gauge button next to the probe in the toolbar, or Place → Meter probe), or tick **Show value on the schematic** for any probe: in the inspector when the probe is selected, or in the right-click menu of its name in the scope. Put a tag wherever you want the reading: with the probe tool, click the wire or part where the value should show, and the tag lands there. Drag any tag to move it. Away from its probe, a dashed line joins them. Double-click a tag to put it back beside its probe. Tag positions are saved with the circuit and are part of undo. Probes are saved in the circuit file, can be selected on the canvas and are part of undo.

27.1 Probe tags and meter probes

WHAT	HOW
Place a tag where you want it	With the probe tool, click the wire or part where the reading should show: the tag lands there. A tag is a small box in the trace colour with the probe's name, and the value when the probe shows it.
Move a tag	Drag it anywhere. Away from its probe, a dashed line joins them. Tags follow the probe through moves, rotation and mirroring, and keep their place at any zoom.
Name the probe	Double-click its tag. See the next section. Esc during a drag, or switching tab, cancels the drag and nothing moves.
Put a tag back	Right-click the probe and choose **Tag back beside the probe**.
Meter probe	Shift + P, or the gauge button in the toolbar. The probe shows its live value in the tag. P gives the plain probe again, and so does Esc.
Show value on the schematic	A tick box in the inspector when the probe is selected, and an entry in the right-click menu of the trace name in the scope. A meter probe on a net that already has a probe turns that probe's value on.

WHAT	HOW
Colours	A tag and its ring use the trace colour chosen in the scope, also inside a sheet.

Tag positions and the value switch are saved with the circuit (the probe's **tag** and **value**) and are part of undo.

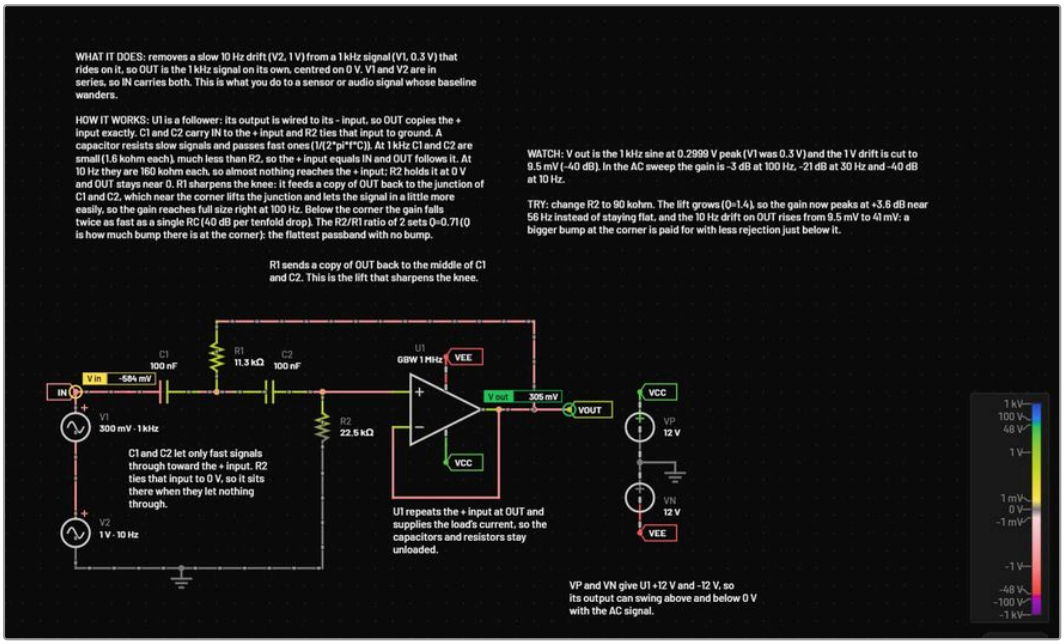


Figure 27.1 Two meter probes: V in and V out show their live values in the tags on the wires.

27.2 Names and colours of probes

A probe has a name of its own. Type it in the **Name** field of the inspector, double-click the probe's tag on the schematic, double-click its chip in the scope or Analysis legend, or choose **Name...** in the probe's right-click menu. Clear the field to go back to the automatic name, such as **V OUT**. A voltage and a current probe that share one tag read **V name** and **I name**. Two probes with the same name get a warning in the inspector.

The name shows everywhere the probe does: the schematic tag, the scope legend, the statistics table, the hover card, the CSV headers, the logic analyzer channels, every analysis (transient, AC gain and phase, DC, parameter step, FFT, tolerance and All signals), kept references, the exports and the report. In a measurement the name works as a signal. Renaming updates every view at once and does not run the analysis again.

Each probe keeps one colour, stored with it. Removing another probe never recolours it, and every analysis draws the probe's traces in that colour. A parameter step draws later values of the step in a shade toward the background. Pick a colour from the swatches in the right-click menu of a trace in the scope. In **All signals**, an engine signal that a probe reads shows under the probe's name and colour, and other names read in the scope's words (**V(PWM)** as **V PWM**, **I(R1)** as **I R1**).

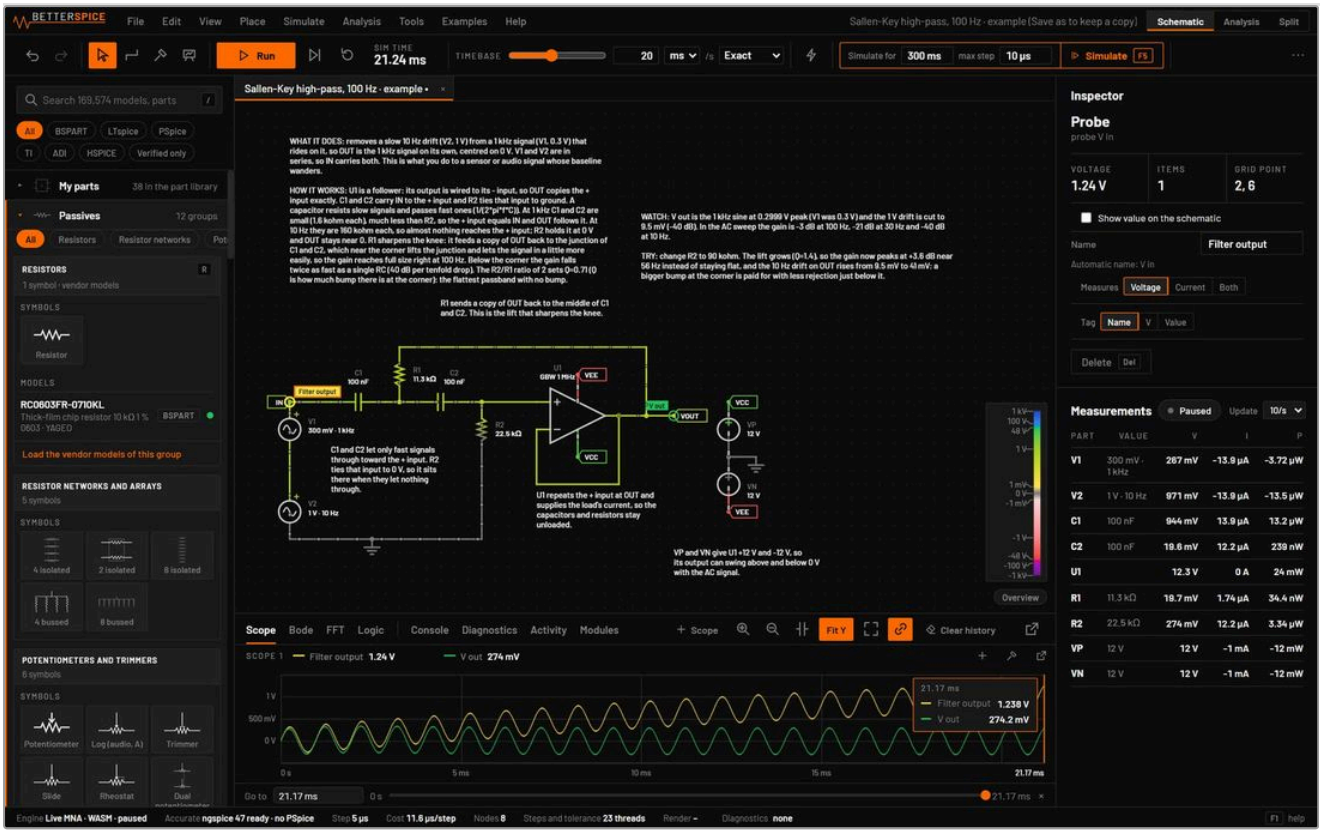


Figure 27.2 A probe named Filter output: the name field in the inspector, the tag on the schematic and the scope legend.

27.3 Adding probes

HOW	PROBE	LABEL
Probe tool P, click a wire	The net voltage to ground, named after the net (a label, or a part pin)	**V OUT**
Meter probe tool Shift + P, click a wire or part	The same probes as the probe tool, with the live value shown in the tag on the schematic	**V OUT 4.98 V**
Probe tool, click near a pin	The voltage at that pin	**V U1 pin 2**
Probe tool, click the body of a two-pin part	The current through it	**I R1**
Probe tool, click the lead of a pin of a part with three or more pins (next to the pin, not on its end)	The current into that pin	**I Q1 B**
Right-click a pin of a part with three or more pins, **Probe this pin's current**	The current into that pin. On a point the pin shares with another part, that part's menu offers it as **Probe the current into Q1 B**	**I Q1 B**
Inspector, **Add to scope**	The voltage across a two-pin part, or at pin 1 of a one-pin part	**V C1**
Right-click a part, **Add probe**	The current through a two-pin part, otherwise the voltage at pin 1	**I C1**
Right-click a wire, **Add probe (scope)**	The net voltage	**V net**
Probe tool on a net of an isolated side	The voltage against that side's own ground (a differential probe)	**V OUT (ISO2)**

HOW	PROBE	LABEL
Probe tool, **Shift+click** on an isolated side	The voltage against the main ground GND, even on an isolated side	**V OUT (vs GND)**
Split view, **Alt+click** a net or part	A trace in the Analysis view, not a saved probe	

27.4 A probe for voltage, current or both

Select a probe, or right-click it, and choose **Measures**: **Voltage**, **Current** or **Both**. Current is offered on a pin of a two-pin part and on a wire with exactly two part pins on it. It is the current into the part's first pin. On a net where several pins meet there is no single current path, so only voltage is offered and the inspector says why.

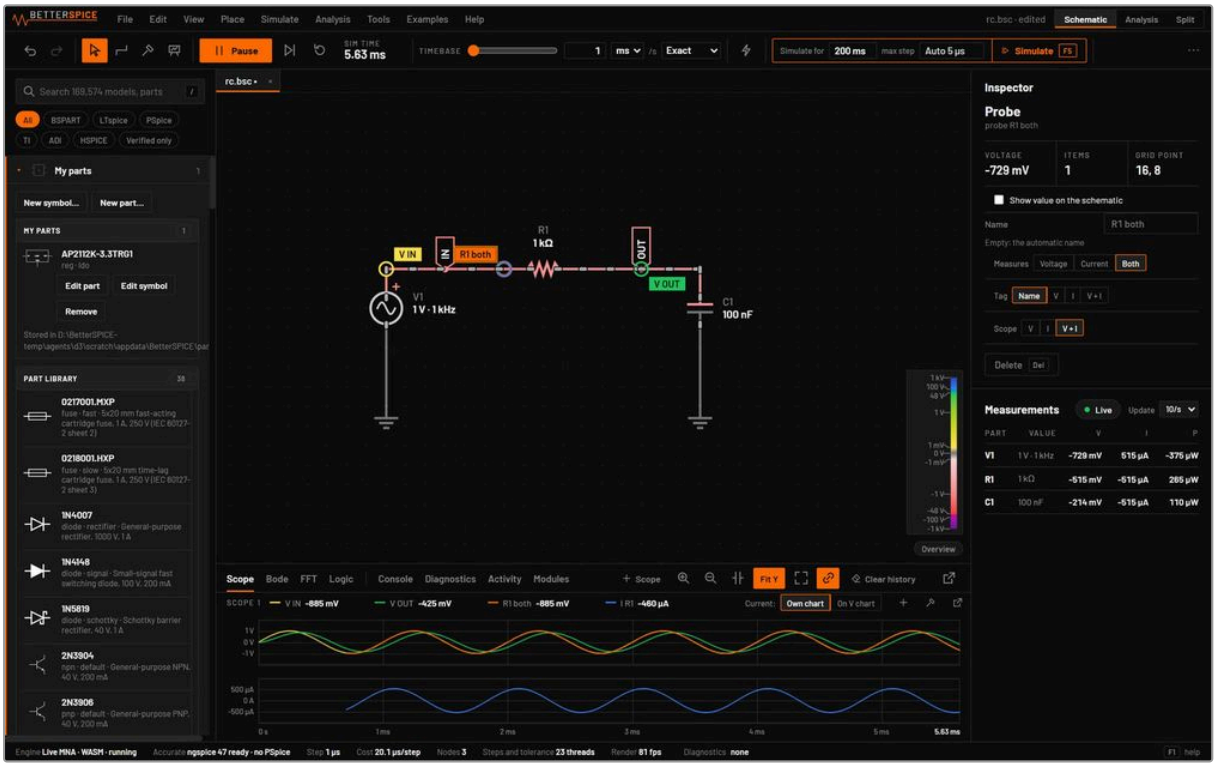


Figure 27.3 A probe set to Both on the RC circuit: one trace of each in the scope, the volts in one chart and the amps in their own chart below, and the inspector with Measures, Tag and Scope.

SETTING	WHAT IT DOES
Measures	Voltage, Current or Both.
Tag	What the tag on the canvas reads: the name, the voltage, the current or both, for example **OUT 4.98 V 1.21 A**.
Scope	Which scope the probe draws in, and whether it draws the voltage, the current or both.

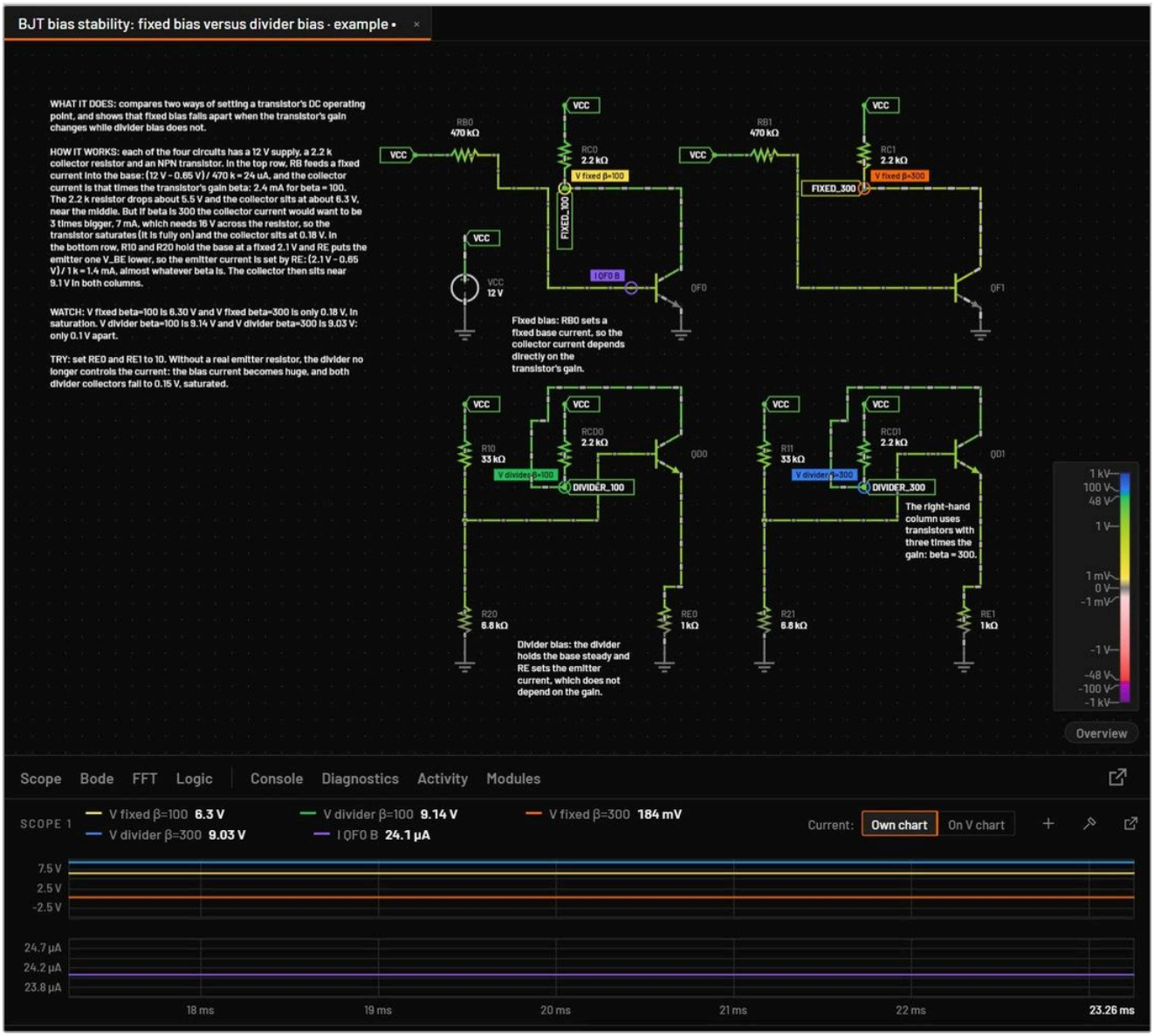


Figure 27.4 A probe on the base pin of a transistor, I Q1 B: the current into that pin has its own trace in the scope.

A pin current also works in Simulate for a part with a vendor model: the desktop app puts a 0 V source in series with that pin only for the ngspice run, so the vendor model is not changed. A PSpice run has no pin currents. Neither do a built-in op-amp or transmission line in an ngspice run, because they are written as subcircuits, and a warning names the part.

A probe set to Both puts one trace of each on the scope. With **Current: Own chart** the amps get a chart of their own. With **On V chart** they share the voltage chart on a second axis at the right. The Analysis view plots the same quantities. In the file it is two ordinary probes (a voltage probe and a current probe that share a **pair**), so older builds and older files work as before. In the MCP tools the probe operation takes **quantity** with **"v"**, **"i"** or **"vi"**.

Labels follow one rule everywhere: the net's name if it has one (**V OUT**), else the part and pin (**V R1 pin 2**), the same words the hover card uses. On an isolated side the probe, the part menu's **Add probe** and the net menu's **Add probe (scope)** measure against that side's ground, because a voltage

against a ground the side isn't connected to would show the float of the whole side. Capacitors, transformers, optocouplers, solid-state relays, relays and isolators keep their two sides apart, so they aren't joined by a probe. Probing the same pair twice finds the existing probe.

To remove a probe, right-click its name in the scope header and choose **Remove from scope** (or press Del while that menu is open), click the **×** that appears when you hold the pointer over the name, or click the probe on the canvas and press Del. Undo brings it back.

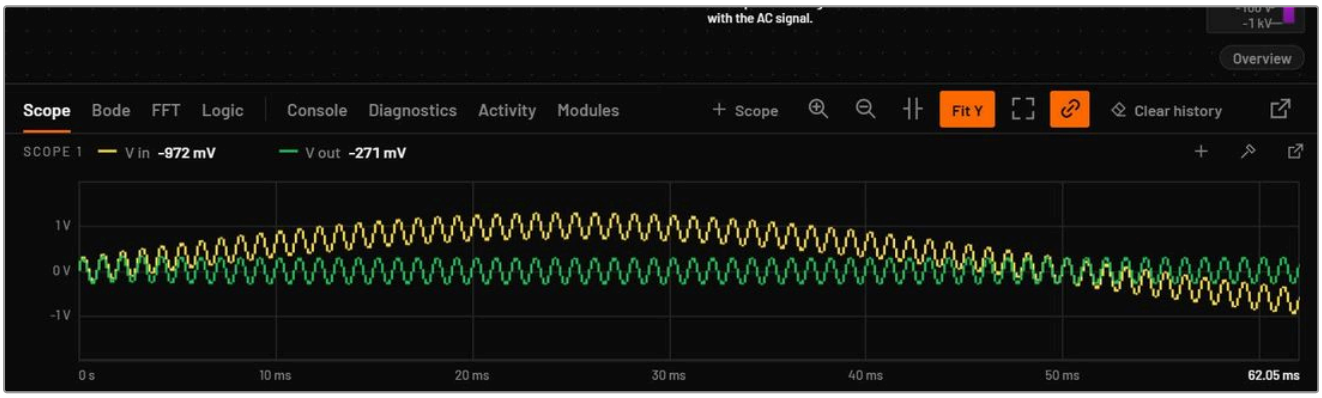


Figure 27.5 The Scope tab: two voltage probes, each with its live value in the header.

27.5 The scope

- The scope keeps the most recent 6 seconds of real time. At a timebase of 10 ms/s that is 60 ms of circuit time. The axis shows the time since the run started: it starts at 0 when you press Restart, and the right end shows the time of the newest sample in brighter text.
- Traces of different units on one scope, such as a voltage and a current, get a pane each, with a shared time axis, so both stay readable. A scope that shows both has a **Current: Own chart | On V chart** switch in its header. **On V chart** draws the currents over the voltages, with their own scale on a second axis at the right in the current's colour. **Own chart** gives them their own chart below. The choice is also in the scope menu under Display, and new scopes start with the last one you made. Even a small pane shows at least three labelled values on its axis.
- A scope with no probes shows one line, *No probes yet. Select a part and press Add to scope, drag a trace name here, or*, and a **Probe tool (P)** button, with no axes. It still accepts a trace dragged onto it. A scope with no data yet reads 0 … window, never a negative time, and a new run resets each scope's own zoom.
- The header of each scope shows its name, a chip per trace with its colour and latest value, and buttons for adding traces (**+**), the probe tool, pop out and remove.
- The **+** button lists every net of the circuit (its voltage) and every two-pin part (its current), with a search box. Click an entry to add it to that scope. An entry with a ✓ is already shown, and a click removes it. Enter picks the first match.

- Click a trace chip to hide or show it. Right-click it for its own menu: **Remove from scope**, **Hide (keep recording)**, **Show value on the schematic**, **Rename...**, its colour, **Currents on the voltage chart (right axis)** when the scope has both, **Move to scope 2** or **Move to a new scope**, and **Spectrum (FFT)**. Drag a chip onto another scope to move the trace there.
- Hold the pointer over the plot to read every trace at that instant. The readout has one digit more than the axis ticks (2.92 ms against 1 ms ticks). Drag a box to zoom, use the wheel to zoom in time, Ctrl-drag or right-drag to pan, and double-click to reset. Neighbouring ticks never read the same: an ordinary axis gains digits as you zoom in (65.501 ms, 65.502 ms), and when a label would need more than 6 significant digits or would not fit, the base is written once in the corner and the ticks show the offset from it.
- The header has the **– Digits Auto +** control beside the trace values. It sets how many significant digits the readouts show, from 3 to 9, and is shared with the Analysis view (**Axis labels and readout digits**, p. 261). A narrow dock drops the word Digits, and a very narrow one leaves the setting to **Readout digits** in the scope menu.
- The dock header has **+ Scope**, **Zoom in**, **Zoom out**, **Cursors**, **Fit**, **Link time axes** (the chain button, on by default), **Clear history** (clears the history of all scopes and restarts the auto scale) and **Pop out the dock**. Zoom, cursors and fit are greyed on a tab with no data yet. When the window is narrow, the dock tabs scroll, with ‹ and › arrows on the side that has more tabs. Each tab's tooltip shows its key.
- With the run paused and the time axis zoomed in, the vertical axis **fits the voltages and currents in view**, as the Analysis plot does. The **Fit Y** button in the dock header and **Scale, Fit Y to the zoomed view when paused** in the scope menu turn this off, which keeps the axis of the whole record. The choice is remembered. While the run is going the scale works as before.
- The corner of a scope shows **Hold**, **Trig ↑** or **Trig ↓**, **Max** or **Fixed** while those options are on.

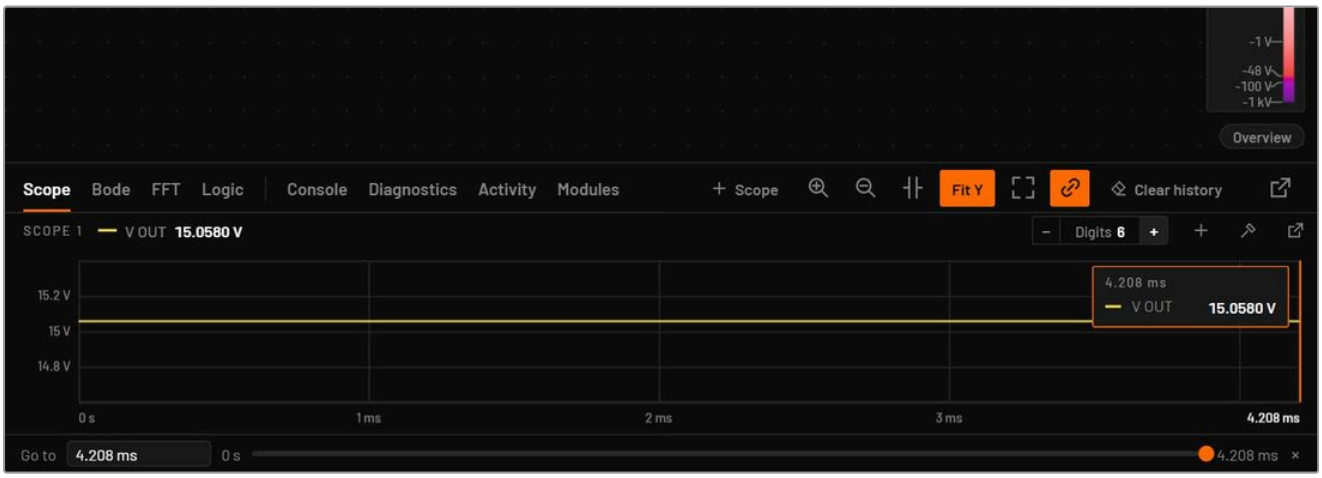


Figure 27.6 A paused scope at Digits 6: the control in the scope header, the trace chip and the hover readout with six digits.

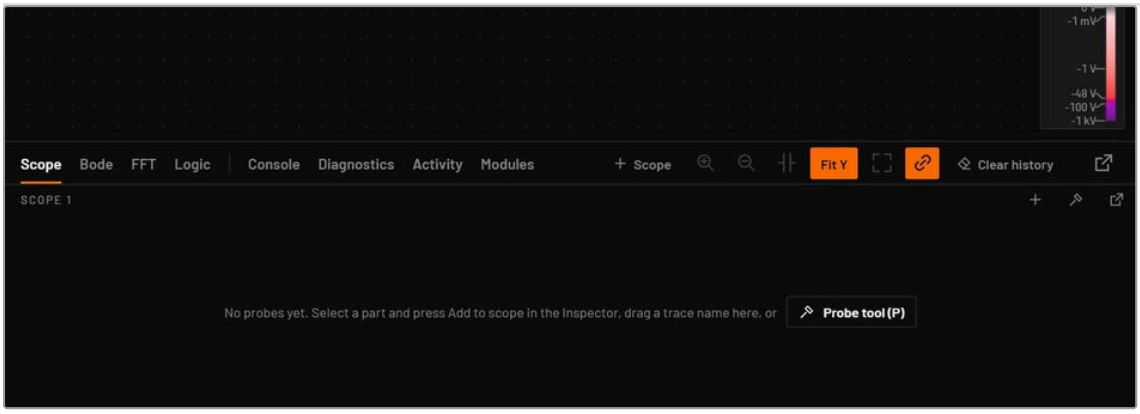


Figure 27.7 A new circuit's scope before any probe: one line and a Probe tool button, no axes.

27.6 Probe suggestions

The empty scope of a circuit that has no probes offers up to four key nets to probe. They are chips with a live value each: an output or a labelled net, the switching node, an inductor current and the input rail. The offer sits inside the scope's empty space and is never a pop-up.

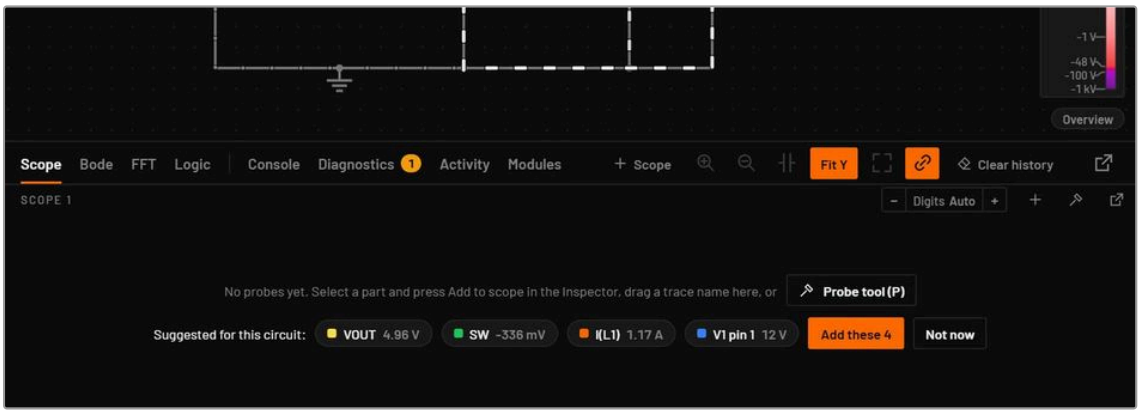


Figure 27.8 A buck converter without probes: the scope offers its output, switching node, inductor current and input rail, with live values.

- Hold the pointer over a chip and its net lights up on the schematic. The chip's tooltip says why it was picked.
- Click a chip to add that probe. **Add these N** adds all of them in one undo step.
- The offer shows once per circuit. **Not now**, using a suggestion, or adding probes any other way hides it for good.
- **View** › **Suggest probes for circuits without any** turns the offer off for every circuit. Turn it on again the same way.
- A scope with probes is unchanged. The offer shows on the top sheet only.

27.7 Several scopes

The **+ Scope** button, or **New scope** in the right-click menu, adds a scope below. Click a scope to make it the target: new probes go there. Removing a scope moves its traces to the scope above it. Which scope each probe is on is saved in the circuit, so a file with probes on scope 3 opens with three scopes. Each scope remembers its display choices (stacked, stats, scale, trigger and its edge), and Link time axes is remembered too.

With **Link time axes** on (the chain button in the dock header, on by default), zooming, panning or resetting any scope moves every scope to the same time window, so related signals line up. Turn it off to zoom each scope on its own. **Fit** returns every scope to the full window.

27.8 Scrubbing a paused run

Pause the simulation (Ctrl + R or **Pause**) and one **Go to** bar appears below all the scopes. Its ends are the start of the run (0 s after Restart or Clear) and the time you paused. While running, the scopes show only the last screen of time. Once paused they hold the whole run, so you can scrub or zoom out back to the start.

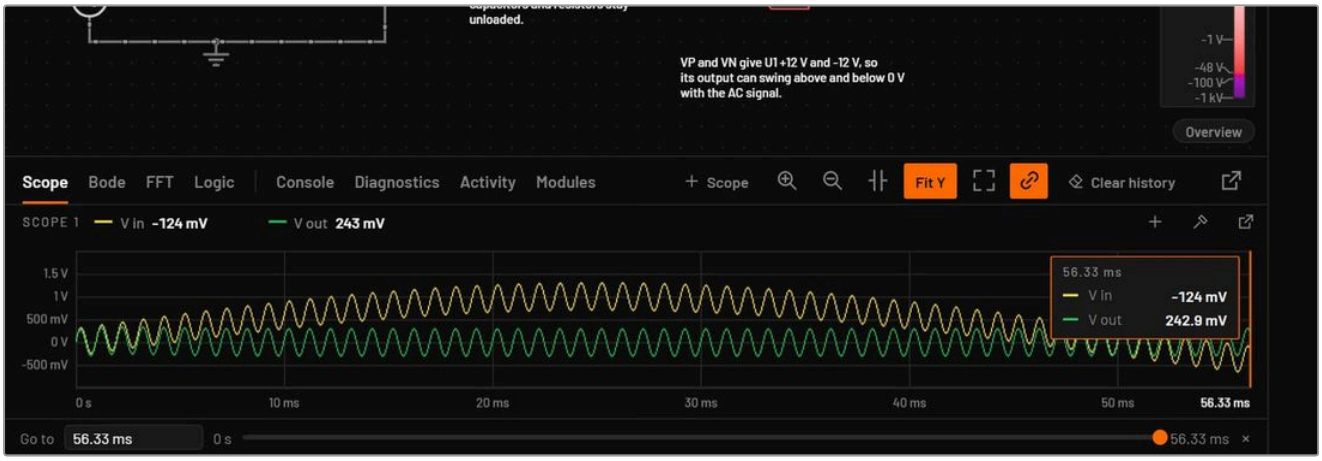


Figure 27.9 A paused run: the Go to bar under the scopes and the orange playhead with the value of each trace.

- The playhead starts at the end of the paused run, and Restart clears the paused window and the playhead. Type a time in the box, for example **65.5m** or **65.5 ms**, and press Enter, or drag the slider through the run.
- The slider follows the zoom. Zoomed out, a drag sweeps the whole run. Zoomed in, the playhead moves at the scale of the plot, so a drag of one plot width moves it one screen of time. Click the track to jump there. The shaded band on the track, the window the scopes show, can be dragged too. With the slider focused, the arrow keys step (Shift for bigger steps), Home and End go to the ends.
- An orange playhead marks that time on every scope, with a box listing the value of each trace there.

- When the scopes are zoomed in and linked, they centre on the playhead and keep their zoom, so you can step through the run in detail.
- The view stays on what you were looking at when you paused. Double-click a plot, or zoom out, to see the whole run.
- A very long run keeps all of it at a coarser spacing: once it holds 262,144 points per trace it drops every other point, so short spikes from early in the run can be thinner than they were live.
- Drag the playhead line on any plot to move it. The × at the end of the bar removes it. Pressing Run again removes it and the scopes follow the run again.

TRY IT

Step through an overload

1. Open a circuit with a load step and press Ctrl + R a little after the step.
2. Wheel-zoom one scope until the step fills the window: all scopes follow.
3. Type the step time in **Go to** and press Enter, then drag the slider a little either side.

YOU SHOULD SEE Every scope centres on the step, and the playhead boxes show the voltages and currents at each instant.

27.9 The scope menu

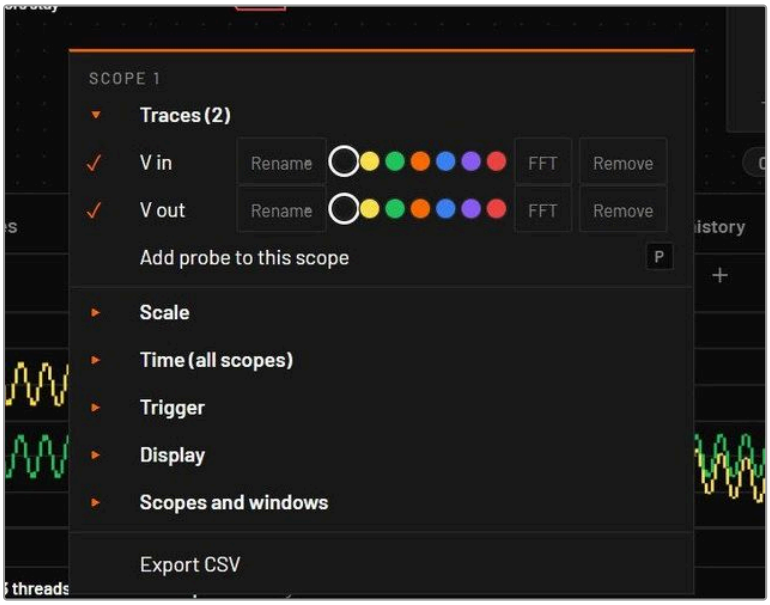


Figure 27.10 The scope menu, opened by right-clicking the plot.

The menu has groups, and one group is open at a time: **Traces**, **Scale**, **Time (all scopes)**, **Trigger**, **Display**, **Scopes and windows**, then **Export CSV**. It fits the window height and scrolls when it must.

GROUP	ENTRY	WHAT IT DOES
Traces	A tick per trace	Shows or hides the trace.
	Rename	Renames the trace in place: one undo step. The probe keeps its point, scope and colour.
	Colour swatches	One of the six trace colours, or the default (by order). Saved with the probe.
	→ **2**, → **3** …	Moves the trace to that scope.
	FFT	Shows the spectrum of that trace in the FFT tab.
	Remove	Deletes the probe from the circuit.
	Add probe to this scope (P)	Makes this scope the target and starts the probe tool.
Scale	Auto fit	The vertical range follows the data. It grows at once and shrinks only after the traces used less than half of it for a second, so it doesn't jump. Paused, it fits at once.
	Max hold (grow only)	The range only grows.
	Fix current scale	Freezes the range as it's now.
	Manual min and max	Type a Min and a Max for each unit shown (volts, amps), for example **-5** and **500m**. A field left empty follows the auto scale on that side. Min has to be below Max, and nothing changes until it is. The same entry is in the Analysis view's Scale menu.
	Readout digits	The **– Digits Auto +** control: how many significant digits the readouts of every scope and the Analysis view show, 3 to 9 or Auto (**Axis labels and readout digits**, p. 261).
Time (all scopes)	Faster (window ÷ 2) / Slower (window × 2)	Halves or doubles the time window.
	Reset zoom, Clear scope history	
Trigger	Off (free running)	The trace scrolls.
	Rising edge / Falling edge	Holds the newest matching edge of the source trace at a quarter of the window, at the middle of the trace's range, so a periodic signal stands still.
	Source: *trace*	Click to cycle the trigger source.
Display	Stack traces	One pane per trace instead of overlaid.
	Show stats (max, min, RMS, freq, duty)	A table per trace with Max, Min, Avg, RMS, P-P, Freq and Duty over the visible window.
	Cursors	Cursor lines A and B with a readout.
	Hold picture	Freezes the picture while the simulation keeps running.
Scopes and windows	New scope, Move *trace* to a new scope, Remove scope N	Adds or removes a scope. A removed scope's traces move to a neighbour.
	Pop scope N out / Put scope N back	Moves the scope into its own window and back. Move scope N to scope window k joins another one.
	Pop all scopes out / Pop the whole dock out	All scopes, or the whole dock, in their own window.
Export CSV		Saves the rows in the visible window as **scopeN.csv**: a time column in run time and one column per trace with its unit.



Figure 27.11 Show stats: maximum, minimum, average, RMS, peak to peak, frequency and duty cycle for each trace.

Average and RMS are weighted by time. Frequency and duty cycle are measured at the middle level with hysteresis, and show a dash when the signal has no real swing.

27.10 Cursors

Cursors put two vertical lines on the plot, A (solid) and B (dashed), at 30 % and 70 % of the window. Drag a line to move it. The readout on the right lists the time at A and B, their difference Δ and 1/Δ in hertz, and each trace's value at A and B with the difference. The same cursors work in the scope, the Bode and FFT tabs and the Analysis view.

TRY IT

Measure a ripple and its frequency

1. Open **Diode circuits** and a bridge rectifier example.
2. Probe the output and set the timebase to 10 ms per second.
3. Right-click the scope, choose **Show stats**, then **Rising edge** in Trigger.

YOU SHOULD SEE The waveform stands still. The stats table shows P-P, the ripple, and Freq, 100 Hz for a 50 Hz full-wave bridge.

27.11 Bode tab

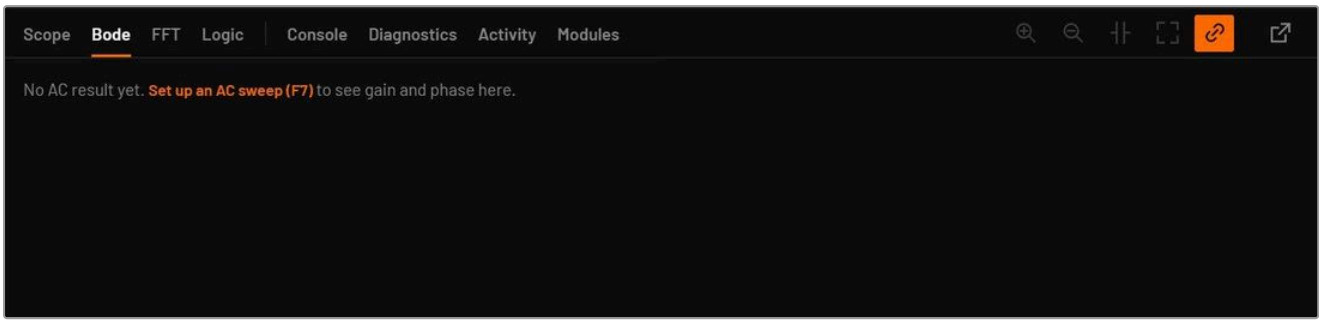


Figure 27.12 The Bode tab in the dock.

The Bode tab shows the last AC sweep: magnitude in dB and phase in degrees against a logarithmic frequency axis, for the probes. Before any AC sweep it says *"No AC result yet. Set up an AC sweep (F7) to see gain and phase here."*Zoom and cursors work as in the scope.

27.12 FFT tab

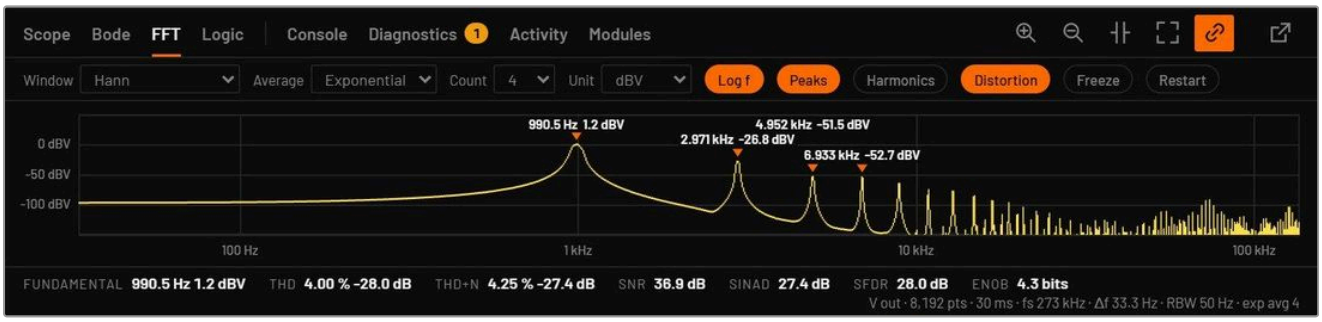


Figure 27.13 The FFT tab: the spectrum of a Wien-bridge oscillator.

The FFT tab shows the live spectrum of one scope trace, the one chosen with **FFT** in the scope menu or the first trace. Levels are RMS values, so a 1 V peak sine reads -3.01 dBV in every window. The line under the plot gives the record length, the sample rate, the bin spacing and the resolution bandwidth.

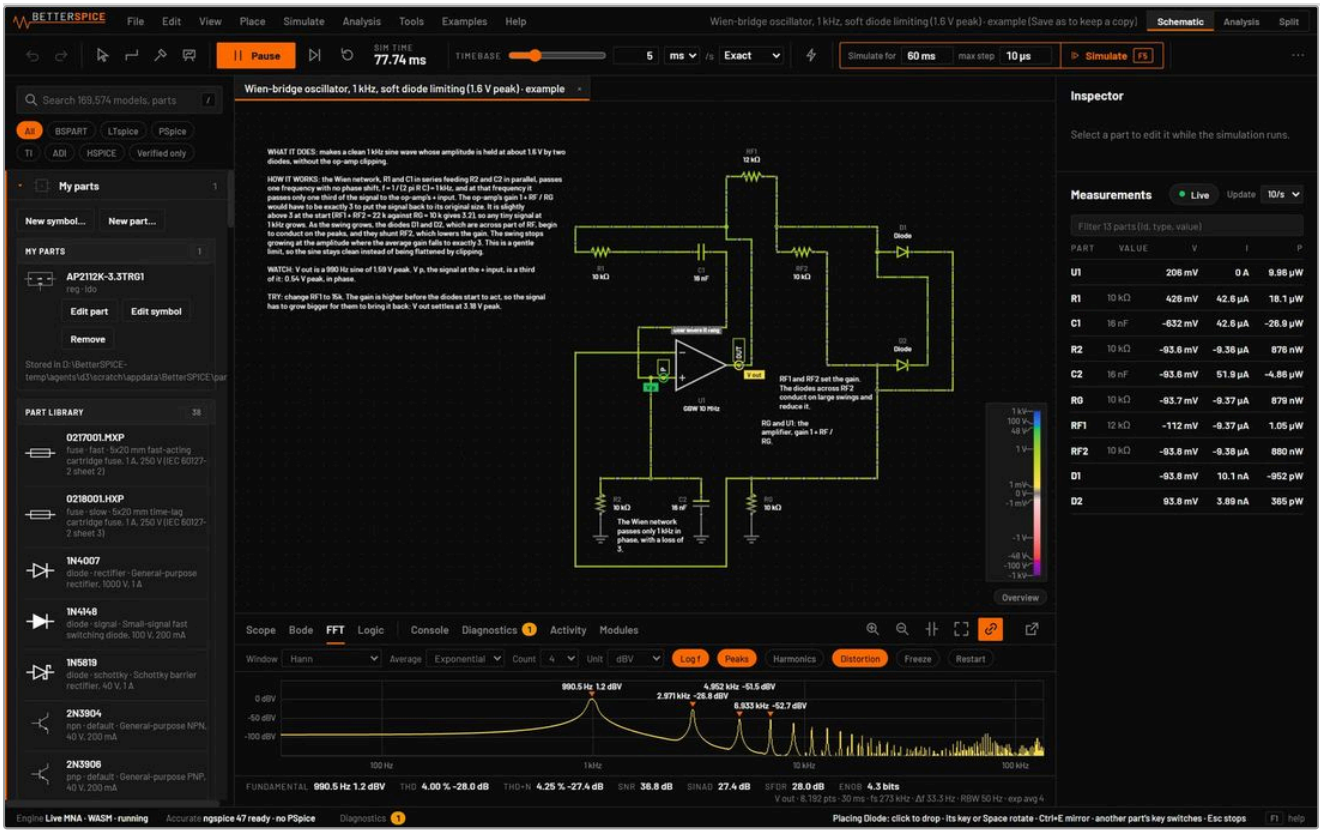


Figure 27.14 The FFT tab with peaks, harmonics and distortion on: the strongest tones with frequency and level, the harmonics tagged, and THD, THD+N, SNR, SINAD, SFDR and ENOB.

CONTROL	WHAT IT DOES	KEY
Window	Hann, Hamming, Blackman, Blackman-Harris, flat top or rectangular.	W
Averaging	Linear, exponential or max hold, with a count. R restarts it.	A
Unit	dBV, dBm into a load you type, V rms or V peak.	U
Axis	Logarithmic or linear frequency.	L
Peaks	Marks the strongest tones with frequency and level.	P
Harmonics	Tags the fundamental and its harmonics.	H
Distortion	THD, THD+N, SNR, SINAD, SFDR and ENOB of the strongest tone, which is found automatically.	D
Freeze	Holds the picture.	Space

The keys work with the plot focused. The choices are remembered. The Analysis view's FFT (**FFT**, p. 241) reads peak amplitude in its dBV. Use it for the spectrum of an accurate transient.

27.13 Logic analyzer

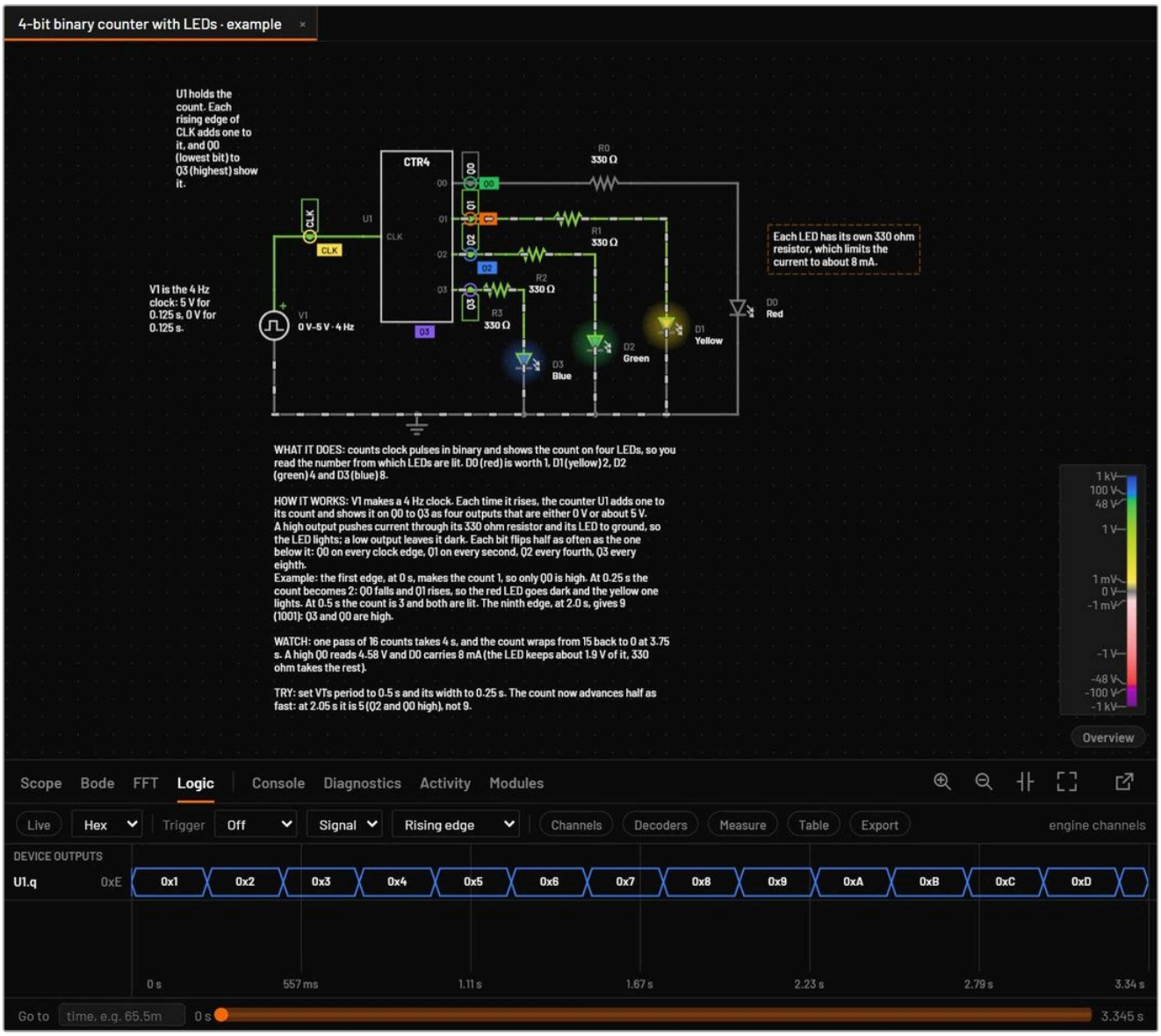


Figure 27.15 A binary counter driving LEDs, with the Logic tab open.

Alt + 4 opens the Logic tab, a digital waveform viewer that shares its time axis with the first scope (with linked scopes, with the shared window).

GROUP	WHAT APPEARS
DEVICE OUTPUTS	The digital outputs of logic gates, flip-flops, counters and control blocks, named like **U3.q0**, and buses like **U2.d**.
PROBED NETS	Nets you added with **Add to logic analyzer…** from a wire's right-click menu, labelled **D net**, read as high or low at the threshold you chose.

CONTROL	WHAT IT DOES
Live / Hold	Follows the newest sample, or holds the picture. Panning or zooming back to the live end follows the run again.
+ / –	Zooms time in or out by a factor of two. The dock header has the scope's own zoom in, zoom out, cursors and Fit buttons on this tab.

CONTROL	WHAT IT DOES
Fit	Shows the whole recording when the run is paused, and the live window while it runs. A double-click on the plot does the same.
History bar	Under the plot: the run start and end times, a band for the window you are looking at, and a **Go to** box. Click the bar to jump, drag the band to scroll through the recording. It works while the run goes and while it is paused, and it sets cursor A.
Find	Type a decoded value, as **0x41**, **65**, **b101**, a character or some text. Enter goes to the next match and Shift + Enter to the previous one. The matches are outlined and counted.
Export	Saves the channel edges as a CSV file. The decoded table has its own **Save CSV**.
Bus format	Hex, Dec or Bin for bus values.
Trigger	Off, Normal or Single. Single waits for the next matching edge after you arm it (earlier edges don't count), then pauses the simulation with the window held on that edge and the trigger marker still shown.
Signal and condition	The trigger signal and Rising edge, Falling edge, Any change, or Value = with a value box.
Clear cursors	Removes cursors A and B.
Mouse	Click sets cursor A, Shift-click cursor B (Δt and 1/Δt top right). Drag a cursor line to move it. The wheel zooms about the pointer, and a drag pans. The window cannot go before the first sample or past the live time.

Buses are drawn as segments with their value, single bits as high and low lines, and unknown states as a red band. Each signal keeps its last 8192 edges. The engine checks a net you added with **Add to logic analyzer...** against its threshold on every step, so the channel catches every edge the engine computes, however long the scope's timebase is.

When there are more channels than fit, the channel rows scroll. Turn the wheel over the channel names (over the plot the wheel still zooms in time), drag the bar at the right edge or click its track, or press the up and down arrows or Page Up and Page Down. The decoder lanes and the time axis stay where they are.

27.14 Decoders

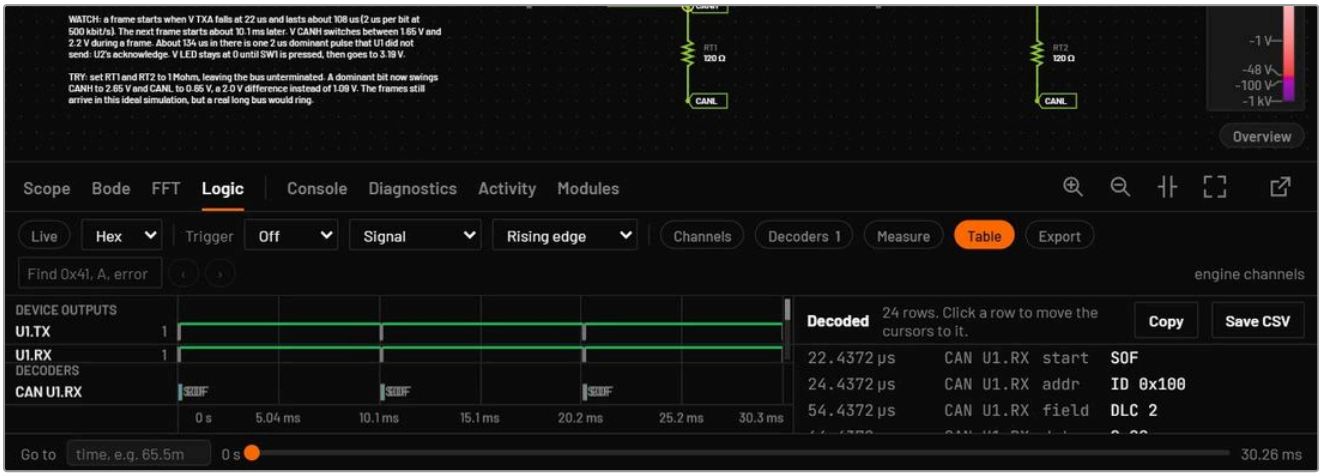


Figure 27.16 The Logic tab on the two-MCU CAN example: the CAN decoder lane under the channels, and the decoded table with the start of frame, the identifier and the length.

The **Decoders** button adds a UART, I2C, SPI, CAN, 1-Wire, PWM or Manchester decoder. Pick its channels (a guess is made from the names) and its settings. Decoded frames are drawn over the waveforms in their own lane, and **Table** lists them with the time, kind and value. Click a row to put the cursors on that frame. Errors are marked in red. The decoders are saved in the circuit, so an example or a shared file opens with its decoded lanes. Save keeps them and Undo takes a change back. The channel names, colours and buses belong to the session.

DECODER	WHAT IT READS
UART	Bytes, also as text. Framing and parity errors and a short byte are marked. The baud rate can be Auto.
I2C	The 7-bit address, read or write, data, ACK or NACK, start, repeated start and stop. An acknowledge cut off by the end of a recording does not end before it starts. A control block's own outputs show only what the master drives: to see the slave's ACK add the net itself.
SPI	Modes 0 to 3, with an optional chip select. A clock paused in the middle of a word is marked.
CAN	One logic-level line, dominant low: a controller's RX (the bus as it reads it) or TX. It finds the start of frame on an idle bus, takes out the stuff bits and reads standard (11-bit) and extended (29-bit) identifiers, remote frames, the length, the data bytes and the CRC, which it checks. The ACK slot reads ACK when a receiver drove it, so decode RX to see it: TX shows NACK there, because the sender leaves the slot recessive. Errors are stuff error, CRC error and form error. Bit rate Auto finds the rate from the shortest pulse. Try **mcu-can-two-nodes**.
1-Wire	The one data line. A low of 480 µs or more is a reset, a low that a device starts up to 300 µs later is its presence pulse (or *No presence* when none comes), and each time slot is a bit: a low shorter than 15 µs is a 1, a longer one a 0, eight of them a byte, least significant bit first. **overdrive** uses the faster timing. Try **one-wire-reset-presence-pulse**.
PWM	The duty and the frequency of every period of a pulse train, from one rising edge to the next (the falling edge with **active low**).

DECODER	WHAT IT READS
Manchester	A line with a transition in the middle of every bit. A rising one is a 1 in the IEEE 802.3 convention and a falling one in the G. E. Thomas convention (pick which). It shows the bits on one lane and words of the length you set on another, and marks a missing mid-bit transition as a violation. The bit rate on Auto comes from the shortest pulse, which is half a bit. Set it when every bit alternates, because then all pulses are a whole bit long. Try **manchester-encoder-xor**.

Other controls of the tab: **Channels** renames a channel, picks its colour or hides it, and several 1-bit channels ticked together make a bus with **Group**, read in hex, decimal, binary or ASCII. **Measure** gives the period, frequency, high and low widths and duty of a channel over the window or between the cursors. The trigger takes a value or a pattern such as **5**, **0x1F** or **b10x1**, where **x** is a bit that does not matter. With the plot focused: **+** and **–** zoom, the left and right arrows pan, the up and down arrows scroll the channels, **L** live or hold, **C** clears the cursors, **T** the table, **H** channels, **D** decoders, **M** measure and **F** the next format.

The window always shows the recording. Zooming the running scope keeps the Logic tab live with the scope's time span. It only holds when the scope is paused or zoomed into the past. A held window that has drifted outside the recording (after a long run, a Restart or a scope zoom) goes back to Live by itself. While you haven't set a zoom of your own, the time span widens until the busiest signal shows a few edges, so a slow signal is never an empty lane. Switching to another document tab starts the Logic tab live for that circuit.

TRY IT

Trigger on a counter

1. Open **Counters and registers** and a binary counter example.
2. Press Alt + 4. Set Trigger to **Normal**, the signal to the most significant bit and the condition to **Rising edge**.

YOU SHOULD SEE The picture locks on each rollover of the top bit. Click and Shift-click two edges to read their spacing.

27.15 Console

The Console tab shows the lines that programmable control blocks print with **log()** and that microcontrollers print with **print**, and their script errors: the clock time, the simulated time, the part and the message. Error lines are red and counted on the tab. Click a line to select the part. It keeps the last 5000 lines, from every circuit you opened in the session. **Tools** › **Clear console** empties it (greyed when it's empty, and the message offers Undo). **Programmable control blocks**, p. 369 and **Programming the MCU**, p. 373 describe the scripting.

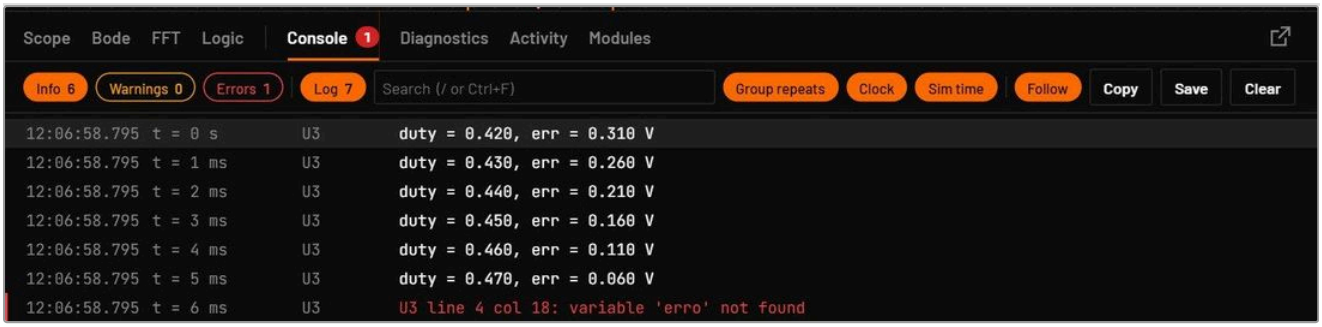


Figure 27.17 The Console with its level chips, channel chips and search box.

Chips filter the lines by level (information, warnings, errors) and by channel (Log, MCU, Serial). The search box takes words that must all appear, **"a phrase"**, **-word** to leave lines out and **part:U1** for one part. Ctrl + F or / focuses it and Esc clears it. Identical lines in a row fold into one line with a count (**Group repeats**). **Copy** (Ctrl + Shift + C) and **Save** write the lines shown as text, Ctrl + L clears with Undo, and **Follow** (or End) keeps the newest line in view. Scrolling up pauses it.

The input bar for a USB-UART bridge

When the circuit has a USB-UART bridge (a **chip** of variant **usb_uart**, **Chips and displays**, p. 359), the Console gets an input bar under the lines. The bridge is the Console's other end: what the microcontroller sends to it shows as lines, tagged with the bridge's designator, and what you type goes out on the bridge's TXD pin to the microcontroller's RX.

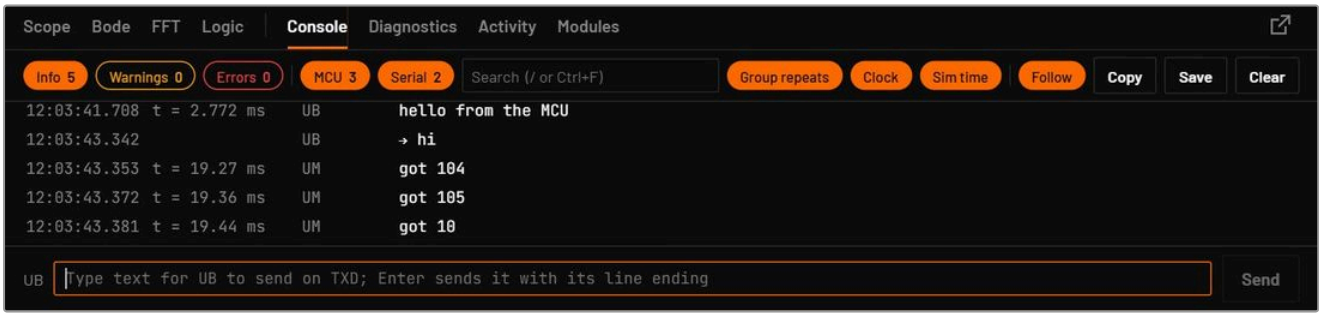


Figure 27.18 The Console with a USB-UART bridge: the MCU's line from UB, and below the input bar with the text sent, echoed as →.

PART OF THE BAR	WHAT IT DOES
Name of the bridge	The bridge that sends. With more than one bridge in the circuit, it is a list: pick the one to send through.
Text box	Type text and press Enter, or click **Send**. The bridge adds the ending set in its **Console line ending** field (**lf** by default, or **cr**, **crlf**, **none**) and sends the bytes as 8N1 at its baud rate.
→ **text** line	Each text you send is echoed in the Console with an arrow, so the log shows both directions.

Text goes out only once the live simulation has started (press Play first, otherwise an error line follows the arrow line), and the bridge must be powered (VCC above 2.5 V). A line that reaches the bridge with the wrong

baud rate arrives garbled and raises **W_UART** (**Diagnostics and what they mean**, p. 86).

27.16 Activity

The Activity tab (Alt+7) lists every edit and run, by you or by an AI agent: the time, the author (**you**, or the agent's name in violet), what happened and the parts. It includes undo and redo, opening, importing and exporting, runs such as *"Ran transient in 42 ms"*, reloads from disk and take-overs. Click a row to highlight its parts and zoom to them. It keeps the last 2000 entries. **Tools** › **Clear activity log** (Ctrl+Alt+L) empties it.

28 Simulate (F5) and its engines

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Simulate runs a transient from t = 0 to the stop time in the toolbar and plots your probes in the Analysis view. BetterSPICE picks the engine, so you never choose one.

28.1 Running Simulate

1. Set **Simulate for** (the stop time, default 200 ms) and **max step** (the largest timestep, **Auto** unless you type one) in the toolbar.
2. Place probes on the signals you want to see.
3. Press F5 or click **Simulate**. From the Schematic view the window splits so the schematic stays visible. In Split and Analysis it stays as it is.
4. While it runs, the Simulate button shows the percentage, the seconds so far and Cancel, and the Analysis view a progress bar. Click either to cancel.
5. When it finishes, the plot shows your probes. In Split, hold Alt and click a net or a part on the schematic to add more traces.

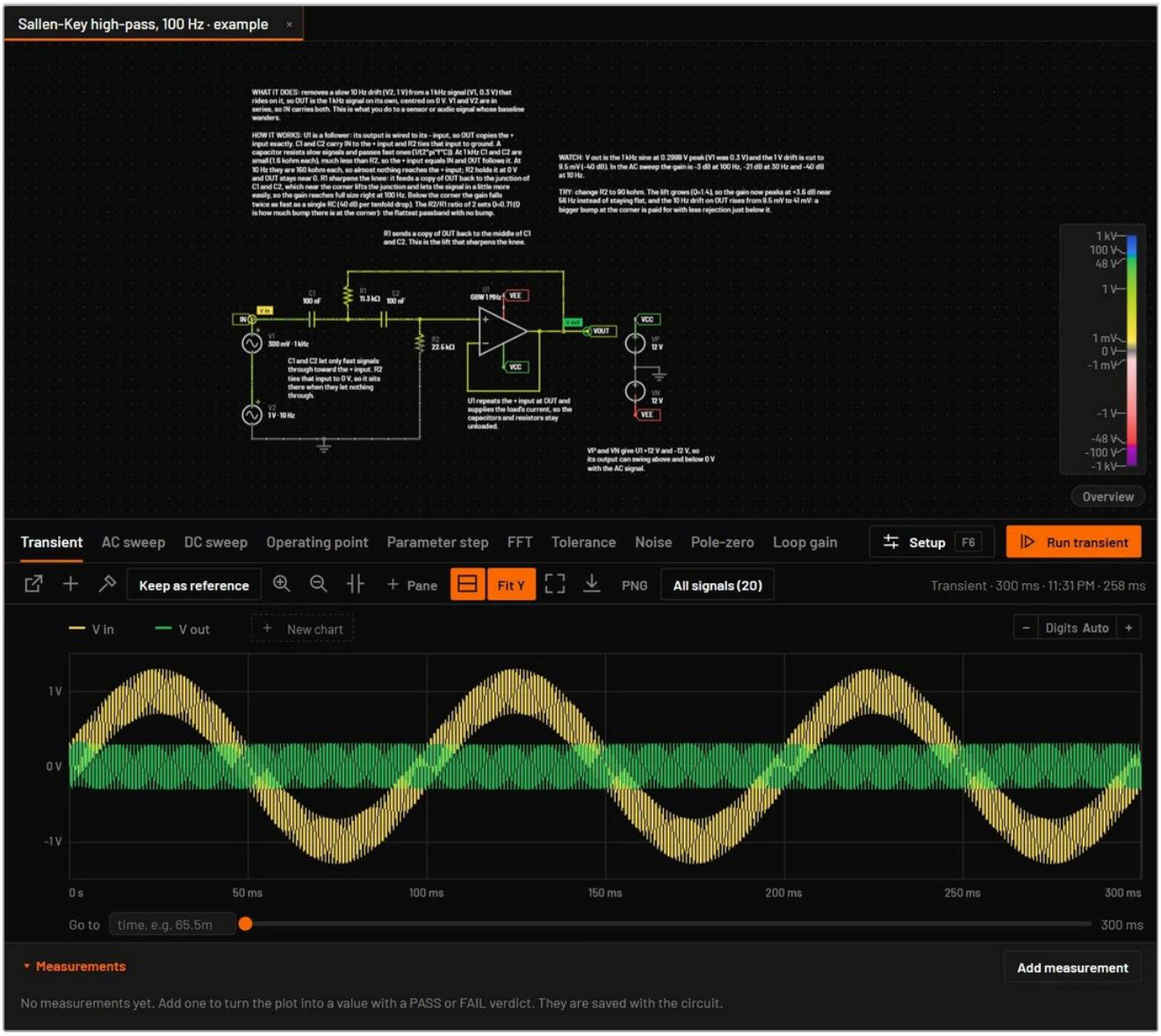


Figure 28.1 Simulate: the result in Split view.

28.2 Which engine runs

THE CIRCUIT CONTAINS	DESKTOP APP	BROWSER
Only built-in parts and discrete vendor models (diodes, BJTs, MOSFETs, JFETs)	The BetterSPICE engine	The BetterSPICE engine in WebAssembly
Vendor subcircuit models (op-amps, regulators, current-sense amplifiers, references)	ngspice-47 with the vendor's own files. The progress line says **in ngspice (vendor models)**.	Not available. A banner says the circuit needs the desktop app.
Cadence-encrypted vendor models	PSpice for TI, hidden. The progress line says **in PSpice (encrypted vendor models)**.	Not available.

You never choose the engine. A circuit is sent to ngspice when it has a part with a vendor model file, and to PSpice when one of those files is Cadence-encrypted. Everything else stays in the BetterSPICE engine, which is faster. Logic parts (gates, flip-flops, latches and the counter) are written into those

ngspice runs as well, so a circuit that mixes them with vendor models runs whole, and a gate or flip-flop output switches at the moment its input crosses the threshold, not up to a step later. A transient starts exactly at the operating point, also with JFETs, capacitors and inductors.

28.3 What the plot shows

- Your probes, named as on the schematic. A circuit without probes shows *"No probes: press P and click a net, or Alt+click a net/part in Split view to add a trace"*, not every node at once.
- In Split view, **Alt+click** a net (voltage) or a two-pin part (current) on the schematic to add its trace. It stays until you remove it. A plain click selects and edits as usual.
- A run that has warnings of its own, such as *F1 blew at t = 1 ms* for a fuse, shows them in the note under the result, unless Diagnostics already lists them.
- **All signals** in the plot toolbar shows every node voltage and branch current the run kept, with a signal list beside the plot.
- Placing or deleting a probe while a result is shown updates the plot at once. It re-reads the result, or reruns when the last run took less than two seconds.

28.4 Progress, cancel and errors

- A run never fails silently. A run that takes more than a moment shows its progress.
- Pressing F5 during a run says *"A simulation is already running (N s, P %). Press Cancel to stop it, then Simulate again."*
- A failed run shows a red banner, **Simulation failed:** with the reason, which stays until you press **Dismiss**.
- A run in the browser's built-in engine can't be cancelled halfway. It says so and stops by itself at the stop time.
- Results belong to the circuit they ran on. Opening another circuit clears them, and a run in flight on a changed circuit is discarded with a message.
- Some vendor op-amp and current-sense models have no DC operating point at 0 V. If ngspice finds none, BetterSPICE runs the transient again from 0 V with every capacitor discharged, as at power-up. A warning tells you it did this. The run doesn't fail.
- When ngspice finds the DC point only through its transient fallback, Simulate runs Newton iteration again from that state with every node set, so a TI macromodel such as the OPA2990 lands on the point PSpice gives. Transients, DC sweeps and AC analyses start from that point.
- A switching circuit with no DC point, such as the UC3843 boost and SEPIC examples, never settles. The search then stops after a short power-up

and the run starts from 0 V with a warning. The search never stops a run for memory: a helper run over the memory limit is skipped.

- The bar names the step: *Step 5 of 6: Simulating in ngspice* until the engine is done, then *Wrapping up*.

28.5 Threads

Simulate › **Threads** sets how many processor cores simulations may use: **Auto** (the default) or a fixed number. Auto uses every core but one, so the window stays responsive while a run goes on. The choice is remembered on this computer. The status bar always shows what may run side by side, for example **Steps and tolerance 16 threads**, and after a run it says what that run used: **Last run 1 thread (a transient goes step by step)**, or **Last run 5 threads** after a parameter step. Hold the pointer over it for the setting and the reason.

RUN	THREADS IT USES
Simulate, a transient, AC or DC sweep, an operating point	One for the steps, because each time step depends on the one before. A big circuit, whose device load takes more than about 9 µs a step, evaluates its parts on up to 4 threads and adds their contributions in the same order as one thread, so the result is the same to the last bit. A typical circuit stays on one thread: its step takes a few microseconds, less than it costs to hand work to another thread.
Parameter step of a circuit without vendor models	One worker per value, up to the setting (Auto: all cores but two, because the live simulation keeps one).
Parameter step of a circuit with vendor models (desktop app)	Its ngspice runs go side by side, up to the setting. Each extra run goes to a hidden ngspice worker process. Circuits that need PSpice still take turns.
ngspice device models	BSIM3 and BSIM4 MOSFET models are evaluated on up to the setting's threads inside ngspice. Other models run on one.

Results don't depend on the setting: a run on one thread and on many gives the same numbers, in the same order. From 0.5.0 every exp, log, power and sine of the engine comes from one correctly rounded math library, in the desktop app, the command line and the live view alike, so a circuit also gives the same numbers on Windows, Linux and macOS. Processors with AVX2 and FMA take a faster path that gives the same bits. Set Threads to **1** to keep the other cores free for something else, for example a long build.

> TIP **Command line.** Every **bspice** command takes **—threads auto** or **—threads N**, and the variable **BSPICE_THREADS** sets the same thing. **bspice verify** runs its circuits side by side and prints, for example, *"Simulated on 23 threads (144 circuits in 0.9 s)"*(**Conventions**, p. 596).

28.6 Auto maximum step

Leave **max step** empty, or type **auto**, and Simulate picks the step from the circuit. The step is the smallest of these, rounded down to a short number such as 1, 2, 5 or 8 times a power of ten:

- a fiftieth of the period of each source (sine, square, pulse, function generator, or the switching frequency of a block),
- a fifth of a slow edge of a source: the rise or fall of a pulse, or a ramp of a piecewise-linear source. A step that ends inside a slow ramp lets a transistor switch off too fast and lift its collector above the supply. An edge so short that it would need more than 50 000 steps is left to the solver, which crosses it from corner to corner as a sharp edge,
- a fiftieth of the PWM period that the code of a microcontroller or control block sets (**pwm 25kHz**, **pwm(0, 20000.0, d)**), like a source,
- a twentieth of an RC time constant, for a capacitor and a resistor that share a net that can move,
- a fiftieth of an LC period, where the windings of a transformer count as inductors,
- a twentieth of the L/R time constant of a resistor in series with an inductor,
- a 25th of the period of the ring that an inductor makes with the capacitance of the diodes and transistors on its net, which the parts put there themselves (the coil of a relay with the drain capacitance of its MOSFET). The trapezoidal rule reads a ring slow by $(2\pi/N)^2 / 12$ for N points per period, 0.5 % at 25 points. A ring that 50 000 steps would resolve with fewer than 10 points is left alone, because a capped step reads it no better and costs time,
- a thousandth of the stop time.

Time constants, edges and rings are estimates, so they never ask for more than 50 000 steps over the stop time. A source's own period is what the circuit is driven at, so it goes down to a ten-millionth of the stop time. When a limit holds the step back, the reason says *limited to 50,000 steps over the stop time*, and the notice before a long run names what set an Auto step in one muted line. The Transient setup then says *Auto, from the circuit: 8 µs* with the reason, for example *50 points per period of V2's 100 kHz source*, and the toolbar field reads **Auto 50 µs**. A value you type still wins, and with one typed the setup says how to go back. Auto is not written into the circuit file, and a file that has a saved step keeps it. Every analysis uses the resolved step, and so do the pre-run estimate, the long-run notice and an AI agent's **run_analysis**.

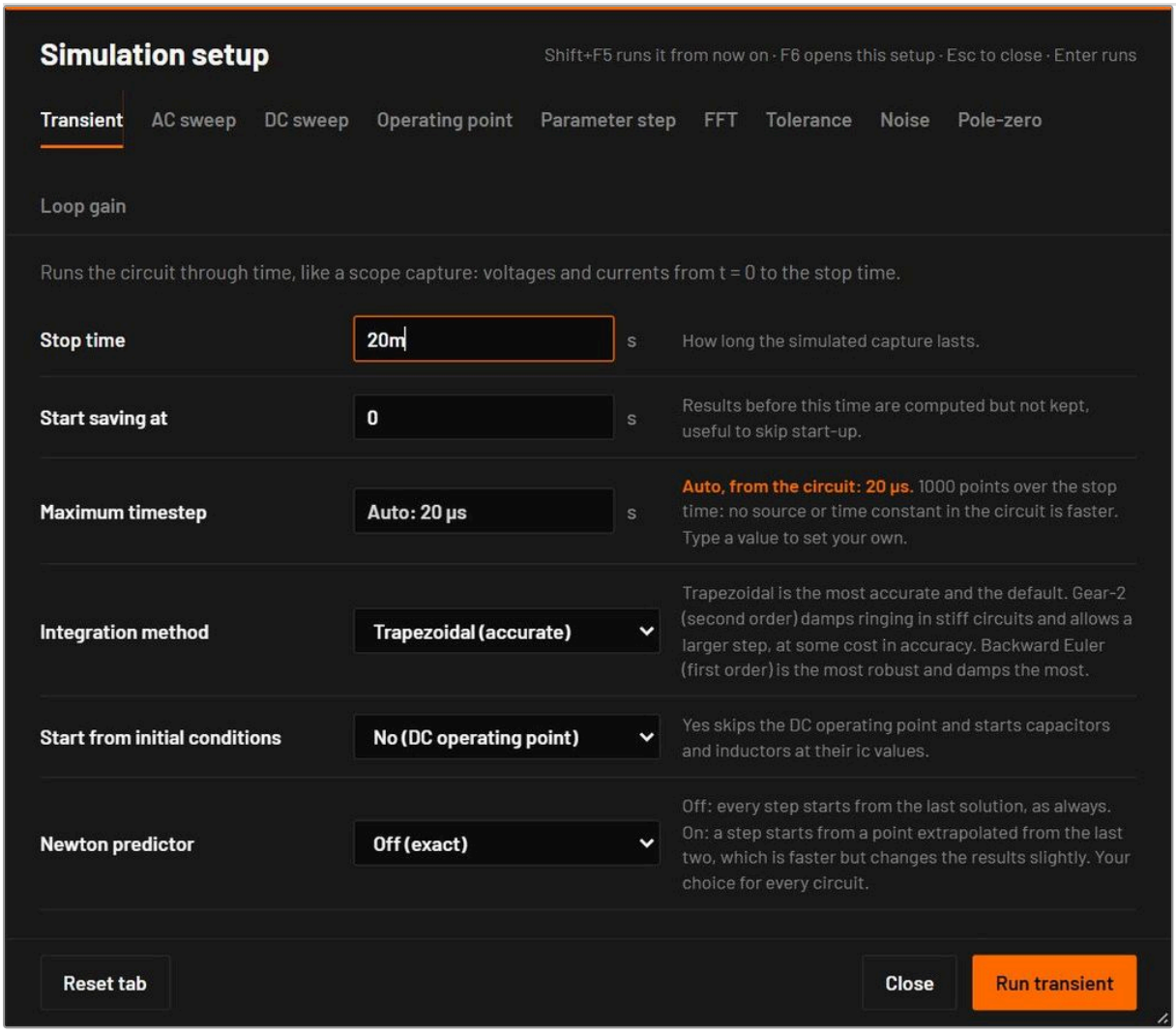


Figure 28.2 The Transient setup with the maximum timestep left empty: Auto, with the step and the reason.

- **Vendor models.** A run that goes through ngspice counts only the limits from sources, PWM and the stop time, because ngspice chooses its own internal steps and a guessed limit made a vendor model fail that ran at 1 µs.
- **When an Auto run fails in ngspice,** Simulate repeats it at 2 µs in a fresh ngspice process and a note (**W_AUTO_STEP_FALLBACK**) says so. The retry gives the same answer as typing 2 µs yourself.
- **A ring that reads slow.** The inductive-load flyback example rang at 38.7 kHz at the stop time divided by 1000, where the part values give 41.1 kHz. With the ring rule the step is 800 ns and the ring reads 40.95 kHz.

The old fixed step of 1 µs was wrong both ways. A Colpitts oscillator read 951.6 kHz where 997 kHz is right, and a 14 Hz astable took 400 000 steps. Auto reads the Colpitts at 997.7 kHz and runs the astable in about a twentieth of the time.

28.7 Start-up kick for oscillators

Some oscillators sit exactly balanced in a simulation and never start, where a real one starts from noise. When a transient of a circuit with something that has gain and something that stores energy sits still, BetterSPICE repeats it with a 5 µV pulse on one input of the part with gain. If that run oscillates, the Analysis view offers it, once per circuit:

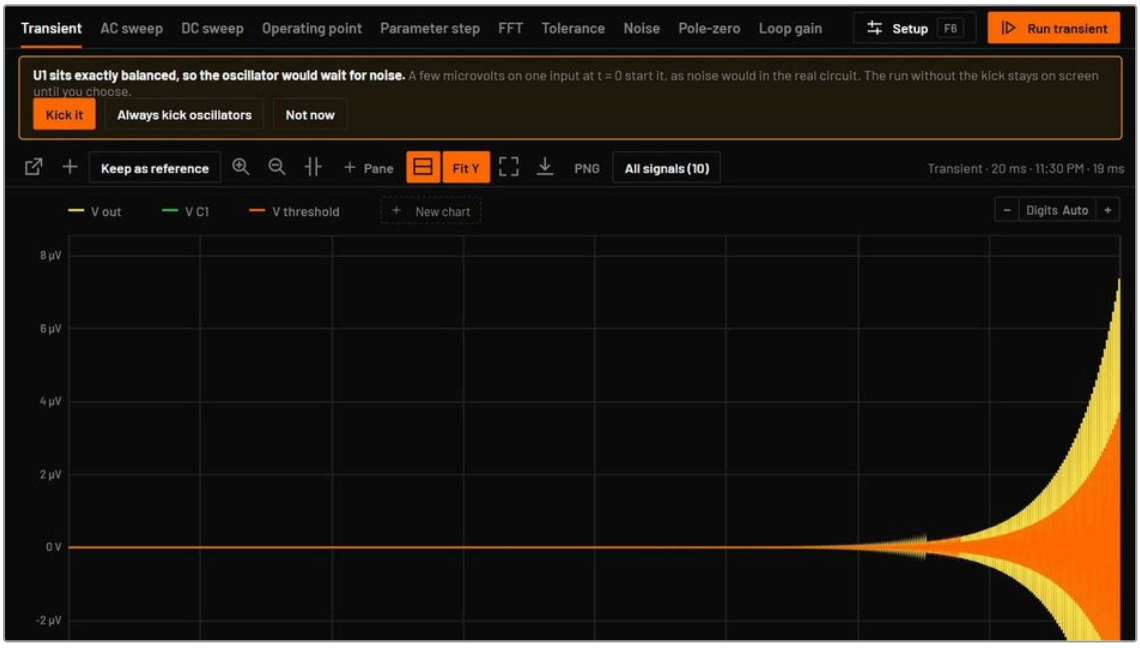


Figure 28.3 The offer after a run that sat balanced: Kick it, Always kick oscillators or Not now.

- **Kick it** shows the kicked run at once. Its note says *Started with a 5 µV kick on U1's input at t = 0, because the circuit sat exactly balanced.* Your circuit file is never changed.
- **Always kick oscillators** kicks every balanced oscillator from now on, and says so in a message. It is saved on this computer, and **Simulate** › **Always kick oscillators** turns it off.
- **Not now** hides the offer for this circuit.
- **Simulate** › **Simulate with a start-up kick** asks for a kick directly, without waiting for an offer.

A run that already starts is never changed, and a circuit where the kick dies away, such as a stable follower, shows nothing. The live view is not kicked, only Simulate runs.

28.8 Integration method and long runs

The Transient tab has an **Integration method**. **Trapezoidal** is the default and keeps the most detail. **Gear-2** is a variable-step second order method that damps ringing in stiff circuits. **Backward Euler** is first order and the most robust, and it damps real ringing too. The choice is saved in the circuit as **method**.

Trapezoidal ringing guard. The trapezoidal rule does not damp a very fast mode, such as a junction capacitance across a conducting junction or a switch node that drives an inductor: the value reverses direction at every step and only the step size hides it. The engine watches every charge and flux. When one reverses three steps in a row, the next four steps use Gear-2 and the trapezoidal rule resumes, with no restart. A signal that the steps resolve never does this, and a growing oscillation, such as an oscillator starting up, is left alone. There is nothing to set. A run set to Gear or backward Euler is not watched. When the guard acted, the run carries a note, **W_TRAP_GEAR**, tagged *Gear where it rang*, that says when it first happened, how many times and what share of the steps it took. It is a note and not a fault, and it needs nothing from you. To run Gear throughout, set the method to Gear in the setup. In the live view the note goes out once, at the first window. On an interleaved buck at a 20 ns step the guard removes a 26 mV limit cycle that the plain rule had, and the cost is a few percent more steps.

Before a long or data-heavy transient starts, the Analysis view says how long it will take and how much data it holds, with **Run**, **Keep less** when it holds more than 240 MB, a faster **Gear** setting that names its step, or **Cancel**. The estimate comes from the stop time, the maximum step and the measured cost of a step: the speed of this circuit's last Simulate run, else a guess from the live view, which then reads *Up to about*. **Run** keeps every signal at every step, gigabytes too, and the notice says when that needs more memory than is free now. **Keep less** keeps the probes at every step and every other signal as the lowest and highest value of short time slices. While a run goes, the bar shows the percentage and the time left. The time left is projected from the speed of the last seconds of the run (the last quarter of the run so far, at least 3 s) and follows the run. A run that slows down, as a switching circuit does once its start-up is over, says *at least*, because the end can be slower again. A run that turns out to take longer than 30 seconds shows the same figure in a notice during it, with the two buttons below.

Vendor-model runs (ngspice). ngspice adds a point at every switching edge, so a switching circuit makes far more points than its stop time over its maximum step: the mains flyback example makes about 4.95 million where its setup gives 90,000. Before the first run of such a circuit the notice counts *at least* that many steps. While the run goes, from 3 % of the way on, the Analysis view says where it is heading when that is big: the points, the result size, the memory it needs and the limit, 80 % of the memory free when the run started. The points are projected from the recent progress, and said as *at least* while each part of the run makes more points than the part before. **Stop and keep less** stops it and runs it again with only the probed signals, each at every step. **Keep going** lets it run. A run heading over the limit stops by itself with **E_MEMORY** and keeps nothing, in a box with the ways out: a shorter stop time, a larger maximum step, or **Keep less and run again**. The next run of the circuit counts with the points the last one made, so its notice gives the real size. Keep less in ngspice keeps only the probed signals, so a circuit with no probe is told to add one first. Nothing is thinned unless you choose Keep less.

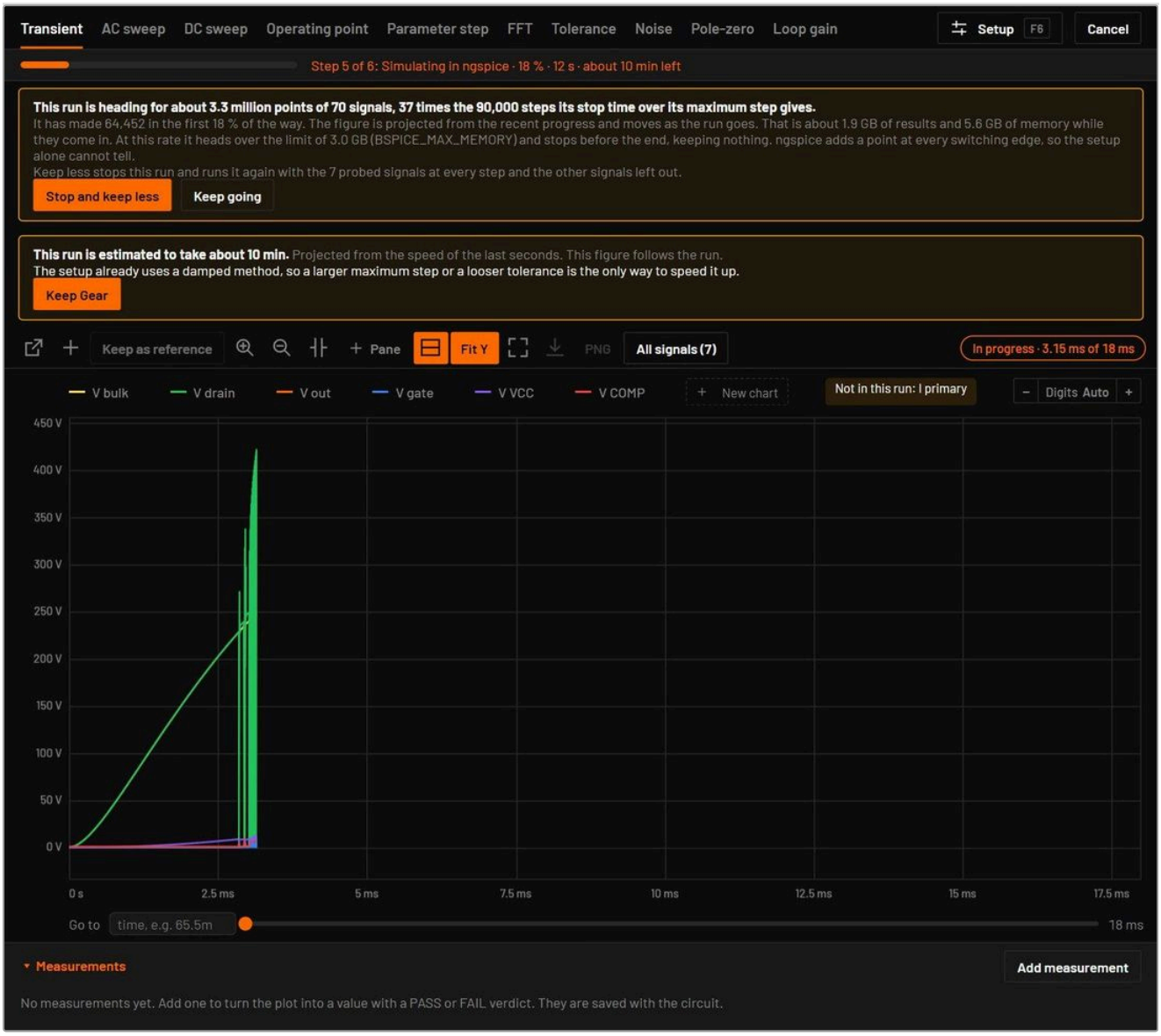


Figure 28.4 The mains flyback example in ngspice with a 3 GB limit: the warning (heading for about 3.3 million points of 70 signals, 1.9 GB of results and 5.6 GB of memory) with Stop and keep less and Keep going, the time notice that follows the run, and the run so far.

The run so far. While a long Simulate transient goes in the desktop app, the Analysis view draws the waveform so far, about once a second, with an **In progress** chip that gives the time reached out of the stop time. The picture is thinned to short slices that keep the lowest and highest value, so a spike still shows. Export CSV and PNG wait, and the full result replaces it when the run ends.

When the estimate passes 30 seconds, the notice gives a faster choice: Gear-2 with a maximum step four times larger. It takes up to four times fewer steps where the maximum step sets them, but a switching circuit takes most of its steps at its edges, and those stay, so the notice promises no time. It also states the two drawbacks of that choice.

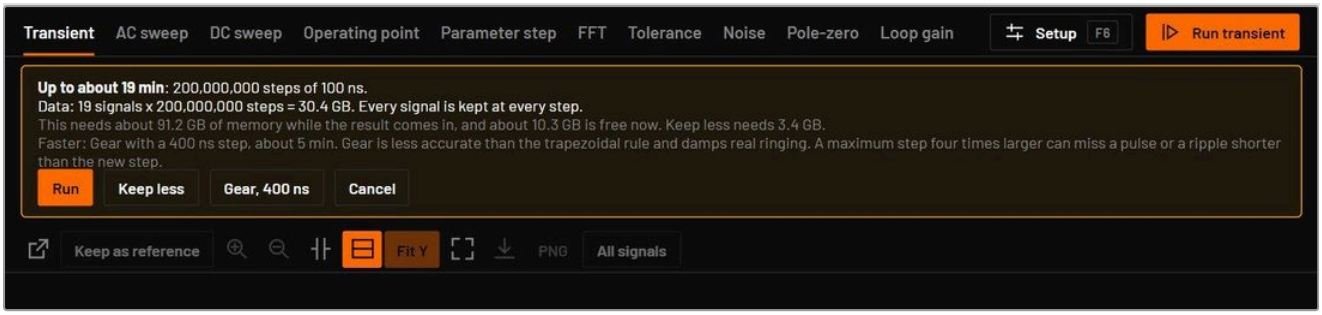


Figure 28.5 The long-run notice on a 20 s run at a 100 ns step: the estimate, the faster choice with its two drawbacks, and the two buttons.

- **Switch to Gear and 400 ns** (the button names the new step) writes the setup, says so in a message, cancels the run and runs again.
- **Keep trapezoidal** changes nothing, and the next long run shows the notice again.
- Nothing switches without the click.

28.9 Convergence doctor

When a run stops because the solver did not converge (**E_NEWTON**, **E_SINGULAR** or **E_TIMESTEP**), the engine tries again by itself and stops at the first setting that works. The order is a slower, finer DC solve with more Newton iterations, a larger gmin (1 nS, then 100 nS), Gear-2 integration, a maximum step ten times smaller, and the last two together with gmin. For an operating point only the first three apply. The result is the run that worked, and a **W_CONVERGENCE_AIDS** row says in plain words which setting worked, names the part at fault where it can, and gives a sentence on how to fix it (a switch that flips in no voltage range, a source edge of zero time, an ideal source on a gate).

- When the setting can be saved, the row has a **Fix convergence** button. It writes the method, the maximum step or gmin into the Simulate setup as one undo step.
- A run that converges the first time is never touched and takes the same steps as before.
- In the live view the same ladder runs on a step that fails, and the settings it found stay on until you reset.
- For vendor models Simulate has its own retry with ngspice's aids, reported with the same code.
- An agent reads the row with **get_diags**. It carries **apply**, for example **{"method": "gear", "maxStep": 2e-7}**, which can be written to **sim.simulate**.

28.10 Ratings and stress warnings

A part that carries a rating and runs over it gets a warning, a red pulse on the canvas and a row in the Diagnostics tab, with no need to open the inspector. The codes are **W_OVER_POWER**, **W_OVER_VOLTAGE** and **W_OVER_CURRENT**.

W_DIODE_ACROSS_SOURCE needs no rating: a diode or LED across both pins of a DC source, carrying more than 5 A (1 A for an LED), has nothing to limit its current. A part with no rating is never warned about. In a transient the power is the average over 1 % of the run and voltage and current are peaks. The live view keeps a warning for 2.5 s after the last frame that went over, so a pulsed load does not flicker. **Diagnostics and what they mean**, p. 86 lists the codes.

28.11 Settings saved in the circuit

A circuit file can carry the Simulate settings it needs in **sim.simulate**. The Transient tab opens with them, and Simulate applies them:

KEY	EXAMPLE	WHAT IT DOES
stop, **maxStep**	**0.075**, **1e-6**	The stop time and largest timestep, as in the toolbar.
method	**"gear"**	The integration method: **trap**, **gear** or **be**.
uic	**true**	Start from initial conditions (a power-up from 0 V). A circuit that sets it always starts this way, even when the Transient tab says no.
options	**"rshunt=1e10 abstol=1e-9"**	ngspice options the circuit needs, added as an **.options** line. Only *name=value* words pass, so a file can't add other commands to the run.

Use **options** for models that need a looser tolerance. The op-amp macromodels from TI, for example, can stall ngspice with *"timestep too small"* when their output reaches a rail, and **abstol=1e-9** cures that without changing the results.

28.12 ngspice and vendor models

When a part has a vendor model, Simulate writes a netlist with the vendor's own **.lib** or **.sub** file included, the pin map from the symbol to the model, and the analysis. Models written for PSpice, LTspice or HSPICE are converted to ngspice syntax first where needed. **Dialects and conversion**, p. 405 describes what is converted.

- **Several vendor libraries in one circuit.** Vendor macromodels reuse helper names with other contents: two TI op-amps both have a **VNSE_0** with their own noise figures. Each library gets a namespace of its own. A **.subckt**, **.model**, **.param** or **.func** that an earlier library or the circuit defines differently is renamed in that library's lines only, and a comment in the netlist lists the renames. A circuit with one vendor model gets the same netlist as before. **bspice export-spice** writes the netlist Simulate runs.
- **Library sections.** **.lib "file" SECTION** reads only that section of the file, as ngspice and HSPICE do.
- **LTspice OTAs and flip-flops** follow LTspice: the source and sink current limits (**Isrc**, **Isink**, a default **Iout** of 10 µA), **PowerUp** and **Ioffset**. In an SR or D flip-flop, reset wins over set.

- **PSpice LAPLACE blocks** take the coefficients each instance sets, and a leading denominator coefficient of 0 runs the lower-order transfer function, as PSpice does. ngspice has no LAPLACE source, so the conversion runs from the start.
- **PSpice voltage-controlled switches** keep their off resistance: a 1 TΩ ROFF stays 1 TΩ. Before 0.8.0 it ran as 17.6 MΩ, which made the clamps of TI op-amps leak.
- **Op-amp pins by name.** An op-amp model whose pin names give each of in+, in-, out, V+ and V- once is placed by those names, so the MAX4091 buffers as it should.
- **Gear from the start.** The mains flyback and the boost PFC examples run Gear from the start, because their trapezoidal run always rang and was run again with Gear.

> TIP **Large vendor models.** A transient with many vendor subcircuits, for example five op-amps and fifteen current-sense amplifiers, takes about 30 seconds in ngspice. The progress bar shows how far it has got.

28.13 PSpice for encrypted models

About 18 000 models in the catalogue are encrypted by Cadence, mostly Texas Instruments parts. ngspice can't read them, but PSpice for TI can. When the circuit contains one and PSpice for TI is installed, Simulate runs the whole circuit in PSpice, hidden, and reads the result back.

LIMIT	WHY	WHAT TO DO
One run at a time	PSpice for TI runs one simulation per Windows session.	Wait for a run to finish, or close your own PSpice window, before pressing Simulate.
At most four probed signals	The free PSpice for TI keeps at most four traces.	Probe the four signals you need. The run repeats with the ones you choose. The full Cadence PSpice has no such limit (point **BSPICE_PSPICE** to it).
Desktop only	PSpice is a Windows program.	Use the desktop app.
Approximate live simulation	The live simulation uses parameters fitted in PSpice.	Use Simulate for numbers you rely on.

PSpice takes the first definition of a subcircuit name for every instance. When two libraries of the circuit define a subcircuit of the same name (OPAMP3A is in four encrypted TI files), the later part is called through a small wrapper library, so each part gets its own model. Library rows for these models say *"Cadence-encrypted, verified in PSpice"*. If PSpice isn't installed, the run stops with a message that names PSpice for TI and where to get it.

28.14 Simulate and the live simulation

	LIVE SIMULATION	SIMULATE
Purpose	Watch the circuit while you design	A result you can measure, for a fixed stop time
Timestep	Fixed by the circuit, kept small	Adaptive, never above max step
Agreement	The same engine: the first step is Simulate's, and at the same step the frames are the same bit for bit	The reference
Vendor subcircuits	Fitted behavioural models	The vendor's own files in ngspice or PSpice
Output	Colours, dots, readings, scope	The Analysis view: plots, cursors, CSV, PNG

29 Analyses and their setup fields

29.1	The setup dialog	226	29.7	Tolerance	237
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The Analysis menu runs the classic SPICE analyses. F6 opens **Simulation setup**, with one tab per analysis, an explanation beside every field, and a Run button. The setup is saved in the circuit file.

29.1 The setup dialog

- Tabs: Transient, AC sweep, DC sweep, Operating point, Parameter step, FFT, Tolerance, Noise, Pole-zero and Loop gain. The last three are in the Analysis menu and have no function key.
- Values read from the circuit show in engineering notation (**1G**, **1µ**, **1.59155k**, up to six digits so nothing is lost on save), and the fields read them back.
- Number fields check what you type as you type. Text that's not a number turns red with *"Not a number. Use plain values or SI prefixes such as 200m, 1u, 10k, 1Meg."* and disables Run.
- The dialog puts the focus in its first field and keeps Tab inside. Enter anywhere runs, also from a number field. **Reset tab** restores that tab's defaults. **Close** (or Esc) keeps your changes without running.
- **Run** closes the dialog and runs, and the result shows as for every run: from the Schematic view the window splits. In Split and Analysis it stays.
- A new circuit fills the setup from its own parts: the AC and DC sources are real sources of the circuit, the step parameter is its first resistor, the FFT signal its first probe.
- Source, output node, parameter and probe fields list what the circuit has to choose from, and say when a name you typed isn't in it. A current source's DC sweep is in amperes.
- The source, output-node and probe fields have a **pick on schematic** button: the dialog closes, you click the source, net or probe on the canvas, and it opens again with the field filled. Esc cancels. Clicking something that doesn't fit says why.
- The settings of every tab are saved in the circuit file, as an undoable edit that marks the circuit changed, and a circuit reopens on the analysis it

showed last. Running an analysis doesn't mark the circuit changed and isn't an undo step.

The analysis keys. Shift+F5 (transient), F7 (AC), F8 (DC), Shift+F7 (step) and Shift+F8 (FFT) run that analysis with the setup saved in the circuit. The first time, when the circuit has no setup for it, the key opens the setup instead, and **Run** there saves it, so the key runs it from then on. The setup header says so: *F7 runs it from now on · F6 opens this setup.* F6 opens the setup of the current analysis at any time, and the toolbar's **.ac** and **.step** buttons open theirs. F9 runs the operating point at once. F5 runs a transient with the toolbar's stop time and max step.

ANALYSIS	KEY	RESULT
Transient	Shift+F5, or F5 to run it directly	Signals against time
AC sweep	F7	Gain and phase against frequency, with -3 dB points and margins
DC sweep	F8	Signals against a swept source value
Operating point	F9 runs it at once	A table of node voltages and branch currents
Parameter step	Shift+F7	One curve per parameter value, overlaid
FFT	Shift+F8	A spectrum in dB against frequency
Tolerance	Shift+F9	Monte Carlo or worst case on the part tolerances
Noise	Analysis menu	Noise density at an output, each part's share, and the totals
Pole-zero	Analysis menu	Poles and zeros of a transfer function, on the s-plane and in a table
Loop gain	Analysis menu	Bode plot of a feedback loop with the crossover, phase margin and gain margin

29.2 Transient

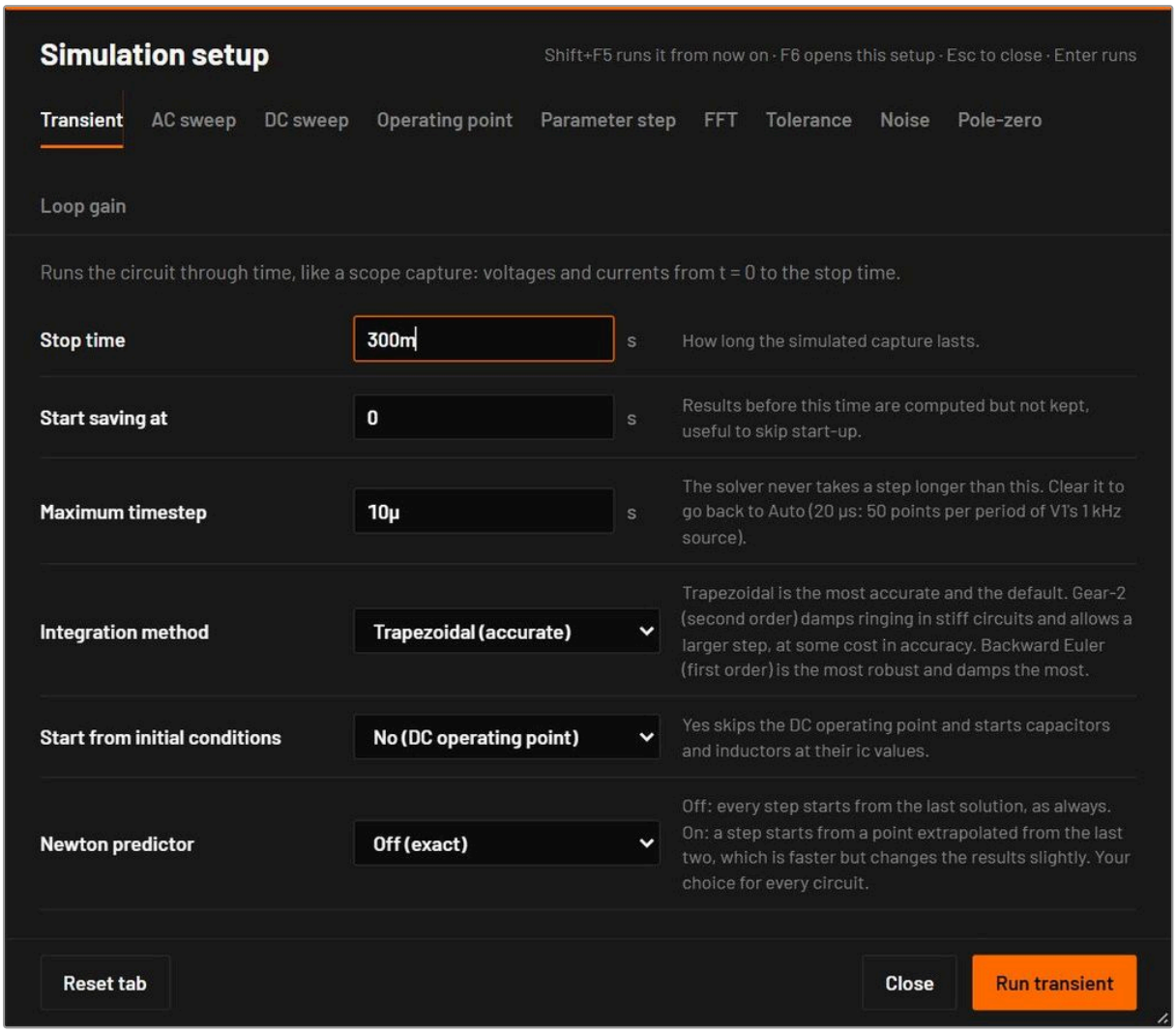


Figure 29.1 Setup, Transient tab.

Runs the circuit through time, like a scope capture: voltages and currents from t = 0 to the stop time.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Stop time	seconds, above 0	200m	How long the simulated capture is. Also the **Simulate for** field in the toolbar.
Start saving at	seconds, 0 or more	0	Results before this time are computed but not kept, to skip the start-up. It must be earlier than the stop time: otherwise the field says *"Must be earlier than the stop time..."* and Run is greyed.
Maximum timestep	seconds, above 0, or empty or **auto**	Auto	The solver never takes a longer step. Smaller is more precise and slower. Empty means Auto: the step is chosen from the circuit (**Auto maximum step**, p. 217). Also the **max step** field in the toolbar.
Integration method	Trapezoidal (accurate), Gear-2 (damps ringing), Backward Euler (most robust)	Trapezoidal	Trapezoidal keeps the most detail. Gear-2 (second order) damps ringing in stiff circuits and allows a larger step, at some cost in accuracy. Backward Euler (first order) is the most robust and damps the most. Used by ngspice runs and by the BetterSPICE engine. Choose a damped method when the run warns **W_TRAP_RINGING** (a numerical oscillation of the trapezoidal rule, explained in the Fix chapter).
Start from initial conditions	No (DC operating point), Yes (ic values)	No (DC operating point)	Yes skips the DC operating point and starts capacitors and inductors at their **ic** values. Used by ngspice runs. The BetterSPICE engine starts from **ic** values when the circuit sets them. A circuit can set this, the method and ngspice options itself (**Settings saved in the circuit**, p. 223).

TRY IT

A buck converter start-up

1. Open **Switching converters**, a synchronous buck.
2. Press Shift + F5. Set Stop time **2m** and Maximum timestep **50n**. Press Enter.

YOU SHOULD SEE The output rises to its set voltage with the soft start, and the inductor current shows the ripple. Zoom into the end to read the steady ripple.

29.3 AC sweep

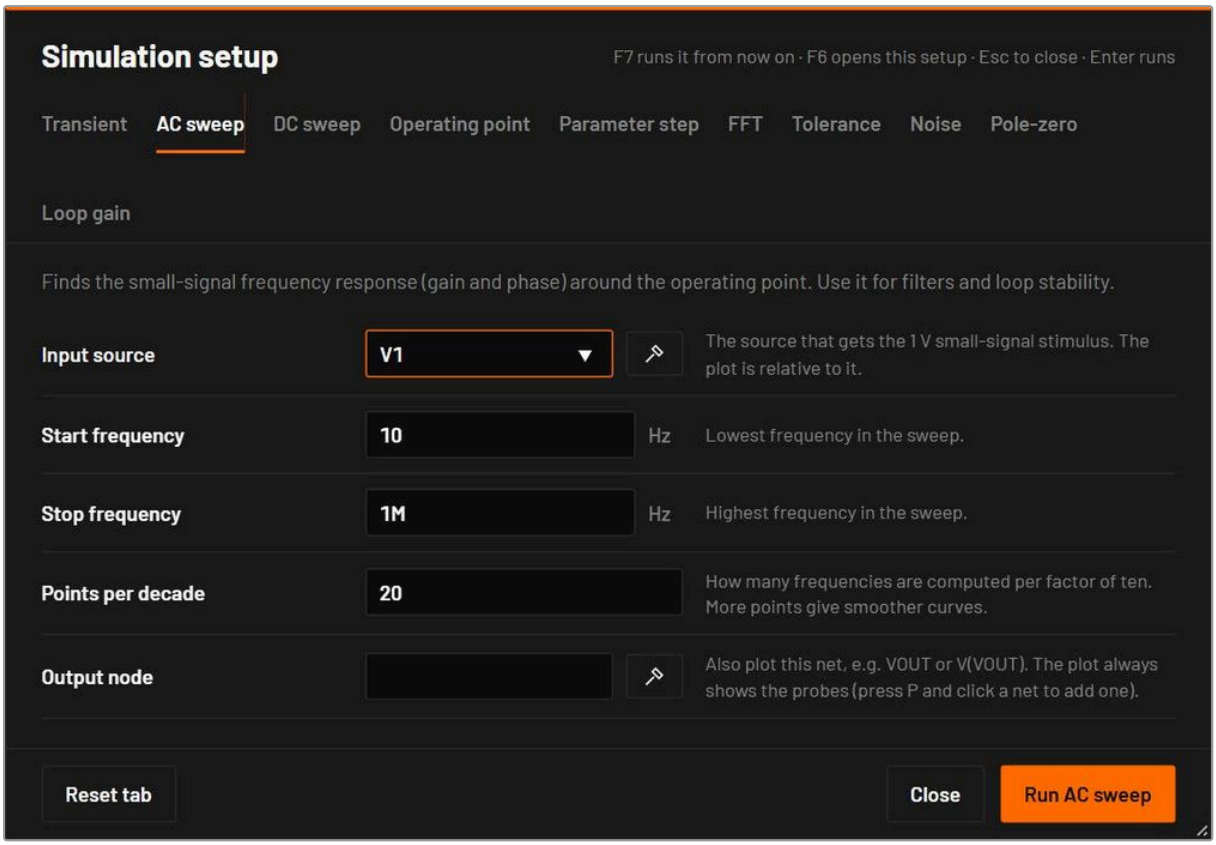


Figure 29.2 Setup, AC sweep tab.

Finds the small-signal frequency response, gain and phase, around the operating point. The circuit is linearised at its DC operating point, the input source gets a 1 V small-signal stimulus, and every probe is plotted relative to it.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Input source	a source designator	the circuit's first source	The source that gets the 1 V stimulus. An unknown name is refused with the list of the circuit's sources.
Start frequency	Hz	1	The lowest frequency.
Stop frequency	Hz	1Meg	The highest frequency.
Points per decade	number, at least 1	50	Frequencies per decade.
Output node	a net name, optional	empty	Also plot this net, written **VOUT** or **V(VOUT)**. Probes are always plotted.

The result is a Bode plot: magnitude in dB and phase in degrees. Where the gain is below –200 dB the phase isn't drawn, and when every probe sits at that floor the result says *"No small-signal path from V1 to … at this operating point"*. The phase is unwrapped, so it runs on past –180° without jumping by 360°, in the plot and in **bode.csv**. The margins strip above it shows, for the output trace, the **-3 dB** frequencies (up to two), the **Gain crossover**, the **Phase margin** (amber below 45°), the **Phase crossover** and the **Gain margin** (amber below 6 dB).



Figure 29.3 AC sweep of the active high-pass filter: gain and phase.

29.4 DC sweep

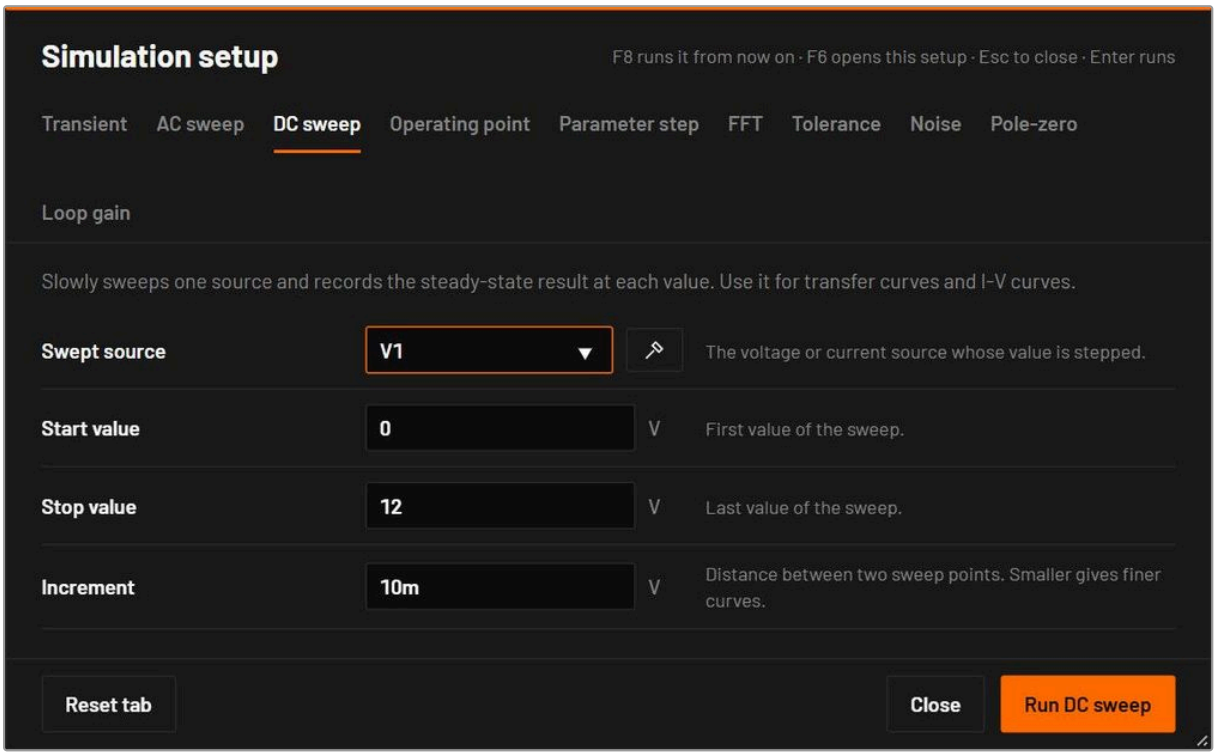


Figure 29.4 Setup, DC sweep tab.

Slowly sweeps one source and records the steady-state result at each value.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Swept source	a DC voltage or current source	the circuit's first source	A battery can't be swept. The message suggests a DC voltage or current source instead.
Start value	V or A	0	The first value.
Stop value	V or A	twice the source's value	The last value. For a 300 mV source the default sweep is 0 to 600 mV.
Increment	V or A	about 1/500 of the range	The step between values (1 mV for a 300 mV source).

The caption of the result carries units, for example *V1 0 V to 600 mV*.

TRY IT

A diode curve

1. Place a DC source, a 100 Ω resistor and a diode in series, and probe the current through the diode.
2. Press F8. Sweep the source from **0** to **2** in **5m** steps.

YOU SHOULD SEE The current stays near zero until about 0.6 V across the diode, then rises steeply, limited by the resistor.

29.5 Operating point

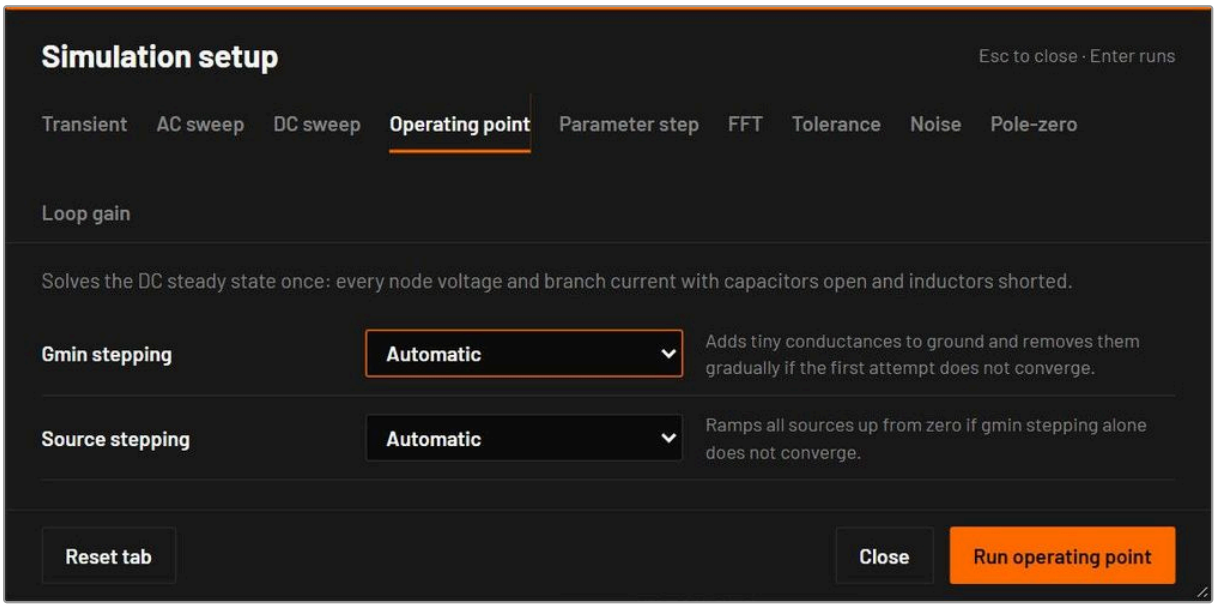


Figure 29.5 Setup, Operating point tab.

Solves the DC steady state once. F9 runs it at once without the dialog.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Gmin stepping	Automatic, Off	Automatic	If the first attempt fails, adds tiny conductances to ground and removes them step by step.
Source stepping	Automatic, Off	Automatic	If gmin stepping fails too, ramps the sources up from zero.

Off only applies to ngspice runs. The BetterSPICE engine uses both when it needs them and says so. The result is a table: probes first, then **V(net)** for every net, then **I(part)** and, for runs in the BetterSPICE engine, **P(part)**. Nets are named as on the schematic: a label, else a part pin such as **V(C1 pin 2)**. Click a row to mark its net or part on the schematic. With more than 12 rows a filter box appears, and 300 rows show until **Show all**. **Copy as table** puts the table on the clipboard. Export CSV writes Quantity, Value and Unit.

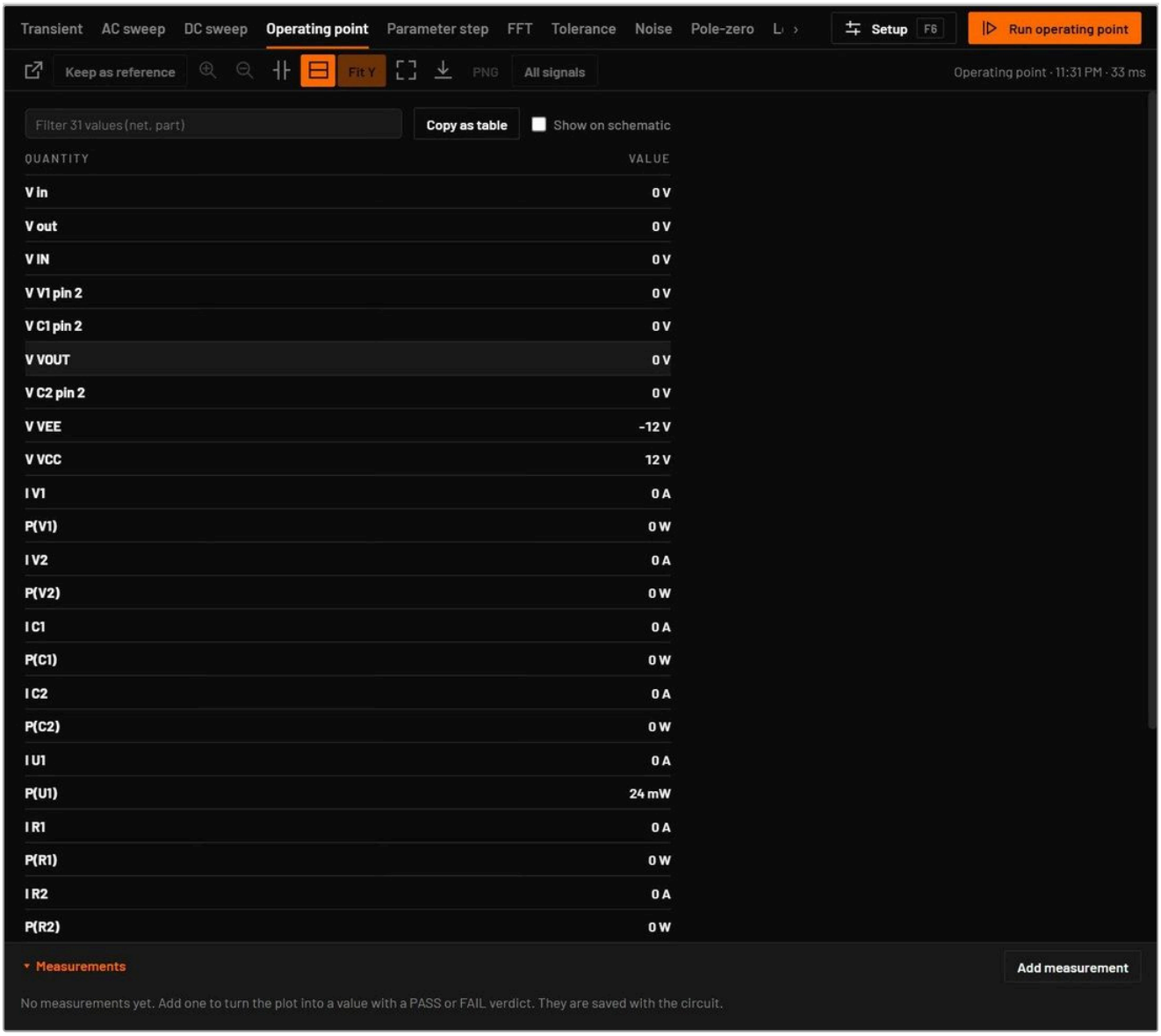


Figure 29.6 Operating point table.

Show on schematic above the table (or **View** › **Operating point on the schematic**) writes the result on the circuit: every net's DC voltage (ground left out) beside its net label or along one of its wires, and the current of every two-pin part that carries DC current, with a small arrow in the direction it flows through the part. A capacitor carries none and gets no label. The text is small and muted, the numbers are those of the table, and each one is placed clear of parts, labels, probe tags and the other values. When there is no room for one, it is left out: zoom in, or read it in the table. The values go away as soon as the circuit changes and come back with the next F9. The switch is remembered.

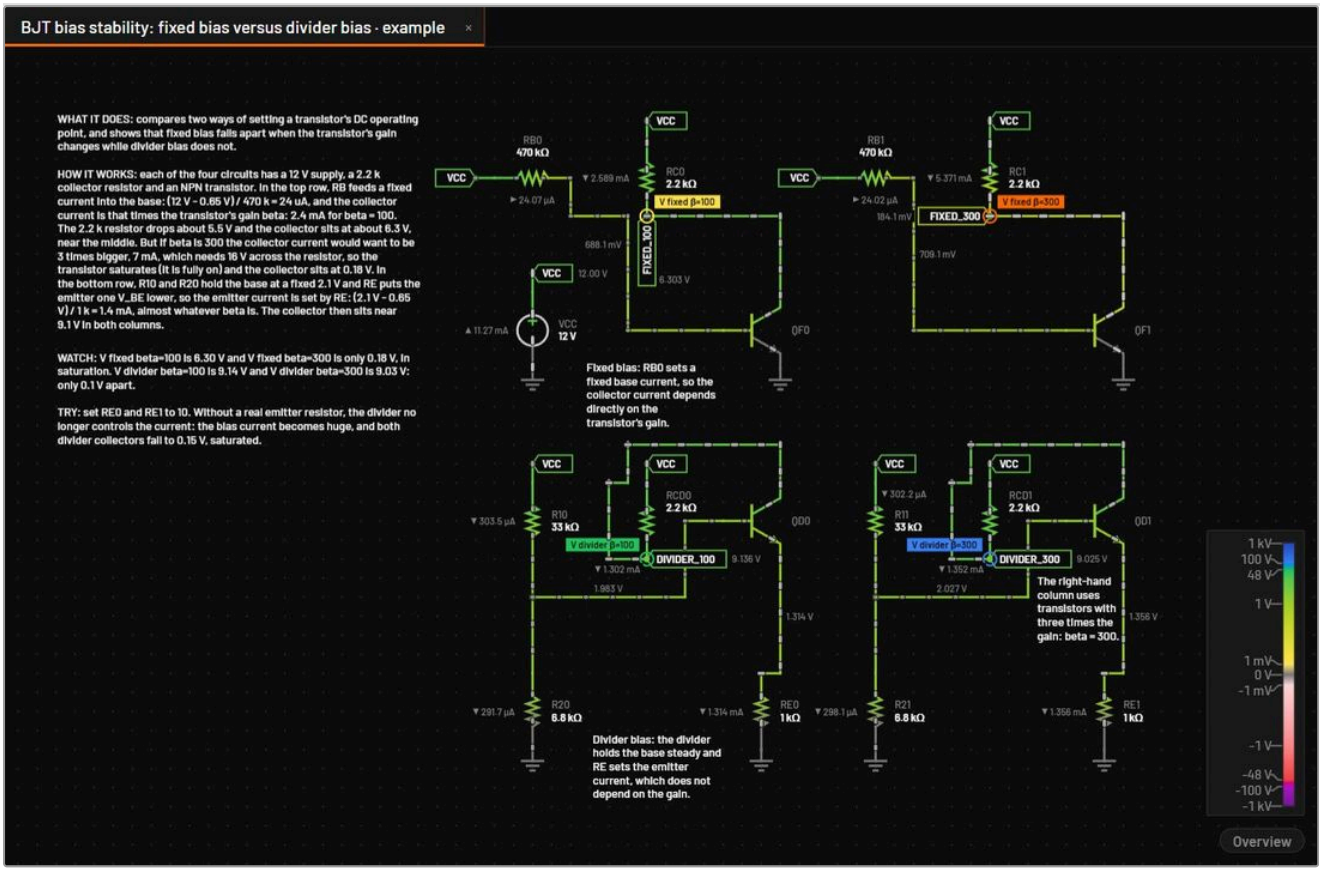


Figure 29.7 An operating point shown on the schematic: the DC voltage of every net and the current of every two-pin part, with an arrow for its direction.

29.6 Parameter step

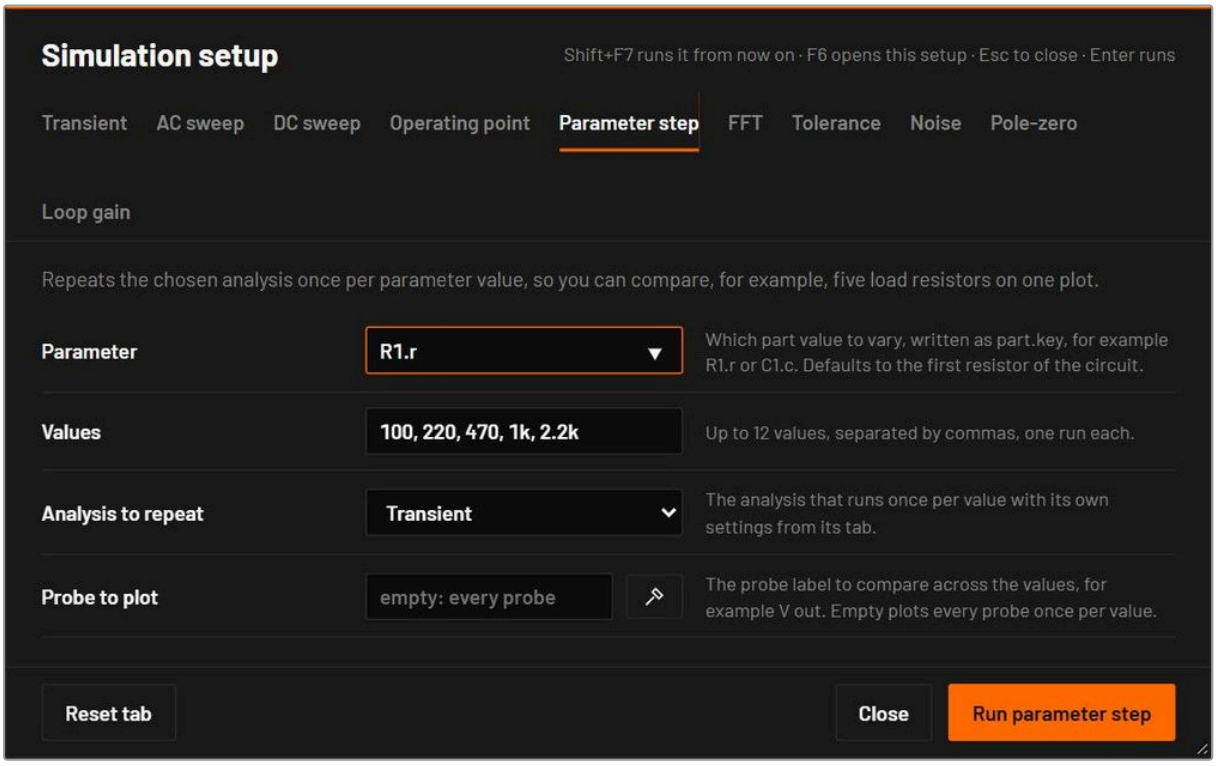


Figure 29.8 Setup, Parameter step tab.

Repeats the chosen analysis once per parameter value and overlays the results.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Parameter	**part.key**	the first resistor, **R1.r**	The value to step, written as the designator, a point and the parameter key: **R1.r**, **C1.c**, **V1.v**. The keys are in the parameter tables of the device chapters, from **Devices: passives**, p. 265 on.
Values	a comma list, at most 12	100, 220, 470, 1k, 2.2k	The values to run. For parameters other than resistance the default is half, the same and double the present value.
Analysis to repeat	Transient, AC sweep, DC sweep	Transient	Which analysis, with the setup of its own tab.
Probe to plot	a probe label, optional	every probe	Only this probe, for example **V out**.

Each curve is named like **V out · R1.r = 470**. The Analysis bar shows the progress as a percentage. In the browser the values run in parallel, one per processor core. Errors name the problem, for example *"X has no value "key", its values: ..."*.

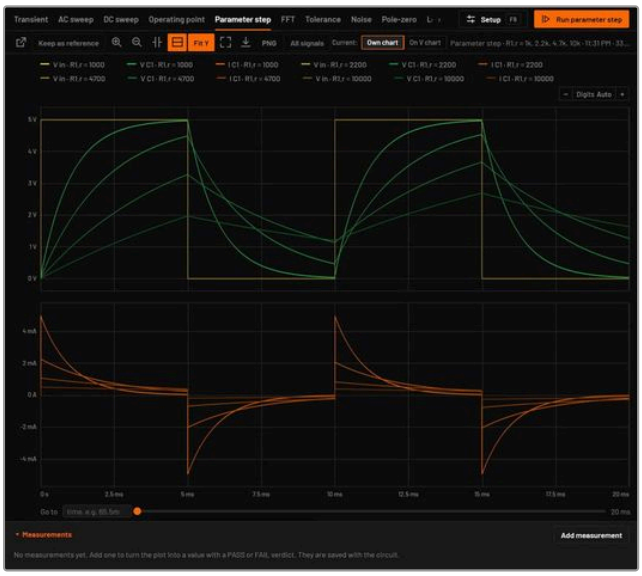


Figure 29.9 Parameter step over a transient: an RC charge for four resistor values.

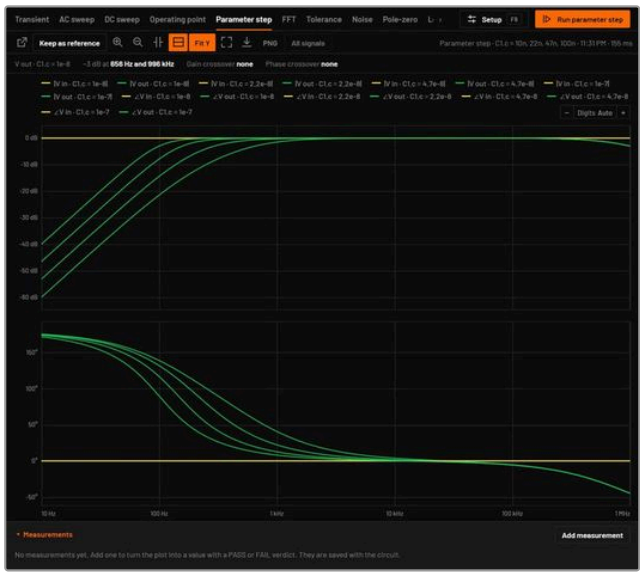


Figure 29.10 Parameter step over an AC sweep: a high-pass filter for four capacitor values.

29.7 Tolerance

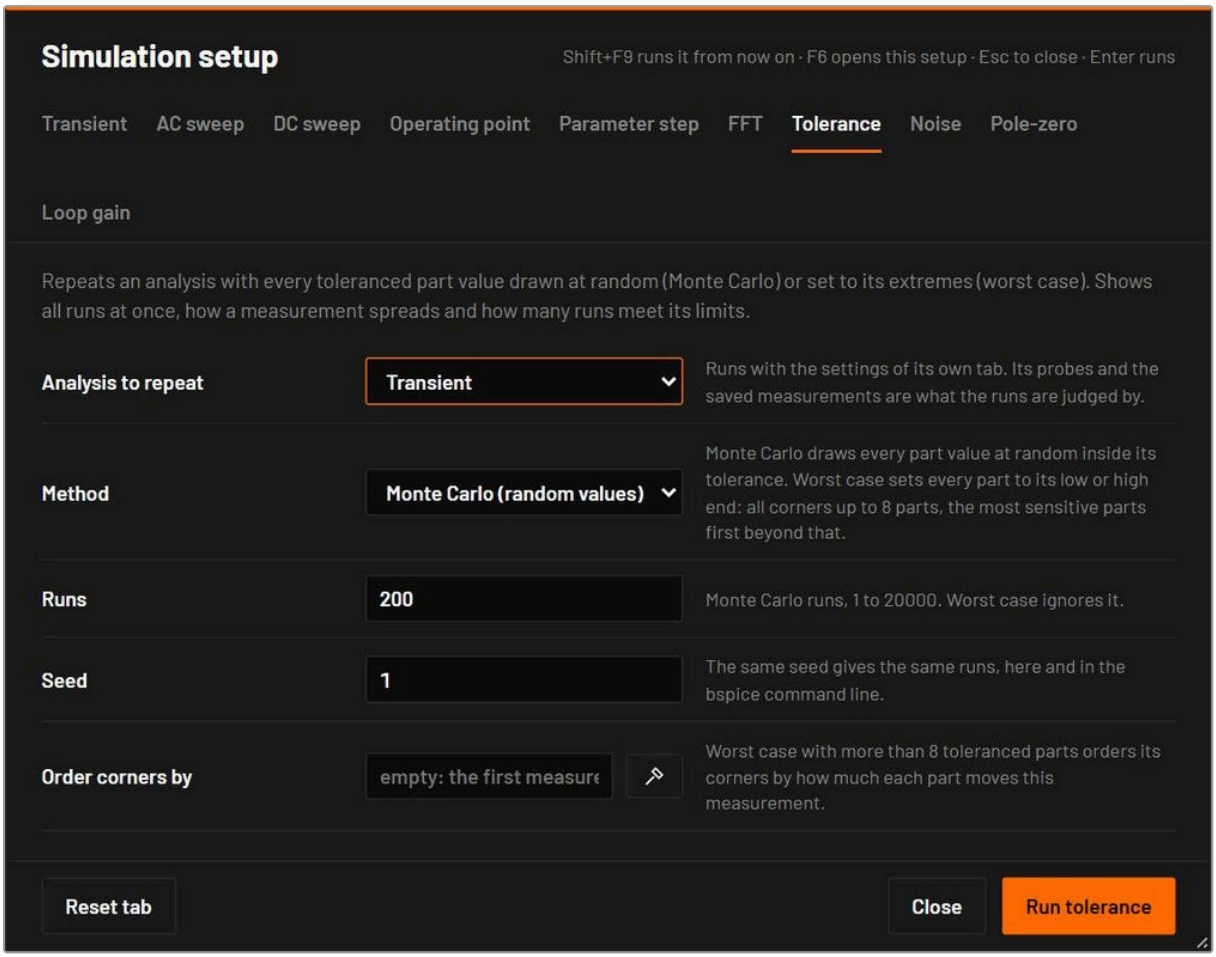


Figure 29.11 Setup, Tolerance tab.

Repeats an analysis many times with the part values changed inside their tolerances. It answers how much the result moves and how many builds would still meet the specification.

Tolerance of a part. Select a part and set **Tolerance** (percent) in the inspector, and **Tolerance distribution** under All parameters. **Gauss** means the tolerance is the 3-sigma limit and a draw is cut at plus and minus 3 sigma. **Uniform** means every value inside the tolerance is equally likely. The two are saved in the circuit as **p.tol** and **p.tolDist**. In this analysis a resistor with no tolerance counts as 1 %, a capacitor as 10 % and an inductor as 20 %. Sources and batteries are exact unless they get one, and a tolerance of 0 makes any part exact. Every other analysis keeps the exact value of every part.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Analysis to repeat	Transient, AC sweep, DC sweep or Operating point	Transient	The analysis to run again, with the settings of its own tab.
Method	Monte Carlo, Worst case	Monte Carlo	Monte Carlo draws every part at random. Worst case sets every part to its low or high end.
Runs	1 to 20000	200	The number of Monte Carlo runs.
Seed	a whole number	1	The same seed gives the same runs, here and in **bspice**.
Order corners by	a measurement	the first	Worst case with more than 8 toleranced parts orders its corners by this measurement.

More parts than resistors, capacitors and inductors have a tolerance of their own, set in the inspector under **Accuracy**: the input offset limit of an op-amp or comparator (**vos_max**), the forward voltage spread of an LED or diode (**vf_tol**), a zener voltage (**bv_tol**), a regulator output (**tol**), a crystal frequency (**ppm_tol**), a transformer ratio (**ratio_tol**), the 555 threshold and trigger levels, NTC, PTC and RTD resistance, sensor sensitivity and offset, and the offset and gain error of an ADC or DAC. A part is varied only when it sets the value, and an old circuit gives the same runs for its resistors, capacitors and inductors. The full list is in **docs/DEVICES.md** under Tolerance analysis keys.

Worst case runs every corner (2 to the power of the number of parts) up to 8 parts. With more parts it first moves one part at a time, then sets the most sensitive part, the two most sensitive, and so on, all pushing the chosen measurement up and all pushing it down. That finds the extremes of a smooth response in 4 runs per part. No more than 6 runs go at the same time. The runs use the built-in engine, like a parameter step, and a circuit with vendor models runs with their fitted models.

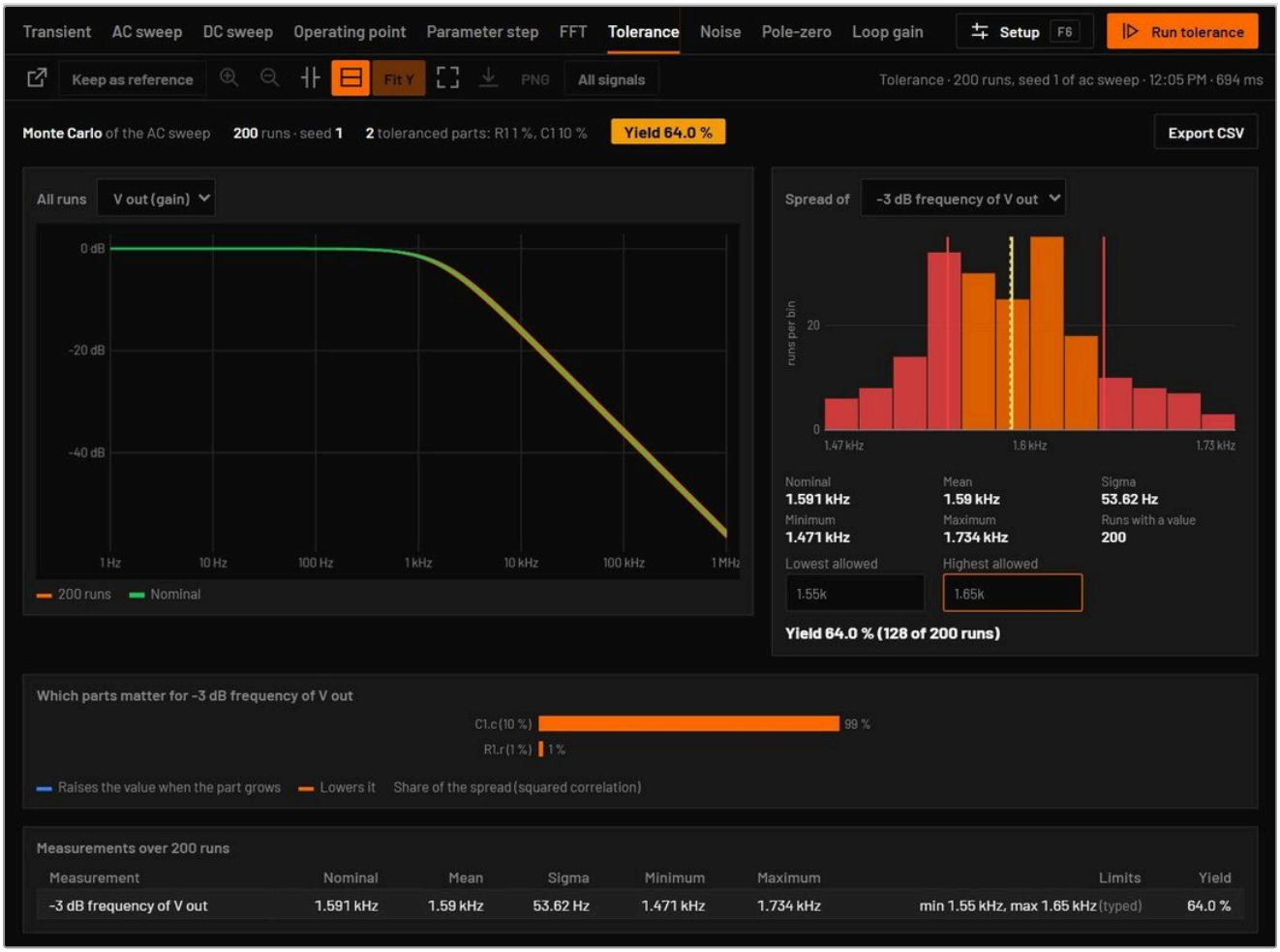


Figure 29.12 A tolerance analysis of the RC low-pass filter, 200 Monte Carlo runs: the cloud of runs behind the nominal curve, the histogram of the -3 dB frequency, the yield against the typed limits and the bars of which parts matter.

What is judged is the circuit's **measurements** that fit the analysis (**Measurements**, p. 253). A circuit with none uses the final value of its first probes, or the -3 dB frequency for an AC sweep. The result has these parts.

PART OF THE RESULT	WHAT IT SHOWS
The cloud	All runs drawn over each other, with the nominal run on top.
Spread of	A histogram of one measurement, marked with the nominal value and the mean, with sigma, minimum and maximum beside it.
Yield	Type the lowest and highest allowed value and the share of runs inside shows at once. Limits saved in a measurement start there. A run the engine could not solve counts as a failure.
Which parts matter	A bar per part with its share of the spread. For Monte Carlo it is the squared correlation of the part value with the measurement. For worst case it is the change of the measurement when the part goes from low to high.
Table	Every measurement with nominal, mean, sigma, minimum, maximum and yield. **Export CSV** writes one row per run.

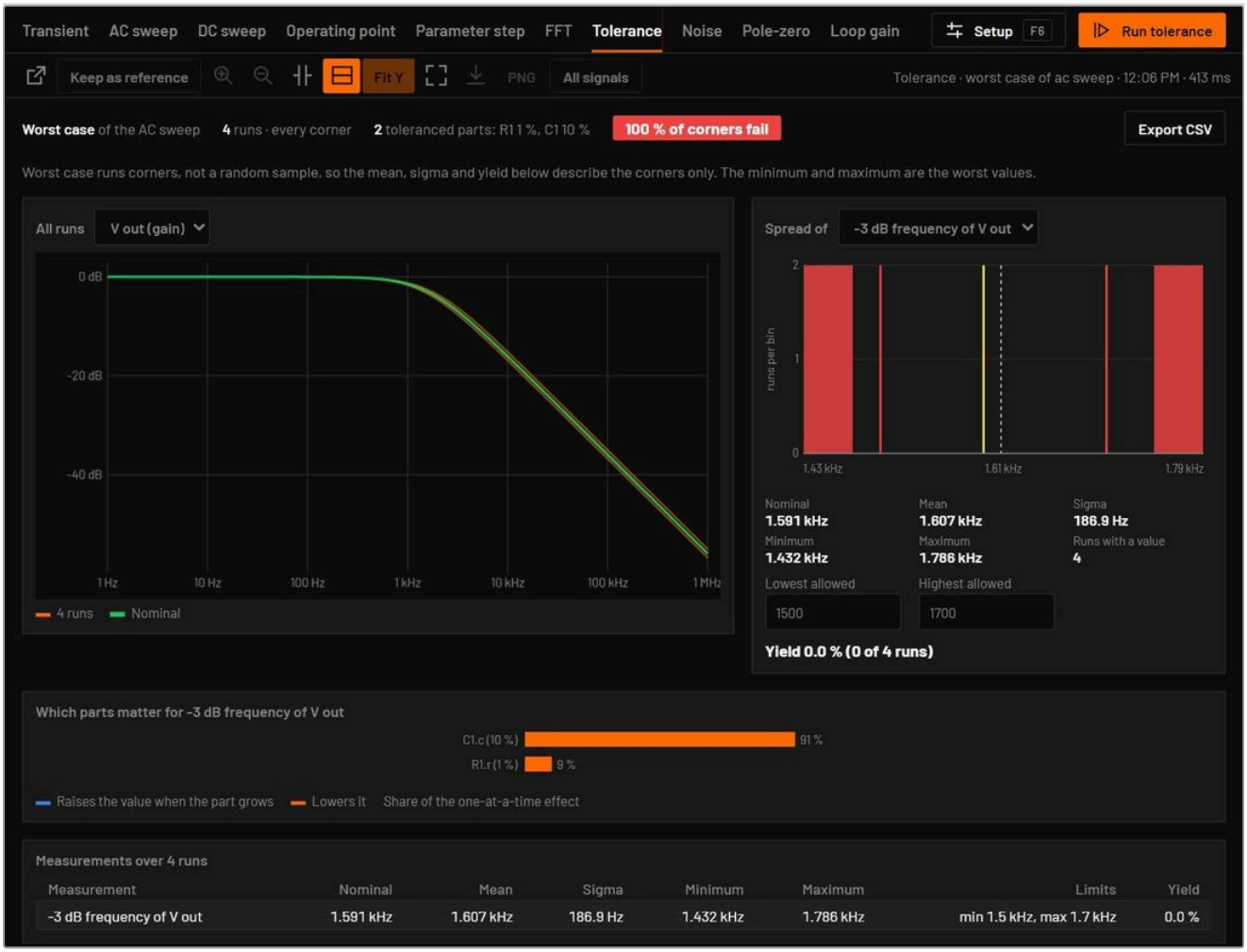


Figure 29.13 The same circuit as a worst case: the 4 corners run from 1.432 kHz to 1.786 kHz, outside the limits 1.5 kHz to 1.7 kHz, so every corner fails. Read the minimum and maximum, not the mean.

Worst case runs corners, so its mean, sigma and yield describe the corners only. Agents reach this with the **tolerance** tool.

29.8 FFT

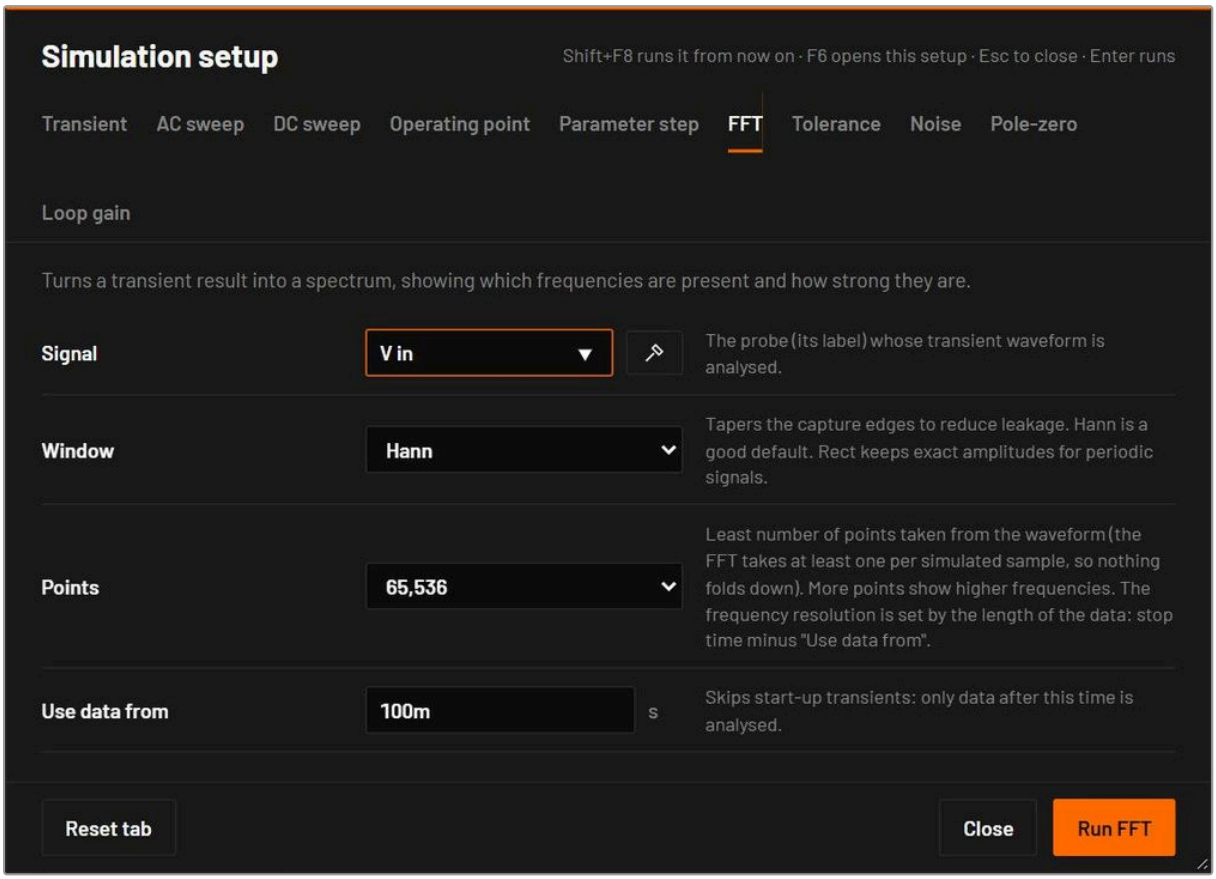


Figure 29.14 Setup, FFT tab.

Turns a transient result into a spectrum. The FFT first runs a transient with the Transient tab's stop time and maximum timestep, then analyses one probe.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Signal	a probe label	the first probe	Whose waveform is analysed.
Window	Hann, Blackman, Rectangular (none)	Hann	The taper against leakage. Amplitudes are corrected for the window: a 1 V sine reads 0 dBV with every window. Rect keeps exact amplitudes for signals that are periodic in the window.
Points	4096, 16384, 65536, 262144	65536	The least number of points taken from the waveform. The FFT takes at least one per simulated sample, so nothing folds down, and past 2^{20} points each point is the average of the waveform over its interval. More points show higher frequencies. The frequency resolution is set by the length of the data: the stop time minus **Use data from**.
Use data from	seconds	half the transient	Skips the start-up. The field warns when it's past the end of the run. At most the first half of the run is skipped. With fewer than 16 samples left the run asks for a longer stop time.

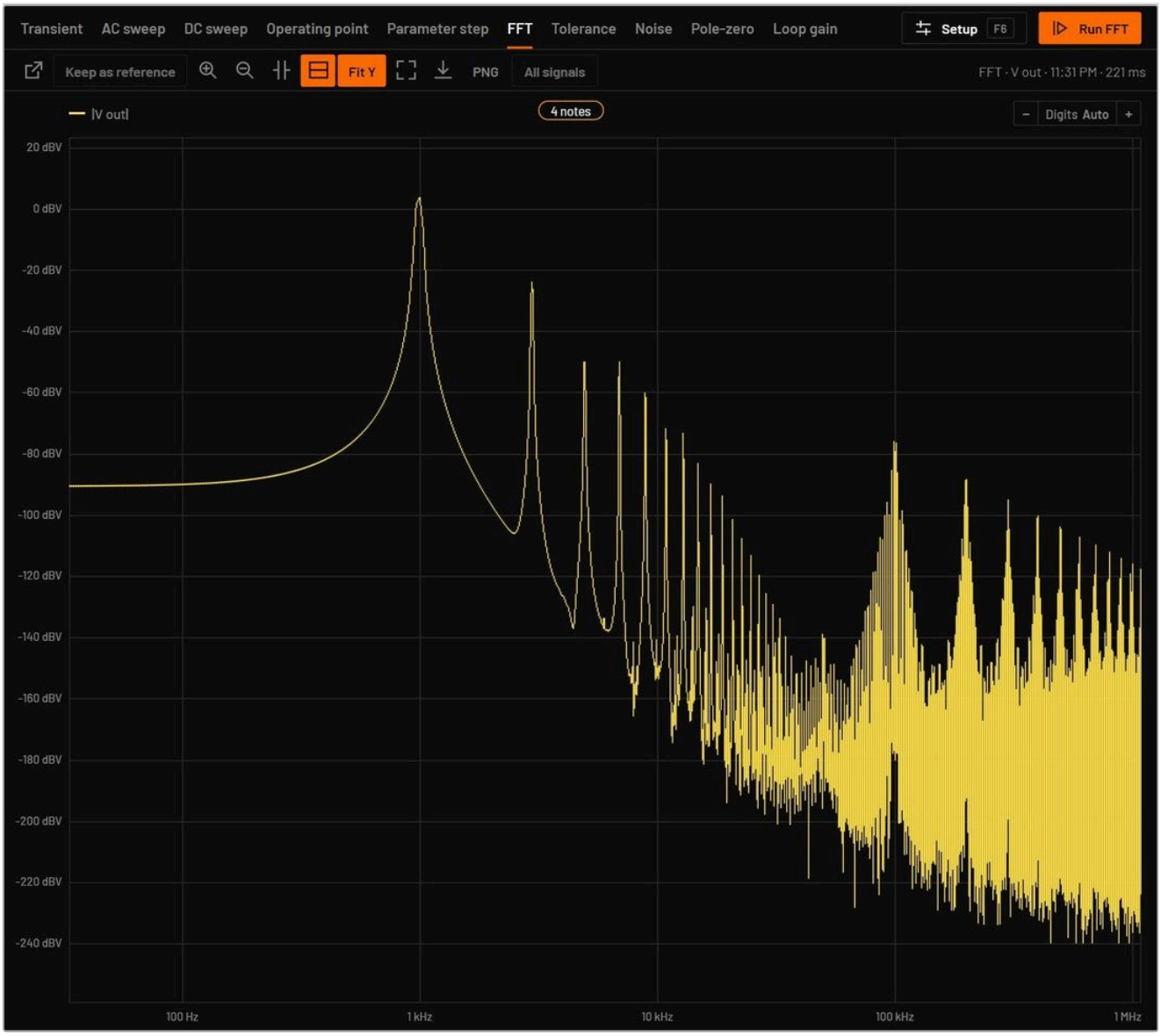


Figure 29.15 FFT of a Wien-bridge oscillator.

TRY IT

Distortion of an amplifier

1. Open a transistor amplifier example and probe its output.
2. Set the Transient stop time to **50m**, then press Shift + F8. Window **Blackman**, Use data from **10m**.

YOU SHOULD SEE The fundamental stands out with its harmonics below it. Their height in dB below the fundamental is the distortion.

29.9 Noise

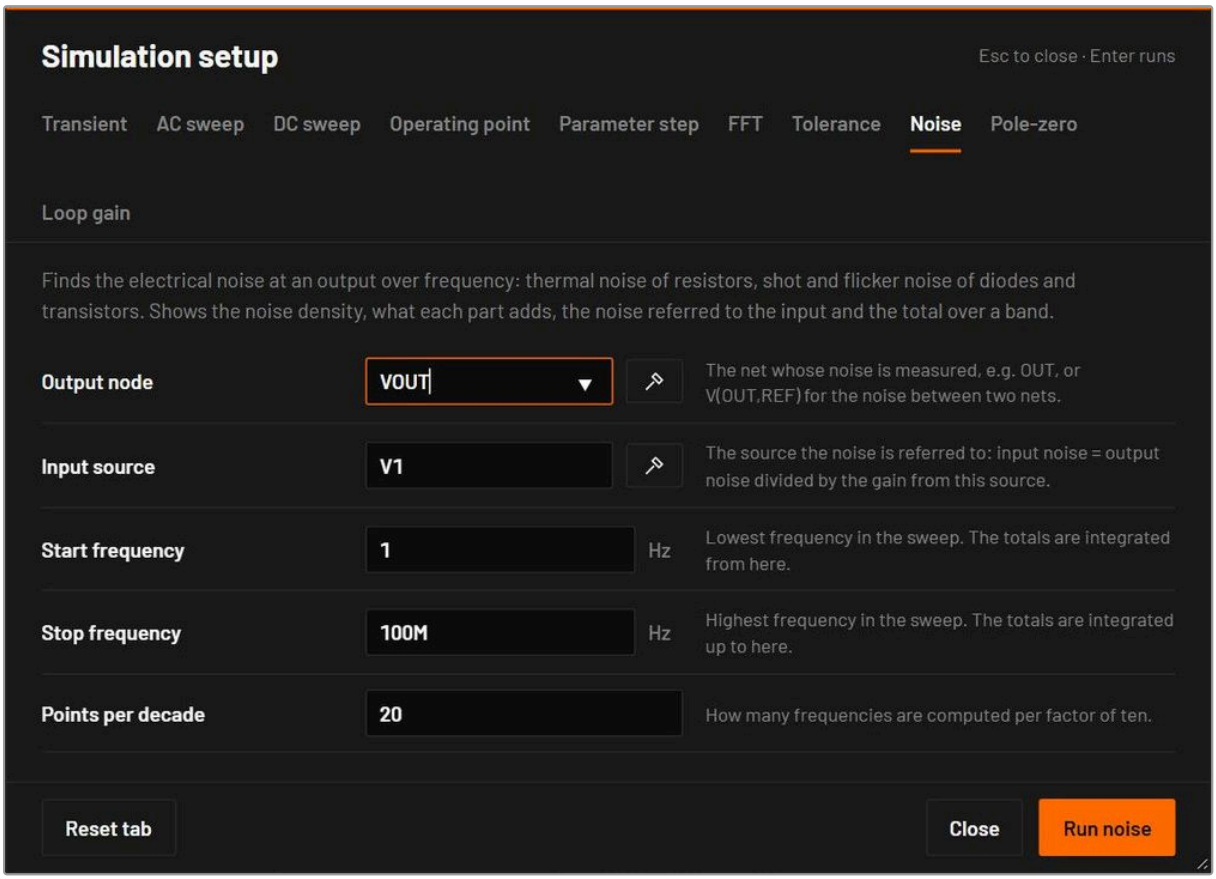


Figure 29.16 Setup, Noise tab.



Figure 29.17 The Noise tab on a common-emitter amplifier: the density at the output, the share of each part, the totals and the table of parts.

Finds the electrical noise at an output over a frequency sweep. It is the analysis of ngspice's **.noise**. Every part with noise adds its sources at the operating point.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Output node	a net, or **V(OUT,REF)** for two nets		Whose noise is measured. The **pick on schematic** button fills it from a click.
Input source	a source of the circuit	V1	The source the noise is referred to: input noise is the output noise divided by the gain from this source.
Start frequency, Stop frequency	Hz	1 and 1Meg	The sweep. The totals are integrated over it.
Points per decade	whole number	20	How many frequencies are computed per factor of ten.

PART	NOISE IT ADDS
Resistor	Thermal noise 4kT/R.
Diode, BJT	Shot noise 2qI, and flicker noise KF · I^{AF} / f. RS, RB, RC and RE add thermal noise.
MOSFET, JFET	Channel noise 4kT · (2/3) gm and flicker noise. MOSFET levels 1 to 3 follow ngspice's NLEV (default 2).
Built-in op-amp	The thermal noise of its 1 Ω pole node.
Ideal sources, capacitors, inductors without resistance	None. A behavioural block with no noise model is named under the table.

Set **KF** and **AF** on a part, or in its model card, for flicker noise. A circuit with vendor models runs in ngspice in the desktop app, so the noise sources inside the vendor subcircuits count. The result shows:

- **Total output noise** in V rms over the sweep, and the **input-referred** total (V for a voltage source, A for a current source). Type a band in **Integrate from … to** and the totals, the table and the shading follow that band. The integration takes the density as a power law between two points, as ngspice does, so 1/f and white noise integrate exactly.
- The **density** in V/√Hz on log-log axes: the total and each part's own curve. **Input-referred** switches the plot to the input. Under it, **Share of the noise power** stacks what each part adds at every frequency (the six largest, the rest as Other parts). Hold the pointer over the plot for the values at a frequency.
- A table of every part: its rms output noise over the band, its share of the noise power and its noise sources (thermal, rb, ib, ic, flicker). Hold the pointer over a row to mark the part on the schematic.

The result was checked against ngspice-47 on a divider, an RC filter, a common-emitter amplifier, an op-amp amplifier, MOSFET and JFET stages and a diode: the densities agree to 0.005 % and the output totals to 0.003 %. ngspice's own input-referred total holds the gain of each interval's upper point over the whole interval, which reads up to 11 % high at 10 points per decade. BetterSPICE integrates the input-referred density itself.

29.10 Pole-zero

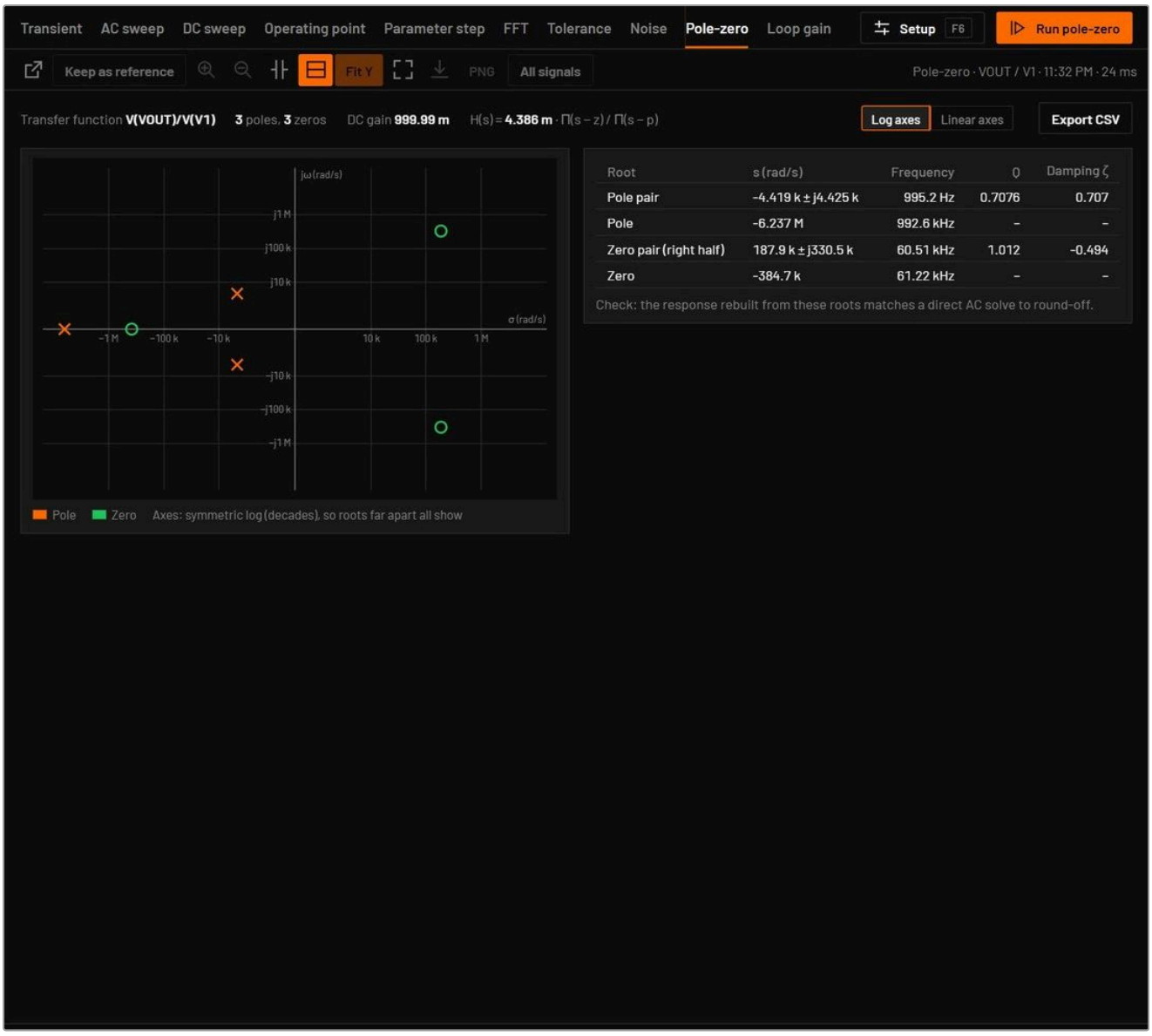


Figure 29.18 The Pole-zero tab on a Sallen-Key filter: poles (×) and zeros (○) on the s-plane, and the table with frequency, Q and damping.

Finds the poles and zeros of the transfer function from an input source to an output node, at the operating point, like ngspice's **.pz**. A voltage source gives V(OUT)/V(V1), a current source V(OUT)/I(I1).

FIELD	VALUES	DEFAULT	WHAT IT DOES
Output node	a net, or **V(OUT,REF)**		The output of the transfer function.
Input source	a source of the circuit	V1	The input: a voltage source gives a voltage gain, a current source a transimpedance.

The result shows the roots on the s-plane (poles as ×, zeros as ○). **Log axes** spread roots that lie decades apart and **Linear axes** show them as they are. The table lists each root in rad/s, its natural frequency in Hz, and Q and

damping ζ for a complex pair. A pole in the right half plane is flagged, because the circuit is unstable. The summary gives the DC gain and the constant k in H(s) = k · Π(s − z) / Π(s − p).

The roots are the eigenvalues of the circuit's small-signal matrices, each refined and checked. The result checks itself: the response rebuilt from the poles, zeros and k is compared with a direct AC solve, and the line under the table says how well they agree. ngspice's **.pz** searches for roots one at a time and often gives up on filters and amplifiers (*iteration limit reached*). Where it finishes, BetterSPICE agrees with it to 10 significant figures. A transmission line has no finite set of poles and zeros and is refused. Pole-zero handles at most 600 unknowns, so run it on the stage that sets the response.

29.11 Loop gain

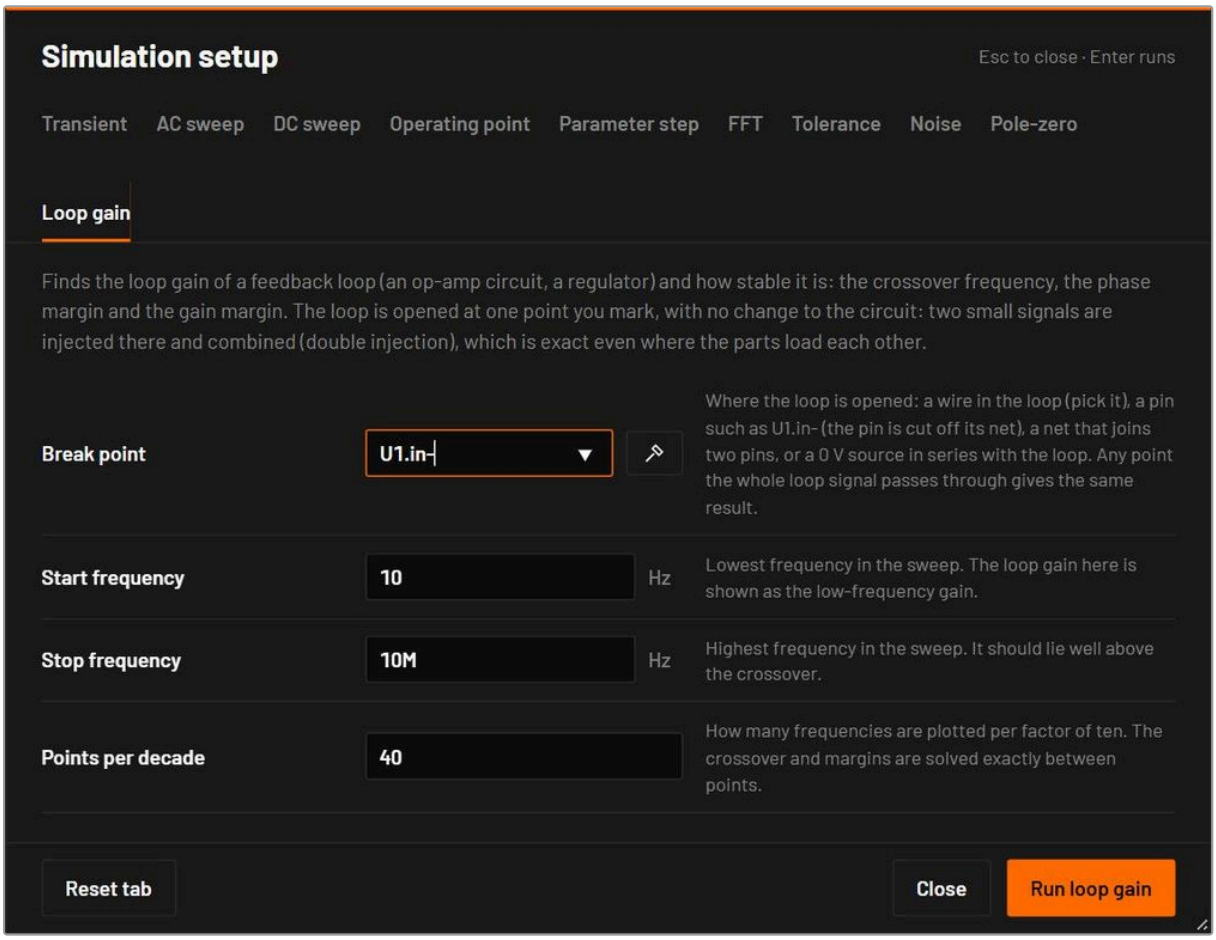


Figure 29.19 Setup, Loop gain tab.

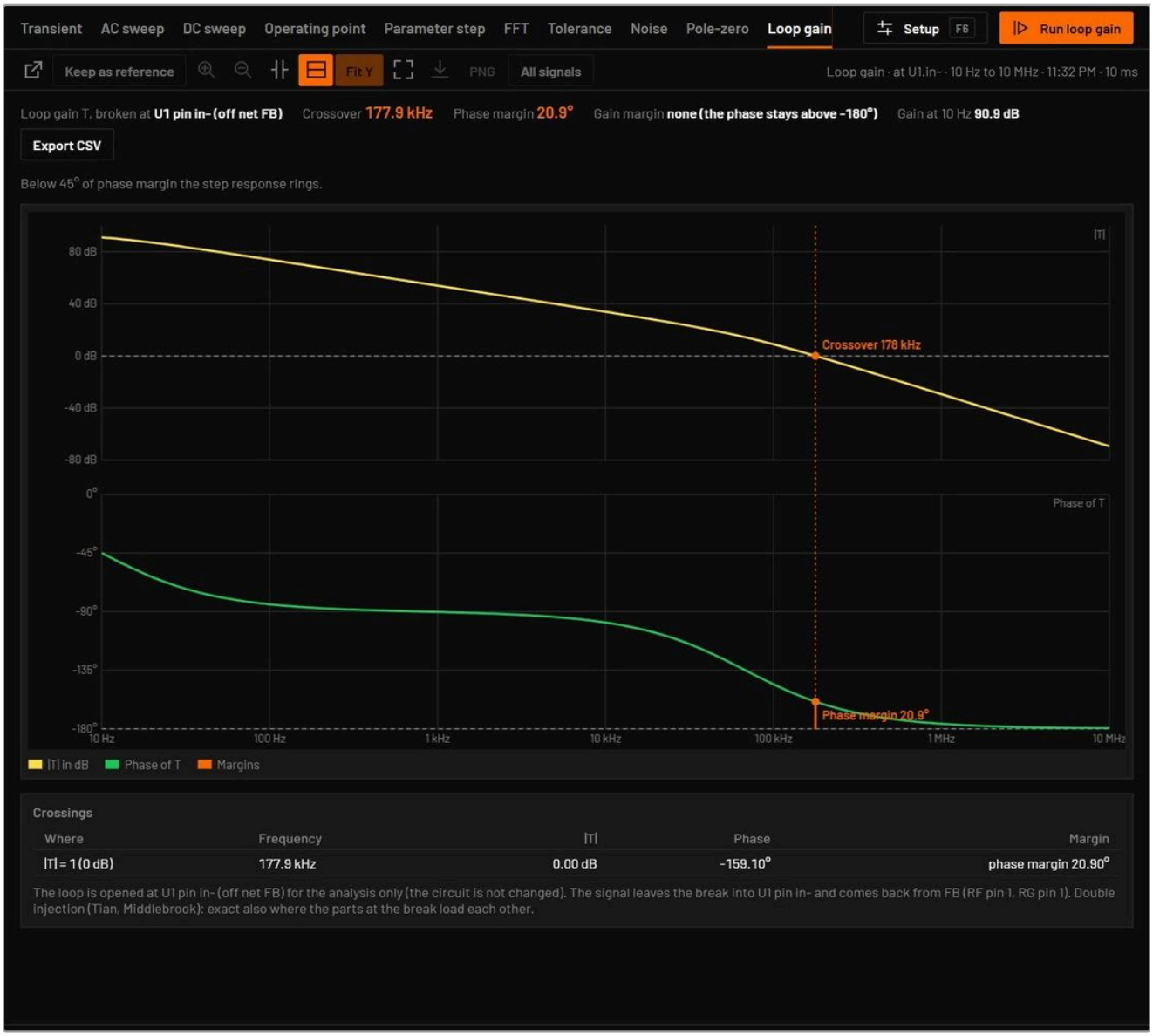


Figure 29.20 The Loop gain tab on an op-amp that drives a capacitive load: the loop gain T(f) as a Bode plot, with the crossover, the phase margin and the gain margin.

Measures how stable a feedback loop is: an op-amp circuit, a linear regulator, a switching regulator with an averaged or vendor model. It plots the loop gain T(f), the gain a small signal picks up on one trip around the loop.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Break point	a wire, a pin, a net or a 0 V source		Where the loop is opened. Press the pick button and click a wire of the loop, or type **U1.in-** (that pin is cut off its net, the usual choice is the inverting input of the error amplifier), a net that joins exactly two pins such as **FB**, a 0 V voltage source already in series with the loop such as **VINJ**, or **wire:x,y** (what the pick writes). A circuit with a 0 V source in series opens with it filled in.
Start frequency, Stop frequency	Hz	10 and 10Meg	The sweep. The stop should lie well above the crossover.
Points per decade	whole number	20	How many frequencies are plotted per factor of ten. The crossover and the margins are solved exactly between points, so they do not depend on it.

- The **crossover** is where |T| falls through 1 (0 dB).
- The **phase margin** is 180° plus the phase of T at the crossover. Below 45° the step response rings, at 0° the loop oscillates.
- The **gain margin** is how far |T| is below 0 dB where the phase reaches -180°. There is none when the phase never gets there.
- The gain at the start of the sweep, and a table of every crossing. A conditionally stable loop crosses 0 dB several times, and the margins in the header are at the highest crossing.

The circuit is not changed: the break exists only during the analysis. Any point that the whole loop signal passes through gives the same loop gain, and the direction of the break does not matter, because the analysis finds it. At the break it injects a 1 V signal in series and, in a second solve, a 1 A signal into the node, and combines the two (the double injection of Middlebrook, in the form of Tian, Kolar and Middlebrook). Unlike a single voltage injection, which needs a low impedance on one side of the break and a high one on the other, this is exact for any loop, also where the parts at the break load each other. A circuit with vendor models runs both injections in ngspice in the desktop app. An op-amp with a capacitive load agrees with its loop gain worked out by hand to 3e-9 at every frequency, and on four vendor regulator examples it agrees with the AC sweep to 0.001 %. Try the example **Loop gain of an op-amp driving a capacitive load** in Op-amp circuits.

30 The Analysis view

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The Analysis view shows the result of the analysis tab you have open, with a caption that names the run. When the window is too narrow for every tab, the strip scrolls and shows ‹ and › arrows, and the open tab is kept in view. Each tab keeps its own last result, per circuit, also across circuit tabs: an AC result is still there after you ran a DC sweep, and a result that arrives after you switched tabs goes to the tab that ran it. A tab that hasn't been run says *No operating point result yet* (or the name of its analysis) with a **Run** button. When you change parts or wires after a run, a **Circuit edited since this run** chip appears. Run again for the current circuit. The Bode dock tab shows the AC result. While a run is going, the plot area says **Simulating** with a **Cancel** button. Ctrl + 2 shows it alone, Ctrl + 3 under the schematic.



Figure 30.1 An AC sweep in the Analysis view. **1** analysis tabs, **2** Setup and Run, **3** tools, **4** margins strip, **5** legend, **6** magnitude pane, **7** phase pane.



Figure 30.2 An AC result after a resistor was changed: the chip **Circuit edited since this run** appears.

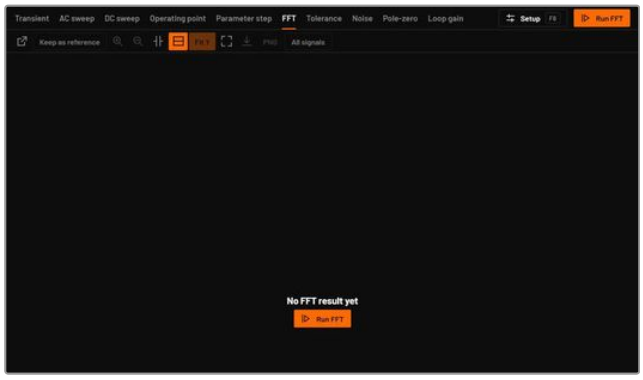


Figure 30.3 The FFT tab of the same circuit, not run yet: it says so and offers Run.

30.1 The bars

BAR	CONTENTS
1 2 Top	The analysis tabs, a line such as **Transient · 4 002 points · 37 ms**, **Setup F6** and **Run**, which becomes **Cancel** during a run.
Progress	While running: a bar and *"Step 5 of 6: Simulating in ngspice · 42 % · 6 s · about 30 s left"*. A vendor run that heads for a big result shows its memory warning here, with Stop and keep less and Keep going.
Error	After a failure: **Simulation failed:** with the reason, and **Dismiss**.
3 Tools	Pop out, Cursors, One pane per unit, Fit, Export CSV, PNG, All signals, Remove probed traces.
4 Margins	AC results only: –3 dB points, crossovers, phase and gain margin.
5 Legend	One entry per trace. Hold the pointer over a name to light up its net or part on the schematic. The **– Digits Auto +** control at its right end sets the readout digits (**Axis labels and readout digits**, p. 261). In a narrow window the toolbar row wraps instead of running under the Inspector.

30.2 The tools

TOOL	WHAT IT DOES
Pop out / Dock back	Moves the Analysis view into its own window. The main window then says where it is and offers to bring it back.
Cursors	Cursor lines A and B with a readout (**Cursors**, p. 204).
One pane per unit	On by default: volts, amps and decibels on separate panes with a shared time axis. Off: all traces on one pane.
Fit	Resets the zoom.
Fit Y	On by default. Each pane's vertical axis fits the part of the run you have zoomed to, and follows zoom and pan. The scope's flags **Max**, **Fixed** and **Manual** show, and **Fit Y off** when it is off. Turn it off to keep the range of the whole run. It also sits in the plot menu under Scale, as **Fit Y to the zoomed view**, and is remembered.
Export CSV	Saves the data: **transient.csv**, **bode.csv** or **operating-point.csv**. Up to 200 000 rows it saves at once. In the desktop app a longer run writes every row, in pieces of about 4 MB, so a result of millions of rows saves without filling memory. The desktop asks where to save.
PNG	Saves the plot with its legend as a picture.
All signals / Probes only	Works on any run. Every signal is kept at every step; only **Keep less**, or the browser version (its engine holds at most 240 MB), keeps the signals that are no probe as the lowest and highest value of short time slices (a spike shorter than a slice still shows). Switching between All signals and Probes only never runs the analysis again. All signals opens a signal list beside the plot: a filter (several words, all must match), **V** or **I**, a click on a row to plot it or take it off, and Shift or Ctrl click to pick several. Each row shows the value at the pointer, else at the playhead, else at the end of the run. Drag rows onto a chart, or onto **New chart**. **Delete** takes a trace off. With more than 16 traces the hover box lists the ten nearest the pointer, and a plot of 100 or more traces stays quick.
Remove N probed traces	Removes the traces you added by clicking the schematic.

30.3 Measurements

Under the plot of a transient, DC sweep, AC sweep, operating point or parameter step, the **Measurements** panel lists named measurements with a value and, when limits are set, **PASS** or **FAIL**. **Add measurement** opens the editor. Measurements are saved in the circuit, evaluated after every run, shown for every value of a parameter step, and judged in every run of a tolerance analysis. **Export CSV** saves the table.



Figure 30.4 A measurement of the -3 dB frequency of V out with the limits 1.5 kHz and 1.7 kHz: the value and PASS.

MEASUREMENT	WHAT IT READS
Minimum, maximum, average, RMS, peak to peak, final value	The window From to To, or the whole run when empty. Average and RMS are time-weighted.
Value at	One time (or swept value), interpolated.
Frequency, duty cycle	Rising edges through the middle level, with 10 % hysteresis.

MEASUREMENT	WHAT IT READS
Rise time, fall time	Between the lower and upper threshold (default 10 % and 90 % of the step) on the first edge.
Overshoot	Percent past the final value after a step.
Settling time	From the window start until the output stays within a band (default 2 % of the step) of its final value.
Ripple	Peak to peak after a start time. Set From past the start-up.
Delay between signals	From the first signal crossing its middle level to the second one doing so.
Efficiency	Average output power over average input power, in percent. Both are expressions of probe labels, for example **"Vout"*"Iout"** over **-"Vin"*"Iin"**.
Gain at, phase at	An AC result at one frequency.
-3 dB frequency, unity-gain frequency	An AC result.
Phase margin, gain margin	An AC result that is a loop gain. A loop whose low-frequency phase starts near 180 degrees is handled.

Rise, fall, overshoot and settling take the first and last value of the window as the two levels when the window holds one clean step (they differ by at least half the swing). Otherwise rise and fall use the minimum and maximum, and overshoot and settling say the window holds no single step. Start the window before the edge and end it after the output has settled. A limit on a value that cannot be measured counts as a FAIL and the row says why. Total harmonic distortion is not a measurement here. It is in the FFT.

30.4 Keep as reference

Keep as reference in the Analysis toolbar keeps the transient, DC sweep or AC sweep on screen. Later runs of the same kind draw it dashed behind their own traces, and the hover readout shows the difference of each trace to it. Up to five runs are kept at once, as Ref 1 to Ref 5, each in its own colour: its traces are named **Ref 2 · V out**. Each kept run has a chip next to the button: click it to hide or show that run, and its **×** deletes it. A sixth kept run takes the place of the oldest. Opening or starting another circuit clears them. They are not saved with the circuit, and the report draws the last one shown.



Figure 30.5 An RC charge after the capacitor was changed: the first run kept as the dashed reference, and the readout with the difference to it.

30.5 Fit Y in the Analysis view

With **Fit Y** on, zooming in time also rescales each pane vertically, so a small part of a large signal fills the pane. The button in the plot toolbar is lit, and a flag in the corner of the plot names the scale in use.



Figure 30.6 A transient zoomed in with the wheel: Fit Y has rescaled the vertical axis to the part of the run in view.

30.6 Notes about a result

Warnings about a result, such as a node held only by leakage or a switch to Gear after ringing, are one small chip at the end of the plot's legend, for example **4 notes**. Click it to read them in a panel. Close, Esc or a click outside closes it. A note never covers the traces.

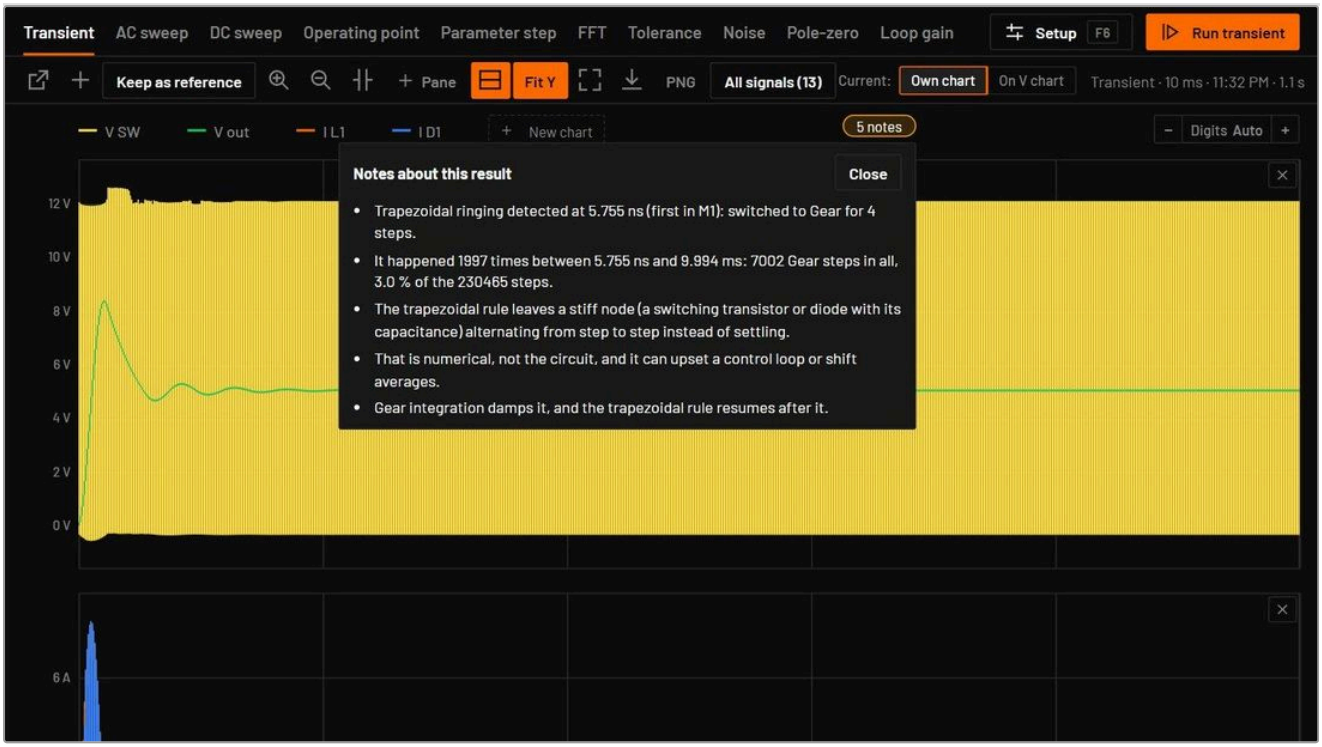


Figure 30.7 A transient of an op-amp relaxation oscillator with its notes open: the chip at the end of the legend opens the panel.

30.7 Newton predictor

Simulate › **Newton predictor** (also in Simulation setup, Transient tab, off by default) starts each time step's Newton solve from a point extrapolated from the last two steps. Measured on 92 circuits it is not faster on most of them (up to 1.55x on smooth analog circuits, 1.14x on a 578-part board) and changes results slightly: typically under 0.001 %, up to 6 % of a signal's swing near switching edges. Leave it off unless a long analog run needs it. A run made with it says so with a **Newton predictor on** chip beside its trace names, the measured differences in the chip's tooltip and in the notes. **bspice tran —predictor** does the same, and verify always runs exact.

30.8 Plot drawing

The Analysis plot draws its traces on the graphics card (WebGL2), up to 144 frames a second with 100 traces, from the same minimum and maximum of each pixel column as before, so the picture does not change.
View › **Plot drawing** picks **Automatic** (the default: the graphics card where it works), **Graphics card** or **Processor**. Where the card is missing or fails, the processor draws the plot. A big run also needs about 40 % less memory on its way to the plot: its columns are sized up front, and the desktop app sends big pieces compressed when that is faster on the machine.

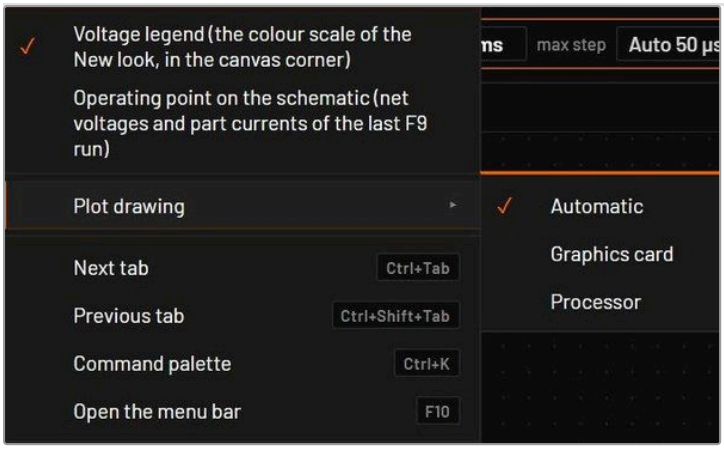


Figure 30.8 View, Plot drawing: Automatic, Graphics card or Processor.

30.9 Working with the plot

ACTION	HOW
Read values	Hold the pointer over the plot. A line follows the pointer and a box lists every trace at that point, up to 16.
Zoom	Drag a box. A box taller than 12 px also zooms that pane vertically. The wheel zooms in time around the mouse. Neighbouring ticks never read the same (see below).
Go to a time	The **Go to** bar below a transient plot: type a time such as **65.5m** and press Enter, or drag the slider through the run (zoomed in, it moves at the scale of the plot). An orange playhead marks the time with a box of the value of every trace there. When you're zoomed in, the view centres on it and keeps the zoom. Drag the playhead line to move it, and click × to remove it.
Pan	Ctrl-drag, Shift-drag, right-drag or middle-drag.
Reset	Double-click.
Find a trace on the schematic	Hold the pointer over its name in the legend. The net or part lights up on the canvas.
Add a trace	In Split view, **Alt+click** a net for its voltage or a two-pin part for its current. A plain click selects and edits as in the Schematic view. If the last run kept only the probes, it reruns with the new trace and says so.

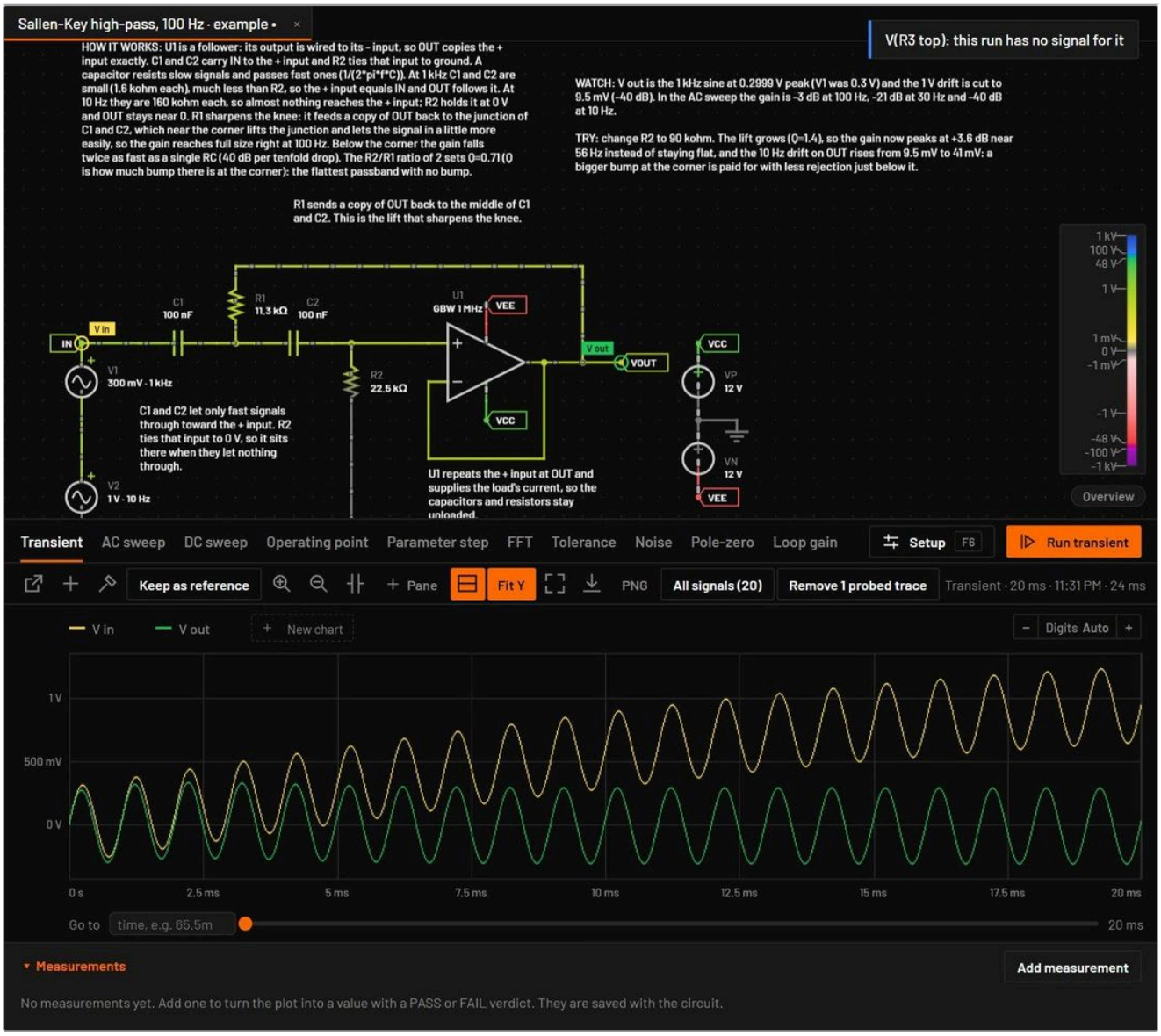


Figure 30.9 Split view: a trace added by Alt+clicking a net on the schematic.



Figure 30.10 Cursors A and B on a transient, with the readout of both cursors, their difference and 1/Δ.



Figure 30.11 Go to 2.5 ms: the playhead and the value of every trace at that time.

30.10 Axis labels and readout digits

Every plot (the Analysis view, Split, pop-outs, the live scope, Bode and FFT) writes its ticks so that no two read the same. An ordinary axis looks as it always did. When a label would need more than 6 significant digits or would not fit the axis, as with a 0.2 nV ripple on 15 V, the base is written once, in bold, in the corner of the pane (**15.0579 V +**) and the ticks show the offset from it (+88 µV to +98 µV). The time axis does the same when you zoom far in: **86.5933 µs +** at the left of the labels, then +90 ps to +130 ps. dB and degree axes get more decimals, or an offset with one exponent far below one.



Figure 30.12 A 5 µV ripple on 15.058 V at Digits 6: the base 15.0579 V written once in the corner, the ticks as offsets in µV, and the trace chip and the playhead with six digits.

– Digits Auto + at the right end of the legend strip (also in Split and the pop-out) and in each live scope's header sets how many significant digits the readouts show, from 3 to 9:

- **–** and **+** step it, the mouse wheel over it steps too, and a click on the number goes back to **Auto**. Auto keeps the look of earlier versions: 4 digits in tooltips and chips, 3 in tables.
- One setting serves the Analysis view and every scope, so a value read in two places shows the same digits. It is remembered.
- It covers the hover tooltip, the playhead values, the cursor table, the trace chips, the signal list, the statistics, the operating point table and Measurements.
- A number keeps its trailing zeros, so a readout keeps its width while the value moves: 15.0580 V at 6 digits, where Auto reads 15.06 V.

- It changes only what is shown. CSV export and **Copy as table** write every digit. Time readouts already follow the zoom and keep their own digits.

Traces cycle through yellow, green, orange, blue, violet and red. The vertical range fits the visible data with a small margin. A footnote lists probes the run has no signal for, for example an AC current through a part that has none.



Figure 30.13 DC sweep of a voltage divider.

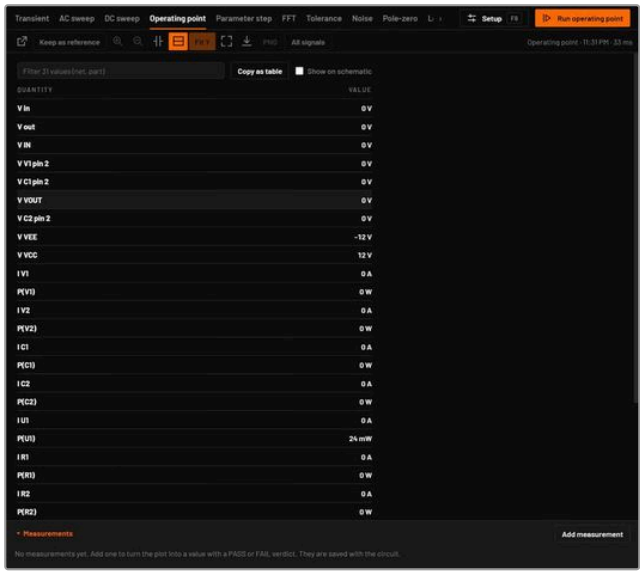


Figure 30.14 Operating point table with its filter.

PART

VI

Parts and models

Every device with every parameter, its unit, default, range and where its value comes from. Digital logic, control blocks, transmission lines, the model catalogue, the model dialog, the Part Wizard and the symbol editor.

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31 Devices: passives

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31.4	Inductor	267			

Each device below has a facts line and a parameter table.

COLUMN	MEANING
Type	The device type in the circuit file and the AI tools, and the designator prefix.
Key	The key that places it. "library" means it's placed from the library or the Place menu.
Pins	The pins in order. The order matters for the pin map of a vendor model.
Variants	Symbol styles and physics variants. Most variants only change the symbol. Where a variant changes the behaviour, the text says so.
Class	**exact**: the same equations as ngspice, compared point by point. **approximate**: a behavioural model, measured against a reference (**Exact and approximate**, p. 34).
Package and rating	Resistors, potentiometers and shunts, capacitors, inductors, diodes, LEDs and zeners have a **Package** list and a rating field in the inspector (power in W, working voltage, rated current, or maximum forward current and reverse voltage). A package fills in its typical rating. The ratings are notes on the part: the engines and the SPICE export never see them. When the part's reading goes over its rating (live, paused or while scrubbing) the part pulses red on the canvas, the inspector says so, and its Measurements row is marked. A part with no rating is never warned about.
Parameter, Key, Unit	The label in the inspector, the key used in the file, in a parameter step (**R1.r**) and by AI agents, and the unit.
Default	The value the engine uses when the part doesn't set one. A part placed from the library can carry its own starting value, given in the text.
Range	Values outside the range are refused with **E_PARAM**, for example *"R1 parameter r = 0 is out of range, allowed > 0."*
Value comes from	Where the value can be set: the default, the inspector (typed or with a slider), the Quick model fit, a vendor model card, a part file, or a board import. Every parameter can also be set in the All parameters tab and by an AI agent.

Numbers in a circuit file are plain SI values. Text with a suffix (**"4.7k"**) is accepted too. A key that is missing takes its default. A key the device doesn't know is kept in the file and ignored.

31.1 Typical values in the inspector

For a part with no model, the inspector shows typical values for its variant where the part doesn't set a key, for example a Schottky diode's saturation current. These values are shown, not stored: the part simulates with the

engine default until you type a value, assign a model or apply a Quick model. The tables give the engine default.

The Zener, Schottky, TVS and varactor diode variants start with the values their name promises, for example a Zener with a 5.1 V breakdown (bv 5.075 V at 5 mA). Set your own with the inspector, a model or Quick model.

31.2 Resistor

TYPE	KEY	PINS	VARIANTS	CLASS
res (R)	R	1, 2	none	exact

An ideal resistor: current = (V1 - V2) / r.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Resistance	**r**	Ω	1 kΩ	> 0. Slider 0.1 Ω to 10 MΩ.	Default, inspector, Quick model, board import	Values below 1 nΩ are raised to 1 nΩ.
Temperature coefficients	**tc1, tc2**	1/°C, 1/°C²	0	any	Default, inspector	The value is multiplied by 1 + tc1·ΔT + tc2·ΔT², ΔT = temp - tnom. Used by the operating point, every analysis and the ngspice export.
Temperature, reference	**temp, tnom**	°C	27, 27	any	Default, inspector	
Voltage coefficients	**vc1, vc2**	1/V, 1/V²	0	any	Default, inspector	R(v) = r (1 + vc1·v + vc2·v²), v across the resistor. The factor is held at 0.001 or more.
Series inductance, parallel capacitance	**esl, cp**	H, F	0	≥ 0	Default, inspector	Parasitics of the whole part.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

> **NOTE** **No 0 Ω resistor.** r = 0 is refused. For a link use a wire, a net label or a very small resistance such as 1 µΩ.

31.3 Capacitor

TYPE	KEY	PINS	VARIANTS	CLASS
cap (C)	C	1, 2	ideal, ceramic, polarized (electrolytic), tantalum, polymer, film, trimmer, safety X, safety Y. Supercap is a separate model (**Batteries and supercapacitors**, p. 350).	exact

An ideal capacitor, i = C dV/dt, with an optional series resistance. Open in a DC operating point. A part placed from the library starts at 10 µF.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Capacitance	**c**	F	1 µF	> 0. Slider 1 pF to 1 F.	Default, inspector, Quick model, board import	
ESR	**esr**	Ω	0	≥ 0	Default, inspector, Quick model	Equivalent series resistance. Above 0 it adds an internal node.
Series inductance	**esl**	H	0	≥ 0	Default, inspector	Equivalent series inductance. It makes the capacitor self-resonate.
Leakage resistance	**rleak**	Ω	none	> 0	Default, inspector	Insulation resistance across the capacitor itself, after the ESR.
Capacitance against DC bias	**cbias**	curve	none	points	Default, inspector	Curve editor. Small-signal capacitance = c × ratio at the bias. The charge follows the curve, so a large signal sees the same capacitance. Flat beyond the ends.
DC-bias loss, rated voltage	**dc_bias, vrated**	-, V	0, 50	dc_bias 0 to 0.95	Default, inspector	A ceramic capacitor without a curve: $C(V) = c\,(1 - dc_bias\,(V / vrated)^2)$ up to vrated, held at c (1 - dc_bias) beyond it. A **cbias** curve wins.
Trimmer range and position	**cmin, cmax, pos**	F, F, -	0, none, 0.5	pos 0 to 1	Default, inspector	Trimmer: C = cmin + pos (cmax - cmin) when cmax is set, else c.
Temperature coefficients	**tc1, tc2**	1/°C, 1/°C²	0	any	Default, inspector	The value is multiplied by $1 + tc1 \cdot \Delta T + tc2 \cdot \Delta T^2$, ΔT = temp - tnom. Used by the operating point, every analysis and the ngspice export.
Temperature, reference	**temp, tnom**	°C	27, 27	any	Default, inspector	
Initial voltage	**ic**	V	none	any	File or All parameters only	Voltage at t = 0. When any capacitor or inductor sets ic, a transient skips the operating point and starts from these values, like ngspice **uic**. The live simulation does the same. Shown as Initial voltage under All N parameters. It reads 0 while unset.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Quick model also takes ESL, which the engine now simulates. The DC-bias curve and the temperature coefficients are in the inspector, with the curve editor for the bias curve.

31.4 Inductor

TYPE	KEY	PINS	VARIANTS	CLASS
ind (L)	L	1, 2	ideal, power, rf, adjustable	exact

An inductor with winding resistance: V = dcr · i + L di/dt. A short in DC. A part placed from the library starts at 10 mH.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Inductance	**l**	H	1 mH	> 0. Slider 1 nH to 10 H.	Default, inspector, Quick model, board import	
Winding resistance	**dcr**	Ω	0	≥ 0	Default, inspector, Quick model	Series resistance in the same branch.
Winding capacitance, parallel resistance	**cp, rp**	F, Ω	0, none	≥ 0	Default, inspector	
Self-resonant frequency	**srf**	Hz	none	> 0	Default, inspector	Sets cp = 1 / (L (2π·srf)^2) when cp is not given.
Inductance against current	**lisat**	curve	none	points	Default, inspector	Curve editor. Small-signal inductance = l × ratio at the current. The flux follows the curve.
Saturation current	**isat**	A	none	> 0	Default, inspector	L(i) = l / (1 + (i / isat)^2), the flux its integral. A **lisat** curve wins.
Temperature coefficients	**tc1, tc2**	1/°C, 1/°C^2	0	any	Default, inspector	The value is multiplied by 1 + tc1·ΔT + tc2·ΔT^2, ΔT = temp - tnom. Used by the operating point, every analysis and the ngspice export.
Temperature, reference	**temp, tnom**	°C	27, 27	any	Default, inspector	
Initial current	**ic**	A	none	any	File or All parameters only	Current at t = 0, used as for the capacitor.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

The saturation current **isat** (from Quick model or typed) makes the inductance fall as L / (1 + (i / isat)^2), and a saturation curve (**lisat**) wins over it. Without either the inductor stays linear. An inductor with dcr = 0 in parallel with a voltage source is a loop (**E_VSRC_LOOP**): give it a small dcr.

31.5 Potentiometer

TYPE	KEY	PINS	VARIANTS	CLASS
pot (RV)	library	1 (A), 2 (B), wiper	lin, log (audio A), rlog (reverse log C), trimmer, slide, rheostat	exact

Two resistors, A to wiper and wiper to B, set by the wiper position. The **log** and **rlog** variants change the taper: log gives f = (10$^{2·pos}$ - 1) / 99. The other variants are linear. The inspector shows **A** → **wiper** and **Wiper** → **B** live.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Total resistance	**r**	Ω	10 kΩ	> 0. Slider 10 Ω to 10 MΩ.	Default, inspector	Track resistance.
Wiper position	**pos**		0.5	0 to 1	Default, inspector	0 is the wiper at A, 1 at B. Drag the slider while the circuit runs.
End resistance	**r_end**	Ω	0.5 % of r	≥ 0	File or All parameters only	Added to both sides, so neither segment reaches zero.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

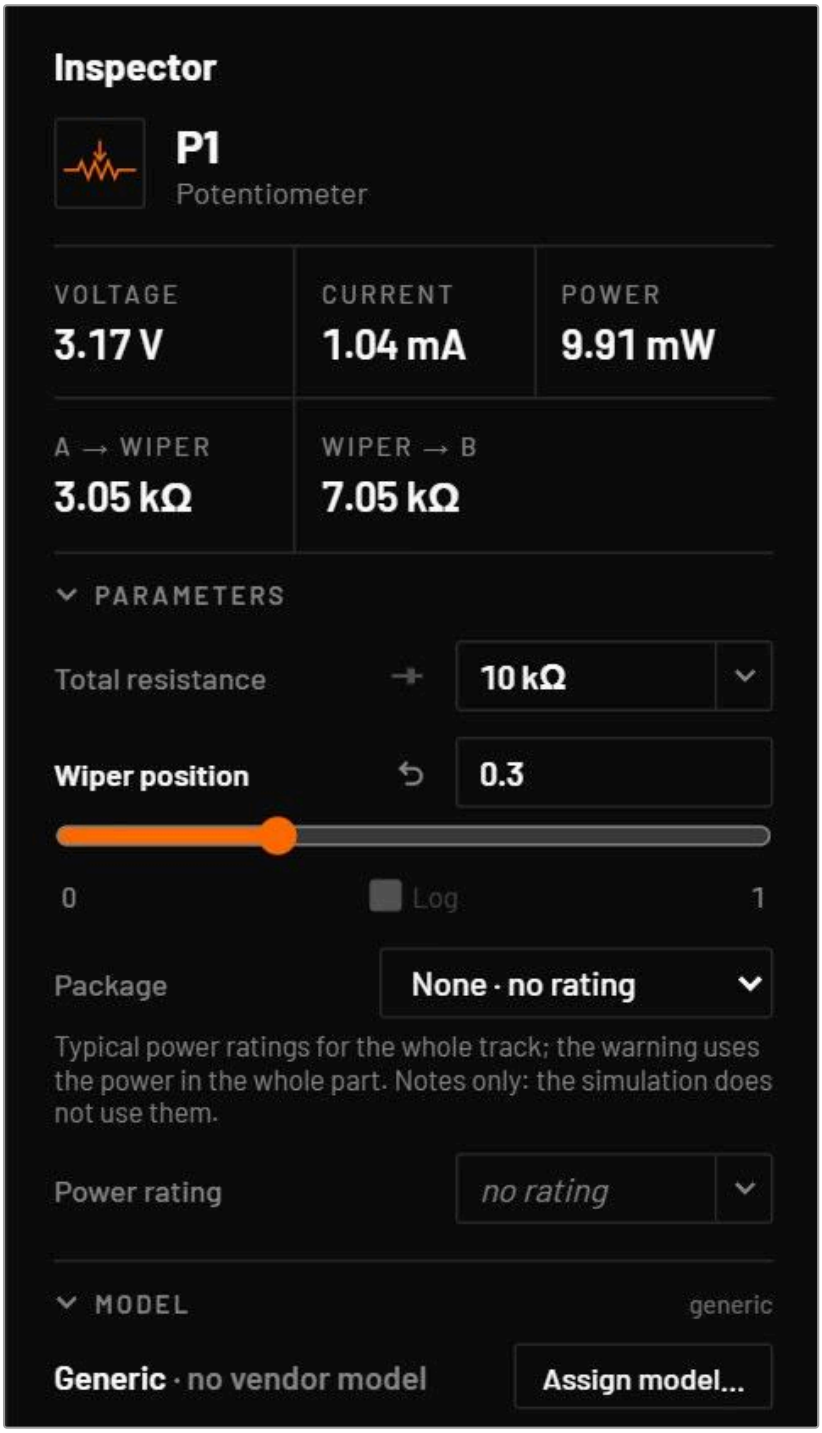


Figure 31.1 A potentiometer in the inspector: the two segment resistances update as the wiper moves.

31.6 Transformer

TYPE	KEY	PINS	VARIANTS	CLASS
xfmr (T)	Alt + T	p1, p2, s1, s2	standard, centre tap, coupled L (symbols)	exact

Two coupled inductors: L1 = lp, L2 = lp · ratio^2, mutual inductance M = k · lp · ratio. Dots at p1 and s1. Each winding has a fixed 1 µΩ resistance so DC is well defined. There's no core loss or winding resistance parameter. Multi-winding transformers are a separate model (**Analog building blocks**, p. 352).

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Primary inductance	**lp**	H	1 mH	> 0	Default, inspector	L1. The magnetising inductance seen from the primary.
Turns ratio	**ratio**		1	> 0. Slider 0.01 to 100.	Default, inspector	Ns / Np. Open-circuit voltage ratio ≈ k · ratio.
Coupling	**k**		0.999	0 to 1 (used up to 0.999999)	Default, inspector	Coupling coefficient. 1 - k sets the leakage inductance.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

For switching supplies there is a second transformer, **Transformer with windings and taps** (type **xfmr_wdg**, from the library). Its pins and symbol come from a list of windings (primary, secondary, auxiliary, reset), each with any number of taps, a turns count per section and a dot. The inspector has a winding editor; the magnetising side is given as Lp, as AL, or from the core and its air gap, with optional leakage, winding resistance, capacitance, core loss and a saturating core. Changing the windings keeps every pin that keeps its name and its wires; a new tap starts unconnected and a removed one leaves its wire with a free end. It runs live and in Simulate, and the two agree. The formulas are in **docs/TRANSFORMER.md**.

31.7 Wire (length, gauge)

TYPE	KEY	PINS	VARIANTS	CLASS
wireseg (W)	library	1, 2	none	approximate

A real wire: its DC resistance and self-inductance from its length, size, material and temperature. R = ρ(T) · length / area, with copper 1.724 x 10^{-8} Ω·m and aluminium 2.82 x 10^{-8} Ω·m at 20 °C. L = 2 x 10^{-7} · length · (ln(2 · length / r) - 0.75). No skin effect and no return path: for a cable with a return conductor use a transmission line.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Length	**len**	m	1	> 0	Default, inspector	
Cross-section	**mm2**	mm^2	0.5	> 0	Default, inspector	Wins over AWG and diameter. The metric picker offers 0.14 to 120 mm^2.
AWG	**awg**	gauge		-3 (0000) to 60	Inspector picker (converted to mm^2)	Diameter = 0.127 mm · $92^{(36 - n)/39}$.
Diameter	**d**	m	0.8 mm	> 0	File or All parameters only	Used when neither mm2 nor awg is set.
Material	**material**		cu	cu, al	Default, inspector	Copper or aluminium.
Temperature	**temp**	°C	20	any	Default, inspector	Resistance rises 0.393 % per °C for copper.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

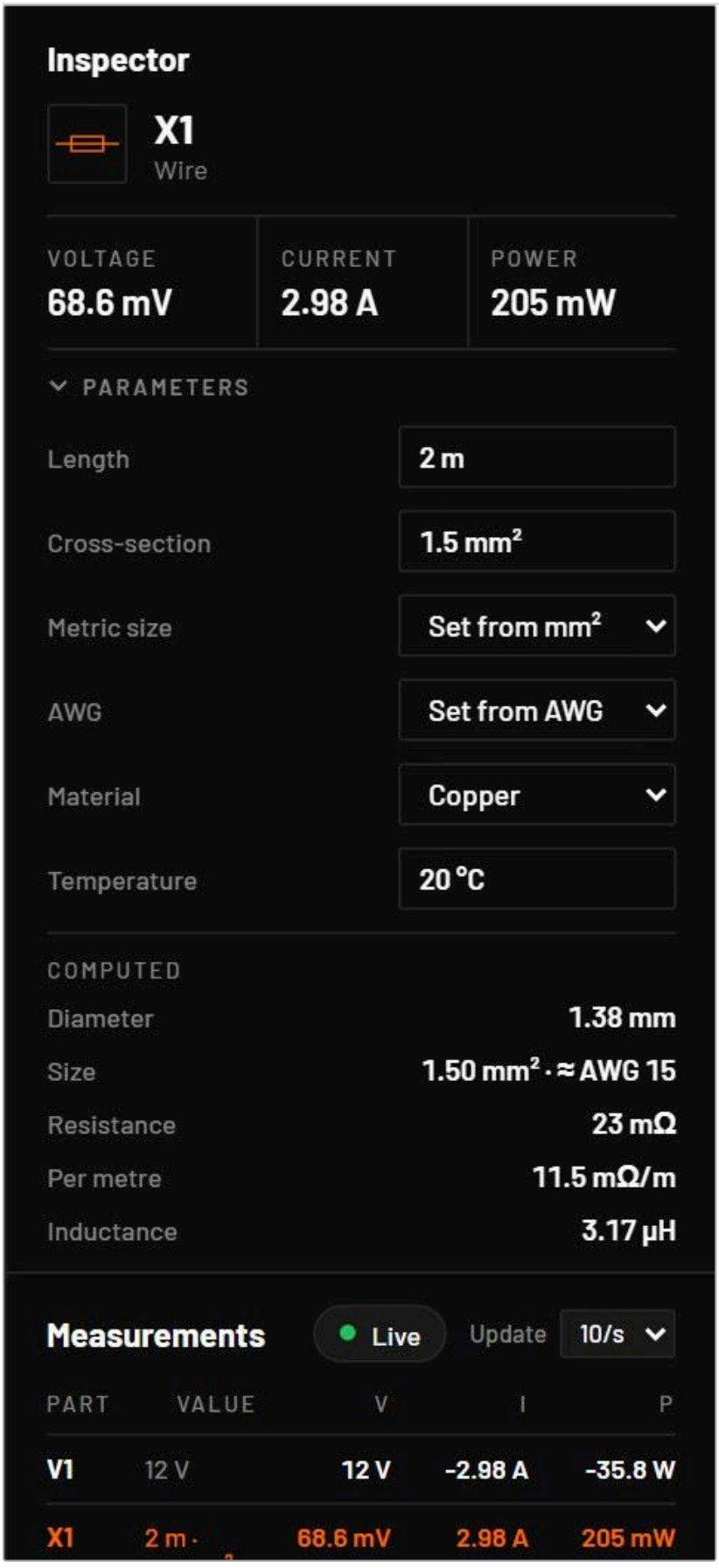


Figure 31.2 A 2 m, 1.5 mm² copper wire carrying 3 A: diameter, AWG, resistance and the drop computed live.

32 Devices: sources

32.1	Changing the source type	273	32.9	DC current source	280
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32.7	Function generator	277	32.15	Battery	283
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Every voltage source has a **+** and a **–** pin and forces V(+) - V(-). Every current source drives its current out of the **+** pin into the circuit and back in at **–**. A source delivering power shows a negative current at its + pin, because pin currents are measured into the part.

32.1 Changing the source type

The inspector's **Source type** list turns a source into another kind in place, keeping its pins and wires: DC voltage, Sine (AC), Square, Function generator, Pulse, PWL, Battery, DC current, Sine current, Function generator current. Levels and frequency carry over as far as the new waveform allows. Every source shows a live preview of its waveform. A battery keeps its chemistry and never gets pinned to a made-up voltage.

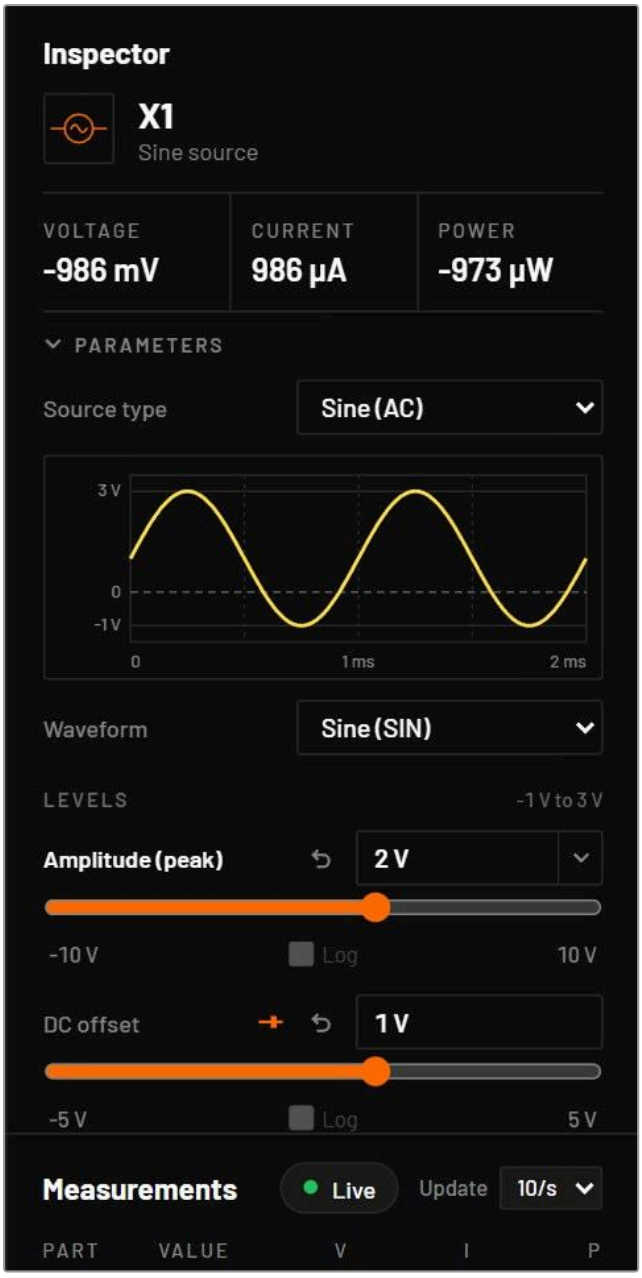


Figure 32.1 A sine source: amplitude, frequency, offset and phase, with the preview.

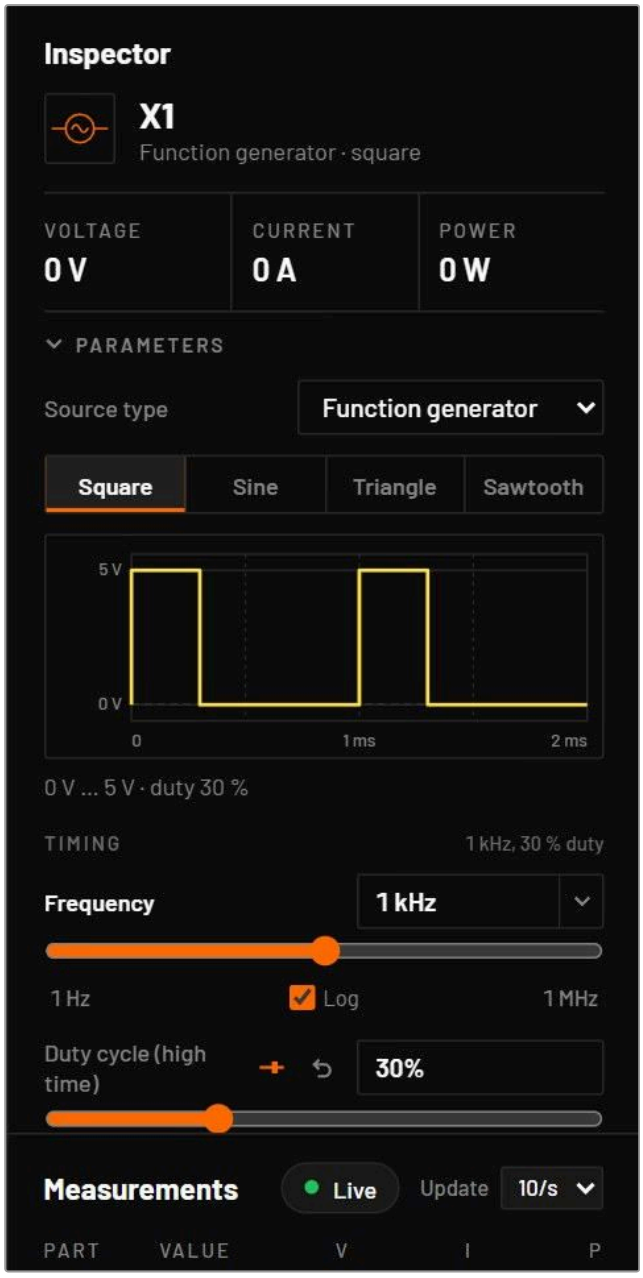


Figure 32.2 A function generator set to a 30 % square wave.

32.2 How sources behave in each analysis

ANALYSIS	BEHAVIOUR
Operating point	The value at t = 0: sine = offset + amp · sin(phase), pulse = low level, PWL = first point.
Transient	The full waveform. Pulse, square, function generator and PWL corners are exact breakpoints, so edges are never skipped. A sine limits the timestep to a twentieth of its period.
AC sweep	The source chosen as input gets 1 V (or 1 A) at 0°, whatever its own parameters. Other sources are at their DC value.
DC sweep	The swept source becomes a DC value. For a sine, the offset is swept. A battery cannot be swept.

32.3 DC voltage source

TYPE	KEY	PINS	VARIANTS	CLASS
vdc (V)	V	+, -	none	exact

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Voltage	**v**	V	5	any. Slider -50 to 50 V.	Default, inspector, board import	V(+) - V(-).
Series resistance	**rs**	Ω	0	≥ 0	Default, inspector	A real source: a resistor in the + lead. A battery keeps its own r.
AC magnitude, phase	**ac_mag, ac_phase**	V, °	1, 0	any	Default, inspector	The drive when this is the source an AC analysis sweeps. Noise, loop gain and pole-zero ignore them, as ngspice does.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Two voltage sources in parallel, or one shorted, are refused before the run (**E_VSRC_LOOP**, **E_VSRC_SHORT**).

32.4 Sine source

TYPE	KEY	PINS	VARIANTS	CLASS
vsin (V)	A	+, -	none	exact

$v(t) = \text{offset} + \text{amp} \cdot \sin(2\pi \cdot \text{freq} \cdot t + \text{phase})$.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Amplitude (peak)	**amp**	V	5	any. Slider 0 to 400 V.	Default, inspector	Peak, not peak to peak or RMS. 230 V RMS mains is 325 V peak.
Frequency	**freq**	Hz	50	0 to 10^{15}. Slider 0.1 Hz to 10 MHz.	Default, inspector	
Damping	**theta**	1/s	0	any	Default, inspector	Amplitude × exp(-theta (t - delay)), as the SPICE SIN source.
DC offset	**offset**	V	0	any	Default, inspector	
Phase	**phase**	°	0	any	Default, inspector	
Start delay	**delay**	s	0	≥ 0	Default, inspector	The source holds its starting value (offset + amp · sin(phase)) until then, with no jump. Like SIN TD in SPICE.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

32.5 Pulse source

TYPE	KEY	PINS	VARIANTS	CLASS
vpulse (V)	Alt + A	+, -	none	exact

The SPICE pulse: low, a linear rise, high for the width, a linear fall, low until the end of the period.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Low (initial)	**v1**	V	0	any	Default, inspector	Level before the delay and between pulses.
High (pulsed)	**v2**	V	5	any	Default, inspector	
Start delay	**delay**	s	0	≥ 0	Default, inspector	Time before the first rising edge.
Rise time	**rise**	s	1 ns	≥ 0 (used ≥ 1 ps)	Default, inspector	
Fall time	**fall**	s	1 ns	≥ 0 (used ≥ 1 ps)	Default, inspector	
Pulse width	**width**	s	5 µs	≥ 0	Default, inspector	Time at the high level between the end of the rise and the start of the fall.
Period	**period**	s	10 µs	≥ 1 fs	Default, inspector	If rise + width + fall is longer, the pulse is cut at the period and the run warns **W_PARAM**.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

For a PWM signal of duty D at the 50 % level, set width = D · period - (rise + fall) / 2.

A pulse that doesn't fit in its period is cut off when the next period starts, so it never settles back to the low level. The run says so with a **W_PARAM** warning that names the numbers and the fix: *"V2: rise 1 µs + width 9 µs + fall 1 µs = 11 µs is longer than the period 10 µs; each pulse is cut off when the next period starts …"*, then *"Make V2 width at most 8 µs (period − rise − fall), or the period at least 11 µs."* When the two edges alone are longer than the period, the fix says to shorten them. A negative delay, rise, fall or width is still an **E_PARAM** error that names the key and **>= 0**.

32.6 Square wave source

TYPE	KEY	PINS	VARIANTS	CLASS
vsquare (V)	library	+, -	none	approximate

A square wave with fixed edges of 1 ns or a thousandth of the period, whichever is shorter, and an optional start delay. For phase or slow edges use the function generator.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Low level	**vlo**	V	0	any	Default, inspector	
High level	**vhi**	V	5	any	Default, inspector	
Frequency	**freq**	Hz	1 kHz	> 0	Default, inspector	
Duty cycle	**duty**	% (stored 0 to 1)	50 %	0 to 1	Default, inspector	High time at the 50 % level.
Start delay	**delay**	s	0	≥ 0	Default, inspector	The output stays low until then.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

32.7 Function generator

TYPE	KEY	PINS	VARIANTS	CLASS
vfunc (V)	library	+, -	square, sine, triangle, sawtooth (the waveform)	approximate

A bench function generator. The variant is the waveform, chosen with the Square, Sine, Triangle and Sawtooth buttons. The current version, **ifunc**, is the same with **ipp** in amps (default 2 mA, centred).

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Frequency	**freq**	Hz	1 kHz	> 0	Default, inspector	
Amplitude (peak to peak)	**vpp**	V	5	any (magnitude used)	Default, inspector	
Levels	**levels**		From 0	From 0, Centred on 0, Custom offset	Default, inspector	Presets for the offset. From 0: 0 to vpp. Centred: ± vpp/2. Custom: around the DC offset you typed.
DC offset (mid level)	**offset**	V	0	any	Default, inspector	Always shown, with the mid level the waveform has now (2.5 V for 5 Vpp from 0). Typing a value sets Levels to Custom offset: 1 V offsets the wave by 1 V.
Duty cycle / Symmetry	**duty**	% (stored 0 to 1)	50 %	0 to 1	Default, inspector	Square: high time. Triangle: the rising fraction. Not used by sine and sawtooth.
Rise time	**rise**	s	1 ns	≥ 0 (up to 45 % of the period)	Default, inspector	Square edges.
Fall time	**fall**	s	1 ns (sawtooth: period / 1000)	≥ 0	Default, inspector	Square falling edge, or the sawtooth flyback.
Phase	**phase**	°	0	any	Default, inspector	A positive phase advances the waveform.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Start delay	**delay**	s	0	≥ 0	Default, inspector	Every waveform, the sine too, holds its starting level until then and then starts its first period.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

32.8 Piecewise-linear source

TYPE	KEY	PINS	VARIANTS	CLASS
vpwl (V)	library	+, -	none	exact

Straight lines between time and value points. Before the first point the first value holds, after the last the last value holds. Two points at the same time make a step. The points are sorted by time. The inspector shows them as a table, under a preview of the waveform.

IN THE TABLE	WHAT IT DOES
A cell	Type a time or a value, with units such as **1ms** or **5V**. Enter or Tab applies, Esc puts the stored value back.
+	Adds a point after the last one.
× on a row	Deletes the point. At least one point stays.
Edit as text	The same points as text, one per line (**1ms 5V**) or separated by commas (**0 0, 1m 5, 2m 5, 3m 0**). Press Ctrl+Enter or click away to apply.
Right-click the source, **Edit points...**	Opens the inspector with the first cell of the table selected.

Undo, and an AI agent's edits, show in the table at once.

Under the table, **Time offset** starts the whole list later (the first value holds until then), and **Repeat the points** plays the list again and again, like **td=** and **r=** in a SPICE PWL source. Ticking the box sets **Repeat from** to the first time, so the whole list repeats. Raise it to repeat only the later part: with **Repeat from** at 1 ms, a list that ends at 3 ms plays once from the start, and from then on the section from 1 ms to 3 ms repeats every 2 ms. The note under the field says what repeats and how often, for example *"After the last point the points from 0 s on repeat, every 2 ms."* Each pass jumps back to the value at the repeat time, and the corners of every pass are exact breakpoints. A repeat time that isn't before the last point is a mistake: the points play once and the run warns **W_PARAM**.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Points	**points**	s, V	[[0, 0]] (placed: 0 V, then 5 V at 1 ms)	times rising from 0	Default, inspector	A list of [time, value] pairs in the file.
Time offset	**td**	s	0	any	Default, inspector	Shifts the whole list later. The first value holds until then. Its slider spans the length of the list.
Repeat from	**r**	s	none (plays once)	≥ 0, before the last point	Default, inspector	A time in the list. After the last point, the section from r to the last point repeats forever. 0 repeats the whole list. Unticking **Repeat the points** removes it. Exported as **r=** and **td=**.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

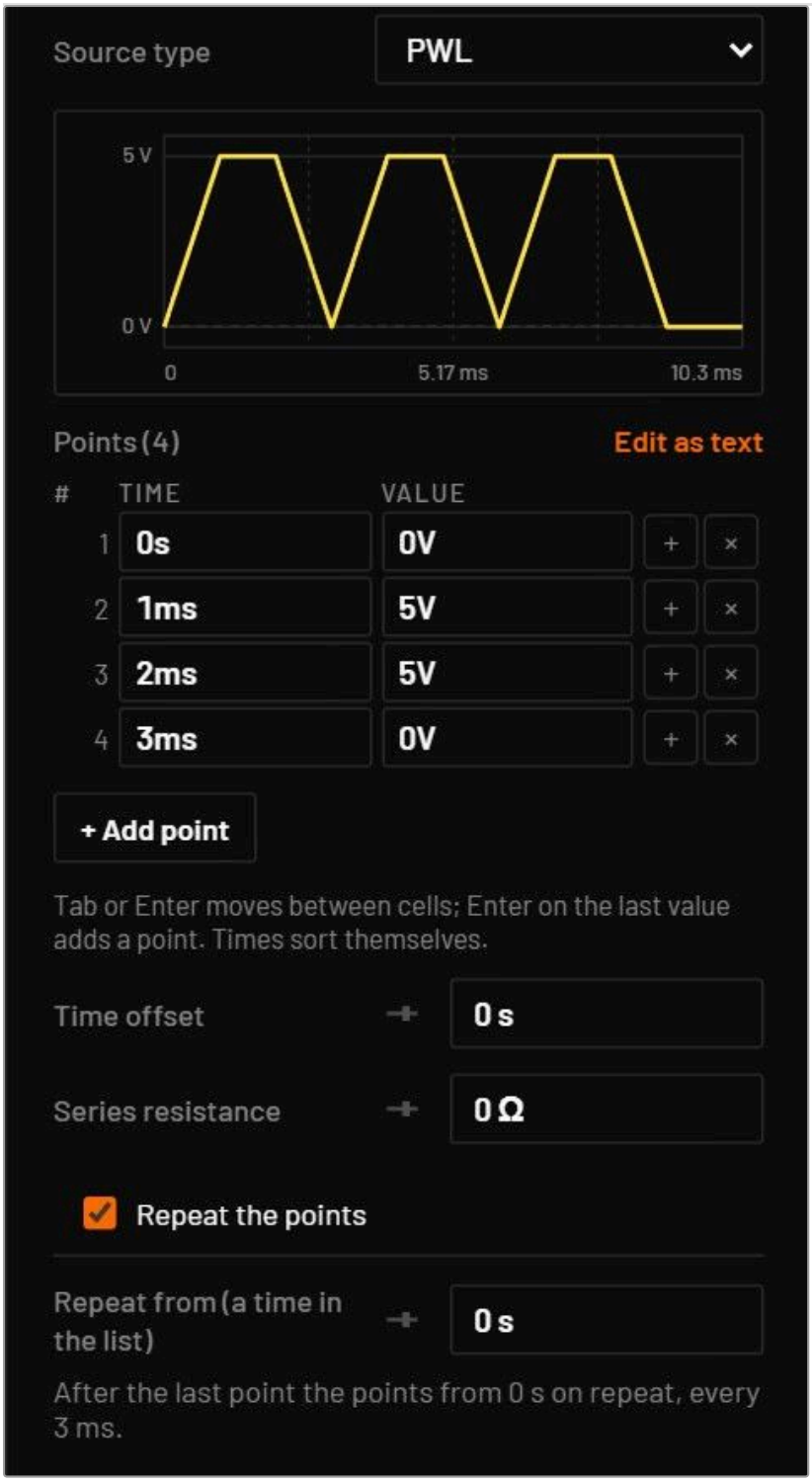


Figure 32.3 A PWL source set to repeat: the preview shows the passes, and under the points table are the Time offset, Repeat the points and Repeat from.

32.9 DC current source

TYPE	KEY	PINS	VARIANTS	CLASS
idc (I)	I	+, -	none	exact

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Current	**i**	A	1 mA	any. Slider -10 to 10 A.	Default, inspector	Leaves the + pin into the circuit.
Parallel resistance	**rp**	Ω	none	> 0	Default, inspector	A real source: a resistor across its output.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

A current source with nowhere to send its current is refused (**E_ISRC_OPEN**).

32.10 Sine current source

TYPE	KEY	PINS	VARIANTS	CLASS
isin (I)	library	+, -	none	exact

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Amplitude	**amp**	A	1 mA	any	Default, inspector	Peak.
Frequency	**freq**	Hz	50	0 to 10^{15}	Default, inspector	
Offset	**offset**	A	0	any	Default, inspector	
Phase	**phase**	°	0	any	Default, inspector	
Start delay	**delay**	s	0	≥ 0	Default, inspector	As for the sine voltage source.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

32.11 Voltage-controlled voltage source (E)

TYPE	KEY	PINS	VARIANTS	CLASS
vcvs (E)	library	+, -, c+, c-	none	exact

V(+) - V(-) = gain · (V(c+) - V(c-)). The control pins draw no current.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Gain	**gain**	V/V	1	any. Slider -1000 to 1000.	Default, inspector	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

32.12 Voltage-controlled current source (G)

TYPE	KEY	PINS	VARIANTS	CLASS
vccs (G)	library	+, -, c+, c-	none	exact

A current gm · (V(c+) - V(c-)) flows from + through the part to -. The control pins draw no current.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Transconductance	**gm**	S	1 mS	any	Default, inspector	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

For a source controlled by a current, use the CCVS or CCCS below.

32.13 Current-controlled voltage source (H)

TYPE	KEY	PINS	VARIANTS	CLASS
ccvs (H)	library	+, -, s+, s-	none	exact

V(+) - V(-) = rt · I(sense), where I(sense) is the current that flows into **s+** and out of **s-**. The sense port is a 0 V branch, an ideal ammeter: wire it **in series with the branch whose current you want to sense**, the way you put a meter in a line. A positive current goes into s+. Swap the two pins to reverse the sign. The port needs no extra 0 V source in the schematic.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Transresistance	**rt**	Ω	1 kΩ	any. Slider -1 MΩ to 1 MΩ.	Default, inspector	Volts out per amp sensed. A sensed 5 mA with rt = 200 Ω gives 1.000 V.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Live value: **Sensed current** (**i_sense**), and every pin shows its current. The exported SPICE netlist has an H element with a 0 V source for the sense port.

32.14 Current-controlled current source (F)

TYPE	KEY	PINS	VARIANTS	CLASS
cccs (F)	library	+, -, s+, s-	none	exact

A current gain · I(sense) flows into + and out of - through the source, as for the VCCS. I(sense) is the current into s+ and out of s-, through the same 0 V sense port as the CCVS. A source may sense the branch it feeds: a gain of 0.5 on its own load current is allowed, and settles at the current the equations give.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Current gain	**gain**	A/A	1	any. Slider -1000 to 1000.	Default, inspector	Amps out per amp sensed. A sensed 5 mA with a gain of 3 gives 15 mA.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Live value: **Sensed current** (**i_sense**). Both are linear and exact, like the VCVS and VCCS, and a change of the field applies while the circuit runs.

Start delay sliders (the **delay** of the sine, square, pulse and function generator sources, and the PWL **Time offset**) span one period of the source, from 0 to 1 / frequency, so a slider on a 100 kHz source runs from 0 to 10 µs instead of 0 to 1 s. A source with a delay that is already longer than one period gets a slider that spans two or more periods. A range you typed yourself wins.

32.15 Battery

The inspector of a battery shows its **Chemistry** (Li-ion, LiFePO4, NiMH, alkaline, coin, lead-acid, LiPo pack), a graph of the open-circuit voltage, and the fields below. The open-circuit voltage is the one the chemistry's curve gives at the charge you set, so the inspector, the preview, the canvas label and the simulation agree: a NiMH cell reads 1.30 V, not 3.7 V. The full model is in **Batteries and supercapacitors**, p. 350.

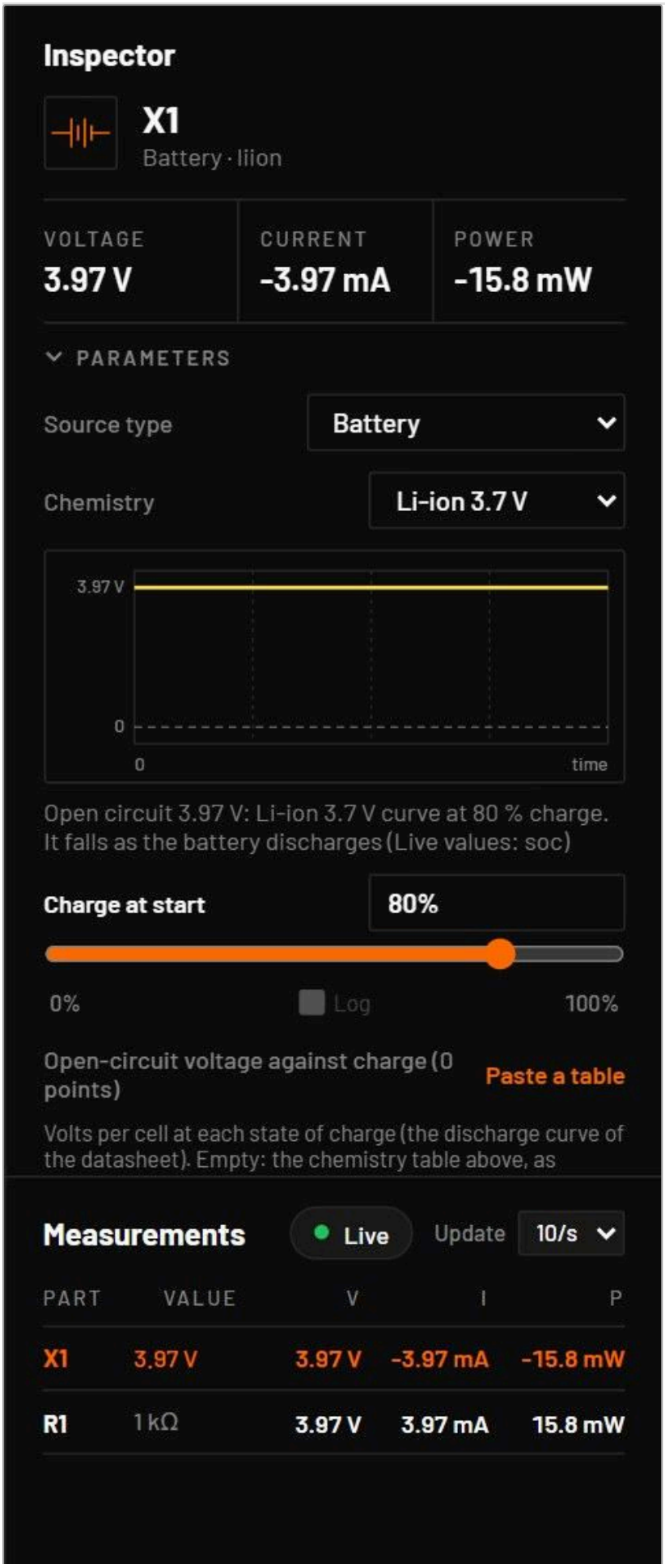

Inspector
X1
Battery · liion
VOLTAGE
3.97 V
CURRENT
-3.97 mA
POWER
-15.8 mW
PARAMETERS
Source type
Battery
Chemistry
Li-ion 3.7 V
3.97 V
0
0
time
Open circuit 3.97 V: Li-ion 3.7 V curve at 80 % charge. It falls as the battery discharges (Live values: soc)
Charge at start
80%
0%
Log
100%
Open-circuit voltage against charge (0 points)
Paste a table
Volts per cell at each state of charge (the discharge curve of the datasheet). Empty: the chemistry table above, as
Measurements
Live
Update
10/s
PART
VALUE
V
I
P
X1
3.97 V
3.97 V
-3.97 mA
-15.8 mW
R1
1 kΩ
3.97 V
3.97 mA
15.8 mW

Figure 32.4 A Li-ion battery: chemistry, the curve, charge at the start, cells in series and capacity.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Chemistry	**variant**		liion	liion, lifepo4, nimh, alkaline, coin, leadacid, lipo_pack	Default, inspector	Picks the voltage curve, resistance and polarisation.
Charge at start	**soc**	0 to 1	0.8		Default, inspector	Shown as a percentage. Falls as the battery delivers charge.
Cells in series	**cells**		1 (LiPo pack 3)	whole number, 1 or more	Default, inspector	
Capacity	**capacity_ah**	Ah	2 (coin cell 0.22)	> 0	Default, inspector	
Internal resistance	**r**	Ω	from the chemistry (coin 15)	≥ 0	Default, inspector	
Fixed voltage	**v**	V	none	any	Default, inspector	If set, the battery is an ideal source with a series resistance and does not discharge. The inspector shows **Fixed voltage** and a **Use the ... curve instead** button.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

A battery with no chemistry (from a file or a source type change) shows **Voltage** (3.7 V) and **Internal resistance** (0.05 Ω) only. The browser's fallback engine uses the curve at the starting charge and doesn't discharge it.

32.16 Ground and power flags

Ground (G, type **gnd**) joins net 0, the main ground. A ground with a name other than GND or 0, such as ISO1, is an isolated ground: every ground of that name is one ground domain, tied to net 0 only through its isolation barrier (**Keep sides isolated with their own grounds**, p. 45).

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Ground name	**net**		empty	a name without spaces	Default, inspector	Empty, GND or 0: the main ground. Any other name: an isolated ground of that domain. Press Tab while placing a ground to step through the domains.
Isolation resistance	**r_iso**	Ω	1 GΩ	> 0	Default, inspector	Isolated ground only. Belongs to the domain: setting it on any symbol sets every symbol of the domain. When symbols of an old file disagree, the first symbol that sets it wins.
Isolation capacitance	**c_iso**	F	10 pF	≥ 0	Default, inspector	Isolated ground only, same rule. 0 leaves only the resistance.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Power flags (Shift + G) are names, not parts: every flag and label with the same name is one net. A power flag doesn't supply voltage. Place a source to drive the net.

33 Devices: semiconductors

33.1	Where semiconductor values come from	287	33.5	MOSFET (N, P)	292
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33.4	Bipolar transistor (NPN, PNP)	291			

The diode, BJT, MOSFET (levels 1, 2 and 3, and VDMOS) and JFET use the same equations as ngspice, ported from its source: defaults, temperature scaling, junction limiting and convergence tests. A vendor **.model** card therefore gives the same result as in ngspice. Its parameters go on the part under their ngspice names in lower case.

33.1 Where semiconductor values come from

SOURCE	WHAT IT SETS
The inspector	The main parameters: is, n, rs, bv and cj0 for a diode, bf, is, vaf, cje and cjc for a BJT, vto, kp, lambda, cgs and cgd for a MOSFET.
A vendor model card	Assigning a model from the library merges every parameter of its card into the part. Simulate uses the vendor card itself.
Quick model	Datasheet values fitted exactly at the stated test point (**Quick model tab**, p. 415).
A part file	Values from a .bspart.
The All parameters tab or the file	Any other ngspice parameter by its ngspice name.

Shared instance parameters: **temp** (°C, default 27, the ngspice default), **dtemp** (offset from the circuit temperature), **tnom** (the temperature the model was measured at, default 27), **mult** (parallel devices), and **area** for diodes, BJTs and JFETs. Variants such as rectifier or darlington only change the symbol, except where the text says otherwise.

33.2 Diode

TYPE	KEY	PINS	VARIANTS	CLASS
diode (D)	D	anode, cathode	rectifier, signal, schottky, zener, tvs, varactor, switching, fast (symbols). The bidirectional TVS is a separate model.	exact

The ngspice junction diode: forward current IS ($e^{V/(N \cdot Vt)} - 1$), reverse breakdown at BV matched to IBV, series resistance, depletion and diffusion charge. A part placed from the library starts with is = 1 nA and n = 1.8.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Saturation current	**is**	A	10 fA	> 0	Default, inspector, Quick model, board import, card	Alias js.
Emission coefficient	**n**		1	> 0	Default, inspector, Quick model, card	
Series resistance	**rs**	Ω	0	≥ 0	Default, inspector, Quick model, card	
Breakdown voltage	**bv**	V	none (no breakdown)	> 0	Default, inspector, Quick model, card	A positive number. Aliases vb, vrb.
Breakdown current	**ibv**	A	1 mA	> 0	Inspector (Zener: **Current at breakdown**), Quick model (Zener), card	Current at bv.
Breakdown emission	**nbv**		= n	> 0	Vendor model card, All parameters tab	
Junction capacitance	**cj0**	F	0	≥ 0	Default, inspector, Quick model, card	Zero-bias capacitance. Aliases cjo, cj.
Junction potential	**vj**	V	1	> 0	Vendor model card, All parameters tab	Alias pb.
Grading coefficient	**m**		0.5	0 to 0.999	Vendor model card, All parameters tab	Alias mj.
Forward-bias coefficient	**fc**		0.5	0 to 0.999	Vendor model card, All parameters tab	
Transit time	**tt**	s	0	≥ 0	Quick model (t_rr / 1.5), card	Diffusion charge, sets reverse recovery.
Knee currents	**ikf, ikr**	A	none	> 0	Vendor model card, All parameters tab	High-injection roll-off.
Recombination	**isr, nr**	A, -	none, 2	≥ 0, > 0	Vendor model card, All parameters tab	
Sidewall	**jsw, ns, cjp, php, mjsw, fcs, ikp**		none, = n, 0, 1, 0.33, 0.5, none		Vendor model card, All parameters tab	Sidewall current and capacitance.
Tunnelling	**jtun, jtunsw, ntun, xtitun, keg**		none, none, 30, 3, 1		Vendor model card, All parameters tab	
Area, perimeter	**area, pj**	-, m	1, 0	> 0, ≥ 0	Vendor model card, All parameters tab	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Temperature model	**eg, xti, tlev, tlevc, cta, ctp, tpb, tphp, trs, trs2, tm1, tm2, ttt1, ttt2, tcv, gap1, gap2**		eg 1.11 eV, xti 3, others 0		Vendor model card, All parameters tab	Temperature dependence of IS, BV, capacitances and resistances.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Not implemented, so models that use them run approximately: LEVEL 3 geometry, RSW, soft recovery (VP) and self-heating. Typical values the inspector shows per variant: rectifier is 7 nA, n 1.98, rs 42 mΩ, bv 1000 V, cj0 26 pF. Signal: is 2.52 nA, n 1.752, bv 100 V, cj0 4 pF, tt 20 ns. Schottky: is 30 µA, n 1.05, bv 40 V, cj0 110 pF. Zener: bv 5.075 V, ibv 5 mA, rs 5 Ω. TVS: bv 6.7 V, cj0 1 nF. Varactor: bv 30 V, cj0 30 pF.

TRY IT

A 3.3 V Zener regulator

1. Place a 12 V DC source, a 470 Ω resistor and a diode with its cathode towards the resistor and anode to ground.
2. Select the diode, press Ctrl + Shift + M and type V_Z **3.3**, I_Z **20m**, Z_Z **10**. Press Apply.
3. Hover the cathode wire.

YOU SHOULD SEE The cathode sits near 3.3 V. Change the source with its slider: the Zener voltage barely moves while the current through it changes.

33.3 LED

TYPE	KEY	PINS	VARIANTS	CLASS
led (LED)	Shift + D	anode, cathode	standard, laser (symbols)	exact

The diode model with colour-dependent defaults. It glows on the canvas in proportion to its current, full at 20 mA.

An LED's forward voltage falls as it warms, by 1.3 to 3 mV/K depending on the colour. From 0.8.1 the model follows the datasheet figure by itself: unless you give the band gap **eg**, it is set from the LED's own is, n and rs so that the forward voltage at the test current **if_test** changes by **vf_tc** per kelvin. Before 0.8.1 the silicon band gap (1.11 eV) made the forward voltage rise with temperature, the wrong way. A typed **eg** wins over vf_tc. The JavaScript fallback engine has no diode temperature law.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Colour	**color**		red	red, orange, yellow, green, blue, white, uv, ir	Default, inspector	Sets is, n and rs unless they are given (is / n / rs): red 10^{-18} A / 1.9 / 2 Ω, orange and yellow 10^{-19} / 1.9 / 2, green 10^{-20} / 2.0 / 2, blue, white and uv 10^{-22} / 2.6 / 2, infrared 10^{-16} / 1.6 / 1. The inspector and All parameters show the values of the chosen colour, and the note under the colour gives the forward voltages.
Saturation current	**is**	A	by colour	> 0	Default, inspector, Quick model	
Emission coefficient	**n**		by colour	> 0	Default, inspector, Quick model	
Series resistance	**rs**	Ω	2	≥ 0	Default, inspector, Quick model	
Forward-voltage tempco	**vf_tc**	V/K	by colour: red, orange, yellow and amber −2.5 mV/K, green, blue, white and UV −3.0 mV/K, infrared −1.3 mV/K	any	File or All parameters only	Datasheet values: OSRAM LO M67F and LY T676 (red, yellow), Kingbright InGaN green (−2.9 mV/K), InGaN white, OSRAM SFH 4248 (infrared). Set it from your LED's datasheet (ΔVF / ΔT). Used only when eg is not given.
Test current	**if_test**	A	20 mA	> 0	File or All parameters only	The current at which vf_tc holds.
Band gap	**eg**	eV	worked out from vf_tc (red 2.52, orange and yellow 2.63, green 3.00, blue, white and UV 3.97, infrared 1.68 with the colour defaults)	> 0	File or All parameters only	EG = Vj − XTI·Vt − T·vf_tc, with Vj the junction voltage at if_test from the part's own is, n and rs, at 27 °C. Typing eg turns this off. The All parameters tab lists eg with the diode default of 1.11 eV, not the worked-out value.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

A white LED at 85 °C

1. Place a DC current source of 20 mA into a white LED, anode on the source's output and cathode to ground.
2. Open All parameters for the LED and set **temp** (Device temperature) to 85.
3. In the Analysis view open the **Operating point** tab and run it.

YOU SHOULD SEE The LED sits at 3.008 V, 175 mV below its 3.184 V at 27 °C: –3.0 mV/K, the InGaN datasheet figure (measured with bspice 0.8.1).

33.4 Bipolar transistor (NPN, PNP)

TYPE	KEY	PINS	VARIANTS	CLASS
npn, pnp (Q)	Q or Shift + Q	c, b, e	default, darlington (symbol), prebias (digital transistor with base resistors)	exact

The ngspice Gummel-Poon model, with quasi-saturation (Kull) when rco is set. The **prebias** variant adds R1 in series with the base and R2 from base to emitter. The substrate capacitance goes to ground. A part placed from the library starts with bf = 100.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Forward beta	**bf**		100	> 0. Slider 10 to 1000.	Default, inspector, Quick model, board import, card	Ideal maximum forward current gain.
Saturation current	**is**	A	10 fA	> 0	Default, inspector, Quick model, card	
Early voltage	**vaf**	V	none (no Early effect)	≥ 0	Default, inspector, Quick model, card	Alias va. 0 also means none.
B-E capacitance	**cje**	F	0	≥ 0	Default, inspector, Quick model, card	With vje (0.75 V) and mje (0.33).
B-C capacitance	**cjc**	F	0	≥ 0	Default, inspector, Quick model, card	With vjc (0.75 V), mjc (0.33) and xcjc (1).
Forward emission	**nf**		1	> 0	Vendor model card, All parameters tab	
Knee current	**ikf, nkf**	A, -	none	≥ 0	Vendor model card, All parameters tab	Beta roll-off at high current.
B-E leakage	**ise, ne**	A, -	0, 1.5	≥ 0, > 0	Vendor model card, All parameters tab	Low-current beta.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Reverse	**br, nr, var, ikr, isc, nc**		1, 1, none, none, 0, 2		Vendor model card, All parameters tab	Reverse-active operation.
Resistances	**rb, irb, rbm, re, rc**	Ω, A	0, 0, = rb, 0, 0	≥ 0	Vendor model card, All parameters tab	Base resistance falls from rb to rbm with current.
Transit times	**tf, xtf, vtf, itf, tr**	s, –, V, A, s	0, 0, none, 0, 0	≥ 0	Vendor model card, All parameters tab	Diffusion charge, sets f_T and storage time.
Substrate	**cjs, vjs, mjs, iss, ns, subs**		0, 0.75, 0, none, 1, ±1		Vendor model card, All parameters tab	
Quasi-saturation	**rco, vo, gamma, qco, quasimod, vg, cn, d**		off unless rco is set		Vendor model card, All parameters tab	Kull model with an extra collector node.
Prebias resistors	**r1, r2**	Ω	10 kΩ, 10 kΩ	> 0, ≥ 0	Default, inspector	Prebias variant only. r2 = 0 removes R2.
Temperature model	**eg, xti, xtb, tlev, tlevc and the t... coefficients**		eg 1.11 eV, xti 3, others 0		Vendor model card, All parameters tab	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Not implemented: excess phase (ptf) and self-heating. Typical values shown for a new NPN: is 6.7 fA, bf 200, vaf 74 V, cje 4.5 pF, cjc 3.6 pF. PNP: is 1.4 fA, bf 180, vaf 18.7 V.

33.5 MOSFET (N, P)

TYPE	KEY	PINS	VARIANTS	CLASS
nmos, pmos (M)	M or Shift + M	d, g, s, and optionally b	enh, dep, 4pin, power, gan, sic	exact

The ngspice MOSFET levels 1, 2 and 3, and the VDMOS model for power devices. With three pins the bulk is tied to the source. Variants that change the behaviour:

- **dep**: depletion mode, the threshold sign is flipped.
- **power**, **gan**, **sic**: a body diode from source to drain. A new part of these variants runs the VDMOS model with the values of a real part of its class (below), a part saved before with level 1 and bodyDiode on.
- **4pin**: the symbol with the bulk pin.
- **vdmos** (from a vendor card or the file): the VDMOS model instead of level 1 to 3.

Where the engine deliberately differs from ngspice. A level 2 card with **vmax** (velocity saturation) and no **nfs**: between the flat-band voltage **vbin** and the threshold voltage ngspice solves a quartic for the saturation voltage whose root goes negative, and the channel then conducts a falling current although there is no inversion charge. A card with vto 0.72 V and gamma 0.94 $V^{1/2}$ (vbin is then slightly below 0) conducts 47 µA at Vgs = 0 in ngspice. BetterSPICE holds the saturation voltage at zero there, so the device is off below its threshold, as the equations and the physics require (a CMOS output with its n-channel off reaches the supply rail: 5.000 V where ngspice shows 4.964 V). Above the threshold both give the same current to five digits. A level 2 part run in ngspice itself (a vendor-model Simulate, **bspice ngspice**) still shows ngspice's own sub-threshold current. The check is the known-difference entry of **verification/circuits/semi/mos_cmos_l2_tran** (**PASS!** in the verify list, **Verification**, p. 678).

A plain MOSFET with no card uses level 1 with vto = ±2 V, kp = 0.1 A/V^2 and lambda = 0.01 /V. If **rds_on** is set and kp isn't, kp = 1 / (rds_on · (10 - |vto|)), so rds_on is the on-resistance at 10 V of gate drive.

Default capacitances. Without gate capacitance a gate switches at once: no Miller plateau, no gate charge to drive. So a new generic MOSFET is placed with the capacitances of a real part of its class, taken from its datasheet and checked with a gate-charge test (constant gate current, clamped drain current, as the datasheets measure it). They are written into the part, so circuits saved before keep their results.

- **enh**, **dep**, **4pin** N-channel (2N7000 class, 60 V 0.2 A): cgs 20 pF, cgd 6 pF. P-channel (BSS84 class, 50 V 0.13 A): cgs 50 pF, cgd 10 pF (Qgs 0.2 nC, Qgd 0.3 nC as the datasheet). The fixed cgd is the mean C_rss over the drain swing, so the gate charge is right although C_rss itself is larger at low voltage.
- **power** N-channel (IRLZ44N class, 55 V 47 A, logic level): VDMOS with vto 1.5 V, kp 20, rd 7 mΩ, rs 3 mΩ, rg 1.5 Ω, cgs 1.55 nF, cgdmin 40 pF, cgdmax 2.9 nF, a 0.4, cjo 1.4 nF, tt 8 ns. C_iss 1.70 nF, C_rss 151 pF, C_oss 397 pF at 25 V. Gate charge at 44 V, 25 A, 5 V: Qg 31.5, Qgs 4.8, Qgd 18 nC (datasheet maxima 48, 8.6, 25).
- **power** P-channel (IRF5305 class, -55 V -31 A): VDMOS with vto -3 V, kp 8, cgs 0.95 nF, cgdmax 2 nF, cjo 1.5 nF. Qg 42.7, Qgd 23.8 nC at -10 V (maxima 63, 29). The gan and sic symbols of a P-channel part get the same values (no such parts are made).
- **gan** (EPC2045 class, 100 V 16 A): VDMOS with vto 1.4 V, rg 0.6 Ω, cgs 0.76 nF, cgdmax 0.2 nF, cjo 0.8 nF, no body diode (it conducts backwards through the channel at about 1.6 V, as the datasheet's 1.7 V). Qg 5.3, Qgs 1.8, Qgd 0.8 nC at 5 V (datasheet 6, 1.9, 0.8).
- **sic** (C3M0060065D class, 650 V 37 A): VDMOS with vto 2.3 V, rg 3 Ω, cgs 1.01 nF, cgdmin 6 pF, cgdmax 1.2 nF, cjo 0.6 nF, body diode about 5 V. C_rss 9 pF and C_oss 81 pF at 600 V. Qg 43.8 nC from 0 to 15 V at 400 V (datasheet 46 nC from -4 to 15 V).

The inspector shows one quiet line under the model of a generic MOSFET or IGBT: the class its capacitances are typical of. A larger part has more gate and output capacitance, and the package inductance (LG, LS, LD, a few nH each) is not in the part: draw it as inductors, or assign a vendor model, which has all of it. A part without any gate capacitance (one saved before) says so instead. The line is not shown for a part with a vendor model. No breakdown voltage is set, so a generic part used above its class does not clamp: set bv for avalanche. A part added with its own level-1 values (cgd, bodyDiode, rds_on or level) on a power symbol stays level 1, as does a vendor model's fit.

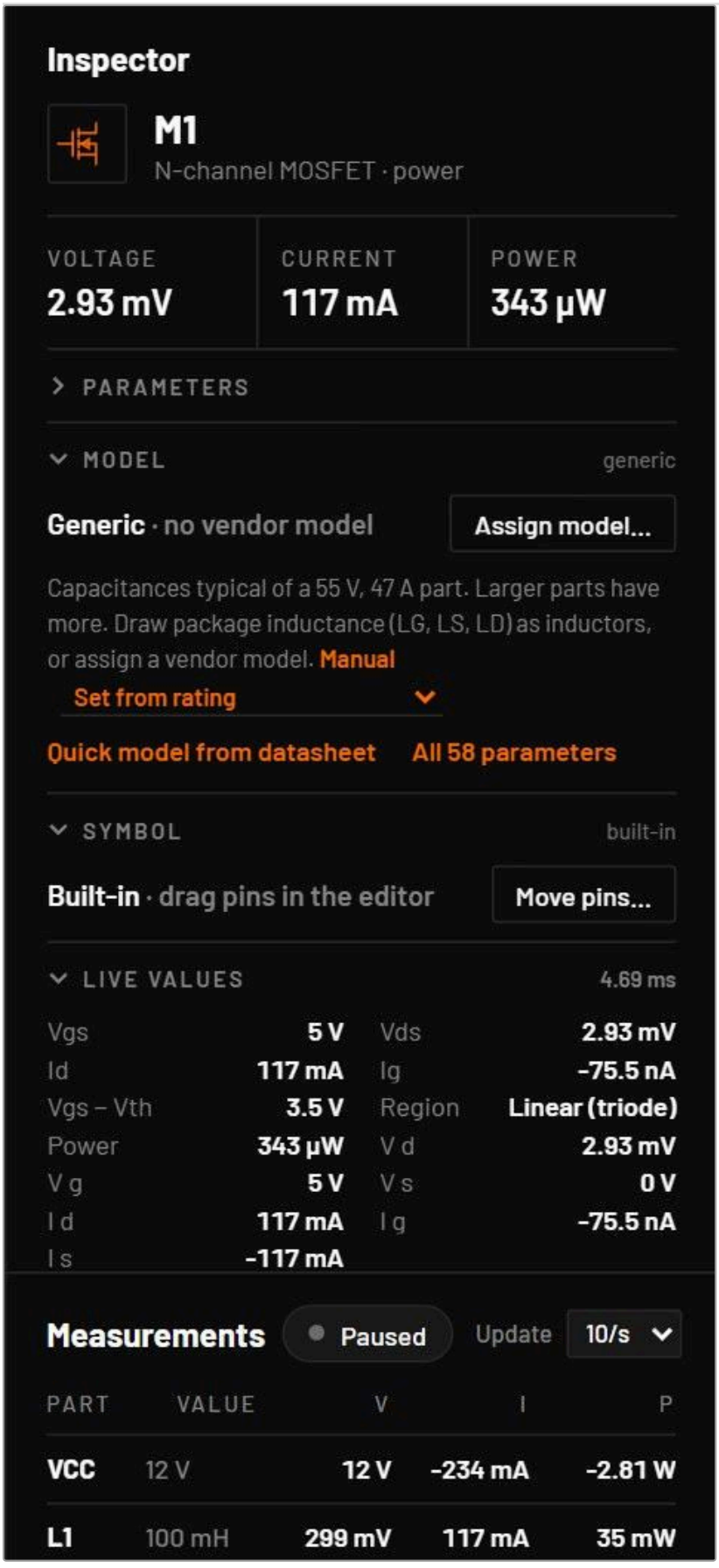


Figure 33.1 The inspector of a generic MOSFET: the quiet line under the model, ending in Set from rating.

On an N-channel MOSFET the line ends in **Set from rating**, a menu of five classes, each with the values of one real part fitted to its datasheet: 30 V 5 A (AO3400A), 60 V 30 A (FQP30N06L), 100 V 50 A (IRF3710), 650 V SiC 30 A (C3M0060065D) and 100 V GaN 30 A (EPC2204). A choice fills the whole model as one undo step, switches the symbol to power, SiC or GaN as the part needs, and the line then names the part. The gate charge of each is within the datasheet's typical or maximum values (docs/DEVICES.md lists them).

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Threshold	**vto**	V	2 (pmos -2)	any. Slider -10 to 10 V.	Default, inspector, Quick model, board import, card	Alias vt0.
Transconductance	**kp**	A/V^2	0.1	> 0	Default, inspector, Quick model, card	
Channel-length modulation	**lambda**	1/V	0.01	≥ 0	Default, inspector, Quick model, card	Output conductance in saturation.
Gate-source capacitance	**cgs**	F	0 (placed with 20 pF, P 50 pF)	≥ 0	Default, inspector, Quick model	A fixed capacitor (BetterSPICE, not ngspice). Quick model: C_iss - C_rss.
Gate-drain capacitance	**cgd**	F	0 (placed with 6 pF, P 10 pF)	≥ 0	Default, inspector, Quick model	A fixed capacitor. Quick model: C_rss.
On-resistance	**rds_on**	Ω		> 0	Default, inspector	Sets kp as above.
Body diode	**bodyDiode**	0 / 1	1 for power, gan, sic		Default, inspector	IS 1 pA, N 1.
Level	**level**		1	1 to 3	Vendor model card, All parameters tab	
Bulk effect	**gamma, phi**	√V, V	0, 0.6	≥ 0, > 0	Vendor model card, All parameters tab	
Resistances	**rd, rs, rsh, nrd, nrs**	Ω	0	≥ 0	Vendor model card, All parameters tab	
Junctions	**is, js, pb, cbd, cbs, cj, mj, cjsw, mjsw, fc**		is 10 fA, pb 0.8 V, others 0 or 0.5		Vendor model card, All parameters tab	
Overlap capacitances	**cgso, cgdo, cgbo**	F/m	0	≥ 0	Vendor model card, All parameters tab	
Process	**tox, uo, nsub, tpg, nss, ld, xj**		tox none, uo 600 cm^2/Vs		Vendor model card, All parameters tab	Derive vto, gamma, phi and kp when given.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Level 2 and 3	**delta, uexp, ucrit, vmax, neff, nfs, theta, eta, kappa, xl, wd, xw, delvto**		ngspice defaults		Vendor model card, All parameters tab	
Geometry	**l, w, ad, as, pd, ps**	m, m^2	l = w = 100 µm	> 0	Vendor model card, All parameters tab	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

VDMOS cards add vto (default ±3 V), kp (20 or 10 A/V^2), rd, rs, rg and rds. They also add quasi-saturation (rq, vq), the non-linear gate-drain capacitance (cgdmin, cgdmax, a), cgs, and a built-in body diode (is, n, rb, cjo, vj, m, tt, bv). Not implemented: self-heating and soft recovery. Typical values shown in empty fields of a new N-channel: vto 1.3 V, kp 0.2 A/V^2, cgs 20 pF, cgd 6 pF.

33.6 JFET (N, P)

TYPE	KEY	PINS	VARIANTS	CLASS
njf, pjf (J)	J	d, g, s	none	exact

The ngspice JFET with the Sydney University doping-tail parameter b. For a P-channel JFET, vto is entered as the P-channel value, positive for depletion.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Pinch-off voltage	**vto**	V	-2 (pjf +2)	any	Default, inspector, Quick model, board import, card	Quick model: -|V_GS(off)|.
Transconductance	**beta**	A/V^2	1 mA/V^2	> 0	Default, inspector, Quick model, card	Quick model: I_DSS / vto^2.
Channel-length modulation	**lambda**	1/V	0	≥ 0	Default, inspector, card	
Doping tail	**b**		1		Vendor model card, All parameters tab	
Resistances	**rd, rs**	Ω	0	≥ 0	Vendor model card, All parameters tab	
Capacitances	**cgs, cgd, pb, fc**	F, V	0, 0, 1, 0.5		Vendor model card, All parameters tab	
Gate junction	**is, n**	A, -	10 fA, 1		Vendor model card, All parameters tab	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Temperature	**tcv, vtotc, bex, betatce, xti, eg**		0, eg 1.11		Vendor model card, All parameters tab	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

33.7 IGBT

TYPE	KEY	PINS	VARIANTS	CLASS
igbt (Q)	library	c, g, e	none	approximate

A behavioural IGBT: an N-channel MOSFET behind a collector diode that gives the saturation knee. It has no reverse conduction: add an antiparallel diode for a co-pack.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Threshold	**vth**	V	5	any. Slider 1 to 10 V.	Default, inspector	
Transconductance	**kp**	A/V^2	1	> 0	Default, inspector	
V_CE(sat)	**vce_sat**	V	1.5	≥ 0	Default, inspector	On-state voltage scale at about 1 A.
Gate capacitances	**cgs, cgd**	F	0 (placed with 0.9 nF, 0.2 nF)	≥ 0	File or All parameters only	A new IGBT gets the values of a 600 V, 20 A part (IKW20N60T: C_ies 1.1 nF, Q_G 120 nC at 480 V). cgd is the mean C_res over the collector swing, so the gate charge is right (112 nC). Package inductance is drawn as inductors.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

34 Devices: amplifiers, power blocks and ICs

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These parts are behavioural models: fast enough for the live simulation and good for design, measured against vendor models and reference circuits (**Exact and approximate**, p. 34). When a vendor model is assigned, Simulate runs the vendor model instead. In a Simulate run that goes to ngspice because of another part's vendor model, behavioural parts without their own vendor model are left out with a warning, so give every IC a vendor model when you need ngspice results.

34.1 Op-amp

TYPE	KEY	PINS	VARIANTS	CLASS
opamp (U)	U	in+, in-, out (3-pin), v+, v- (5-pin), null1, null2 (8-pin), en (shutdown)	3pin (ideal, internal ±15 V rails), 5pin (supplies), 8pin (offset null pins, not loaded), sd (with shutdown)	approximate

A macromodel with gain, bandwidth, slew rate, offset, output swing and supply current. A slew-limited transconductance drives a dominant pole set so that the DC gain is **gain** and the unity-gain frequency **gbw**. The output follows, limited to the supplies minus **rail**, behind **rout**. The 3-pin variant has internal ±15 V rails. The shutdown variant turns its output off when **en** is below v- + 0.8 V.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Gain-bandwidth	**gbw**	Hz	1 MHz	> 0. Slider 1 kHz to 1 GHz.	Default, inspector, Quick model, vendor fit	Unity-gain frequency.
Slew rate	**slew**	V/s	1 V/µs	> 0	Default, inspector, Quick model, vendor fit	Type 0.5 V/µs as **500k**.
Rail headroom	**rail**	V	0 (rail to rail)	≥ 0	Default, inspector, Quick model, vendor fit	The output reaches each supply minus this.
Offset	**vos**	V	0	any	Default, inspector, Quick model, vendor fit	Input offset voltage.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Open-loop gain	**gain**	V/V	10^5	> 0	Default, inspector, Quick model (avol_db)	Not in dB.
Supply current	**iq**	A	1 mA	≥ 0	Default, inspector, Quick model	5-pin and shutdown variants.
Output resistance	**rout**	Ω	50	> 0	Default, inspector, Quick model	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Typical values shown for an ideal op-amp: gain 10^6, gbw 10 MHz, slew 10 V/µs, rout 1 Ω. General purpose: gbw 1 MHz, slew 0.5 V/µs, vos 2 mV, rail 1.5 V. Rail to rail: gbw 5 MHz, slew 3 V/µs, rail 20 mV. A vendor op-amp placed from the library uses parameters fitted by running its model, while Simulate runs the model itself.

34.2 Comparator

TYPE	KEY	PINS	VARIANTS	CLASS
comparator (U)	library	in+, in-, out, v+, v-	none	approximate

The output switches when V(in+) - V(in-) crosses +hyst/2 going up or -hyst/2 going down, and moves between the supplies in **tpd** behind 10 Ω. With **opendrain** it only pulls low.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Hysteresis	**hyst**	V	0	≥ 0. Slider 0 to 1 V.	Default, inspector, Quick model	Total band.
Propagation delay	**tpd**	s	100 ns	≥ 0	Default, inspector, Quick model	Output transition time.
Open drain	**opendrain**	No / Yes	No		Default, inspector, Quick model	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

34.3 Voltage reference

TYPE	KEY	PINS	VARIANTS	CLASS
vref (U)	library	out, gnd (series), cathode, anode, ref (shunt)	default (series reference), shunt (TL431 style)	approximate

The series reference is an ideal voltage behind rout. The shunt variant regulates V(ref) - V(anode) to v by sinking current from cathode to anode, like a TL431, and needs about 1 V of headroom.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Voltage	**v**	V	2.5	any. Slider 0.5 to 10 V.	Default, inspector, vendor fit	TL431: 2.495 V.
Output resistance	**rout**	Ω	0.1	> 0	Default, inspector	Series reference only.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

34.4 555 timer

TYPE	KEY	PINS	VARIANTS	CLASS
timer555 (U)	library	gnd, trig, out, reset, ctrl, thr, dis, vcc	none	approximate

The classic bipolar 555 by default. Three 5 kΩ resistors from vcc to gnd set ctrl at 2/3 of the supply. The trigger comparator works at ctrl/2 and the threshold comparator at ctrl. An SR latch, a reset below 0.7 V and a discharge transistor complete it: reset beats trigger, and trigger beats threshold. The output sits about 1.7 V below vcc when high, and the supply current is 3 mA. Driving the ctrl pin moves both thresholds. The 556 (**timer556**) is two of these sharing the supply, with the same parameters.

The inspector has no fields for it: right-click it and choose **Properties**, or press **All N parameters**, to open the **All parameters** tab, which lists the keys below in the groups Thresholds, Inputs, Output and Supply. **family** and **tdelay** (0.8.1) are not listed there yet: set them in the circuit file, through an AI agent, or by placing the circuit from the 555 calculator, which sets them for the chip you pick. Once set, they show in the tab under **Other**.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Family	**family**		bipolar	bipolar (NE555), cmos (TLC555, LMC555, ICM7555)	File or All parameters only	**cmos** changes the defaults to a CMOS 555: rdiv 100 kΩ, voh_drop 0 V and vol 0 V (rail to rail), rout 200 Ω (from the TLC555's 4.8 V high level at −1 mA on 5 V), iq 180 µA, ithr and itrig 10 pA. A key you set yourself wins over the family.
Divider resistor (each of 3)	**rdiv**	Ω	5 kΩ (cmos 100 kΩ)	≥ 1 Ω	File or All parameters only	The three equal resistors that set the 2/3 and 1/3 supply levels. They also load the control pin.
Threshold level	**kthr**		1		File or All parameters only	Of the control voltage (2/3 of the supply with the control pin open). The output goes low above it.
Trigger level	**ktrig**		0.5		File or All parameters only	Of the control voltage (1/3 of the supply). The output goes high below it.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Reset threshold	**vreset**	V	0.7		File or All parameters only	Below it the output is held low and the discharge is on.
Threshold pin current	**ithr**	A	0 (cmos 10 pA)		File or All parameters only	Current into the threshold pin (0.1 µA typical for the NE555). It matters with timing resistors of megohms.
Trigger pin current	**itrig**	A	0 (cmos 10 pA)		File or All parameters only	Current into the trigger pin (0.5 µA typical for the NE555).
High-level drop below the supply	**voh_drop**	V	1.7 (cmos 0)		File or All parameters only	
Low level	**vol**	V	0.1 (cmos 0)		File or All parameters only	
Output resistance	**rout**	Ω	10 (cmos 200)	> 0	File or All parameters only	
Discharge on resistance	**rdis**	Ω	10	> 0	File or All parameters only	The discharge transistor when on.
Output edge time	**tpd**	s	100 ns	> 0	File or All parameters only	How long the output and discharge edge takes.
Propagation delay	**tdelay**	s	0	≥ 0	File or All parameters only	From the comparator trip to the start of the output and discharge edge. The capacitor keeps charging or discharging for that time, so each half period grows: it matters at high frequency. Used by BetterSPICE's own engines, not exported to ngspice.
Supply current	**iq**	A	3 mA (cmos 180 µA)		File or All parameters only	
Threshold and trigger level tolerance	**kthr_tol, ktrig_tol**	%	0	≥ 0	File or All parameters only	The part-to-part spread a tolerance or Monte Carlo run draws for the two levels. Both halves of a 556 move together.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

An astable at 1 kHz

1. Open **Timing** and the 555 astable example, or build it with RA = 1 kΩ, RB = 6.8 kΩ, C = 100 nF.
2. Probe the output and the capacitor.

YOU SHOULD SEE The capacitor swings between 1/3 and 2/3 of the supply and the output toggles at f = 1.44 / ((RA + 2 RB) C) ≈ 990 Hz.

34.5 Power block

TYPE	KEY	PINS	VARIANTS	CLASS
reg (U)	B	in, out, gnd (iso: in, out, gnd1, gnd2, the two sides joined only by r_iso and c_iso)	ldo, buck, boost, buckboost, chargepump, iso, ref (the kind)	approximate

A fast averaged regulator for system-level design: the output follows a target with a first-order lag, with a current limit, efficiency, quiescent current and ripple. Targets: LDO = min(vset, vin - vdo). Buck = min(vset, 0.95 vin). Boost = max(vset, vin - 0.4 V). Buck-boost and isolated = vset. Charge pump = mult · vin (-1 inverting, 2 doubler). Reference = vset. The block is off below its UVLO. A switcher adds a triangle ripple at fsw only when the timestep is short enough to show it. An LDO passes input ripple attenuated by its PSRR.

For real IC pinouts with enable, feedback and switching nodes, use the LDO, buck and boost ICs (**Power ICs**, p. 336).

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Kind	**kind**		ldo	ldo, buck, boost, buckboost, chargepump, iso, ref	Default, inspector	Set by the variant when placed.
Output voltage	**vset**	V	5	any. Slider 0.5 to 48 V.	Default, inspector	
Dropout	**vdo**	V	0.3	≥ 0	Default, inspector	LDO.
Current limit	**ilim**	A	1	> 0	Default, inspector	
Output resistance	**rout**	Ω	0.05	> 0	Default, inspector	Load regulation.
Quiescent current	**iq**	A	1 mA	≥ 0	Default, inspector	
PSRR	**psrr_db**	dB	60	≥ 0	Default, inspector	LDO ripple rejection.
Efficiency	**eff**		0.9	0.01 to 1	Default, inspector	Switchers. Input power = output power / eff.
Switching frequency	**fsw**	Hz	500 kHz	> 0	Default, inspector	Ripple frequency.
Ripple	**ripple**		0.02	≥ 0	Default, inspector	Peak to peak, as a fraction of the output.
Response time	**tau**	s	20 µs	> 0	Default, inspector	Output lag.
Charge pump gain	**mult**		-1 (2 for doubler)		File or All parameters only	
UVLO	**uvlo**	V	1		File or All parameters only	Input voltage for full operation.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Typical values shown per kind: LDO vset 3.3 V, vdo 250 mV, iq 55 µA, ilim 750 mA, PSRR 65 dB. Buck and buck-boost 5 V, boost 12 V, eff 0.9, fsw 500 kHz, ilim 2 A.

34.6 Mixed-signal building blocks

The blocks below measure every voltage relative to their own **gnd** pin. Their digital inputs switch at **vth** (default half of vhi) with hysteresis **hyst** (default 2 % of vhi) and load their net with 1 GΩ. Their outputs are **vhi** (default 5 V) behind **rout** with smooth edges of **tr** (default 10 ns). Sample instants and edges are exact breakpoints. They all show in the logic analyzer.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Output high	**vhi**	V	5	any	Default, inspector	
Input threshold	**vth**	V	vhi / 2	any	Default, inspector	
Input hysteresis	**hyst**	V	2 % of vhi	≥ 0	Default, inspector	
Output resistance	**rout**	Ω	50 (1 for DAC, S/H, PID, filter, LUT)	> 0	Default, inspector	
Edge time	**tr**	s	10 ns	> 0	Default, inspector	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

BLOCK	TYPE	PINS	WHAT IT DOES	ITS OWN PARAMETERS (DEFAULT)
PWM generator	**pwmgen**	ctrl, out, gnd	A sawtooth at freq compared with the control voltage. Duty = (V(ctrl) - vramp_lo) / (vramp_hi - vramp_lo).	freq (100 kHz), vramp_lo (0 V), vramp_hi (1 V), vhi (5 V), rout (10 Ω), tr (10 ns)
ADC	**adc**	ain, clk, d0 … d(bits-1), gnd	Samples at fs, or on each rising clk edge when fs = 0. Code = round(V / LSB), LSB = vref / 2^{bits}, ready after tconv. arch = sigma_delta makes a first-order modulator with sinc decimation.	bits (8), fs (100 kHz, placed 1 MHz), vref (= vhi, placed 3.3 V), tconv (half a sample), osr (64), arch (sar)
DAC	**dac**	d0 … d(bits-1), out, gnd	Output = code · vref / 2^{bits}, settling in tsettle.	bits (8), vref (= vhi, placed 3.3 V), tsettle (1 µs), rout (1 Ω)
Sample and hold	**sh**	in, ctrl, out, gnd	Tracks while ctrl is high, holds on an internal 1 nF while low.	tacq (1 µs), droop (0 V/s)
VCO	**vco**	ctrl, out, gnd	f = f0 + kvco · V(ctrl), clamped to fmin and fmax, square output.	f0 (1 kHz, placed 100 kHz), kvco (1 kHz/V, placed 10 kHz/V), fmin, fmax, duty (0.5)
Phase-frequency detector	**pfd**	ref, fb, up, dn, gnd	A ref edge sets up, an fb edge sets dn, both reset when both are set.	none
Frequency divider	**divider**	in, out, gnd	Divides the input edge count by n.	n (2)

BLOCK	TYPE	PINS	WHAT IT DOES	ITS OWN PARAMETERS (DEFAULT)
PID controller	**pid**	in, sp, out, gnd	Discrete PID at fs on e = V(sp) - V(in), clamped with anti-windup.	kp (1), ki (0), kd (0), fs (10 kHz, placed 100 kHz), out_min (0), out_max (5 V, placed 1 V)
Digital filter	**filter**	in, out, gnd	Samples at fs and runs an FIR, IIR or biquad cascade. coeffs: a list of taps, **{"b": [...], "a": [1, ...]}**, or **[b0, b1, b2, a1, a2]** per section.	kind (fir, placed iir), coeffs (none = pass through), fs (10 kHz, placed 100 kHz)
Lookup table	**lut**	in, out, gnd	out = table(V(in)), continuous. x must rise. Ends hold.	table ([[0, 0], [1, 1]]), interp (linear, cubic, step)
Dead-time generator	**deadtime**	in, outA, outB, gnd	outA follows the input, outB is its complement, every rising edge delayed by td.	td (100 ns)
Soft-start	**softstart**	en, out, gnd	Ramps to vset in tss when en goes high, down in tdis when low.	vset (1 V), tss (1 ms), tdis (10 µs)
UVLO	**uvlo**	in, out, gnd	Output high above von, low below voff, after tpd.	von (4.5 V), voff (von - 0.5 V), tpd (100 ns)
Over-current protection	**ocp**	cs, out, gnd	Faults when V(cs) ≥ vth for tdelay. Latches, or retries after tretry.	vth (0.1 V), tdelay (1 µs), latch (1), tretry (1 ms), invert (0)
State machine	**fsm**	in0 ..., out0 ..., gnd	States with output bits and transitions with a condition over the inputs and an optional dwell time.	inputs (2), outputs (2), states, transitions, initial, clk (0 = event driven)

34.7 Editing the filter, lookup table and state machine

The filter coefficients, the lookup table and the state machine are edited as tables in the inspector, under the block's own fields, in the same look as the PWL points table. You don't write the JSON. An old circuit that stores them as JSON text opens in the tables too.

BLOCK	WHAT THE INSPECTOR SHOWS
Digital filter	The table follows the **Kind**. **FIR**: one row per tap **h**, with the sum of the taps under it (the DC gain). **IIR**: a table of the numerator **b** and one of the denominator **a**, with the difference equation under them. **a[0]** may not be 0. **Biquad**: a table of sections with columns **b0 b1 b2 a1 a2** (a0 = 1), run in series.
Lookup table	Two columns, **In (V)** and **Out (V)**, at least two rows. The rows sort themselves by input, and outside the table the end values hold.
State machine	**States**: a name and the output bits for each state (out0 first, as many bits as **Outputs**), and a **Starts in** list for the initial state. **Transitions**: two lines each. The first has **From** (a state, or ***** for any) and **To**. The second has **After** (the dwell time, such as **5m**) and **When** (the condition over in0, in1 ..., empty means always).

- Each cell takes a number with SI prefixes (**1k**, **5m**). Enter or Tab applies it, Esc puts the stored value back. **+** on a row inserts a copy of it after the row, **×** deletes it, **+ Add row** (**+ Add state**, **+ Add transition**) appends one. One change is one undo step.
- Renaming a state renames it in the transitions and in **Starts in**. Deleting a state drops the transitions that use it.

- A bad entry isn't saved. A line in red says why: a state name must be letters, digits and underscores, and unique. The output bits must be as many 0 and 1 as Outputs says. A time must be 0 or more. A condition may use only in0 …, **!**, **&&**, **||**, parentheses, **true** and **false**.

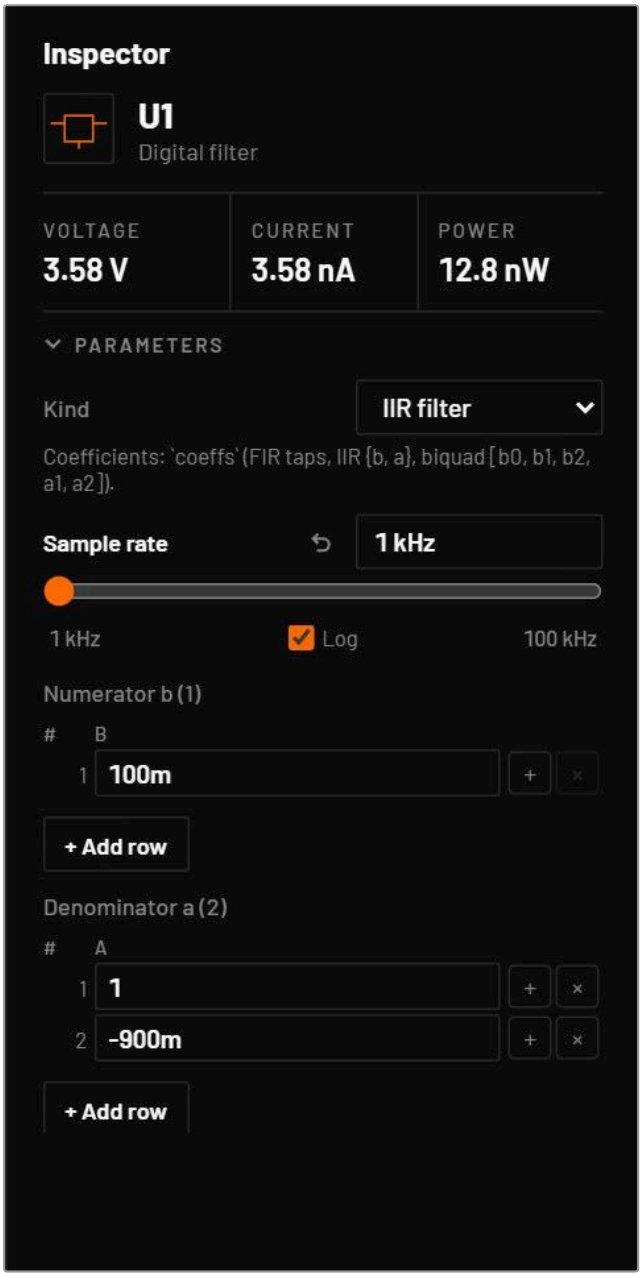


Figure 34.1 An IIR digital filter: the numerator b and denominator a as tables.

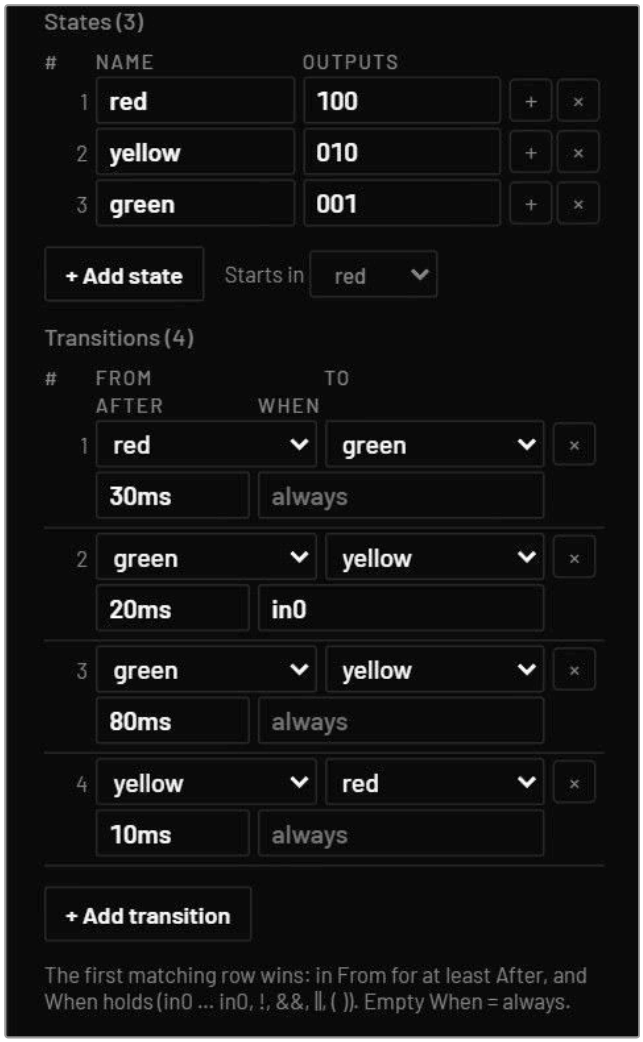


Figure 34.2 A state machine: the states with their output bits, the starting state, and the transitions on two lines each.

State machine example

```
"states": [ { "name": "idle", "out": "00" }, { "name": "run", "out": "10" }, { "name": "done", "out":
"01" } ],
"transitions": [
  { "from": "idle", "to": "run",  "when": "in0 && !in1" },
  { "from": "run",  "to": "done", "after": 0.002 },
  { "from": "*",    "to": "idle", "when": "in1" } ]
```

The same machine in the file. A condition uses **in0**, **in1** …, **true**, **false**, **!**, **&&**, **||** and parentheses. **after** is the time in the state before the transition may fire. The first matching transition wins. **"*"** matches every state.

34.8 Generic IC box (subcircuit)

TYPE	KEY	PINS	VARIANTS	CLASS
subckt (X)	X	From its pinout, for example **1:l 2:l 3:r 4:r**	none	approximate

A box with any number of pins for a vendor subcircuit. It is the one **Generic IC** tile of the library. **pinout** lists the pins as name:side (l, r, t, b) and **title** is drawn in the box. In the inspector they are the **Pins** field (one entry for each pin, with the count, names and sides shown) and **Title on the symbol**. A space can be typed in them, and the text is tidied when you leave the field. **Assign model** takes a vendor subcircuit, and **Move pins** opens the symbol editor to drag the pins to new places. With no model its pins are open and it warns **W_NO_MODEL**. Double-click it, or right-click it and choose **Edit subcircuit**, to build its inside yourself: it becomes a sheet with one port per pin (**Editing a subcircuit**, p. 151). With a vendor model and no behavioural equivalent it runs only in Simulate, and the live simulation leaves its pins open with a message. With **equiv** (a behavioural part and a pin list) the live simulation runs that equivalent. Placing a vendor model from the library normally places it as the fitted device type instead, so the IC box is mainly for models with their own pins.

35 Devices: relays, switches, motors and audio

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Relays, switches and buttons, motors and actuators, buzzers and speakers. The parameter tables use the same columns as **Devices: passives**, p. 265. Every part has labelled fields with units in the inspector and in All parameters, and the live stimulus of a sensor (light, temperature, field, strain, distance, load) is its main field, first in the list, with a slider range that fits it. A field that shows *auto* takes a value derived from other parameters until you type one (for example the must-operate voltage of a relay is 0.75 of its coil voltage). Clear it to go back. A variant placed from the library starts with its own typical values, such as 1 kΩ for a Pt1000 or 1.2 V dropout for an AMS1117. A part placed from the library can start with its own values, and a part made with the Part Wizard takes them from its datasheet fields (**Part templates reference**, p. 606).

35.1 Relays

TYPE	PINS	VARIANTS	CLASS
relay (K)	spdt: coil+, coil-, com, no, nc. spst_no and reed: coil+, coil-, com, no. spst_nc: coil+, coil-, com, nc. dpst_no: 6 pins. dpdt: coil+, coil-, com1, no1, nc1, com2, no2, nc2. 4pdt: 14 pins.	spdt, spst_no, spst_nc, dpst_no, dpdt, 4pdt, reed	approximate, coil exact (verified ±0.01 %)

A real relay: the coil is a resistance in series with an inductance that grows as the armature closes, and the armature picks up when the coil current reaches vpick / rcoil and drops out below vdrop / rcoil, so pick-up and drop-out are found to the exact instant. t_op and t_rel are the datasheet operate and release times: a step to the rated coil voltage closes the NO contact t_op later, the rise of the coil current to pick-up included, and removing the coil power closes the NC contact t_rel later. A lower coil voltage, a hot coil or a flyback diode makes the relay slower, as on the bench. Normally closed contacts open when the armature is 40 % of the way, so a changeover contact breaks before it makes. A pulse shorter than the travel time never closes the NO contact. Placed from the library (K): 5 V coil, 70 Ω, 50 mΩ contacts, 5 ms operate, 3 ms release.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Nominal coil voltage	**vcoil**	V	5	> 0	Default, inspector, part file	Sets the default pick-up and drop-out. A coil voltage above 1.5 x vcoil warns.
Coil resistance	**rcoil**	Ω	70 (reed 500)	> 0	Default, inspector, part file	Datasheet coil resistance, or V^2 / P.
Must-operate voltage	**vpick**	V	0.75 x vcoil	> 0	Default, inspector, part file	
Must-release voltage	**vdrop**	V	0.1 x vcoil	≥ 0, below vpick	Default, inspector, part file	
Operate time	**t_op**	s	5 ms (reed 0.5 ms)	≥ 0	Default, inspector, part file	Datasheet operate time: from the rated coil voltage applied to the NO contact closed.
Release time	**t_rel**	s	3 ms (reed 0.1 ms)	≥ 0	Default, inspector, part file	Datasheet release time without a diode: from the coil power removed to the NC contact closed.
Contact resistance	**ron**	Ω	0.05 (reed 0.15)	> 0, below roff	Default, inspector, part file	
Open resistance	**roff**	Ω	1 GΩ	> 0	File or All parameters	
Coil inductance, open	**lcoil**	H	50 mH (reed 5 mH)	≥ 0	File or All parameters	
Coil inductance, closed	**lcoil_closed**	H	1.5 x lcoil	≥ 0	File or All parameters	
Contact bounce	**bounce**	s	0	≥ 0	Default, inspector, part file	Each closing bounces open three times inside this window.
Rated contact current	**imax**	A	10 (reed 0.5)	> 0	Default, inspector, part file	Warns when a contact carries more.
Max switching voltage	**vmax**	V	250	> 0	Default, inspector, part file	Warns when an open contact sees more.
Coil diode	**diode**	0 / 1	0		Default, inspector, part file	A suppression diode across the coil. It also makes the coil polarised.
Polarised coil	**polar**	0 / 1	0		File or All parameters	Only positive coil current operates it.
Initial state	**state**	0 / 1	0		File or All parameters	1 starts operated.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Readouts: state, armature position and coil current. The logic analyzer shows **coil** and **state**.

TRY IT

Hear the flyback spike

1. Place a 5 V source, a switch, the relay coil and ground in series. Probe the coil+ pin.
2. Run, click the switch closed, then open.

YOU SHOULD SEE Opening the switch makes a large negative spike on the coil, the stored energy of its inductance. Set the relay's diode to 1 and the spike is clamped to about -0.7 V, and the release gets slower.

35.2 Latching relays

TYPE	PINS	VARIANTS	CLASS
relay_latch (K)	single_coil: coil+, coil-, com, no, nc. single_coil_2p: 8 pins. dual_coil: set+, set-, reset+, reset-, com, no, nc. dual_coil_2p: 10 pins.	single_coil, single_coil_2p, dual_coil, dual_coil_2p	approximate

A single-coil latch sets on a positive coil pulse and resets on a negative one. A dual-coil latch has separate set and reset coils. With no coil current it holds its state, and part way through a move the magnet pulls it to the nearer end. Clicking the part toggles it like the test lever. Placed (Shift + K): 5 V, 125 Ω, 3 ms, 10 ms minimum pulse.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Nominal coil voltage	**vcoil**	V	5	> 0	Default, inspector, part file	
Coil resistance	**rcoil**	Ω	125	> 0	Default, inspector, part file	
Set / reset voltage	**vpick**	V	0.75 x vcoil	> 0	Default, inspector, part file	
Set time	**t_op**	s	3 ms	≥ 0	Default, inspector, part file	Also the reset time.
Minimum pulse width	**pulse_min**	s	10 ms	≥ 0	Default, inspector, part file	A switch on a shorter pulse warns **W_LATCH_MARGIN**.
Contact resistance	**ron**	Ω	0.05	> 0	Default, inspector, part file	
Rated contact current	**imax**	A	2	> 0	Default, inspector, part file	
State	**state**	0 / 1	0		Click it on the canvas	Set or reset.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Energising both coils of a dual-coil latch at once doesn't move it and warns **W_LATCH_BOTH**.

35.3 Solid-state relays

TYPE	PINS	VARIANTS	CLASS
ssr (K)	in+, in-, out1, out2	dc (MOSFET output), ac (triac, zero cross), photomos (AC and DC)	approximate, LED exact

An LED input that turns the output on above if_on and off below if_off, after t_on or t_off. The dc output is a MOSFET with a body diode from out2 to out1. The photomos output conducts both ways. The ac output is a triac: it fires only when the output voltage is below vzc and stays on until its current falls below ih, so a DC load never turns it off.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Input operate current	**if_on**	A	5 mA	> 0	Default, inspector, part file	
Input release current	**if_off**	A	0.4 x if_on	> 0, below if_on	File or All parameters	
LED forward voltage	**vf**	V	1.2	> 0	Default, inspector, part file	At 10 mA.
Turn-on time	**t_on**	s	100 µs	≥ 0	Default, inspector, part file	
Turn-off time	**t_off**	s	100 µs	≥ 0	Default, inspector, part file	
On resistance	**ron**	Ω	0.1	> 0	Default, inspector, part file	
Off resistance	**roff**	Ω	10 MΩ (ac 1 MΩ)	> 0	File or All parameters	
On-state voltage	**vtm**	V	1.0	≥ 0	Default, inspector, part file	ac only.
Holding current	**ih**	A	50 mA	> 0	Default, inspector, part file	ac only.
Zero-cross window	**vzc**	V	15	≥ 0	Default, inspector, part file	ac only.
Rated load current	**imax**	A	2	> 0	Default, inspector, part file	Warns when exceeded.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

35.4 Switches and buttons

TYPE	PINS	VARIANTS	CLASS
sw (SW)	spst, push_no, push_nc, reed: com, a. spdt, toggle, slide: com, a, b. dpst: com1, a1, com2, a2. dpdt: com1, a1, b1, com2, a2, b2. tact4: a1, a2, b1, b2. micro: com, nc, no. dip1 … dip10: two pins per switch. rotary: com, p1 … p8.	spst, spdt, toggle, slide, dpst, dpdt, push_no, push_nc, tact4, micro, reed, dip1 … dip10, rotary	approximate

Real switch contacts with resistance, bounce and break-before-make. Click a switch while the circuit runs: a toggle changes position, a push button is pressed while you hold the mouse button, a rotary switch steps to its next position. A tactile switch joins a1 to a2 and b1 to b2 permanently, and a1 to b1 while pressed. A reed switch closes when **state** is 1 or the applied field reaches b_close, and opens below 60 % of it. A DIP switch's **state** is a bit mask: bit k closes switch k + 1. Click a DIP switch on the canvas and the one under the pointer flips (the row from its **com** pin to its **a** pin that is nearest), so one click on switch 3 and then one on switch 1 gives a mask of 5. The Activity tab records it, for example *SW1: switch 3 on*. The core switch (key S, **Devices: passives**, p. 265) is a simpler two-pin version.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Position	**state**		0	0 to 1023, a whole number below the number of positions	Click it on the canvas, part file	Lever position, pressed state, DIP bit mask or rotary position.
Contact resistance	**ron**	Ω	0.02	> 0, below roff	Default, inspector, part file	Can change while running.
Open resistance	**roff**	Ω	1 GΩ	> 0	File or All parameters	
Bounce time	**bounce**	s	0	≥ 0	Default, inspector, part file	Three bounces on every closing. 2 ms is realistic for a tactile switch.
Break-before-make gap	**t_break**	s	1 ms for changeover types, 0 otherwise	≥ 0	File or All parameters	
Rotary positions	**positions**		8	2 to 8	Default, inspector, part file	
Reed closing field	**b_close**	T	1 mT	> 0	File or All parameters	
Applied field	**b_field**	T	0	≥ 0	Live slider	Reed only.
Rated current	**imax**	A	50 mA for buttons and DIP, 3 A otherwise	> 0	Default, inspector, part file	Warns when exceeded.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

See contact bounce on a button

1. Place a 5 V source, a 10 kΩ pull-up, a push button (sw, push_no) to ground, and probe the node.
2. Set the button's bounce to **2m** and the timebase to 10 ms per second.
3. Click and hold the button.

YOU SHOULD SEE The node falls to 0 V with three short bounces back up inside the first 2 ms. A logic input on that node would count several presses.

35.5 DC motors

TYPE	PINS	VARIANTS	CLASS
dcmotor (M)	+, -	brushed, fan, vibration, gear	approximate, verified ±0 % at no load

An armature resistance and inductance with a back-EMF ke · ω, and a rotor with inertia, viscous friction and a load torque: J dω/dt = kt · i - b ω - T_load, with kt = ke. All of it comes from datasheet numbers: R = v_rated / i_stall, ke from the no-load speed and current, J from the mechanical time constant. A fan adds an aerodynamic load that rises with speed squared. Reversing the voltage reverses it, and driving it from outside makes it a generator. Readouts: rpm (of the output shaft), torque, mechanical power and efficiency.

The **gear** variant places a yellow TT gear motor: 6 V, a motor of 10 000 rpm at no load, a 1:48 gear (so about 208 rpm at the output), 1.5 A stall and 0.15 A no load. The two shafts differ: **No-load speed** belongs to the motor shaft, while the **rpm** readout and the **Load torque** belong to the output shaft after the gear.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Rated voltage	**v_rated**	V	12	> 0	Default, inspector, part file	
No-load speed	**rpm_noload**	rpm	3000	> 0	Default, inspector, part file	At v_rated, of the **motor shaft**, before any gear. The **rpm** live value is the output shaft: this number divided by the gear ratio.
Stall current	**i_stall**	A	1	> 0	Default, inspector, part file	Sets R = v_rated / i_stall.
No-load current	**i_noload**	A	0.05	≥ 0, below i_stall	Default, inspector, part file	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Armature inductance	**l**	H	1 mH	≥ 0	Default, inspector, part file	
Mechanical time constant	**tau_mech**	s	50 ms	> 0	Default, inspector, part file	Start-up to 63 %.
Load torque	**t_load**	N·m	0	≥ 0	Live slider	
Gear ratio	**gear**		1	> 0	Default, inspector, part file	Gear variant: output speed = motor speed / gear. The load torque acts on the output shaft.
Commutation ripple	**ripple, segments**		0, 3	0 to 0.3, 1 to 64	Default, inspector, part file	Adds current ripple at segments x 2 per revolution.
Max current	**i_max**	A	2 x i_stall	> 0	Default, inspector, part file	Warns when exceeded, and when stalled above 80 % of i_stall for 2 s.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

Load a motor

1. Place a 12 V source and a DC motor. Probe the motor current.
2. Run, then drag the motor's load torque slider up.

YOU SHOULD SEE The current starts high, falls to the no-load 50 mA as the motor reaches 3000 rpm, then rises as you add load while the rpm readout falls.

35.6 Stepper motors

TYPE	PINS	VARIANTS	CLASS
stepper (M)	bipolar: a+, a-, b+, b-. unipolar6: a1, acom, a2, b1, bcom, b2. unipolar5 (28BYJ-48): com, a1, b1, a2, b2.	bipolar, unipolar6, unipolar5	approximate, windings exact

Two phases with resistance, inductance and a back-EMF that depends on the rotor angle, a detent torque, inertia and damping. Full, half and micro stepping, resonance, missed steps and the fall of current at speed all come out of the equations. Readouts: shaft angle, rpm and step.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Steps per revolution	**steps**		200	> 0	Default, inspector, part file	
Phase resistance	**r_phase**	Ω	2.8	> 0	Default, inspector, part file	Per half winding for unipolar.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Rated phase current	**i_rated**	A	1	> 0	Default, inspector, part file	
Holding torque	**t_hold**	N·m	0.4	> 0	Default, inspector, part file	Two phases at i_rated.
Phase inductance	**l_phase**	H	3 mH	≥ 0	Default, inspector, part file	
Rotor inertia	**j**	kg·m^2	5.4 x 10^{-6}	> 0	Default, inspector, part file	
Detent torque	**t_detent**	N·m	0.02	≥ 0	Default, inspector, part file	
Viscous damping	**b**	N·m·s	10^{-4}	≥ 0	Default, inspector, part file	
Load torque	**t_load**	N·m	0	≥ 0	Live slider	
Gear ratio	**gear**		1	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

35.7 BLDC motors

TYPE	PINS	VARIANTS	CLASS
bldc (M)	sensorless: u, v, w. hall: u, v, w, ha, hb, hc, hvcc, hgnd	sensorless, hall	approximate

Three star-connected phases with a trapezoidal (or sine) back-EMF. The Hall variant has three open-drain sensor outputs that need pull-ups.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Velocity constant	**kv**	rpm/V	1000	> 0	Default, inspector, part file	
Phase resistance	**r_phase**	Ω	0.1	> 0	Default, inspector, part file	
Magnet poles	**poles**		14	2 to 100	Default, inspector, part file	
Phase inductance	**l_phase**	H	20 µH	≥ 0	Default, inspector, part file	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Rotor inertia	**j**	kg·m^2	2 x 10^{-6}	> 0	Default, inspector, part file	
Load torque	**t_load**	N·m	0	≥ 0	Live slider	
Back-EMF shape	**emf**		trap	trap, sine	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

35.8 Solenoids, servos and encoders

TYPE	PINS	VARIANTS	CLASS
solenoid (L)	+, -	pull, push, valve, lock (same physics)	approximate, coil exact

A coil whose inductance grows as the plunger moves in, with the plunger's mass, a return spring and end stops, so the current dips at pull-in as on a real solenoid.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Rated voltage	**v_rated**	V	12	> 0	Default, inspector, part file	
Coil resistance	**r**	Ω	24	> 0	Default, inspector, part file	
Travel	**stroke**	m	5 mm	> 0	Default, inspector, part file	
Inductance out / in	**l_out, l_in**	H	20 mH, 60 mH	> 0, l_out < l_in	Default, inspector, part file	
Pull-in time	**t_move**	s	10 ms	> 0	Default, inspector, part file	
Pull-in current	**i_pull**	A	0.7 x v_rated / r	> 0	Default, inspector, part file	
Drop-out current	**i_release**	A	0.3 x v_rated / r	≥ 0, below i_pull	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
servo (M)	sig, vcc, gnd	analog, digital, continuous	approximate

Measures each pulse on sig and moves the horn towards the matching angle at its slew rate, which scales with the supply. Analog and continuous servos stop holding 25 ms after the last pulse, digital servos keep holding. A continuous servo turns at a speed set by the pulse width.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Travel	**range**	°	180	> 0	Default, inspector, part file	
Slew rate	**speed**	°/s	600	> 0	Default, inspector, part file	At 5 V.
Pulse at 0° / full range	**pw_min, pw_max**	s	1 ms, 2 ms	> 0, pw_min < pw_max	Default, inspector, part file	
Minimum supply	**v_min**	V	4	≥ 0	Default, inspector, part file	
Idle / stall current	**i_idle, i_stall**	A	6 mA, 0.8 A	≥ 0	Default, inspector, part file	
Initial angle	**angle**	°	90	any	Default, inspector, part file	
Signal threshold	**vth**	V	1.5	> 0	Default, inspector, part file	
Deadband	**deadband**	s	4 µs	≥ 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
encoder (SW)	3pin: A, C, B. 5pin: plus S1, S2 (push switch)	3pin, 5pin	approximate

A mechanical quadrature encoder: contacts A and B close in quadrature as the shaft turns, A leading B for increasing position, both open at a detent. Change **pos** to turn it one detent per 20 ms, or set **rpm** to turn it continuously.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Pulses per revolution	**ppr**		20	1 to 1000	Default, inspector, part file	
Detents per revolution	**detents**		20	1 to 1000	Default, inspector, part file	
Shaft position	**pos**	detents	0	any	Live slider	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Continuous speed	**rpm**	rpm	0	±100 000	Live slider	
Contact resistance	**ron**	Ω	2	> 0	Default, inspector, part file	
Bounce	**bounce**	s	0	≥ 0	Live slider	
Push switch	**push**	0 / 1	0		Live slider	5pin.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

35.9 Buzzers and speakers

TYPE	PINS	VARIANTS	CLASS
buzzer (BZ)	+, -	magnetic, piezo (passive), active, active_piezo (self-oscillating)	approximate

A passive magnetic buzzer is its coil plus a tuned motional network. A passive piezo is a capacitance with a motional branch. An active buzzer draws v_rated / i_rated above v_min with a small ripple at its tone. The **spl** readout is the relative sound level, 0 to 1.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Frequency	**f0**	Hz	2700 (piezo 4000)	> 0	Default, inspector, part file	
Rated voltage	**v_rated**	V	5	> 0	Default, inspector, part file	
Rated current	**i_rated**	A	30 mA	> 0	Default, inspector, part file	
Coil resistance	**r**	Ω	16	> 0	Default, inspector, part file	Magnetic.
Coil inductance	**l**	H	1.5 mH	> 0	Default, inspector, part file	Magnetic.
Capacitance	**c**	F	20 nF	> 0	Default, inspector, part file	Piezo.
Mechanical Q	**q**		8	> 0	Default, inspector, part file	
Minimum voltage	**v_min**	V	3	≥ 0	Default, inspector, part file	Active.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
speaker (LS)	+, -	none	approximate

The Thiele-Small electrical equivalent: voice-coil resistance and inductance, then the motional resonance at fs set by qms and qes. Warns above its rated power.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Nominal impedance	**z**	Ω	8	> 0	Default, inspector, part file	Sets re.
Voice-coil resistance	**re**	Ω	0.8 x z	> 0	Default, inspector, part file	
Voice-coil inductance	**le**	H	0.1 mH	≥ 0	Default, inspector, part file	
Resonance frequency	**fs**	Hz	150	> 0	Default, inspector, part file	
Mechanical / electrical Q	**qms, qes**		3, 0.8	> 0	Default, inspector, part file	
Rated power	**p_rated**	W	1	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36 Devices: sensors, optoelectronics and displays

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Optocouplers, thermal parts, crystals and oscillators, light and field sensors, LED assemblies, displays and lamps. The parameter tables use the same columns as **Devices: passives**, p. 265. Every part has labelled fields with units in the inspector and in All parameters, and the live stimulus of a sensor (light, temperature, field, strain, distance, load) is its main field, first in the list, with a slider range that fits it. A field that shows *auto* takes a value derived from other parameters until you type one (for example the must-operate voltage of a relay is 0.75 of its coil voltage). Clear it to go back. A variant placed from the library starts with its own typical values, such as 1 kΩ for a Pt1000 or 1.2 V dropout for an AMS1117. A part placed from the library can start with its own values, and a part made with the Part Wizard takes them from its datasheet fields (**Part templates reference**, p. 606).

36.1 Optocouplers and opto sensors

TYPE	PINS	VARIANTS	CLASS
opto (U)	transistor, darlington, slot, reflective: anode, cathode, collector, emitter. transistor_b: plus base. triac, triac_zc: anode, cathode, mt1, mt2. logic: anode, cathode, vcc, out, gnd, en.	transistor (PC817), transistor_b (4N25), darlington, triac (MOC3021), triac_zc (MOC3041), logic (6N137), slot (photo-interrupter), reflective (TCRT5000)	approximate, verified ±0.33 % (PC817 class)

An input LED whose current, filtered with the rise time, drives a photocurrent into the base of an output transistor. Saturation emerges from the transistor model. The triac outputs fire above ift and hold above ih, the zero-cross version only while the output voltage is below vinh. The logic output is an open collector that pulls low while the LED is above if_th and en is high, after tp. The slot interrupter has **blocked** and the reflective sensor **reflect**, both live sliders.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Current transfer ratio	**ctr**	A/A (1 = 100 %)	1 (darlington 5, slot 0.2, reflective 0.05)	> 0	Default, inspector, part file	At if_test.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
LED forward voltage	**vf**	V	1.2	> 0	Default, inspector, part file	At if_test.
Test current	**if_test**	A	10 mA	> 0	Default, inspector, part file	
CTR exponent	**ctr_exp**		0	-1 to 2	Default, inspector, part file	CTR · (I_F / if_test)^{ctr_exp}. 0 is constant.
Output transistor gain	**bf**		300	> 0	Default, inspector, part file	
Rise / fall time	**tr**	s	4 µs (darlington 60 µs)	> 0	Default, inspector, part file	
Dark current	**iceo**	A	10 nA	≥ 0	Default, inspector, part file	
Max collector-emitter voltage	**bvceo**	V	70	> 0	Default, inspector, part file	Warns when exceeded.
Slot interrupted	**blocked**	0 to 1	0		Live slider	Slot only.
Reflectance	**reflect**	0 to 1	1		Live slider	Reflective only.
Triac trigger current	**ift**	A	10 mA	> 0	Default, inspector, part file	
Triac holding current	**ih**	A	100 µA	> 0	Default, inspector, part file	
Triac on-state voltage	**vtm**	V	1.8	> 0	Default, inspector, part file	At 100 mA.
Zero-cross inhibit voltage	**vinh**	V	20	> 0	Default, inspector, part file	triac_zc only.
Logic LED threshold	**if_th**	A	5 mA	> 0	Default, inspector, part file	
Logic propagation delay	**tp**	s	50 ns	≥ 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36.2 Fuses and circuit breakers

TYPE	PINS	VARIANTS	CLASS
fuse (F)	a, b	very fast (FF), fast (F), slow (T), breaker, thermal, thermostat (none: instant trip)	approximate, checked against datasheet curves

A fuse heats with I^2t and blows when the melting energy reaches i2t: dW/dt = i^2 - W / τ with τ = i2t / $itrip^2$. It never blows below itrip and blows after about i2t / I^2 on a heavy overload. Its resistance rises towards r_hot · r as it heats. Each family has defaults of its own, taken from the published opening-time limits (IEC 60127-2 sheets 2 and 3, Schurter SA, Littelfuse 0217 and 0218, IEC 60898-1): a very fast fuse has itrip 1.6 and i2t 0.15, a fast fuse 1.9 and 0.7, a slow fuse 1.9 and 6.5, a breaker 1.3 and 20 (itrip times irated, i2t times $irated^2$). A slow fuse has a second thermal node, its body, which holds it for minutes just above itrip while a large overload still melts the element at its I^2t. A breaker adds an instant magnetic trip at imag. A thermal cut-off opens when the ambient reaches t_open. A thermostat opens above t_open and recloses at t_close. A UL 248-14 fuse opens at 135 % within an hour: set itrip to about 1.25 times irated. The rating label shows the speed, for example "1 A T". The library has fuse parts with their datasheet values and time-current points to start from: Littelfuse 0217 (fast) and 0218 (time-lag), Bel 5HF and Schurter SA 5x20 (very fast).

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Rated current	**irated**	A	1	> 0	Default, inspector, part file	Scales the defaults of r, itrip, i2t and imag.
Cold resistance	**r**	Ω	$0.1 / irated^{1.3}$ (instant type 0.01)	> 0	Default, inspector, part file	
Minimum fusing current	**itrip**	A	very fast 1.6, fast 1.9, slow 1.9, breaker 1.3 x irated (instant type 1)	> 0	Default, inspector, part file	Steady-state melting current. The instant type opens above it.
Melting I^2t	**i2t**	A^2s	very fast 0.15, fast 0.7, slow 6.5, breaker 20 x $irated^2$	> 0	Default, inspector, part file	Enter the datasheet value to follow its curve.
Body share, body time constant	**k_body, tau_body**	-, s	slow 0.3 and 200 s, others 0	0 to 1, > 0	File or All parameters	The second thermal node of a slow fuse. 0 is the one-node law.
Hot / cold resistance ratio	**r_hot**		4	1 to 1000	Default, inspector, part file	
Voltage rating	**vrated**	V rms	250	> 0	Default, inspector, part file	An AC rms rating: warns when the peak across the open fuse is above vrated x 1.414.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Breaking capacity	**ibreak**	A	none	> 0	File or All parameters	Warns W_RATING when the current at the blow is higher.
Arcing time	**t_arc**	s	0 (1 µs)	>= 0	File or All parameters	The conductance falls over this time. The readout i2t_arc is the clearing I^2t.
Magnetic trip current	**imag**	A	10 x irated	> 0	Default, inspector, part file	Breaker only.
Opening temperature	**t_open**	°C	98 (thermostat 70)	any	Default, inspector, part file	
Reclose temperature	**t_close**	°C	t_open - 15	any	Default, inspector, part file	Thermostat.
Ambient temperature	**t_amb**	°C	25	any	Live slider	
Self-heating, time constant	**rth, tau_th**	K/W, s	50, 10		File or All parameters	Thermostat.
Blown resistance	**roff**	Ω	1 GΩ	> 0	File or All parameters	
Starts blown	**blown**	0 / 1	0		Inspector	
Replaced	**replaced**	count	0		Replace fuse	Counts up each time you replace a fuse or reset a breaker. A blown fuse then closes again, cold.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

A blown fuse warns **W_FUSE_BLOWN** with the time, the current and the I^2t. On the schematic a blown fuse or tripped breaker pops: the element is drawn broken with sparks and a glow for 0.7 s, and BLOWN (TRIPPED for a breaker) stays under its value. A fuse that only a Simulate run blew has a dashed outline and the time. Click the part, press **Replace fuse** (**Reset breaker**) at the top of its Inspector, or use the same item in its right-click menu to close it again, as one undo step. Thermostats and PPTCs reset by themselves. The ngspice export writes a fuse as the resistance it starts with, and ngspice does not blow it.

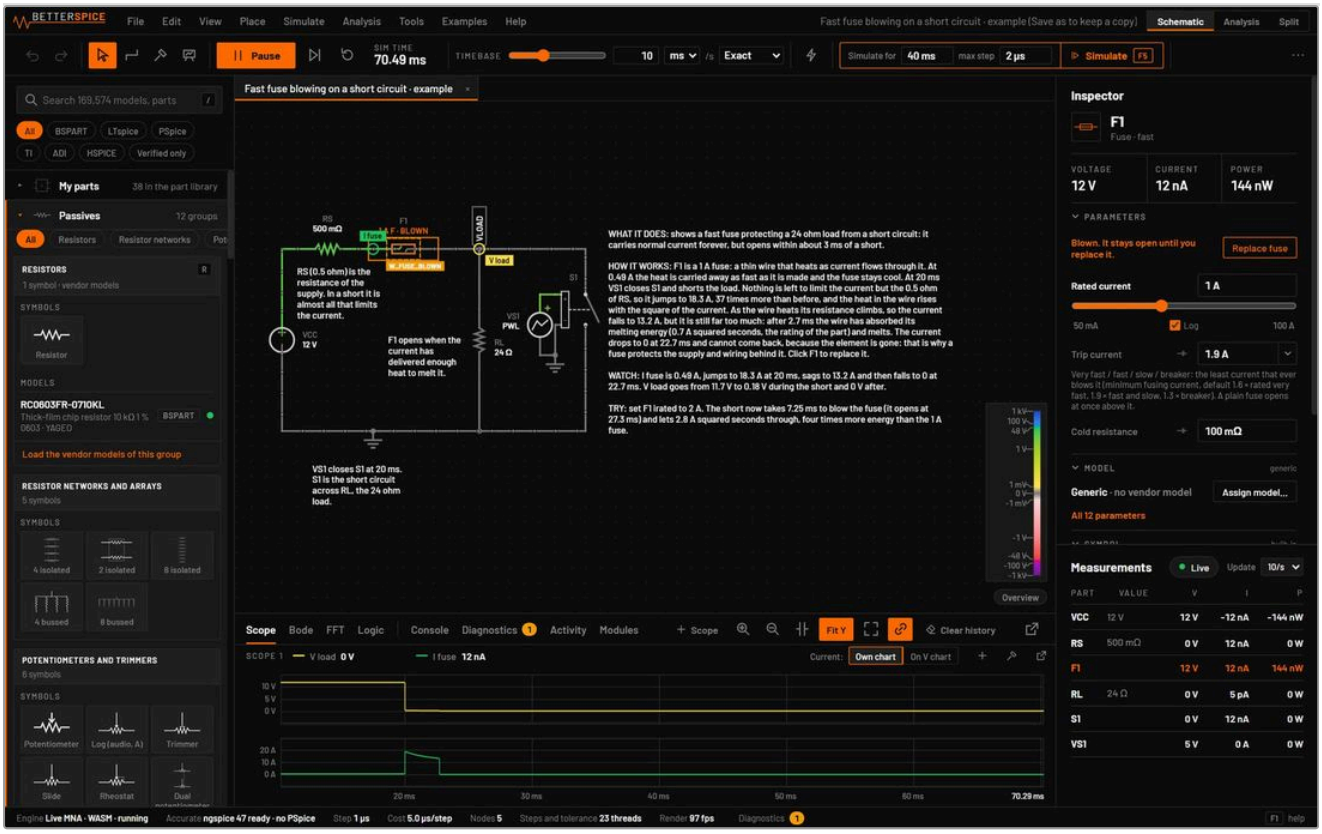


Figure 36.1 A fast fuse that has just blown on a short circuit: the element is drawn broken, BLOWN stays under its value, and the Inspector offers Replace fuse.

36.3 Resettable fuse (PPTC)

TYPE	PINS	VARIANTS	CLASS
pptc (F)	a, b	none	approximate, checked against a datasheet

A polymer fuse whose resistance rises five decades over about 10 K around its switching temperature, heated by its own current, and cools back to reset. It holds ihold and trips at itrip at 25 °C, and both derate with the ambient temperature. After the first trip it does not return to its initial resistance within a simulation. The symbol shows TRIPPED while it is open. The model follows the Bourns MF-R050 datasheet, which is also in the library as a part, at the fault current you enter in t_trip and i_ttrip, and trips later than the typical curve far above that current.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Hold current	**ihold**	A	0.5	> 0, below itrip	Default, inspector, part file	
Trip current	**itrip**	A	1	> 0	Default, inspector, part file	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Initial resistance, minimum	**r_min**	Ω	0.15	> 0	Default, inspector, part file	
Initial resistance, maximum	**rmax**	Ω	1.8 x r_min	> 0	File or All parameters	The untripped resistance is the mean of r_min and rmax.
Resistance 1 h after trip	**r1max**	Ω	0.6	> 0	Default, inspector, part file	
Time to trip	**t_trip**	s	0.1	> 0	Default, inspector, part file	At i_ttrip.
Fault current for t_trip	**i_ttrip**	A	8 x itrip	> 0	Default, inspector, part file	
Max voltage	**vmax**	V	15	> 0	Default, inspector, part file	
Switching temperature	**t_sw**	°C	125	any	Default, inspector, part file	
Resistance rise below the switch	**r_rise**		2.2	> 1	File or All parameters	Set by pd when pd is given.
Tripped dissipation	**pd**	W	none	> 0	File or All parameters	The datasheet figure. It sets r_rise.
Ambient	**t_amb**	°C	25	any	Live slider	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36.4 Thermistors and RTDs

TYPE	PINS	VARIANTS	CLASS
ntc, ptc, rtd (RT)	a, b	ntc: sensor, icl (inrush limiter). ptc: switching (ceramic), linear (KTY). rtd: pt100, pt1000, ni1000	approximate, R(T) exact

Each has a resistance law and a single thermal node, so it heats with its own power: $P = V^2 / R$ into a thermal resistance 1 / dissipation with time constant tau. The ambient **t_amb** is a live slider: drag it to heat or cool the sensor while the circuit runs.

PART	LAW
NTC	$R = r25 \cdot \exp(\text{beta} \cdot (1/T - 1/T_{ref}))$, T in kelvin. With sh_b set, the Steinhart-Hart law $1/T = A + B \ln R + C (\ln R)^3$ replaces beta.
PTC switching	Falls slowly up to the Curie temperature t_c, then rises with slope per kelvin up to r_max_ratio x r25.
PTC linear (KTY)	$R = r25 \cdot (1 + \text{alpha}\ \Delta T + \text{beta2}\ \Delta T^2)$, $\Delta T = T - 25$ °C.
RTD	Callendar-Van Dusen: $R = r0 \cdot (1 + A\ T + B\ T^2 + C\ (T - 100)\ T^3)$, the C term only below 0 °C.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
R at reference temperature	**r25**	Ω	NTC 10 kΩ (icl 5 Ω), PTC 100 Ω (linear 1 kΩ)	> 0	Default, inspector, part file	
B constant	**beta**	K	3950 (icl 2800)	> 0	Default, inspector, part file	NTC.
Reference temperature	**t_ref**	°C	25		Default, inspector, part file	NTC.
Steinhart-Hart	**sh_a, sh_b, sh_c**		0	any	Default, inspector, part file	NTC.
Curie temperature	**t_c**	°C	80	any	Default, inspector, part file	PTC switching.
Slope above t_c	**slope**	1/K	0.15	> 0	Default, inspector, part file	
Ceiling	**r_max_ratio**		10^4	> 0	Default, inspector, part file	
KTY coefficients	**alpha, beta2**	1/K, $1/K^2$	7.88×10^{-3}, 1.937×10^{-5}		Default, inspector, part file	
R at 0 °C	**r0**	Ω	100 (pt1000, ni1000: 1000)	> 0	Default, inspector, part file	RTD.
CVD coefficients	**cvd_a, cvd_b, cvd_c**		Pt: 3.9083×10^{-3}, -5.775×10^{-7}, -4.183×10^{-12}		Default, inspector, part file	RTD.
Dissipation constant	**dissipation**	W/K	NTC 2 mW/K (icl 12), PTC 5, RTD 2	> 0	Default, inspector, part file	
Thermal time constant	**tau**	s	NTC 10 (icl 60), PTC 20, RTD 3	> 0	Default, inspector, part file	
Max power	**pmax**	W	NTC 0.2 (icl 2.5)	> 0	Default, inspector, part file	Warns when exceeded.
Ambient temperature	**t_amb**	°C	25	-273 to 10 000	Live slider	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

An NTC in a divider

1. Place a 3.3 V source, a 10 kΩ resistor and an NTC (10 kΩ, B 3950) to ground. Probe the middle.
2. Drag the NTC's ambient slider from 25 to 50 °C.

YOU SHOULD SEE The middle falls from 1.65 V to about 0.86 V as the NTC drops to about 3.6 kΩ.

36.5 Thermocouple

TYPE	PINS	VARIANTS	CLASS
tcouple (TC)	+, -	K, J, T, E, N	approximate, NIST polynomials exact

The EMF E(t_hot) - E(t_cold) from the NIST ITS-90 reference polynomials for each type, behind the loop resistance. Type K gives about 41 µV/K near room temperature.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Hot junction	**t_hot**	°C	100	-273 to 2000	Live slider	
Cold junction	**t_cold**	°C	25	-273 to 2000	Live slider	
Loop resistance	**r**	Ω	10	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36.6 Crystals and ceramic resonators

TYPE	PINS	VARIANTS	CLASS
xtal, resonator (Y)	xtal 2pin: x1, x2. 4pin: x1, x2, case1, case2. resonator 3pin: in, gnd, out. 2pin: a, b.	xtal: 2pin, 4pin. resonator: 3pin (built-in capacitors), 2pin	approximate, BVD network exact

The Butterworth-Van Dyke equivalent: a shunt capacitance c0 across a motional branch of esr, Lm and cm. Lm is set so the series resonance lands on freq at the load capacitance cl. A small start-up kick starts the oscillation, which then grows at the rate the amplifier allows, as on a real board. The readouts show the measured oscillation frequency and the drive power. The timestep is limited to a fortieth of a period, so simulate short times.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Nominal frequency	**freq**	Hz	xtal 16 MHz, resonator 8 MHz	> 0	Default, inspector, part file	At the load capacitance.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Load capacitance	**cl**	F	18 pF	≥ 0	Default, inspector, part file	xtal.
ESR	**esr**	Ω	40	> 0	Default, inspector, part file	xtal motional resistance.
Motional resistance	**rm**	Ω	10	> 0	Default, inspector, part file	resonator.
Shunt capacitance	**c0**	F	xtal 3 pF, resonator 20 pF	≥ 0	Default, inspector, part file	
Motional capacitance	**cm**	F	xtal 7 fF, resonator 2 pF	> 0	Default, inspector, part file	
Frequency offset	**ppm**	ppm	0	any	Default, inspector, part file	xtal.
Max drive level	**drive_max**	W	100 µW	> 0	Default, inspector, part file	Warns when exceeded.
Start-up kick	**i0**	A	1 µA	≥ 0	File or All parameters	
Pin-to-case capacitance	**ccase**	F	0.5 pF	≥ 0	Default, inspector, part file	xtal 4pin.
Built-in load capacitors	**cl_int**	F	15 pF	≥ 0	Default, inspector, part file	resonator 3pin, each side.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36.7 Oscillator modules

TYPE	PINS	VARIANTS	CLASS
xo (X)	EN (VC for vcxo), GND, OUT, VDD	xo (CMOS), tcxo (sine), vcxo, mems	approximate

A clock source powered from its own pins: a square wave with duty and edge time, or for the TCXO a sine of vpp centred at VDD/2. It starts startup seconds after enable and is off below vdd_min. The VCXO pulls its frequency by ± pull ppm across VC = 0 to VDD. Period jitter can be added.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Output frequency	**freq**	Hz	25 MHz	> 0	Default, inspector, part file	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Offset	**ppm**	ppm	0	any	Default, inspector, part file	
Minimum supply	**vdd_min**	V	1.6	≥ 0	Default, inspector, part file	Warns below.
Supply current	**idd**	A	5 mA	≥ 0	Default, inspector, part file	
Duty cycle	**duty**		0.5	0.01 to 0.99	Default, inspector, part file	
Edge time	**tr**	s	2 ns	> 0	Default, inspector, part file	
Output resistance	**rout**	Ω	30	> 0	Default, inspector, part file	
Start-up time	**startup**	s	2 ms	≥ 0	Default, inspector, part file	
EN mode	**en_mode**	0 / 1	1		Default, inspector, part file	1: EN high enables, low tri-states. 0: EN ignored.
Sine amplitude	**vpp**	V	0.8	≥ 0	Default, inspector, part file	tcxo.
Pull range	**pull**	ppm	100	≥ 0	Default, inspector, part file	vcxo.
Period jitter	**jitter**	s rms	0	≥ 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36.8 Light and field sensors

These sensors have a live input: illuminance **lux**, irradiance **g** or magnetic field **b**. Drag it while the circuit runs. A photodiode or phototransistor can also be lit by an LED in the circuit: set **link** to the LED's designator and its current adds link_gain lux per amp (10 mA gives 1000 lx by default), which makes a complete optical link.

TYPE	PINS	VARIANTS	CLASS
photodiode (D)	anode, cathode	pin, ir, uv (same physics)	approximate, verified ±0 %

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Sensitivity	**s_lux**	A/lx	50 nA/lx	> 0	Default, inspector, part file	Photocurrent = s_lux x lux, a reverse current.
Illuminance	**lux**	lx	100	≥ 0	Live slider	
Dark current	**i_dark**	A	2 nA	> 0	Default, inspector, part file	Also the diode saturation current.
Junction capacitance	**cj0**	F	70 pF	≥ 0	Default, inspector, part file	Constant.
Linked emitter	**link**	part id	none		File or All parameters	An LED or diode in the circuit.
Link gain	**link_gain**	lx/A	10^5	≥ 0	File or All parameters	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
phototr (Q)	2pin: collector, emitter. 3pin: plus base.	2pin, 3pin	approximate

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Sensitivity	**s_lux**	A/lx	1 µA/lx	> 0	Default, inspector, part file	Collector light current per lux.
Illuminance	**lux**	lx	100	≥ 0	Live slider	Followed with the rise time.
Current gain	**bf**		500	> 0	Default, inspector, part file	
Dark current	**i_dark**	A	100 nA	> 0	Default, inspector, part file	
Rise / fall time	**tr**	s	15 µs	> 0	Default, inspector, part file	
Linked emitter, gain	**link, link_gain**		none, 10^5		File or All parameters	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
ldr (R)	a, b	none	approximate

R = min(r_dark, r10 · (lux / 10)$^{-gamma}$): the dark resistance is the ceiling, following light changes with t_rise (brighter) or t_fall (darker).

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Resistance at 10 lx	**r10**	Ω	15 kΩ	> 0	Default, inspector, part file	
Gamma	**gamma**		0.7	> 0	Default, inspector, part file	Log-log slope.
Dark resistance	**r_dark**	Ω	1 MΩ	> 0	Default, inspector, part file	
Illuminance	**lux**	lx	100	≥ 0	Live slider	
Response time	**t_rise, t_fall**	s	20 ms, 30 ms	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
solar (SC)	+, -	none	approximate, verified ±0.03 %

The single-diode model: a photocurrent isc · g / 1000, a diode set by voc and the number of cells, series and shunt resistance. The open-circuit voltage scales with cells, isc is the whole module's current.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Short-circuit current	**isc**	A	0.1	> 0	Default, inspector, part file	At 1000 W/m^2.
Open-circuit voltage per cell	**voc**	V	0.6	> 0	Default, inspector, part file	
Cells in series	**cells**		1	1 to 1000	Default, inspector, part file	
Irradiance	**g**	W/m^2	1000	≥ 0	Live slider	
Series resistance	**rs**	Ω	0.1	≥ 0	Default, inspector, part file	
Shunt resistance	**rsh**	Ω	1 kΩ	> 0	Default, inspector, part file	
Ideality	**n**		1.3	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

Find the maximum power point

1. Place a solar cell (cells 36) and a resistor across it. Set up a parameter step of the resistor over **5, 10, 20, 40, 80** with a short transient.
2. Read the power readout of the cell, or probe the voltage and current.

YOU SHOULD SEE The power peaks at one load value: the maximum power point, near 80 % of the open-circuit voltage.

TYPE	PINS	VARIANTS	CLASS
hall (U)	VCC, GND, OUT	switch (unipolar), latch (bipolar), omni (omnipolar), linear	approximate

A switch turns on (output low) above bop and off below brp. A latch turns on above bop and off below -bop. An omnipolar switch reacts to either pole. The linear sensor outputs VCC/2 plus sens x B, ratiometric to a 5 V reference.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Magnetic field	**b**	mT	0	any	Live slider	
Operate point	**bop**	mT	10	any	Default, inspector, part file	
Release point	**brp**	mT	7 (latch -bop)	below bop	Default, inspector, part file	
Sensitivity	**sens**	mV/mT	14	any	Default, inspector, part file	Linear.
Supply current	**icc**	A	4 mA	≥ 0	Default, inspector, part file	
Open-drain output	**od**	0 / 1	1 (omni 0)		Default, inspector, part file	Open drain needs a pull-up.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36.9 LED assemblies and displays

TYPE	PINS	VARIANTS	CLASS
led_rgb, led_bar, seg7, seg7x4, ledmatrix (LED, DS)	led_rgb: r, g, b, com. led_bar: a1, k1, a2, k2 … seg7: a … g, dp, com. seg7x4: a … g, dp, d1 … d4. ledmatrix: r1 … r8, c1 … c8.	led_rgb, seg7, seg7x4: cc (common cathode), ca (common anode). led_bar: 10, 8, 4. ledmatrix: row_anode, row_cathode	approximate, LEDs exact

Arrays of LEDs, each fitted to its forward voltage at the test current, with no series resistance: add the resistors as on a real board. Each LED glows on the canvas in proportion to its current. A multiplexed display works as on hardware: drive the digit commons in turn. The four-digit display (**seg7x4**) shares its segment pins between the digits, and the digit whose common is driven lights, so a scanned display shows all four digits at once.

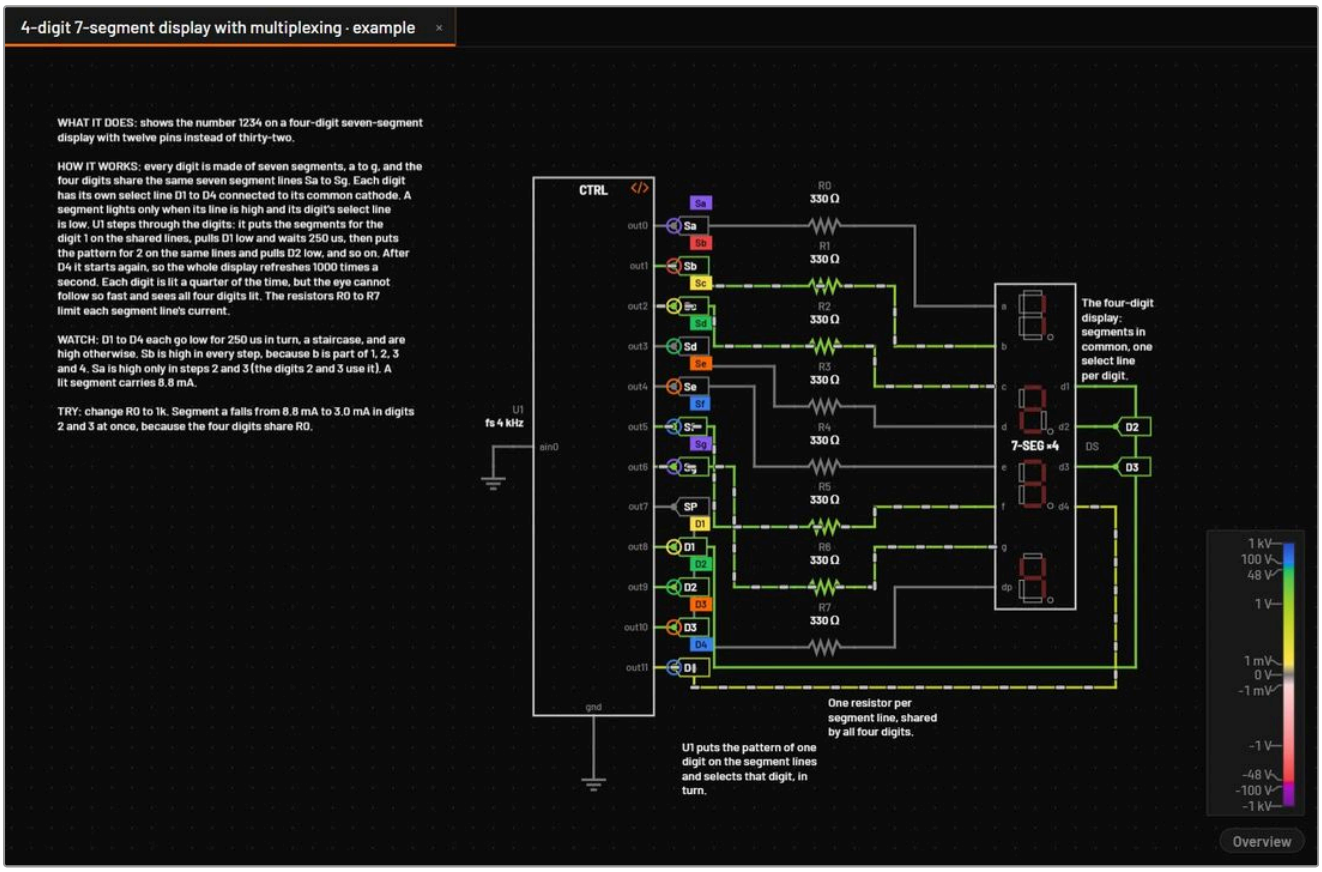


Figure 36.2 The four-digit multiplexed display in its example, with the shared segment lines and one select line per digit.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Forward voltage	**vf**	V	2.0	> 0	Default, inspector, part file	Every LED of a bar, display or matrix.
Forward voltage, red / green / blue	**vf_r, vf_g, vf_b**	V	2.0, 3.1, 3.1	> 0	Default, inspector, part file	RGB LED.
Test current	**if_test**	A	10 mA (RGB 20 mA)	> 0	Default, inspector, part file	Where vf is measured, and full brightness.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36.10 Lamps

TYPE	PINS	VARIANTS	CLASS
lamp (LA)	a, b	lamp (incandescent), neon	approximate, verified ±0 %

An incandescent lamp is a tungsten filament: its resistance rises with temperature (about 14 times from cold to hot), and its temperature comes from the power it radiates. It shows the real inrush current. A neon lamp strikes at v_strike and holds at v_maint.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Rated voltage	**v_rated**	V	12	> 0	Default, inspector, part file	
Rated power	**p_rated**	W	5	> 0	Default, inspector, part file	
Filament time constant	**tau**	s	50 ms	> 0	Default, inspector, part file	
Strike voltage	**v_strike**	V	90	> 0	Default, inspector, part file	Neon.
Maintaining voltage	**v_maint**	V	60	> 0	Default, inspector, part file	Neon.
Rated current	**i_rated**	A	1 mA	> 0	Default, inspector, part file	Neon.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

36.11 Addressable LEDs

TYPE	PINS	VARIANTS	CLASS
ws2812 (LED)	VDD, DOUT, GND, DIN	ws2812b (24 bits, GRB), sk6812_rgbw (32 bits)	approximate

Decodes the first 24 (or 32) pulses on DIN into its colour, then repeats further pulses on DOUT, so LEDs can be chained. A low longer than t_reset latches. The readouts show the latched red, green and blue.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
LED current per colour	**i_led**	A	12 mA	≥ 0	Default, inspector, part file	At full brightness.
One-bit threshold	**t_th**	s	0.6 µs	> 0	Default, inspector, part file	A high pulse longer than this is a 1.
Reset time	**t_reset**	s	50 µs	> 0	Default, inspector, part file	
Quiescent current	**idd**	A	1 mA	≥ 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

37 Devices: power ICs, drivers and protection

37.1 Power ICs 336
37.2 Controller and driver ICs 343
37.3 Diodes, thyristors and protection 348

Regulator, converter, charger and driver ICs with their real pins, controller ICs, and protection parts. The parameter tables use the same columns as **Devices: passives**, p. 265. Every part has labelled fields with units in the inspector and in All parameters, and the live stimulus of a sensor (light, temperature, field, strain, distance, load) is its main field, first in the list, with a slider range that fits it. A field that shows *auto* takes a value derived from other parameters until you type one (for example the must-operate voltage of a relay is 0.75 of its coil voltage). Clear it to go back. A variant placed from the library starts with its own typical values, such as 1 kΩ for a Pt1000 or 1.2 V dropout for an AMS1117. A part placed from the library can start with its own values, and a part made with the Part Wizard takes them from its datasheet fields (**Part templates reference**, p. 606).

37.1 Power ICs

These are regulators and drivers with their real pins: enable, feedback, switch node, power good. Unlike the power block (**Power block**, p. 303) they are wired like the real chip, with the external divider, inductor and capacitors.

LDO regulator ICs

TYPE	PINS	VARIANTS	CLASS
ldo (U)	fixed3: IN, GND, OUT. adj3 (LM317): ADJ, OUT, IN. en5 (SOT-23-5): IN, GND, EN, NC, OUT. en_pg: IN, OUT, EN, PG, GND. neg3 (79xx): GND, IN, OUT. ams1117: GND, OUT, IN. adj5 (MIC29752): EN, IN, GND, OUT, ADJ.	fixed3, adj3, en5, en_pg, neg3, ams1117, adj5	approximate, LM317 verified ±0.76 %

A pass element that regulates the output to vset (or vref above ADJ for the adjustable types), limited by the dropout and the current limit, with a small sink, an overvoltage clamp and an internal 1 MΩ discharge. Enable pins turn it on above ven_on. The power-good output is open drain and releases above 92 % of the target.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Output voltage	**vset**	V	3.3 (neg3 5)	any (magnitude used)	Default, inspector, part file	Fixed types.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Reference / ADJ voltage	**vref**	V	1.25 (adj5 1.24)	> 0	Default, inspector, part file	Adjustable types: Vout = vref x (1 + R2/R1).
Dropout	**vdo**	V	0.3 (ams1117 and adj3 1.2)	≥ 0	Default, inspector, part file	At ilim.
Current limit	**ilim**	A	0.6 (ams1117 1.0)	> 0	Default, inspector, part file	
Quiescent current	**iq**	A	50 µA	≥ 0	Default, inspector, part file	
ADJ pin current	**iadj**	A	50 µA	≥ 0	File or All parameters	adj3.
Enable threshold	**ven_on**	V	1.0	≥ 0	Default, inspector, part file	
Output resistance	**rout**	Ω	0.02	> 0	File or All parameters	
ADJ transconductance	**gm**	A/V	10^4	> 0	File or All parameters	adj5.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

An LM317 at 5 V

1. Place an LDO IC, variant adj3. Wire IN to 9 V, a 240 Ω resistor from OUT to ADJ and 720 Ω from ADJ to ground, and a 100 mA load.
2. Probe OUT.

YOU SHOULD SEE OUT settles at 1.25 x (1 + 720/240) = 5.0 V. Lower the input with its slider and the output follows the input 1.2 V below once it is in dropout.

Buck converter ICs

TYPE	PINS	VARIANTS	CLASS
buckic (U)	async, module: VIN, SW, GND, FB, EN, BST. sync: plus PG.	async (external diode), sync, module	approximate

Regulates V(FB) to vref, so the external divider sets the output, and sources the inductor current from SW. By default it's an averaged model, fast and smooth. Set **ripple** above 0.5 for the switching peak-current-mode form, which shows the real switch node and ripple in a transient. EN has a pull-up to VIN, so an open EN enables. The reference soft-starts over ss_time.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Feedback voltage	**vref**	V	0.8	> 0	Default, inspector, part file	
Switching frequency	**fsw**	Hz	500 kHz	> 0	Default, inspector, part file	Switching form.
Switch current limit	**ilim**	A	3	> 0	Default, inspector, part file	
High-side / low-side Rds(on)	**ron_hs, ron_ls**	Ω	0.1, 0.08	> 0	Default, inspector, part file	
Soft-start time	**ss_time**	s	1 ms	≥ 0	Default, inspector, part file	
Maximum duty	**dmax**		0.95	0.05 to 1	File or All parameters	
Enable threshold	**ven_on**	V	1.2	≥ 0	File or All parameters	
Quiescent current	**iq**	A	0.5 mA	≥ 0	Default, inspector, part file	
Switching form	**ripple**		0	0 to 1	File or All parameters	Above 0.5: switching.
Error-amp gain	**kp**	A/V	2	> 0	File or All parameters	
Dead time	**deadtime**	s	20 ns	≥ 0	File or All parameters	sync.
Reverse current limit	**ilim_neg**	A	0 (diode emulation)	≥ 0	File or All parameters	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Boost converter ICs

TYPE	PINS	VARIANTS	CLASS
boostic (U)	async: SW, GND, FB, EN, VIN. sync: plus VOUT.	async (MT3608), sync	approximate

Peak-current-mode boost: a low-side switch from SW to ground, a PI loop on FB, slope compensation. The async type needs an external diode. EN has a pull-down, so an open EN disables it. It runs above 2 V input.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Feedback voltage	**vref**	V	0.6	> 0	Default, inspector, part file	
Switching frequency	**fsw**	Hz	1.2 MHz	> 0	Default, inspector, part file	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Switch current limit	**ilim**	A	4	> 0	Default, inspector, part file	
Switch on resistance	**ron**	Ω	0.08	> 0	Default, inspector, part file	
Maximum duty	**dmax**		0.9	0.05 to 0.98	Default, inspector, part file	
Soft-start time	**ss_time**	s	1 ms	≥ 0	File or All parameters	
Slope compensation	**slope**	A/s	0.3 x ilim x fsw	≥ 0	File or All parameters	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Load switches, eFuses and ideal diodes

TYPE	PINS	VARIANTS	CLASS
loadsw (U)	loadsw: VIN, VOUT, ON, GND. efuse: VIN, VOUT, EN, ILIM, GND. ideal_diode: IN, OUT, CE, GND. hiside: IN, OUT, ON, GND.	loadsw, efuse, ideal_diode, hiside	approximate

A switch with a controlled output rise and no reverse current. The eFuse limits current to k_ilim / R_ILIM and shuts off after t_flt in limit, until its enable is toggled. The ideal diode conducts only forward, with about 20 mV drop.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
On resistance	**ron**	Ω	0.03	> 0	Default, inspector, part file	
Output rise time	**t_rise**	s	1 ms	> 0	Default, inspector, part file	
ILIM constant	**k_ilim**	A·Ω	10^5	> 0	File or All parameters	eFuse limit = k_ilim / R_ILIM.
ON threshold	**von**	V	1.0	≥ 0	Default, inspector, part file	
Quick output discharge	**qod**	0 / 1	1		File or All parameters	100 Ω on VOUT while off.
Fault time	**t_flt**	s	1 ms	> 0	File or All parameters	eFuse.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Li-ion chargers and battery protection

TYPE	PINS	VARIANTS	CLASS
charger (U)	tp4056: TEMP, PROG, GND, VCC, BAT, STDBY, CHRG, CE. mcp73831: STAT, VSS, VBAT, VDD, PROG.	tp4056, mcp73831	approximate, TP4056 verified ±0.08 %

Constant current set by the resistor on PROG (I = k_prog / R_PROG), a trickle below v_trickle, constant voltage at vfloat, termination below i_term. The status outputs are open drain: CHRG low while charging, STDBY low when done.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Regulation voltage	**vfloat**	V	4.2	> 0	Default, inspector, part file	
PROG constant	**k_prog**	V	1200 (mcp73831 1000)	> 0	Default, inspector, part file	
Termination ratio	**i_term**	x I_chg	0.1	0 to 1	Default, inspector, part file	
Trickle threshold	**v_trickle**	V	2.9	> 0	Default, inspector, part file	
Minimum input	**vin_min**	V	4.0	> 0	File or All parameters	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
batprot (U)	OD, CS, OC, TD, VCC, GND	none (DW01A class)	approximate

Drives the discharge-FET gate OD low on overdischarge or overcurrent and the charge-FET gate OC low on overcharge, each after its delay.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Overcharge detection	**v_oc**	V	4.25	> 0	Default, inspector, part file	
Overdischarge detection	**v_od**	V	2.4	> 0	Default, inspector, part file	
Overcurrent detection	**v_ocp**	V	0.15	> 0	Default, inspector, part file	On CS.
Delays	**t_oc, t_od, t_ocp**	s	80 ms, 40 ms, 10 ms	≥ 0	Default, inspector, part file	
Short-circuit threshold	**v_sc**	V	1.35	> 0	File or All parameters	Trips with no delay.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Power modules and off-line switchers

TYPE	PINS	VARIANTS	CLASS
psu_module (PS)	dcdc: VIN, GND, VOUT, EN. dcdc_iso: VIN+, VIN-, VOUT+, VOUT-. acdc: L, N, V+, V-.	dcdc, dcdc_iso, acdc	approximate

A finished module: a Thevenin output of vout behind rout, input power = output power / eff, on above vin_min. The isolated and AC types keep input and output separate. The output isn't current limited. It warns above 110 % of pout.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Output voltage	**vout**	V	5	any	Default, inspector, part file	
Output power	**pout**	W	3	> 0	Default, inspector, part file	
Efficiency	**eff**		0.75	0.05 to 1	Default, inspector, part file	
Input range	**vin_min, vin_max**	V	4.5, 5.5 (acdc 85, 265 V RMS)		Default, inspector, part file	
Output resistance	**rout**	Ω	0.05	> 0	File or All parameters	
Ripple	**ripple, fsw**	V p-p, Hz	0.05, 65 kHz		Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
offline (U)	buck: D, S, FB, BP. flyback: D, S, FB, VDD.	buck, flyback	approximate

An averaged on/off off-line switcher (LNK, TNY class): the switch current from D to S rises while FB is below vfb, limited to half of ilim and by Rds(on). The supply pin is regulated from the drain.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Current limit	**ilim**	A	0.25	> 0	Default, inspector, part file	
Feedback threshold	**vfb**	V	1.65	> 0	Default, inspector, part file	
MOSFET on resistance	**rds_on**	Ω	24	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Motor drivers

TYPE	PINS	VARIANTS	CLASS
hbridge2 (U)	in_in: AIN1, AIN2, BIN1, BIN2, AOUT1, AOUT2, BOUT1, BOUT2, VM, GND, nSLEEP. pwm_dir: AIN1, AIN2, PWMA, BIN1, BIN2, PWMB, STBY, AO1, AO2, BO1, BO2, VM, VCC, GND.	in_in (DRV8833, L298), pwm_dir (TB6612)	approximate

Four half bridges with body diodes and dead time. in_in truth table per channel: 00 coast, 10 forward, 01 reverse, 11 brake. pwm_dir: IN1 and PWM forward, IN2 and PWM reverse, PWM low brakes, STBY low turns everything off. Overcurrent protection: a switch current above ilim turns that bridge off (a W_RATING warning) and it retries after 1.6 ms, as the DRV8833 does.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Output on resistance	**ron**	Ω	0.36	> 0	Default, inspector, part file	High plus low side.
Overcurrent trip	**ilim**	A	2	> 0	File or All parameters	Per switch; the bridge retries after 1.6 ms.
Dead time	**deadtime**	s	200 ns	≥ 0	File or All parameters	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
stepdrv (U)	EN, MS1, MS2, MS3, RST, SLP, STEP, DIR, VMOT, GND, 1A, 1B, 2A, 2B, VDD, VREF	a4988, drv8825	approximate

Each rising STEP edge moves one microstep in the direction of DIR. MS1 to MS3 set full to 1/16 (A4988) or 1/32 (DRV8825) stepping. The winding currents follow sine and cosine of the step angle, limited by VREF / (8 rsense) for the A4988 or VREF / (5 rsense) for the DRV8825. Set ripple above 0.5 for the chopper form.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Sense resistor	**rsense**	Ω	0.1	> 0	Default, inspector, part file	
Current limit	**ilim**	A	1	> 0	Default, inspector, part file	Used when VREF is not wired.
Output on resistance	**ron**	Ω	0.32	> 0	Default, inspector, part file	Chopper form.
Off time	**toff**	s	20 µs	> 0	Default, inspector, part file	
Chopper form	**ripple**		0	0 to 1	File or All parameters	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

37.2 Controller and driver ICs

These switch for real, edge by edge. Logic inputs and comparators are found to the exact instant. Outputs move with short edges behind their source and sink resistance. Output current comes from the part's own supply pins, so bootstrap capacitors discharge into the gate as on a board.

TYPE	PINS	VARIANTS	CLASS
gatedrv (U)	low: IN, VDD, GND, OUT. high_boot: IN, VDD, GND, HO, HS, VB. half_bridge: HIN, LIN, VDD, GND, HO, HS, LO, VB. isolated: IN, VDD1, GND1, OUT, GND2, VDD2, the two sides joined only by r_iso and c_iso (an old 4-pin isolated driver keeps one ground).	low, high_boot, half_bridge, isolated	approximate, verified ±6.3 %

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
VDD UVLO	**vdd_uvlo, vdd_hys**	V	4.5, 0.3		Default, inspector, part file	Outputs held low below.
VB-HS UVLO	**vb_uvlo**	V	4.2	> 0	Default, inspector, part file	
Peak source / sink current	**src_a, snk_a**	A	2, 3	> 0	Default, inspector, part file	Output resistance = 10 V / current.
Propagation delay	**tpd**	s	20 ns (placed 50 ns)	≥ 0	Default, inspector, part file	
Dead time	**deadtime**	s	0	≥ 0	Default, inspector, part file	Half bridge.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Input threshold, hysteresis	**vth, vhys**	V	1.65, 0.8		Default, inspector, part file	
Interlock	**interlock**	0 / 1	0		Default, inspector, part file	Both outputs low if both inputs are high.
Bootstrap diode	**boot_diode**	0 / 1	1		Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
hbridge (U)	VM, GND, IN1, IN2, OUT1, OUT2	in1_in2 (DRV8871), pwm_dir	approximate

Four switches with body diodes. in1_in2: 00 coast, 10 forward, 01 reverse, 11 brake. A high-side current above ilim recirculates for 25 µs.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Switch on resistance	**rds_on**	Ω	0.5 (placed 0.1)	> 0	Default, inspector, part file	
Dead time	**deadtime**	s	200 ns	≥ 0	Default, inspector, part file	
Current limit	**ilim**	A	3.6	> 0	Default, inspector, part file	
Input threshold	**vth**	V	1.5	> 0	Default, inspector, part file	
VM UVLO	**vm_uvlo**	V	4.0	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
supervisor (U)	VIN, GND, OUT	reset, uvlo, window	approximate

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Threshold	**vth**	V	2.93	> 0	Default, inspector, part file	Falling.
Hysteresis	**hys**	V	1 % of vth	≥ 0	Default, inspector, part file	
Reset delay	**delay**	s	200 µs (reset)	≥ 0	Default, inspector, part file	
Window upper limit	**vth_hi**	V	1.1 x vth	> 0	Default, inspector, part file	
Output	**rout, open_drain, active_high**		100 Ω, 0, 0		Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
pwmctl (U)	VIN, GND, FB, COMP, CS, GATE, SS, EN, RT, and for the synchronous form SW, BOOT, HO, LO	vmode, cmode (UC3843), hyst, cot, pfc_tm (L6562), llc, qr	approximate, verified ±0.04 to ±7.9 %

A switching controller. An error amplifier on FB drives COMP, and the reference starts softly. UVLO and an enable are built in. vmode compares COMP with a ramp. cmode turns off when CS reaches the COMP level (with slope compensation and leading-edge blanking). hyst and cot are hysteretic and constant on-time. pfc_tm is transition-mode PFC and qr is quasi-resonant valley switching. llc is a 50 % half bridge whose frequency falls as COMP rises.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Reference	**vref**	V	0.8 (pfc_tm 2.5)	> 0	Default, inspector, part file	
Switching frequency	**fsw**	Hz	200 kHz	> 0	Default, inspector, part file	
Error amplifier	**ea_gm, ea_gain**	S, -	1 mS, 10^4	> 0	Default, inspector, part file	
Duty limits	**dmin, dmax**		0, 0.9	0 to 1, dmin < dmax	Default, inspector, part file	
Slope compensation	**slope**	V/s	0	≥ 0	Default, inspector, part file	cmode.
CS gain, limit	**cs_gain, cs_limit**	-, V	3, 1.0	> 0	Default, inspector, part file	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Soft start	**ss_time**	s	1 ms	≥ 0	Default, inspector, part file	
UVLO	**uvlo_on, uvlo_off**	V	4.5, uvlo_on - 0.5	uvlo_off < uvlo_on	Default, inspector, part file	Set both when lowering uvlo_on below 4 V.
Dead time	**deadtime**	s	50 ns	≥ 0	Default, inspector, part file	
Gate drive	**gate_drive**	A	1.0	> 0	Default, inspector, part file	
On-time	**ton**	s	1 µs (pfc_tm 10 µs)	> 0	Default, inspector, part file	
Blanking	**blanking**	s	100 ns	≥ 0	Default, inspector, part file	
Ramp amplitude	**vramp**	V	2.0	> 0	Default, inspector, part file	vmode.
Hysteresis window	**vhys**	V	10 mV	≥ 0	Default, inspector, part file	hyst.
Frequency range	**fmin, fmax**	Hz	0.5 x fsw, 2 x fsw	fmin < fmax	Default, inspector, part file	llc, qr, pfc.
ZCD threshold	**zcd_th**	V	50 mV	> 0	Default, inspector, part file	
Gate clamp	**vclamp**	V	15	> 0	Default, inspector, part file	
Minimum off time	**toff_min**	s	200 ns	≥ 0	Default, inspector, part file	
Restart	**t_restart**	s	50 µs	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
ledctl (U)	VIN, GND, CS, GATE, DIM	buck_cc, boost_cc	approximate

Fixed-frequency peak-current LED driver: GATE on each cycle, off when CS reaches vcs. DIM enables it.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
CS threshold	**vcs**	V	0.2	> 0	Default, inspector, part file	
Switching frequency	**fsw**	Hz	100 kHz (placed 200 kHz)	> 0	Default, inspector, part file	
Blanking, gate drive, clamp, dmax, UVLO	**blanking, gate_drive, vclamp, dmax, uvlo_on**		100 ns, 1 A, 15 V, 0.95, 4.5 V		Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
uc384x (U)	COMP, FB, CS, RTCT, GND, OUT, VCC, VREF (the UC3842 / UC3843 DIP order)	none	approximate, checked against the vendor models in Simulate

The live view's stand-in for a vendor UC384x current-mode controller (new in 0.8.0). It is not placed from the library: a vendor UC3843 part carries it as its live equivalent, and Simulate keeps running the vendor model. UVLO on VCC with a clamp, VREF behind its output resistance with a current limit and line regulation, a transconductance error amplifier into COMP, the RT/CT oscillator, the current comparator and the latch set by the oscillator pulse once the comparator releases it (reset wins). With COMP pulled below two diode drops the output stays low, the datasheet's shutdown. The four UC3843 examples set its numbers to the vendor model's.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
UVLO	**uvlo_on, uvlo_off**	V	8.4, 7.6	uvlo_off < uvlo_on	Default, inspector, part file	
Supply current	**iq_off, iq_on**	A	0.5 mA, 11 mA	≥ 0	Default, inspector, part file	The start-up and operating currents of the TI datasheet.
Reference	**vref**	V	5	> 0	Default, inspector, part file	Behind ref_rout, limited by ref_ilim. ref_lnr gives the line regulation around ref_vnom (12 V), 0 by default.
Oscillator thresholds	**osc_hi, osc_lo**	V	2.8, 1.1	osc_lo < osc_hi	Default, inspector, part file	RT/CT, discharged by idis (8.3 mA).
Current sense	**cs_off, cs_gain, cs_max**	V, -, V	1.4, 3, 1	> 0	Default, inspector, part file	The trip level is min(max((V(COMP) - cs_off) / cs_gain, 0), cs_max).

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
chgctl (U)	VIN, BAT, GND, CS, GATE	cccv (Li-ion), float (lead-acid)	approximate

A linear charger that drives an external PMOS or PNP: precharge, constant current set by the sense resistor between CS and BAT, constant voltage, termination.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Charge current	**ichg**	A	1	> 0	Default, inspector, part file	
Float voltage	**vfloat**	V	4.2 (float 13.6)	> 0	Default, inspector, part file	
Termination current	**iterm**	A	0.1 x ichg	≥ 0	Default, inspector, part file	
Precharge current, threshold	**precharge, vpre**	A, V	0.1 x ichg, 3.0		Default, inspector, part file	
Sense resistor	**rsense**	Ω	0.1	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

37.3 Diodes, thyristors and protection

Diodes are fitted to their forward voltage at a test current, and breakdown is a smooth clamp with a dynamic resistance. Thyristors latch on a trigger and hold until their current falls below the holding current.

PART	TYPE	PINS	WHAT IT DOES	PARAMETERS (DEFAULT)
Bidirectional TVS	**diode**, variant tvs_bi	anode, cathode	Clamps at ± bv in both directions.	bv (6.8 V), rdyn (0.5 Ω), cj0 (100 pF)
Bridge rectifier	**bridge** (D)	ac1, ac2, +, -	Four diodes with reverse breakdown.	vf (1 V) at if_test (1 A), bv (1000 V), cj0 (20 pF)
Dual diode	**diode2** (D)	cc: a1, a2, k. ca: k1, k2, a. series: a, mid, k. dual: a1, k1, a2, k2	Two diodes in one package.	kind (signal: 0.75 V at 10 mA, bv 75 V, or schottky: 0.4 V, bv 30 V), is, n, bv, cj0 (2 pF)
ESD protection array	**esd** (D)	1ch: io, gnd. 2ch: io1, io2, gnd. 4ch, 2ch_vbus, 4ch_vbus, usblc6 (6 pins)	Steering diodes to gnd and VBUS and a TVS clamp.	vbr (6.5 V), vc (12 V) at ipp (5 A), cj (1 pF) per line
Current-regulating diode	**crd** (D)	anode, cathode	Holds a constant current above the knee voltage.	ip (10 mA), vk (2.5 V)
SCR	**scr** (Q)	anode, cathode, gate	Fires on gate current above igt, on breakover above vdrm or on dV/dt above dvdt_crit. Holds above ih.	igt (200 µA), ih (5 mA), vtm (1.4 V) at itm (5 A), vgt (0.8 V), vdrm (600 V), dvdt_crit (50 V/µs)

PART	TYPE	PINS	WHAT IT DOES	PARAMETERS (DEFAULT)
TRIAC	**triac** (Q)	mt1, mt2, gate	Fires on gate current of either sign above igt (quadrant 4 only if allowed) or above vdrm.	igt (10 mA), ih (15 mA), vtm (1.5 V) at itm (10 A), vgt (1 V), vdrm (600 V), quadrants (123)
DIAC, SIDAC, surge suppressor	**diac** (D)	a, b	Breaks over at vbo in either direction.	vbo (32 V, sidac 120, tss 58), dv fold-back (6 V), ih, ron
Varistor (MOV)	**mov** (RV)	a, b	$I = 1\text{ mA} \times (V / v1ma)^{alpha}$. Warns when the absorbed energy exceeds e_max.	v1ma (470 V), alpha (30), c (100 pF), r_bulk (1 Ω), e_max (10 J)
Gas discharge tube	**gdt** (GDT)	2pin: a, b. 3pin: a, b, gnd	Sparks over at v_spark (higher for fast edges), glows, then arcs above i_glow, extinguishes below i_hold.	v_spark (90 V), v_arc (15 V), v_glow (0.7 x v_spark), i_glow (0.5 A), i_hold (0.1 A), k_imp (0.1)

TRY IT

A crowbar with an SCR

1. Place a 12 V source with 1 Ω in series, an SCR across the output, a 9.1 V Zener from the output to the gate through 100 Ω, and 1 kΩ from gate to cathode.
2. Raise the source slowly with its slider.

YOU SHOULD SEE Above about 9.8 V the Zener drives the gate, the SCR fires and shorts the output, and it stays on until the source drops below the point where the current falls under ih.

38 Devices: batteries, board parts and analog blocks

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Batteries and supercapacitors, board parts, analog building blocks, sensor modules and RF parts. The parameter tables use the same columns as **Devices: passives**, p. 265. Every part has labelled fields with units in the inspector and in All parameters, and the live stimulus of a sensor (light, temperature, field, strain, distance, load) is its main field, first in the list, with a slider range that fits it. A field that shows *auto* takes a value derived from other parameters until you type one (for example the must-operate voltage of a relay is 0.75 of its coil voltage). Clear it to go back. A variant placed from the library starts with its own typical values, such as 1 kΩ for a Pt1000 or 1.2 V dropout for an AMS1117. A part placed from the library can start with its own values, and a part made with the Part Wizard takes them from its datasheet fields (**Part templates reference**, p. 606).

38.1 Batteries and supercapacitors

TYPE	PINS	VARIANTS	CLASS
battery (BT)	+, -	liion, lifepo4, nimh, alkaline, coin, leadacid, lipo_pack	approximate

A battery with its chemistry's open-circuit voltage curve against state of charge, a series resistance and a polarisation R1-C1, and a state of charge that falls as it delivers charge. Drag **soc** to charge or discharge it at once. It warns when the terminal voltage falls below the cut-off.

CHEMISTRY	CELL VOLTAGE FROM EMPTY TO FULL
Li-ion, LiPo pack	3.0 → 3.6 at 20 % → 3.84 at 60 % → 4.2 V
LiFePO4	2.5 → 3.2 → 3.31 → 3.6 V
NiMH	1.0 → 1.2 → 1.26 → 1.4 V
Alkaline	0.9 → 1.2 → 1.4 → 1.6 V
Coin (lithium)	2.0 → 2.8 → 2.95 → 3.2 V
Lead-acid	1.75 → 1.95 → 2.06 → 2.15 V

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Cells in series	**cells**		1 (lipo_pack 3)		Default, inspector, part file	
Capacity	**capacity_ah**	Ah	2		Default, inspector, part file	
State of charge	**soc**	0 to 1	0.8		Live slider	
Series resistance	**r**	Ω	0.05 (coin 15)		Default, inspector, part file	
Polarisation	**r1, c1**	Ω, F	0.02, 2000		Default, inspector, part file	Recovery after a load step.
Fixed voltage	**v**	V	none		File or All parameters	If set, a fixed EMF with no state of charge.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

Watch a battery sag

1. Place a battery (liion) and a 4 Ω load. Probe the battery voltage.
2. Set the timebase to 1 s per second and run.

YOU SHOULD SEE The voltage steps down by I · r at once, then sags further over a minute as the polarisation charges, and recovers slowly when you remove the load.

A supercapacitor (capacitor variant supercap) is a main ESR-C branch with a slower R2-C2 branch and optional leakage: **c** 1 F, **esr** 0.1 Ω, **r2** 10 x esr, **c2** 0.1 x c, **rleak** none.

38.2 Board parts

PART	TYPE	PINS	MODEL AND PARAMETERS (DEFAULT)
Connector	**conn** (J)	1xN, 2xN, usb_c, usb_micro, usb_a, barrel, trs, trs_sw, rj45, sma, microsd, bat_holder, banana	No electrical element. It only connects its pins to their nets.
Test point, mounting hole, fiducial	**tp**, **mhole**, **fiducial**	one pin	No element.
Net tie	**net_tie** (NT)	a, b (variant 3: a, b, c)	Joins its nets into one.
Jumper	**jumper** (JP)	a, b (3way: a, b, c)	state (0 open, 1 closed, click to toggle), r (1 mΩ closed).
Resistor network	**rnet** (RN)	iso2, iso4, iso8: a1, b1, … bus4, bus8: com, r1 …	r (10 kΩ).

PART	TYPE	PINS	MODEL AND PARAMETERS (DEFAULT)
Strain gauge	**strain** (R)	a, b	R = r0 (1 + gf · strain · 10^{-6}): r0 (350 Ω), gf (2), strain (0 με, live).
Ferrite bead	**ferrite** (FB)	a, b	dcr in series with L, R and C set by z100 (600 Ω at 100 MHz), dcr (0.15 Ω), f_srf (1 GHz). Its impedance falls with DC current above irated (0.5 A).
Feed-through capacitor	**cap3** (C)	in, out, gnd	c (100 nF) to gnd, l_thru (2 nH), rdc (10 mΩ).
Common-mode choke	**cmc** (L)	a1, b1, a2, b2	Two coupled windings: l (1 mH), k (0.995), dcr (50 mΩ).

38.3 Analog building blocks

PART	TYPE	PINS	WHAT IT DOES	PARAMETERS (DEFAULT)
Darlington array	**darr** (U)	uln2003: in1 … in7, gnd, com, out7 … out1. uln2803: 8 channels	Real Darlington pairs with base resistors and clamp diodes to com.	rin (2.7 kΩ), imax (0.5 A, warns)
556 dual timer	**timer556** (U)	14 pins	Two 555 timers sharing the supply.	none
Dual potentiometer	**pot_dual** (RV)	a1, b1, w1, a2, b2, w2	One wiper position moves both gangs.	r (10 kΩ), pos (0.5, live), r_end, variant lin or log
Multi-winding transformer	**xfmr_multi** (T)	ct: p1, p2, s1, sct, s2. ct_pri, dual, flyback, current	Coupled windings, every pair coupled by k.	lp (1 mH), ratio (1), ratio2, ratio_aux (0.2), n (100, current transformer), k (0.999, flyback 0.98), rp, rs
Bridge sensor	**bridge_sensor** (U)	exc+, exc-, out+, out-	Four resistors unbalanced by the measurand: V(out) = (sens · x + zero) mV/V x V(exc).	r_bridge (350 Ω), sens (2 mV/V), x (0 to 1 of full scale, live), zero (0)
Analog sensor	**asensor** (U)	VCC, GND, OUT	OUT = offset + sens · x, optionally ratiometric.	x (25, live), sens (10 mV per unit), offset (0), ratiometric (0), vcc_ref (5 V), rout (100 Ω), icc (60 µA), tau
Instrumentation amplifier	**inamp** (U)	rg: in+, in-, rg1, rg2, ref, out, v+, v-. fixed, diff: 6 pins	Gain 1 + 2 rf / Rg with the real external Rg, or a fixed gain. Offset and common-mode error (vcm / CMRR) are input referred; large steps slew at slew.	rf (24.7 kΩ), gain (1), gbw (1 MHz), slew (1.2 V/µs), vos (50 µV), cmrr_db (100), rail (1.2 V), iq (1.3 mA)
Current-sense amplifier	**csa** (U)	uni: IN+, IN-, OUT, VS, GND. bidir: plus REF. hs: plus REF1, REF2	OUT = gain · (V(IN+) - V(IN-) - vos) + reference, with bandwidth and output swing limits.	gain (50 V/V), bw (350 kHz), vos (100 µV), rail (30 mV), ib (75 µA)
Hall current sensor	**isense_hall** (U)	ip+, ip-, vcc, gnd, out, filt	ACS712 class: OUT = VCC/2 + sens · I, ratiometric.	sens (185 mV/A), r_ip (1.2 mΩ), bw (80 kHz)
Analog multiplier	**mult** (U)	x1, x2, y1, y2, z, w, v+, v-	AD633 class: W = (x1 - x2)(y1 - y2) / scale + z.	scale (10 V), bw (1 MHz)
Audio amplifier	**audioamp** (U)	btl, se, lm386	Bridge-tied, single-ended, or the LM386 with its gain pins (20 open, 200 with a capacitor). btl / se: SD low shuts the amplifier down (outputs high impedance); SD open is on (300 kΩ pull-up).	gain (20), iq (4 mA), rail (0.3 V)

PART	TYPE	PINS	WHAT IT DOES	PARAMETERS (DEFAULT)
Digital potentiometer	**digipot** (U)	updown (X9C103), spi (MCP4131), i2c	Wiper set by code. Up/down counts on nINC. SPI takes 16-bit frames. I2C (MCP4017 rheostat W to B) answers at addr 0x2F: a write sets the wiper, a read returns it, and it ACKs on SDA.	r (10 kΩ), steps (100, spi 129, i2c 128), code (50, live), r_w (75 Ω), addr (47, i2c)
OTA	**ota** (U)	in+, in-, iabc, out, v+, v-	LM13700 class: Iout = Iabc · tanh(Vin / 2 Vt); the output stays 0.8 V inside the rails.	rout (10 MΩ at Iabc = 500 µA, scaling as 1 / Iabc, so at Iabc = 0 the output leaks next to nothing)

38.4 Sensor modules and RF parts

PART	TYPE	PINS	WHAT IT DOES	PARAMETERS (DEFAULT)
PIR motion module	**pir** (U)	VCC, OUT, GND	OUT high (3.3 V) while motion is on and t_hold after.	motion (0, click), t_hold (2 s)
Ultrasonic ranger	**ultrasonic** (U)	VCC, TRIG, ECHO, GND	HC-SR04: after a 10 µs TRIG pulse, ECHO is high for 2 · dist / 343 m/s.	dist (0.5 m, live)
Touch sensor IC	**touch** (U)	Q, VSS, I, AHLB, VDD, TOG	TTP223: Q follows the touch, or toggles with TOG high. AHLB inverts.	touch (0, click), t_resp (60 ms)
Microphone	**mic** (MK)	electret: out, gnd. mems_analog: VDD, GND, OUT. mems_pdm: VDD, GND, CLK, DATA, LR	A test tone at spl dB SPL. The PDM mic outputs a real sigma-delta bit stream.	sens (-42 dBV/Pa), spl (94 dB), tone_f (1 kHz), i_d (0.5 mA), vbias (0.9 V), sens_dbfs (-26)
IR receiver	**irrx** (U)	OUT, GND, VS	With code set, outputs an NEC frame starting at 10 ms, active low.	code
Antenna	**antenna** (AE)	mono: feed. dipole: feed+, feed-. chip, pcb: feed, gnd	Radiation resistance with reactance at f0.	r_rad (50 Ω), x (0), f0 (2.45 GHz)
RF attenuator	**attenuator** (AT)	IN, OUT, GND	A matched pi network.	atten_db (10 dB), z0 (50 Ω)
Balun	**balun** (T)	UNBAL, GND, BAL+, BAL-	Coupled inductors, 1:1, 1:2 or 1:4.	lp (100 nH), k (0.98)
SAW filter	**saw** (FL)	IN, OUT, GND	A series resonance at f0 with the bandwidth and insertion loss.	f0 (433.92 MHz), bw (1 MHz), il_db (2.5 dB), z0 (50 Ω)
RF amplifier	**rfamp** (U)	IN, OUT, VCC, GND	Gain with compression at p1db and a pole at f3db, 50 Ω in and out.	gain_db (15), f3db (3 GHz), p1db (15 dBm), icc (30 mA)
Peltier (TEC)	**peltier** (TEC)	+, -	Resistance plus a Seebeck voltage from the temperature difference it pumps.	r (2 Ω), seebeck (50 mV/K), rth (1 K/W)
Gas sensor	**gas** (U)	h1, h2, a, b	MQ-x: the sensing resistance falls with ppm and needs the heater warm.	r_h (33 Ω), ppm (100, live), r0, ppm0, k (the variant's datasheet curve, below), tau_heat (30 s)

The gas sensor (**gas**) has three variants, and each starts with its own datasheet curve: the sensing resistance is $Rs = r0 \cdot (ppm / ppm0)^{-k}$. The fields **r0**, **ppm0** and **k** show *auto* with the variant's values until you type your own, and a value you typed wins.

VARIANT	GAS	R0	PPM0	K
mq2	LPG	10 kΩ	574 ppm	0.45
mq135	CO_2	76.6 kΩ	117 ppm	0.361
mq7	CO	10 kΩ	99 ppm	0.659

The MQ-135 in 400 ppm of CO_2 reads about 49 kΩ. The sensor still needs its heater warm (**tau_heat** 30 s) before the resistance follows the gas.

39 Devices: interface chips, switches and microcontrollers

39.1	Level translators	355	39.4	Analog switches and multiplexers	357
39.2	RS-485, CAN and RS-232 transceivers	356	39.5	Microcontrollers	359
39.3	Digital isolators	357	39.6	Chips and displays	359

Level translators, bus transceivers, isolators, analog switches, microcontrollers, memory and display chips. The parameter tables use the same columns as **Devices: passives**, p. 265. Every part has labelled fields with units in the inspector and in All parameters, and the live stimulus of a sensor (light, temperature, field, strain, distance, load) is its main field, first in the list, with a slider range that fits it. A field that shows *auto* takes a value derived from other parameters until you type one (for example the must-operate voltage of a relay is 0.75 of its coil voltage). Clear it to go back. A variant placed from the library starts with its own typical values, such as 1 kΩ for a Pt1000 or 1.2 V dropout for an AMS1117. A part placed from the library can start with its own values, and a part made with the Part Wizard takes them from its datasheet fields (**Part templates reference**, p. 606).

39.1 Level translators

TYPE	PINS	VARIANTS	CLASS
lvlshift (U)	1t45: VCCA, GND, A, B, DIR, VCCB. 2t45: 8 pins. txs2: VCCA, VCCB, OE, GND, A1, A2, B1, B2. txs8: 20 pins.	1t45, 2t45 (direction pin), txs2, txs8 (automatic direction)	approximate

The 1T45 and 2T45 buffer in the direction set by DIR, each side powered by its own supply. The TXS types have pull-ups on both sides and a pass transistor: whichever side is pulled low pulls the other low, which works for I²C and other open-drain buses.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Propagation delay	**tpd**	s	5 ns	≥ 0	Default, inspector, part file	1t45, 2t45.
Pull-up resistance	**r_pu**	Ω	10 kΩ	> 0	Default, inspector, part file	TXS, each side.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

39.2 RS-485, CAN and RS-232 transceivers

TYPE	PINS	VARIANTS	CLASS
rs485 (U)	RO, nRE, DE, DI, GND, A, B, VCC	none (MAX485 class)	approximate

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Differential output	**vod**	V	2.0	> 0	Default, inspector, part file	
Driver output resistance	**rout**	Ω	25	> 0	Default, inspector, part file	
Receiver hysteresis	**vth**	V	0.2	> 0	Default, inspector, part file	
Input resistance	**rin**	Ω	12 kΩ	> 0	Default, inspector, part file	
Delay	**tpd**	s	50 ns	≥ 0	Default, inspector, part file	
Fail-safe	**failsafe**	0 / 1	0		Default, inspector, part file	An idle bus reads 1.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
can (U)	5v: TXD, GND, VCC, RXD, VREF, CANL, CANH, S. 3v3: D, GND, VCC, R, VREF, CANL, CANH, RS.	5v (TJA1050), 3v3 (SN65HVD230)	approximate

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Dominant differential voltage	**v_dom**	V	2.0	> 0	Default, inspector, part file	
Recessive bias resistance	**rin**	Ω	25 kΩ	> 0	Default, inspector, part file	
Receiver threshold	**vth**	V	0.7	> 0	Default, inspector, part file	
Delay	**tpd**	s	100 ns	≥ 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TYPE	PINS	VARIANTS	CLASS
rs232 (U)	C1+, V+, C1-, C2+, C2-, V-, T2OUT, R2IN, R2OUT, T2IN, T1IN, R1OUT, R1IN, T1OUT, GND, VCC	max232, max3232	approximate

V+ and V- come from an internal charge pump, so the pump capacitors aren't needed in the simulation. Drivers invert and swing to about V+ - 1 V and V- + 1 V.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Charge pump voltage	**v_pump**	V	0 (2 VCC - 1)	> 0	Default, inspector, part file	
Pump output resistance	**rout_pump**	Ω	200	> 0	Default, inspector, part file	
Receiver input resistance	**rin**	Ω	5 kΩ	> 0	Default, inspector, part file	
Receiver threshold	**vth**	V	1.3 (± 0.25)	> 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

39.3 Digital isolators

TYPE	PINS	VARIANTS	CLASS
isolator (U)	2ch: VCC1, INA, INB, GND1, GND2, OUTB, OUTA, VCC2. 4ch: 13 pins with EN2. i2c: VCC1, SDA1, SCL1, GND1, GND2, SCL2, SDA2, VCC2.	2ch, 4ch, i2c	approximate

Side 2 follows side 1 after tpd, each side powered by its own supply, with no connection across the barrier. The I²C variant passes both lines both ways as open drain.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Delay	**tpd**	s	10 ns	≥ 0	Default, inspector, part file	
Supply current per side	**icc**	A	1.5 mA	≥ 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

39.4 Analog switches and multiplexers

TYPE	PINS	VARIANTS	CLASS
amux (U)	1x8 (4051): Y0 … Y7, Z, S0 … S2, EN, VDD, VSS, VEE. 1x4, 1x16 (4067), 2x4 (4052), 3x2 (4053), spst_quad (4066), spst, spdt, dual_spdt.	1x8, 1x4, 1x16, 2x4, 3x2, spst_quad, spst, spdt, dual_spdt	approximate

The select pins choose the channel joined to the common pin, with break-before-make, an on-resistance that depends on the supply and the signal, capacitances and charge injection. EN is active low unless en_high is set. The family sets the logic thresholds: use cd4000 for the CD405x and 4066.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
On resistance	**ron**	Ω	100	> 0	Default, inspector, part file	At ron_vdd.
Off resistance	**roff**	Ω	1 GΩ	> 0	Default, inspector, part file	
Supply for ron	**ron_vdd**	V	5	> 0	Default, inspector, part file	ron scales with (ron_vdd / supply)$^{0.8}$.
Ron flatness	**ron_flat**		0.3	≥ 0	Default, inspector, part file	Signal dependence.
Switching time	**tsw**	s	100 ns	> 0	Default, inspector, part file	
Break-before-make	**t_bbm**	s	10 ns	≥ 0	Default, inspector, part file	
Channel / common capacitance	**cs, cd**	F	5 pF, 25 pF	≥ 0	Default, inspector, part file	
Charge injection	**qinj**	C	2 pC	any	Default, inspector, part file	
Supply current	**icc**	A	1 µA	≥ 0	Default, inspector, part file	
EN active high	**en_high**	0 / 1	0		Default, inspector, part file	
Normally closed	**nc**	0 / 1	0		Default, inspector, part file	spst.
Logic family	**family**		hc		Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

39.5 Microcontrollers

TYPE	PINS	VARIANTS	CLASS
mcu (U)	generic: the pins you declare in the code, else the pins named in pinout. atmega328p_tqfp32, attiny85_dip8, stm32f103c8_lqfp48: the package pins.	generic, atmega328p_tqfp32, attiny85_dip8, stm32f103c8_lqfp48	behavioural, runs your program

A microcontroller runs the program on its **Code** tab, in a small language made for pins: GPIO, ADC, DAC, PWM, UART, I²C, SPI and CAN. Each pin or bus you declare is added to the chip. **Programming the MCU**, p. 373 describes the language, every peripheral and the warnings. Without a program the chip only draws its supply current (10 mA by default), its pins are inputs with clamp diodes, and the generic variant has just VDD and GND. A program that contains **fn name(** is the old control-block script and runs with a **pinmap**, as in **Programmable control blocks**, p. 369:

```
"pinmap": { "PA0": "ain0", "PA1": "ain1", "PB0": "out0", "PB1": "out1" }
```

The parameters are in **Parameters**, p. 393. For a chip without a program, **gpio** sets the mode of each pin: **PB0=out1 PB1=pwm:1000:0.25 PA0=in_pu**.

39.6 Chips and displays

TYPE	PINS	VARIANTS	CLASS
chip, display (U, DS)	chip: generic (any pins, named from pinout), eeprom, spi_flash, rtc, i2c_dev, spi_dev, usb_uart. display: hd44780, oled_i2c, oled_spi, tft_spi, epaper.	as listed	every variant works: eeprom, spi_flash, rtc, i2c_dev, spi_dev and usb_uart talk on their bus, generic is an IC box you can open as a subcircuit, and the displays decode what they are sent

Five chips answer a microcontroller: **eeprom** (24C02, I²C at 0x50), **spi_flash** (W25Q, JEDEC id, read, page program, sector erase), **rtc** (DS1307, I²C at 0x68, BCD time that counts simulated time), and the configurable **i2c_dev** and **spi_dev** (below). **Memory, flash and RTC chips**, p. 388 lists their commands. The displays decode what's written to them: the HD44780 shows its text on the symbol, the SSD1306 OLED takes I²C or SPI, and the ILI9341 TFT and the e-paper take SPI. A display adds its backlight LED (vf_bl 3.1 V).

USB-UART bridge

The **usb_uart** variant is a CH340C-class USB-to-UART bridge (SOP-16: GND, TXD, RXD, V3, UD+, UD−, NC1, NC2, CTS, DSR, RI, DCD, DTR, RTS, R232, VCC). Its UART side is real. Its USB side is the **Console**: what the chip receives on

RXD shows there as text, and text you type in the Console goes out on TXD. It's how a program running on a microcontroller talks to the PC (**UART**, p. 384).

- **TXD** idles high and sends each byte as an 8N1 frame at **baud**, push-pull from VCC behind 50 Ω with 20 ns edges. The bit times are exact.
- **RXD** has a 50 kΩ pull-up and thresholds at 0.3 and 0.4 of VCC. A start edge is found as an event and every bit is sampled in the middle. Each byte received becomes Console text: a line feed ends a line, a carriage return is dropped, a partial line is shown after 5 idle byte times or at 120 characters, and other control bytes show as **\xNN**.
- **Send:** the **send** text goes out at **send_at** once the chip is powered, and again whenever you change it while the circuit runs (a rebuild doesn't send it twice). Escapes: **\n \r \t \\ \xNN**.
- **DTR#** and **RTS#** are outputs, high until **dtr** or **rts** is 1, which drives the pin low, as a terminal does when it opens the port. Through 100 nF, DTR resets an Arduino. **CTS#**, **DSR#**, **RI#** and **DCD#** have 50 kΩ pull-ups. With **flow** at 1, TXD waits while CTS# is high.
- **V3** is the internal 3.3 V regulator output when VCC is 5 V (give it a decoupling capacitor to GND). It only sources: tied to a 3.3 V VCC it carries nothing. Below 2.5 V on VCC the chip sends and receives nothing.
- A stop bit that is low on RXD is a framing error. The sender's baud rate differs from the chip's, so the chip warns **W_UART** once. More than 4096 bytes waiting to be sent warn **W_UART** too, and the rest are dropped.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Supply current	**idd**	A	1 mA	≥ 0	Default, inspector, part file	
Baud rate	**baud**	baud	115200	300 to 3 000 000	Default, inspector, part file	8N1, the same on both sides.
Text to send on TXD	**send**	text	empty		Default, inspector, part file	Sent at send_at, and again whenever it changes.
Send start time	**send_at**	s	1 ms	≥ 0	File or All parameters	
Console line ending	**eol**		lf	lf, cr, crlf, none	Default, inspector, part file	Added to text typed in the Console input.
DTR asserted	**dtr**	0 / 1	0		Live slider	Live toggle.
RTS asserted	**rts**	0 / 1	0		Live slider	Live toggle.
Hardware flow control	**flow**	0 / 1	0		File or All parameters	TXD waits while CTS# is high.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Live values: **rx_bytes**, **tx_bytes** (bytes received and sent) and **tx_queued** (bytes waiting). The Console input bar and the way to use it are in **Console**, p. 210.

I²C and SPI register devices

i2c_dev (VDD, GND, SCL, SDA, INT, ADDR) and **spi_dev** (VDD, GND, SCK, MOSI, MISO, CS, INT) stand in for any sensor or peripheral that is a block of 8-bit registers: a temperature sensor, an accelerometer, an ADC, a port expander. You give the register map. The chip answers a microcontroller (**Memory, flash and RTC chips**, p. 388) or any bus you drive yourself.

- **Register map: regs** sets the starting values as register=value pairs, hex or decimal: **0x00=0x12 0x01=0x34**. Registers not listed start at 0. **ro** lists read-only registers or ranges (**0x00 0x10-0x13**): writes to them are acknowledged and ignored. After each byte the register pointer moves to the next register, and it wraps after **size** registers (256 for I²C, 128 for SPI).
- **A live reading:** with **value_reg** set, **value** × **scale**, rounded, sits in **value_bytes** (1 or 2) read-only registers from value_reg, most significant byte first, two's complement when negative. Drag **value** while the circuit runs, as you would turn up the heat on a sensor. A TMP102 is **value_reg** 0 and **scale** 16 (0.0625 °C per count).
- **INT** is open drain: it pulls low while value is at or above **int_above**, and stays released when int_above is empty. Give it a pull-up.
- **I²C:** the chip answers at **addr** (7 bit, 0x48 by default), or at addr + 1 with ADDR high, and doesn't acknowledge any other address. The first data byte of a write sets the register pointer and the next bytes are written from there. A read returns the registers from the pointer, so a program writes the pointer, then reads, as with most sensors. SDA is open drain: SDA and SCL need pull-ups (2.2 kΩ to 10 kΩ).
- **SPI:** CS is active low, mode 0 by default (**cpol**, **cpha** choose modes 1 to 3). The first byte after CS falls is the command: bit 7 set reads, bit 7 clear writes, and bits 6 to 0 are the first register. Then data goes in (write) or comes out (read). MISO sends 0x00 during the command byte and is high impedance while CS is high, so several chips can share it.
- Inputs switch at 0.3 and 0.7 of VDD. The live values show the register pointer and the contents of registers 0x00 to 0x0F and of every listed register.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
I²C address	**addr**		72 (0x48)	0 to 127	Default, inspector, part file	i2c_dev. ADDR high adds 1.
Initial register values	**regs**	text	empty		Default, inspector, part file	register=value pairs.
Read-only registers	**ro**	text	empty		Default, inspector, part file	Numbers or ranges.
Number of registers	**size**		256 / 128	1 to 256	File or All parameters	The pointer wraps here.
Live reading	**value**		0	any	Live slider	Changes in place while running.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Counts per unit	scale		1	any	Default, inspector, part file	
Register of the reading	value_reg		none	0 to 255	Default, inspector, part file	Empty: no reading.
Reading width	value_bytes	bytes	2	1 or 2	Default, inspector, part file	
INT low at a reading of	int_above		never	any	Default, inspector, part file	
Clock idles high	cpol	0 / 1	0		Default, inspector, part file	spi_dev.
Sample on the second edge	cpha	0 / 1	0		Default, inspector, part file	spi_dev.
Supply current	idd	A	1 mA	≥ 0	Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

TRY IT

Read a temperature sensor over I²C

1. Place a microcontroller, a chip (variant i2c_dev) with value_reg 0 and scale 16, and 4.7 kΩ pull-ups from SDA and SCL to VDD.
2. Give the microcontroller this program: **bus T i2c SDA SCL 400kHz**, then a loop of **send T 0x48 0**, **read T 0x48 2 into raw**, **print "counts" raw** and **wait 100ms**.
3. Run, then drag the chip's **Live reading** from 25 to 30.

YOU SHOULD SEE The Console shows counts 400 (25 × 16), then 480 after you drag the reading.

Generic IC

The **generic** variant is an IC box with any pins, named by **pinout** (name:side, as the Subcircuit / IC). The library now offers one **Generic IC** tile in its place (the Subcircuit / IC), and a circuit saved with the older box keeps it unchanged. It draws **idd** from each supply pin (a pin named VCC, VDD, V3, VBAT, AVDD, DVDD, VIN or V+) to the ground pin, and every other pin is a high-impedance input with clamp diodes and a 1 GΩ leak, so the board around it simulates. **pullups** lists pins that get 50 kΩ to the supply. To give it a behaviour, double-click it, or right-click it and choose **Edit subcircuit**: it

becomes a sheet in place, with one sheet pin on each pin (the wiring stays connected) and one port per pin inside, and it opens in its own ↳ tab. Draw the inside there (**Editing a subcircuit**, p. 151).

40 Digital logic

40.1 Simple gates, flip-flop and counter 364
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BetterSPICE has two kinds of digital parts. The simple gates below have no supply pins and switch at half their supply parameter. The logic families (74HC, 74LS, CD4000 and others) have real supply pins, real thresholds and output drive (**Logic families**, p. 365). Both run in the same analogue simulation as the rest of the circuit, so edges have real rise times and real loading.

40.1 Simple gates, flip-flop and counter

TYPE	KEY	PINS	VARIANTS	CLASS
not, and, or, nand, nor, xor, dff, counter4 (U)	library	not: in, out. Gates: in1, in2, out. dff: d, clk, q, qn. counter4: clk, q0 … q3	none	approximate

The supply is the parameter **vdd**. Outputs are referenced to ground behind rout. An input is high above vdd/2, with no hysteresis and no input current. Each output edge starts half a propagation delay after the input crosses and lasts one tpd. The D flip-flop samples d on the rising clock edge. The counter counts rising clock edges and wraps from 15 to 0. q0 is the least significant bit.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Supply	**vdd**	V	5	> 0. Slider 1 to 15 V.	Default, inspector	High level and threshold basis.
Propagation delay	**tpd**	s	10 ns	≥ 0	Default, inspector	
Output resistance	**rout**	Ω	50	> 0	File or All parameters only	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

> **NOTE** **Inputs need a driver.** A gate input draws no current, so a net with only gate inputs on it has no DC path and is reported as floating. Drive every input, or tie it to a supply.

40.2 Flip-flops and latches (JK, T, D latch, SR latch)

TYPE	KEY	PINS	VARIANTS	CLASS
jkff, tff, dlatch, srlatch (U)	library	jkff: j, clk, k, set, rst, q, qn. tff: t, clk, set, rst, q, qn. dlatch: d, en, q, qn. srlatch: s, r, q, qn	none	approximate

The same electrical model as the D flip-flop: the supply **vdd**, inputs high above vdd/2, outputs behind rout, each output edge half a propagation delay after the input and one tpd long. All four power up with q low.

The **JK flip-flop** acts on the rising clock edge: J and K both low hold, J high sets, K high resets, both high toggle. The **T flip-flop** toggles on the rising edge while t is high and holds while it is low. Both have an asynchronous **set** (S) and **reset** (R), active high. An open set or reset pin reads low, so it can stay unconnected. Set and reset together drive q and qn both high, as a 74xx part does, and the stored bit returns when they are released.

The **D latch** is transparent while en is high: q follows d. While en is low it holds. The **SR latch** is the pair of cross-coupled NOR gates: s sets, r resets, and with both low it holds. s and r both high is the forbidden input: q and qn are both low. The input released last wins. Released in the same instant, the latch settles reset. A real pair goes metastable there and can settle either way.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Supply	**vdd**	V	5	> 0. Slider 1 to 15 V.	Default, inspector	High level and threshold basis.
Propagation delay	**tpd**	s	10 ns	≥ 0	Default, inspector	
Output resistance	**rout**	Ω	50	> 0	File or All parameters only	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

> **NOTE** **Checked against ngspice.** The four parts are compared with the ngspice XSPICE flip-flops and a pair of XSPICE NOR gates on a random input sequence. Like the D flip-flop they are written to an ngspice export as comments.

40.3 Logic families

The 74xx and 4000-series parts and the single gates with supply pins take their thresholds, output drive, delay and supply current from a logic family, chosen with the **family** parameter. Their outputs are driven from their own VCC and GND pins, so a weak supply or a long line shows up as it would on a board, and a supply outside the family's range warns **W_SUPPLY**.

FAMILY	SUPPLY	INPUT LOW / HIGH	OUTPUT R HIGH / LOW	EDGE	DELAY	QUIESCENT	INPUTS ABOVE VCC
hc (default)	2 to 6 V	0.3 / 0.7 VCC	50 / 40 Ω	6 ns	9 ns	2 µA	clamped
hct	4.5 to 5.5 V	0.8 / 2.0 V	50 / 40 Ω	6 ns	12 ns	2 µA	clamped
ahc	2 to 5.5 V	0.3 / 0.7 VCC	25 / 20 Ω	3 ns	5 ns	2 µA	clamped
lvc	1.65 to 5.5 V	below 2.7 V: 0.35 / 0.65 VCC, else 0.8 / 2.0 V	15 / 12 Ω	2 ns	4 ns	1 µA	tolerant
cd4000	3 to 18 V	0.3 / 0.7 VDD	500 Ω at 5 V	50 ns	100 ns	1 µA	clamped
ls	4.75 to 5.25 V	0.8 / 2.0 V	100 / 25 Ω	8 ns	10 ns	4 mA	tolerant

Drive, edge and delay are taken at 5 V for parts with supply pins. Inputs have 3.5 pF and, unless the family is tolerant, clamp diodes to VCC and GND. Schmitt inputs (the 14 and 1G14, and the buf_st and inv_st gates, or any part with **schmitt** = 1) have a hysteresis of 0.15 VCC. Output changes come tpd after the input, and a glitch shorter than tpd is swallowed (inertial delay). Below the family's minimum supply the outputs release.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Logic family	**family**		hc (cd4000 for 4017, 4040, 4060, 4511)	hc, hct, ahc, lvc, cd4000, ls	Default, inspector, part file	
Propagation delay	**tpd**	s	from the family	≥ 0	Default, inspector, part file	
Supply (gates without supply pins)	**vcc**	V	5	> 0	Default, inspector, part file	
Open drain	**od**	0 / 1	0		Default, inspector, part file	Outputs have no high side.
Schmitt inputs	**schmitt**	0 / 1	0		Default, inspector, part file	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

40.4 Single gates

TYPE	PINS	VARIANTS	CLASS
gate (U)	buf, inv, buf_st, inv_st: in, out. tri_buf, tri_inv: in, oe (active low), out. 2-input: in1, in2, out. 3, 4 and 8-input: in1 …, out. Variants ending _p add VCC, GND.	and2 to and8, nand2 to nand8, or2 to or8, nor2 to nor8, xor2, xnor2, buf, inv, buf_st, inv_st, tri_buf, tri_inv, each also with _p	approximate

Placed with Alt + G. Without _p the gate is powered from its **vcc** parameter and switches relative to ground, with no clamps and no supply current.

40.5 74xx and 4000-series packages

TYPE	PINS	VARIANTS	CLASS
logic (U)	The package pins in order, VCC and GND included.	see the table	approximate

Placed with Alt + L. Every package simulates its full function, with its pins in package order.

VARIANT	FUNCTION	NOTES
00, 08, 32, 86	Quad 2-input NAND, AND, OR, XOR	
02	Quad 2-input NOR	
04, 14	Hex inverter, hex Schmitt inverter	
u04	Hex unbuffered inverter (74HCU04)	A continuous high-gain stage (gain 20, rout 300 Ω) for crystal oscillators. Set from the file or an AI agent.
125	Quad tri-state buffer	nOE active low.
74	Dual D flip-flop with preset and clear	Clocks on the rising edge.
138	3-to-8 decoder	Enabled with G1 high, nG2A and nG2B low. Outputs active low.
151	8-to-1 multiplexer	Y and nW.
157	Quad 2-to-1 multiplexer	
161	4-bit synchronous counter	Asynchronous clear, synchronous load, ENP and ENT, ripple carry.
164	8-bit serial-in parallel-out shift register	Data = A AND B.
165	8-bit parallel-in serial-out shift register	
244	Octal buffer, two enables	
245	Octal bus transceiver	DIR high: A to B.
573	Octal transparent latch	
574	Octal D flip-flop	
595	8-bit shift register with output latch	SRCLK shifts, RCLK latches, QH' cascades.
123	Dual retriggerable monostable	The pulse width follows the external R and C, about 0.45 RC.
4017	Decade counter (Johnson)	CO high for counts 0 to 4.
4040	12-stage ripple counter	Counts on the falling edge.

VARIANT	FUNCTION	NOTES
4060	14-stage counter with oscillator	An RC or crystal around PHI, PHO and PHOB oscillates.
4511	BCD to 7-segment latch and decoder	Blanks above 9.
1g00, 1g08, 1g32, 1g86	Single NAND, AND, OR, XOR (SOT-23-5)	
1g04, 1g14	Single inverter, Schmitt inverter	
1g125	Single tri-state buffer	

TRY IT

Shift out a byte

1. Open **Counters and registers**, a 74HC595 example, or wire a ctrl block to SER, SRCLK and RCLK of a 595 with LEDs on QA to QH.
2. Open the logic analyzer and add QA to QH.

YOU SHOULD SEE Each SRCLK edge shifts a bit in, and the LEDs change all at once on the RCLK edge.

41 Programmable control blocks

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A **Controller (code)** block (**ctrl**) runs a short program at a fixed rate: it samples its analog inputs, runs your code, and drives its outputs with PWM, digital levels or analog levels. A digital power-supply loop, a motor controller or a battery charger can be simulated together with its power stage. The code is written in Rhai, a small scripting language that reads like Rust or JavaScript.

For a program that drives named pins, with GPIO, UART, I²C, SPI and CAN, use the microcontroller and its own small language instead (**Programming the MCU**, p. 373). The control block stays the choice for fixed-rate control loops, complementary PWM with dead time, and ADC triggers.

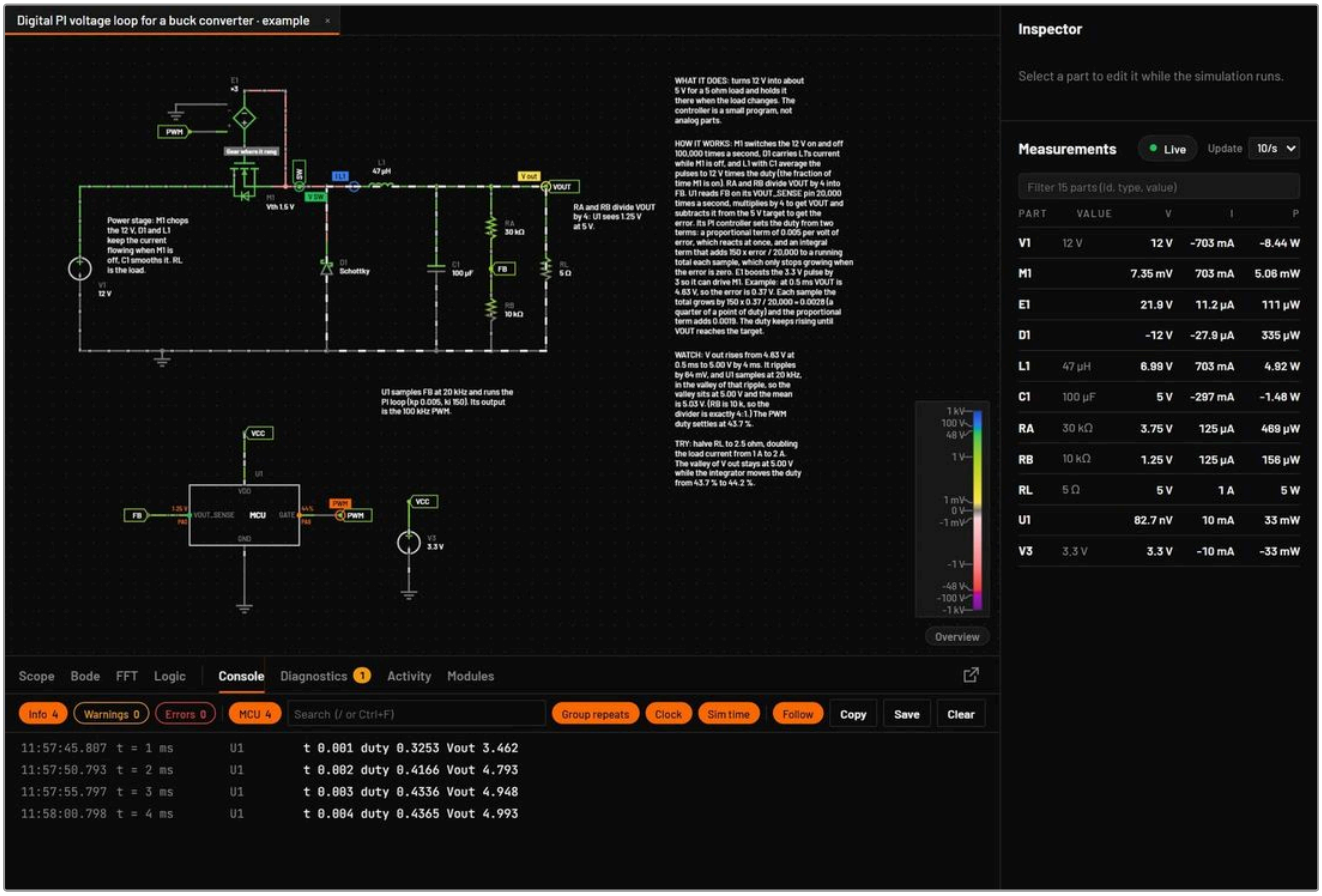


Figure 41.1 A digital PI buck converter: the Code tab in the inspector and log() output in the Console.

41.1 Pins and parameters

TYPE	KEY	PINS	VARIANTS	CLASS
ctrl (U)	library	ain0 … ain(inputs-1), out0 … out(outputs-1), gnd	none	approximate

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Analog inputs	**inputs**		2	0 to 64 (16 in the inspector)	Default, inspector	Number of ain pins.
Outputs	**outputs**		2	0 to 64 (16 in the inspector)	Default, inspector	Number of out pins.
Update rate	**fs**	Hz	100 kHz	> 0. Slider 10 Hz to 10 MHz.	Default, inspector	step() runs every 1/fs, the first time at t = 0.
ADC bits	**bits**		12	1 to 32 (24 in the inspector)	Default, inspector	Input resolution.
ADC reference	**vref**	V	3.3	> 0	Default, inspector	Input full scale.
Output high	**vhi**	V	3.3	≥ 0	Default, inspector	High level of PWM and dout. dac() is clamped to 0 … vhi.
Output resistance	**rout**	Ω	50	> 0	Default, inspector	
Edge time	**tr**	s	10 ns	> 0	Default, inspector	
Code	**code**	text	a PI regulator		Code tab	The Rhai script.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

Each input is high impedance (1 MΩ to the gnd pin) and is read relative to gnd.

A sample is quantised: code = round(clamp(V, 0, vref) / vref · (2^{bits} - 1)), and **ain[k]** is that code converted back to volts. Outputs are voltage sources referenced to the gnd pin.

41.2 The Code tab

The inspector shows **Parameters** and **Code** tabs. The code editor has line numbers and syntax colours, marks error lines in red, and inserts four spaces for Tab. Changes apply when you leave the editor or press Ctrl + S. The line under the editor says **No script errors**, **Edited · applies when you leave the editor or press Ctrl+S**, or the error. Editing the code keeps the script's state, so **init** doesn't run again.

41.3 The functions you write

FUNCTION	WHEN IT RUNS
fn init(s)	Optional. Once, before the first step. **s** is a map that keeps its contents between calls: create fields by assigning them, **s.integ = 0.0;**.
fn step(s, t, ain)	Required. Every 1/fs. **t** is the time in seconds, **ain** the array of input voltages.
fn on_adc(s, ch, v)	When an input set up with adc_config finishes a conversion.
fn on_comp(s, ch, high)	When a comparator set up with comp_config crosses, at the exact instant.
fn on_edge(s, pin, rising)	On every edge of any input. Its presence makes every input also a digital input (threshold vref/2).
fn *name*(s, t)	A timer callback registered with timer_every.

Only the function parameters and **s** exist. An unknown variable is an error.
There are no global constants: use **pi()**.

41.4 The functions you call

CALL	WHAT IT DOES
pwm(ch, freq, duty)	Edge-aligned PWM on output ch. duty 0 to 1. A running channel takes the new values at its next period.
timer_pwm(ch, freq, duty, opts)	A full timer. opts: **complementary** (a second channel with the inverted signal), **deadtime** (s, delays each rising edge of both), **center_aligned** (true or false), **phase** (0 to 1 of a period).
pwm_off(ch)	Cycle-by-cycle limit: the output goes low now and stays low until the next period.
dout(ch, b)	A digital level: true is vhi, false is 0. Stops PWM on that channel.
dac(ch, volts)	An analog level, clamped to 0 ... vhi. Stops PWM on that channel.
timer_every(period, "name")	Calls **fn name(s, t)** every period seconds, at exact instants. Up to 16 timers.
adc_config(ch, opts)	Input ch converts on its own: opts **bits**, **fs**, or **trigger** = **"pwm0_start"**, **"pwm0_mid"** or **"pwm0_end"** to sample in step with a PWM channel. Calls on_adc.
comp_config(ch, opts)	Comparator ch (0 to 15) on an input: opts **ain**, **threshold** (V, default 1), **hyst** (V, default 0). Calls on_comp.
log(msg), **print(msg)**	A line in the Console tab.
clamp(x, lo, hi), **sat(x, lo, hi)**, **min**, **max**	Limits.
pi(), **sqrt**, **exp**, **ln**, **sin**, **cos**, and Rhai's float methods (**abs**, **floor**, **round**, **tan**, **atan**, **log10**, **to_int**, **to_float**)	Maths.
q15(x), **q15_to_f(q)**, **q15_mul**, **q15_add**, **q15_sub**	Q15 fixed point with saturation, as in DSP firmware.

41.5 Limits and errors

Each call runs at most 100 000 operations. A script error becomes an **E_SCRIPT** diagnostic with the line and column, for example *"U3 line 4 col 18: Variable not found: erro"*, and stops that block until the code is fixed. A missing step function, an output channel that doesn't exist and an unknown trigger are reported the same way. The console keeps the last 5000 lines.

41.6 The default program

```
fn init(s) {
    s.integ = 0.0;
}

fn step(s, t, ain) {
    let err = 5.0 - ain[0] * 6.0;            // output divided by 6 on ain0
    s.integ = clamp(s.integ + 0.002 * err, 0.0, 0.95);
    let duty = clamp(s.integ + 0.05 * err, 0.0, 0.95);
    pwm(0, 200e3, duty);                     // 200 kHz PWM on out0
    dout(1, err > 0.5);                      // out1 high while regulating up
}
```

TRY IT

Print the duty cycle once a millisecond

1. Open **Digital control**, the digital PI buck.
2. Select the controller, open the Code tab and add **timer_every(1e-3, "report");** to init, and the function **fn report(s, t) { log("integ=" + s.integ); }**.
3. Press Ctrl + S and open the Console tab.

YOU SHOULD SEE A line per millisecond shows the integrator settling as the output reaches 5 V.

The browser's fallback engine runs a subset of Rhai without adc_config, comp_config and timer_every. The WebAssembly engine, which is normally used, runs all of it.

42 Programming the MCU

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The microcontroller part runs a short program that you write on its **Code** tab, in a small language made for pins. Name a pin in the code and it appears on the chip. The pins behave like real ones: an input can float, an output has a drive limit, and I²C needs pull-up resistors.

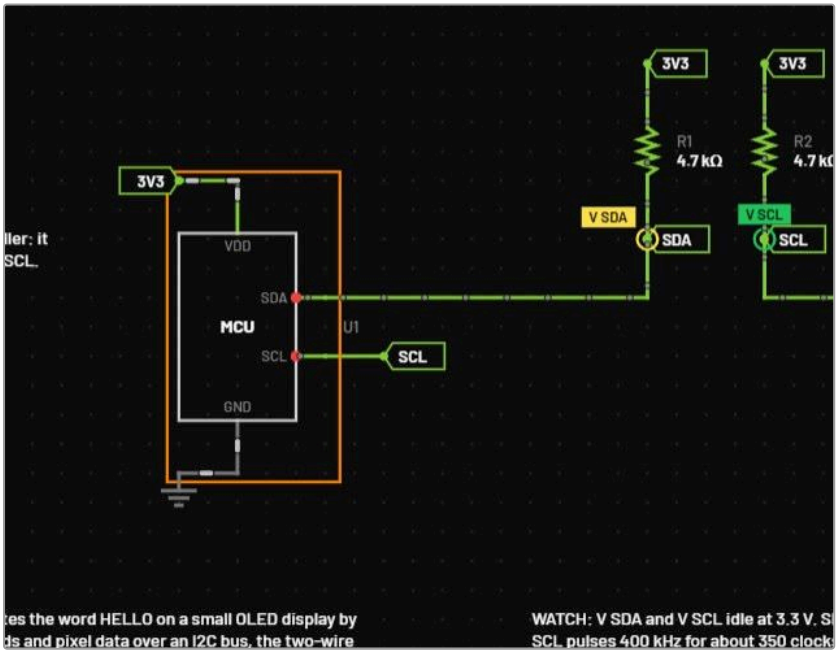


Figure 42.1 An MCU whose code declares **bus OLED i2c SDA SCL 400kHz**: the chip has VDD, GND, SDA and SCL, and nothing else. R1 is one of the two pull-ups.

42.1 What the MCU part is

The part is **mcu** (designator U), placed from the library: type **microcontroller** in the search box and pick the tile **MCU · Generic** (family *"Microcontrollers and processors"*). It has VDD at the top and GND at the bottom. Every pin you declare in the code is added in the order you wrote it: inputs on the left, everything else on the right.

YOU WANT	DO THIS
Your own pins and a program	Use the **Generic** variant (the default). Write the program on the Code tab. Pins come from the code.
A real package, such as ATmega328P, ATtiny85 or STM32F103C8	Pick that variant. The pins are the package pins, and the names you declare must be pin names of the chip, for example **pin PB5 out**.
The old script API (**fn step()**, **pinmap**)	A program that contains **fn name(** still runs as before, as for the control block (**Programmable control blocks**, p. 369). Everything below is the new language.

The program runs in the live simulation and in Simulate, on the same pins, in simulated time. Several MCUs in one circuit each run their own program. It runs from the top when the supply comes up, and stops when VDD falls below the brown-out level.

42.2 Your first program: Blink

This program blinks an LED once a second and takes about five minutes to build. The LED pin of the chip toggles every 500 ms, and the LED lights in step.

1. Press Ctrl + N for a new circuit. Press V, click once, then press G and click under it. Set the source to **3.3** V and wire its two pins.

   YOU SHOULD SEE A 3.3 V source with a ground. This is the supply.

2. Click the library search box, type **microcontroller**, and click the tile **MCU · Generic**. Click the sheet to place it, then press Esc.

   YOU SHOULD SEE A box named U1 with only **VDD** and **GND**. Wire VDD to the + of the source and GND to ground.

3. Select U1. In the inspector click the **Code** tab. Open the **Template...** list and pick **Blink**.

   YOU SHOULD SEE The code box holds **pin LED out** and a **loop**. The chip now has a third pin, **LED**, on its right side.

4. Place a resistor (R, **330** Ω) and an LED (type **LED** in the library search and click the red LED), and wire **LED pin → R1 → LED anode → LED cathode → ground**. Press P and click the wire at the LED pin.

   YOU SHOULD SEE A probe tag **V LED pin** on the wire.

5 Press Ctrl + R if the simulation is paused.

YOU SHOULD SEE The pin goes between 0 V and 3.3 V every 500 ms on the scope, the LED lights and goes dark, and the current through it's about 4 mA.

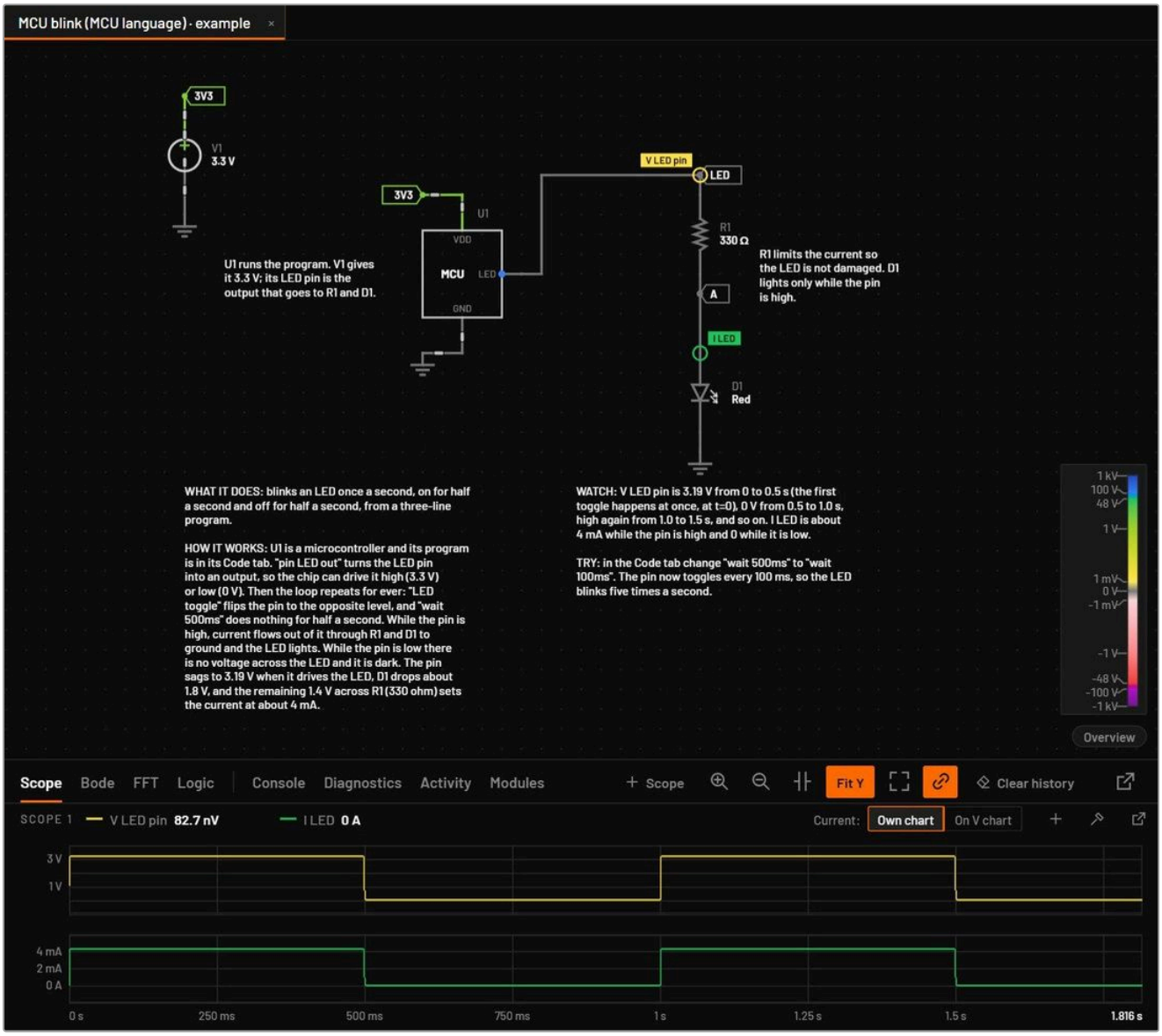


Figure 42.2 The finished Blink circuit running: the LED pin on the scope, and the current through the LED below it. The example **MCU blink** in Digital control is the same circuit.

IF YOU SEE **no LED pin on the chip,** the code does not declare one. Check that the first line is **pin LED out** and that the Code tab shows *No script errors*.

IF YOU SEE **the pin toggles but the LED stays dark,** the LED is wired the wrong way round, or its current path is open. Probe the wire between R1 and the LED.

The Code tab is the whole editor:

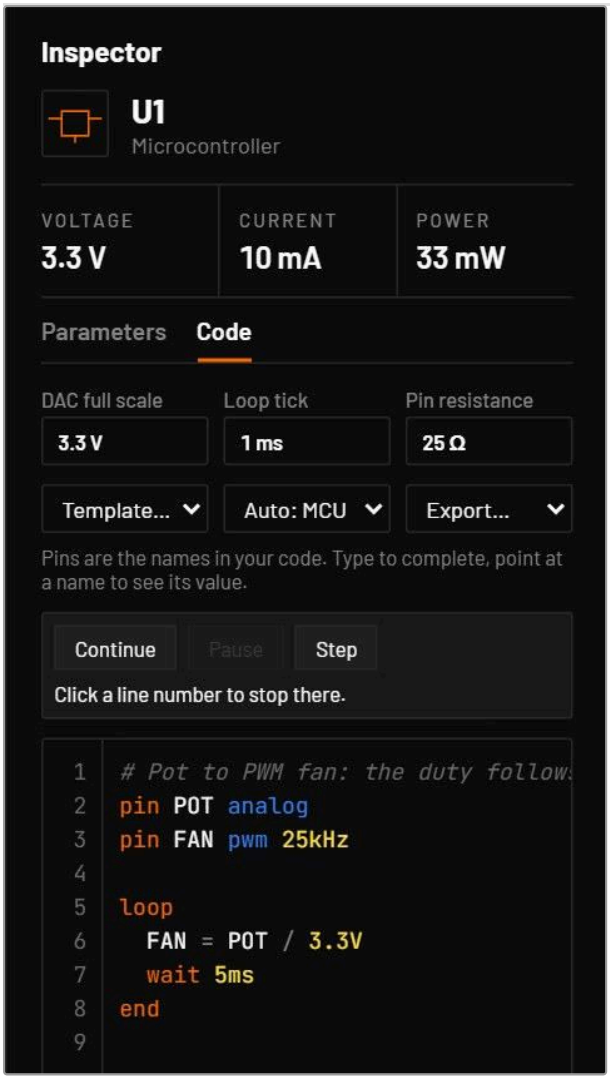


Figure 42.3 The Code tab of an MCU: quick fields, the Template list, the program with colours and line numbers. The chip has the pins POT and FAN because the code declares them.

PART OF THE TAB	WHAT IT DOES
DAC full scale, **Loop tick**, **Pin resistance**	Quick fields for **vdd**, **tick** and **rout** (**Parameters**, p. 393).
Template...	Replaces the code with a ready program (**Templates and examples**, p. 392). One undo step.
The code box	Colours for keywords, pin kinds and numbers. Tab inserts two spaces. A line with an error is marked red in the gutter.
The status line	**No script errors**, or **Line N:** and what to write instead. Circuit warnings (**W_MCU_PIN**, **W_MCU_BUS**) show here with their fix too.
Syntax	A fold-out list of every statement with a one-line meaning.

The code applies when you leave the editor or press Ctrl + S in it. Editing the code redraws the chip. Wires stay on every pin that keeps its name.

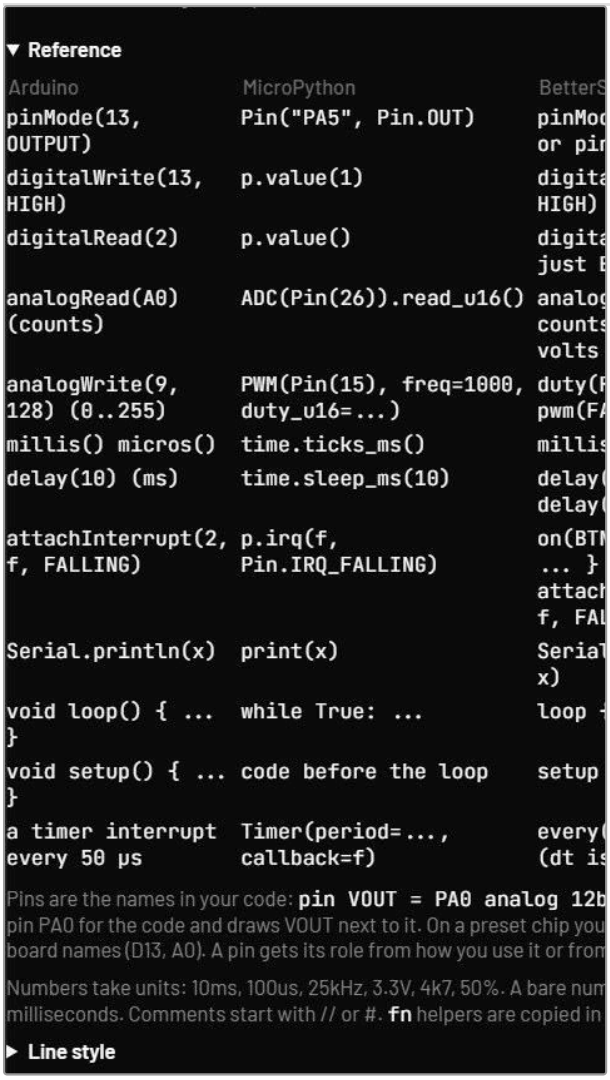


Figure 42.4 The Syntax list under the code.

42.3 Declarations: pin and bus

Declarations come first. Each adds pins to the chip, named as you write them. Names are case-sensitive, and a name can be used once.

LINE	ADDS	OPTIONS
pin NAME out	Digital output	**opendrain**: pulls low only. **high**: starts high.
pin NAME in	Digital input	**pullup** or **pulldown**: an internal 40 kΩ.
pin NAME analog	ADC input, reads volts	**bits N** (default 12).
pin NAME dac	Analog output, volts	**bits N**.
pin NAME pwm FREQ	PWM output, value is the duty 0 to 1	FREQ such as **25kHz**.
pin NAME complement PWMPIN [dead TIME]	Complementary PWM output of a pwm pin declared above it	**dead 200ns**: dead time before each output turns on. Set the duty on PWMPIN, not on NAME.
bus NAME uart TX RX [baud]	Two pins, TX and RX	Baud, default 9600.
bus NAME i2c SDA SCL [rate]	Two open-drain pins, master	Rate such as **400kHz** (default 100 kHz).

LINE	ADDS	OPTIONS
bus NAME spi SCK MOSI MISO CS [rate]	Four pins, master, mode 0	Rate such as **1MHz** (default 1 MHz).
bus NAME can TX RX [rate]	Two pins, standard frames	Rate such as **500k** (default 500 kbit/s).

Pins on the left of the chip are the inputs (**in**, **analog**, UART RX, SPI MISO, CAN RX). The names after a bus (**TX**, **SDA**) are the pin names. The first word (**U**, **OLED**) names the bus in the program: **send OLED ...**. A pin cannot also be a supply pin: **VDD** and **GND** are reserved.

42.4 Blocks: loop, every and when

Lines outside a block run once at the start, in order. A block is closed with **end**. Several blocks run side by side, each with its own place in its code, so a **wait** in one never stops another.

BLOCK	RUNS	EXAMPLE
loop ... **end**	Over and over. A pass that waits for no time lasts one **tick** (1 ms), so a loop without **wait** never hangs the simulation.	**loop** / **LED toggle** / **wait 1s** / **end**
every TIME ... **end**	Periodically, from the start, with no drift. **every 1kHz** works too.	**every 100ms**
when PIN rises ... **end**	When the pin goes high (**falls**: low, **changes**: either). The edge is found at its exact instant.	**when BTN falls**
when BUS gets ... **end**	When a UART byte or a CAN frame arrives. Read it with **BUS.byte**, **BUS.id**.	**when U gets**

- **every** and **when** blocks run before **loop** at the same instant, like interrupts.
- An **every** or **when** block that is still running when it's due again is skipped.
- **wait TIME** pauses only its own block. The time counts from when the block woke up, so a loop of **wait 10ms** doesn't drift.
- A **send** or **read** holds its own block until the transfer is done. While one block uses a bus, another block's transfer on that bus queues.

42.5 Statements

STATEMENT	WHAT IT DOES	EXAMPLE
NAME on / **off** / **toggle**	Set a digital output (**high** and **low** work too).	**LED toggle**
NAME = EXPR	Write a pin (a level, a PWM duty 0 to 1, or volts on a DAC), or set a variable.	**FAN = POT / 3.3V**
wait TIME	Pause this block. The unit is required.	**wait 10ms**
if C / **else if C** / **else** / **end**	Condition.	**if BTN is low**
while C ... **end**	Repeat while the condition holds.	**while BTN is high**

STATEMENT	WHAT IT DOES	EXAMPLE
repeat N … end	Repeat N times.	**repeat 8**
print ITEMS	One line in the Console: texts and values, separated by spaces.	**print "v =" POT**
send BUS ITEMS [into VAR]	UART: text and bytes. I²C: the 7-bit address, then bytes. SPI: bytes (**into** receives the bytes read). CAN: an id, then up to 8 bytes.	**send OLED 0x3C 0x00 0xAF**
read BUS … into VAR	UART: the next byte (waits for it). I²C: **ADDR COUNT**. SPI: **COUNT**.	**read T 0x48 2 into raw**
font "TEXT"	Inside a **send**: the 5 × 7 font column bytes of the text, for a display.	**send OLED 0x3C 0x40 font "HI"**

Variables are global. Each one must be set somewhere in the program, or the code is refused with *y has no value: set it first*. Until that line runs, the variable reads 0. Write a negative number in brackets inside **print** and **send**: **(-1)**.

42.6 Expressions, units and functions

ITEM	FORMS	NOTES
Numbers with units	**10ms 100us 2s 25kHz 1MHz 3.3V 4k7 50%**	A time needs its unit: **wait 10** is an error. **50%** is 0.5.
Hex and binary	**0x3C 0b1010**	Bytes sent are **round(value) & 0xFF**.
Arithmetic	**+ - * / %**	
Bits (whole numbers)	**& | << >>**	
Comparison	**< > <= >= == !=**	True is 1, false is 0.
Logic	**and or not**, **X is high**, **X is low**	**true**, **false**, **high** and **low** are 1 or 0.
Time	**time**	Seconds since the start.
Functions	**min(a, b) max(a, b) abs(x) clamp(x, lo, hi) round(x) floor(x) map(x, a, b, c, d)**	**map(POT, 0, 3.3, 0, 255)** turns volts into a byte.
Reading a pin	the pin's name	A digital input reads 0 or 1, an analog input volts, an output its level, a PWM pin its duty, a DAC pin its volts.
Fields	**.counts .byte .byte(k) .len .id .ack**	**POT.counts** is the raw ADC code. **OLED.ack** is 1 if the last I²C address was answered. **CAN.byte(0)** is the first data byte.
Comments	**#** or **//**	To the end of the line.

42.7 Errors in the code

A mistake in the program is an **E_SCRIPT** error. The message names the line and column and says what to write. It shows under the code and in the Diagnostics tab, and the line is marked red. The program doesn't run until it's fixed.

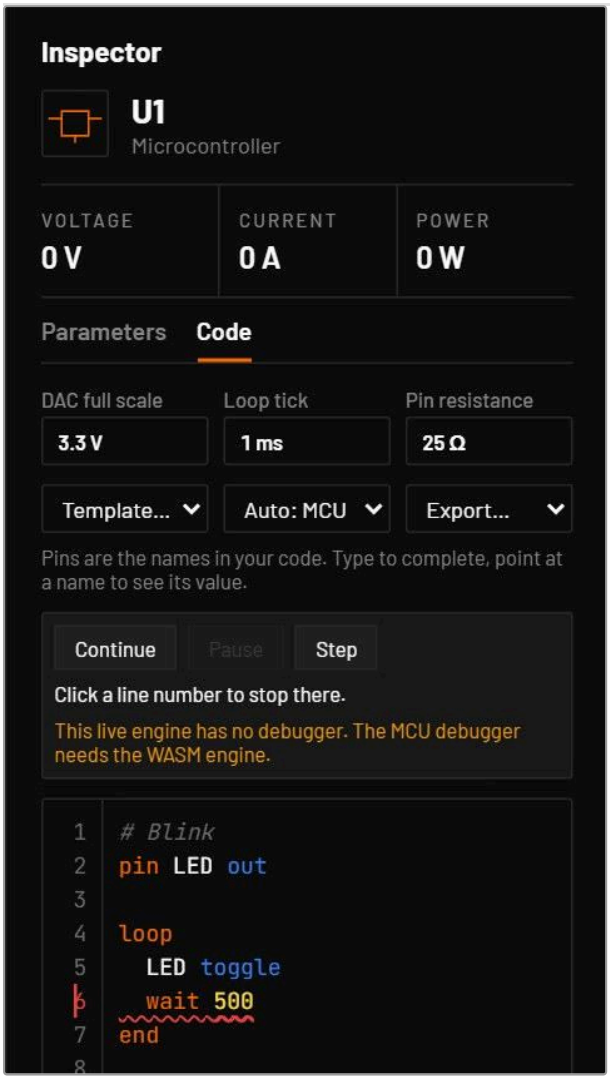


Figure 42.5 **wait 500** has no unit: line 6 is marked and the message says what to write.

MESSAGE	FIX
"FAN is a pwm pin; write FAN = 0.5 for 50 % duty"	Write a duty from 0 to 1 (or **50**%), not **on**.
"wait 10 needs a unit: write wait 10ms or wait 10s"	Add the unit.
"y has no value: set it first (e.g. y = 0) or declare it as a pin"	Assign the variable before the first line that reads it.
"this never runs: the loop on line 2 repeats forever ..."	Lines after a **loop** in the same block can never run. Put them above it, or in an **every** or **when** block.
... is a supply pin	Do not declare VDD or GND. Use other names for I/O pins.
"... = 2 is above 1; a pwm duty goes from 0 to 1" (a warning)	Scale the duty to 0 to 1.

42.8 GPIO: outputs and inputs

```
pin LED out
pin BTN in pullup
pin SDA_X out opendrain
pin CS out high
```

PART	WHAT HAPPENS ELECTRICALLY
Output	Driven from the chip's own VDD and GND pins through **rout** (25 Ω), with 10 ns edges. An output isn't a power source: with the supply unwired it cannot drive anything.
Open-drain output	Pulls low only. It needs a pull-up to go high.
Drive limit	More than **imax** (25 mA) for 10 µs warns **W_MCU_PIN**. If the pin sits at the opposite level the message says it's shorted or fights another output.
Input	Low below 0.3 VDD, high above 0.7 VDD, with hysteresis, measured against the actual supply.
pullup, **pulldown**	An internal 40 kΩ resistor to VDD or GND. A push button to ground needs nothing else.
A floating input	A pin with no pull and nothing connected rests at half the supply, reads random bits, and warns **W_MCU_PIN** after 1 ms.
Edge events	**when BTN falls** runs at the exact instant the input crosses its threshold, not on the next tick.

TRY IT

Press a button, light an LED

1. Open **Digital control** and the example **MCU button to LED with the internal pull-up**.
2. Click the switch SW1 while it runs.
3. Select U1, open the Code tab and delete the word **pullup**.

YOU SHOULD SEE The LED follows the switch within 10 ms. After you delete **pullup**, the pin BTN floats and the warning **W_MCU_PIN** appears in about a millisecond.

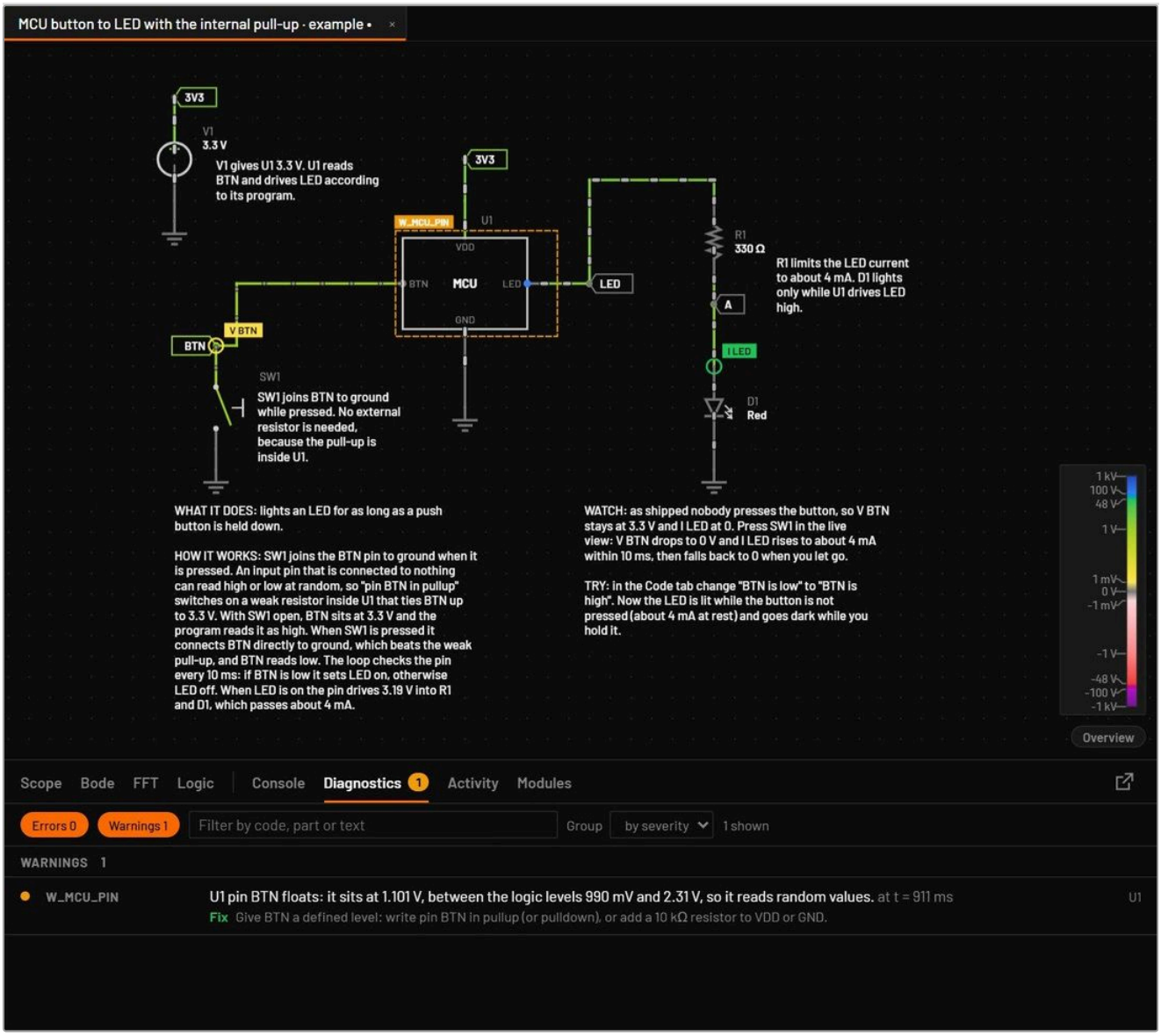


Figure 42.6 Without **pullup** the input BTN floats. The warning names the pin, the level it sits at and the fix.

42.9 ADC and DAC

```
pin POT analog bits 10
pin OUT dac

every 100ms
  print "pot" POT "V," POT.counts "counts"
end

OUT = 1.2V
```

- **ADC:** the pin voltage is measured at the instant it's read and quantised against the actual supply, with **bits** bits (default 12). **POT** reads volts, **POT.counts** the code. If VDD sags, the reading changes, as on a real chip.

- **DAC:** **OUT = 1.2V** sets the code **round(v / vdd · (2^{bits} – 1))**. The pin drives that fraction of the actual supply through **rdac** (100 Ω). Set the full scale with **vdd** in the quick fields.

42.10 PWM

```
pin FAN pwm 25kHz

loop
  FAN = POT / 3.3V
  wait 5ms
end
```

The edges are exact, not sampled on a tick. A new duty takes effect at the next period, as with a timer preload register. The pin reads back its duty, and the live values show **FAN_duty**. A duty above 1 is clamped and warns.

Complementary outputs with dead time

A half bridge needs two outputs that are never on together. Declare the second pin as the **complement** of the first, with a dead time:

```
pin HI pwm 20kHz
pin LO complement HI dead 200ns

HI = 0.3
```

LO follows the period and the duty of **HI**, including the rule that a new duty starts at the next period. **HI** goes high one dead time after the period starts and low at duty · T. **LO** goes high one dead time after **HI** falls and low at the end of the period. They are never high together, and the edges are exact. At duty 0 and duty 1 the pins hold steady levels, with no dead-time notches, as a timer does at CCR = 0 and CCR = ARR. A pwm pin has at most one complement, and the complement is drawn on the right of the chip like any output.

- Write the duty on the main pin. **LO = 0.5** is an error: *"LO is a complementary pwm pin; it follows its pwm pin. Set the duty on that pin"*.
- The main pin must be a pwm pin declared above the complement, and **dead** needs a time (**dead 200ns**).

TRY IT

A pot sets a fan speed

1. Open **Digital control** and **MCU pot to PWM fan speed**.
2. Click the potentiometer RV1 and change its wiper with the slider.

YOU SHOULD SEE The duty and the fan current follow the pot. M1 switches the 12 V fan, and D1 catches the motor current when M1 turns off.

42.11 UART

```
bus U uart TX RX 9600

loop
  send U "hi" 10
  wait 1s
end

when U gets
  print "got" U.byte
end
```

- Each byte is sent as 8N1, bit by bit at the baud rate. The TX line idles high.
- The receiver samples in the middle of each bit, from the start edge it finds. A low stop bit is a framing error: **W_MCU_BUS** says the baud rates probably differ.
- Wire TX of one chip to RX of the other. A floating RX warns, because an idle line must be high.
- **send U "text" 10 0x41** sends text and bytes. **read U into x** waits for the next byte.
- To talk to the PC, wire TX and RX crossed to a USB-UART bridge (**chip**, variant **usb_uart**) at the same baud rate. What the MCU sends shows in the Console as lines, and text typed in the Console input bar arrives in **when U gets** (**Chips and displays**, p. 359).

TRY IT

Send a pot reading to another MCU

1. Open **Digital control** and **Two MCUs over UART**.
2. Open the Console (Alt + 5) and turn the pot.

YOU SHOULD SEE U2 prints *got 127*, *got 140* and so on as the byte changes, and its LED brightness follows.

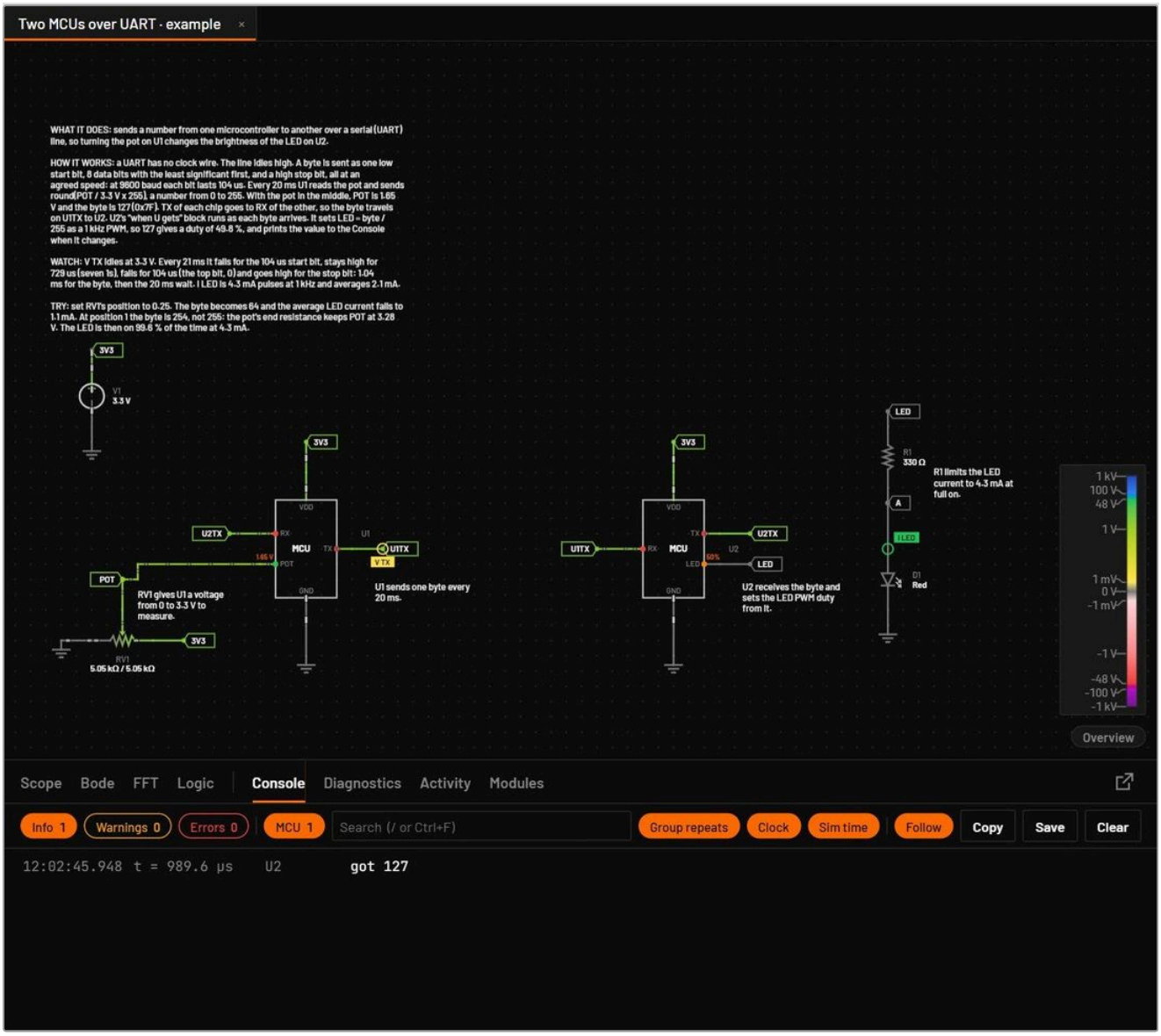


Figure 42.7 Two MCUs over UART: the byte from U1 shows in the Console and sets the LED brightness of U2.

42.12 I²C

```
bus OLED i2c SDA SCL 400kHz

send OLED 0x3C 0x00 0xAF
if OLED.ack == 0
  print "no answer: check the address and the pull-ups"
end
read OLED 0x48 2 into t
```

PART	WHAT HAPPENS ELECTRICALLY
Lines	SDA and SCL are open-drain. They go high only through pull-up resistors, so the circuit needs **2.2 kΩ to 10 kΩ** from each to VDD.
Timing	Quarter-bit steps at the chosen rate (100 kHz or 400 kHz). Both lines are checked to rise when released, at START and at every SCL high.
No pull-up	The transfer fails, **OLED.ack** is 0, and **W_MCU_BUS** says *"add a pull-up resistor (2.2 kΩ to 10 kΩ)"*.
A line held low	A target holding it, a short, or a pull-up far too weak for the bus. The warning says to use a stronger pull-up.
Wrong address	No target answers (NACK). The transfer stops, **.ack** is 0, and **W_MCU_BUS** warns.
Targets	The SSD1306 and the digital potentiometer (I^2C) answer by pulling SDA low. So do the EEPROM and the RTC chips (**Memory, flash and RTC chips**, p. 388).

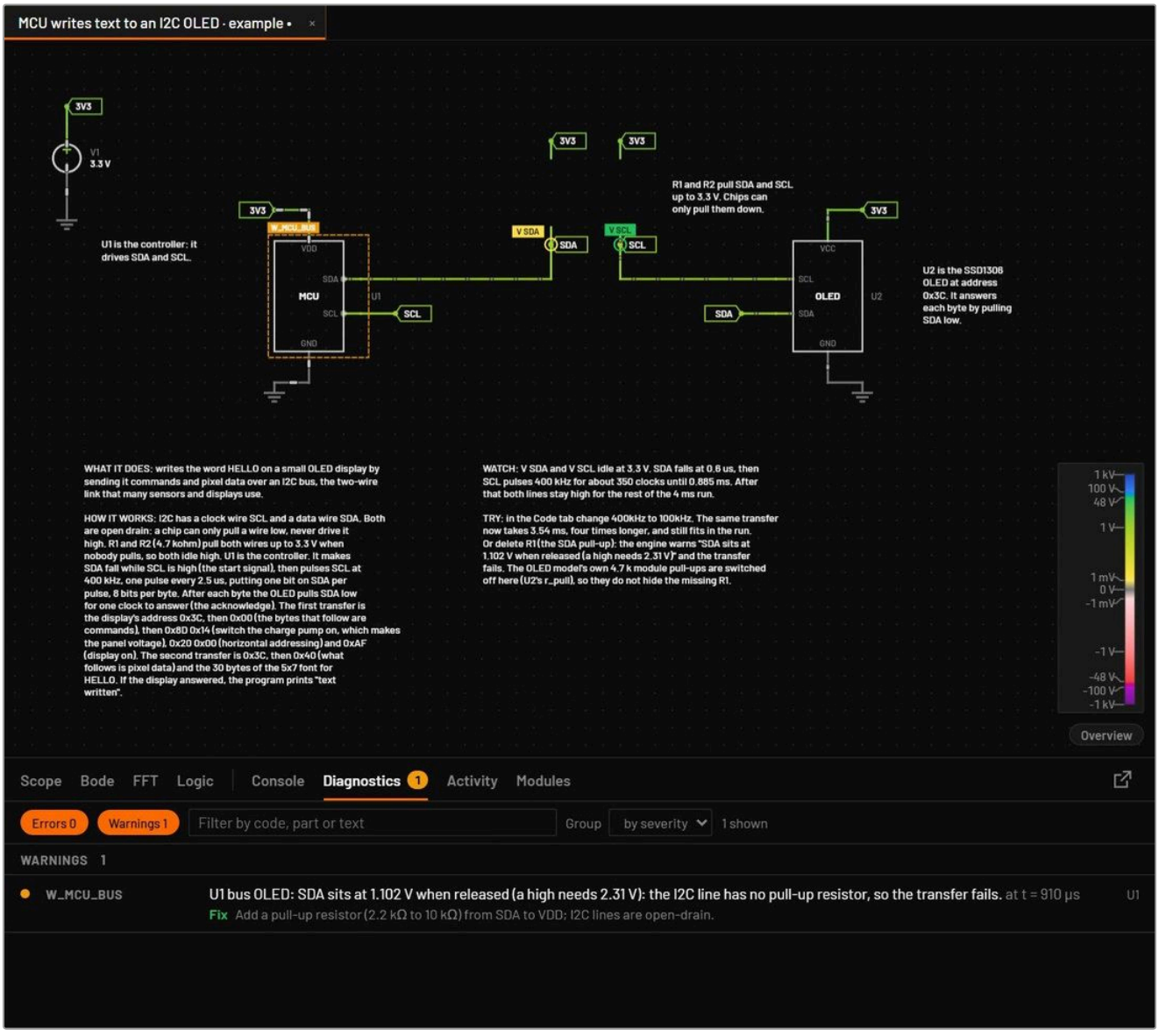


Figure 42.8 The same OLED example with both pull-ups deleted: the transfer fails and the warning says what to add.

TRY IT

Write to an OLED

1. Open **Digital control** and **MCU writes text to an I2C OLED**.
2. Select U2, the display, and look at its symbol.
3. Delete R1 and R2.

YOU SHOULD SEE The display shows HELLO. After the pull-ups go, the Console prints *no answer from the OLED* and Diagnostics shows **W_MCU_BUS**.

42.13 SPI

```
bus DAC spi SCK MOSI MISO CS 1MHz
code = 0

loop
  send DAC 0x00 code
  code = (code + 1) % 129
  wait 1ms
end
```

- Mode 0, chip select active low. CS goes low, MOSI changes while SCK is low, MISO is read on the rising edge, and CS goes high after the last byte.
- **send S 0x12 0x34 into r** transfers two bytes and puts what came back in **r**. **read S 2 into r** clocks out zeros and reads two.
- While the MCU is in reset, a CS with no pull-up floats, and a target could be selected at power-up. **W_MCU_BUS** says *"add a 10 kΩ pull-up from CS to VDD"*.
- Use **pin CS out high** instead of a bus CS when you need several targets on one clock.

42.14 CAN

```
bus CAN can TX RX 500k
pin BTN in pullup

loop
  send CAN 0x100 (BTN is low) * 255
  wait 10ms
end

when CAN gets
  if CAN.id == 0x100
    print "button" CAN.byte(0)
  end
end
```

- Standard 11-bit data frames, sent bit by bit with stuffing and a CRC. Receivers destuff, check the CRC and pull the ACK slot dominant.
- A node waits for 11 recessive bits before it sends or accepts a frame.
- Use a CAN transceiver (the **can** part: CANH, CANL) and a 120 Ω termination at each end of the bus. TX and RX can also be cross-wired directly for a logic-level bus.
- A frame nobody acknowledges sets **CAN.ack** to 0 and warns **W_MCU_BUS**: connect a second node with a **when CAN gets** block, at the same bit rate.

TRY IT

Two nodes on a CAN bus

1. Open **Digital control** and **Two MCUs on a CAN bus**.
2. Click SW1 while it runs.

YOU SHOULD SEE U2 lights its LED while SW1 is pressed, and prints every 50th frame. RT1 and RT2 are the terminations.

42.15 Memory, flash and RTC chips

Five variants of the **chip** part answer the I²C and SPI masters, so a program can read and write them (**Chips and displays**, p. 359).

CHIP VARIANT	BUS AND ADDRESS	WHAT IT DOES
eeprom (24C02)	I²C, **0x50** plus A2 A1 A0	256 bytes, 8-byte page write, a 5 ms write cycle during which it doesn't answer its address (poll with **.ack**), sequential read, WP high ignores writes.
spi_flash (W25Q)	SPI mode 0, nCS	JEDEC id **0x9F** (EF 40 15), read **0x03**, write enable **0x06**, status **0x05**, page program **0x02** (only 1 to 0), sector erase **0x20** (45 ms).
rtc (DS1307)	I²C, **0x68**	BCD seconds, minutes, hours, day, date, month and year registers that count simulated time. The clock starts when the seconds register is written.
i2c_dev (any I²C sensor)	I²C, **addr** (0x48), +1 with ADDR high	Your register map (**regs**, **ro**) and a live reading you drag. **send D 0x48 REG BYTES** writes from REG. **send D 0x48 REG** then **read D 0x48 N into x** reads N registers from REG. Other addresses aren't acknowledged.
spi_dev (any SPI peripheral)	SPI mode 0 (cpol, cpha), CS	The same register map. **send D REG BYTES** writes from REG, and **send D 0x80+REG 0 0** reads, the data in **D.byte(1)** on.

```
bus RTC i2c SDA SCL 100kHz
send RTC 0x68 0 0x00 0x30 0x12   # register 0, then 00 s, 30 min, 12 h
loop
  send RTC 0x68 0
  read RTC 0x68 3 into t
  s = (RTC.byte(0) >> 4) * 10 + (RTC.byte(0) & 15)
  print "seconds" s
  wait 1s
end
```

The fourth variant, **usb_uart**, is a USB-to-UART bridge whose USB side is the Console. It's the way to talk to the PC from a program (**Chips and displays**, p. 359).

42.16 Reset, brown-out and supply current

- While the circuit finds its DC operating point, and whenever VDD is below **vbor** (1.8 V), the pins are released and the program is stopped. It starts again from the top when the supply returns.
- The chip draws **idd** (10 mA) from VDD to GND, plus every pin's drive current. The live values show **idd**, **vdd** and whether the program is running.

42.17 Warnings you may see

The language check finds mistakes in the program. These warnings find mistakes in the circuit around it. They appear in the Diagnostics tab (Alt + 6) and under the code.

CODE AND MESSAGE	CAUSE	FIX
W_MCU_PIN *"pin BTN floats: it sits at 1.1 V, between the logic levels ... so it reads random values"*	An input or UART RX with nothing driving it, for 1 ms.	Write **pin BTN in pullup** (or **pulldown**), or add a 10 kΩ resistor to VDD or GND. For RX, wire it to the other side's TX.
W_MCU_PIN *"pin LED sources 40 mA (an MCU pin is rated about 25 mA)"*	An output loaded more than **imax** for 10 µs.	Add a series resistor (about 330 Ω for an LED) or drive the load through a transistor.
W_MCU_PIN *"pin X drives high but sits at 0.2 V ... shorted to ground or fights another output"*	Two outputs tied together, or an output wired to a rail.	Never join two outputs. Use an open-drain output with a pull-up for a shared line.
W_MCU_BUS *"SDA sits at 0.0 V when released ... has no pull-up resistor"*	An I^2C line with no pull-up.	Add 2.2 kΩ to 10 kΩ from SDA and SCL to VDD.
W_MCU_BUS *"no target answered (NACK) on line 7"*	Wrong address, target not powered, or not wired.	Check the 7-bit address, the target's supply and the wiring.
W_MCU_BUS *framing error*	The baud rates of the two UARTs differ.	Use the same rate in both **bus ... uart** lines.
W_UART *"framing error on RXD (the stop bit is low) ..."*	A USB-UART bridge received a byte at another baud rate than its own.	Set the bridge's **baud** to the MCU's rate (**Chips and displays**, p. 359).
W_MCU_BUS *"chip select CS floats while the MCU is in reset"*	An SPI target could be selected at power-up.	Add a 10 kΩ pull-up from CS to VDD.
W_MCU_BUS *"nobody acknowledged the CAN frame"*	No other node, or a different bit rate.	Add a second node with **when CAN gets** and 120 Ω terminations.
E_SCRIPT *U1 line 3 col 3: ...*	A mistake in the program.	Fix the line the message names.

42.18 Arduino style, pin names and board names

The code can look like Arduino code. Braces, **setup** and **loop**, **pinMode**, **digitalWrite(PIN, HIGH)**, **digitalRead**, **analogRead**, **analogWrite**, **delay**, **millis**, **Serial.println**, **fn** with **return**, **every(50us) { }** and **on(BTN, FALLING, debounce: 20ms) { }** all work. The older line statements (**LED on**, **wait 10ms**, **loop** … **end**) still work in the same program, and old programs run exactly as before. The Arduino style is translated onto the same runtime, so a program in either style gives the same waveforms, and an error still names the line and column you wrote.

```
pin BTN in pullup
pin FAN pwm 25kHz
let level = 0

on(BTN, FALLING, debounce: 20ms) {
  level = (level + 1) % 4
  duty(FAN, level / 3)
}
```

A name becomes a pin of the chip as soon as the code uses it, and its role is taken from its use or from **pinMode**. Two uses that disagree are an error that names both lines. You can also name a chip pin yourself: **pin VOUT = PA0 analog 12bit** makes the chip pin PA0 the pin VOUT in the code. The symbol keeps the chip's pin name and draws your name in small type beside the lead. On the ATmega328P, ATtiny85 and STM32F103 variants the board names also work, such as **D13**, **A0** and **LED_BUILTIN**. A name that is not a pin of the chip is an error with a *Did you mean*. The **Language** box on the Code tab (Auto, MCU language, Rhai) fixes the language when Auto guesses wrong. The MCU language runs on the WASM engine, which is the default, and from 0.8.0 on the JavaScript fallback too, with the same pins, timing, buses, messages, debugger and displays.

42.19 Editor help

- **Completion**: typing offers the pins of the part, the keywords and the Arduino names. It knows the context: **analogRead(** offers analog pins, **pinMode(P,** offers the modes, **on(P,** the edges. Tab or Enter takes one, Esc closes the list and Ctrl+Space opens it.
- **Hover**: pointing at a pin name shows its value now, for example **VOUT (PA0): analog input, 12bit. 1.20 V, 1495 counts**. Pointing at a word of the language shows its form. Pointing at an error shows its sentence.
- **Errors**: a wavy underline from the error column over the token, the plain sentence below it with a click to jump to the line, and *Did you mean* from a distance check over pins, variables, keywords and functions.
- **Reference card**: below the editor, a three-column cheat sheet (Arduino, MicroPython, BetterSPICE). The line style is folded below it.
- Enter keeps the indent and adds one after an opening brace.

42.20 Pin colours and the pin map

While the simulation runs, a dot where each lead meets the symbol shows what the pin is doing.

COLOUR	MEANING
Red	High.
Blue	Low.
Grey	Floating.
Orange	PWM, with its duty in percent.
Green	Analog, with its volts.

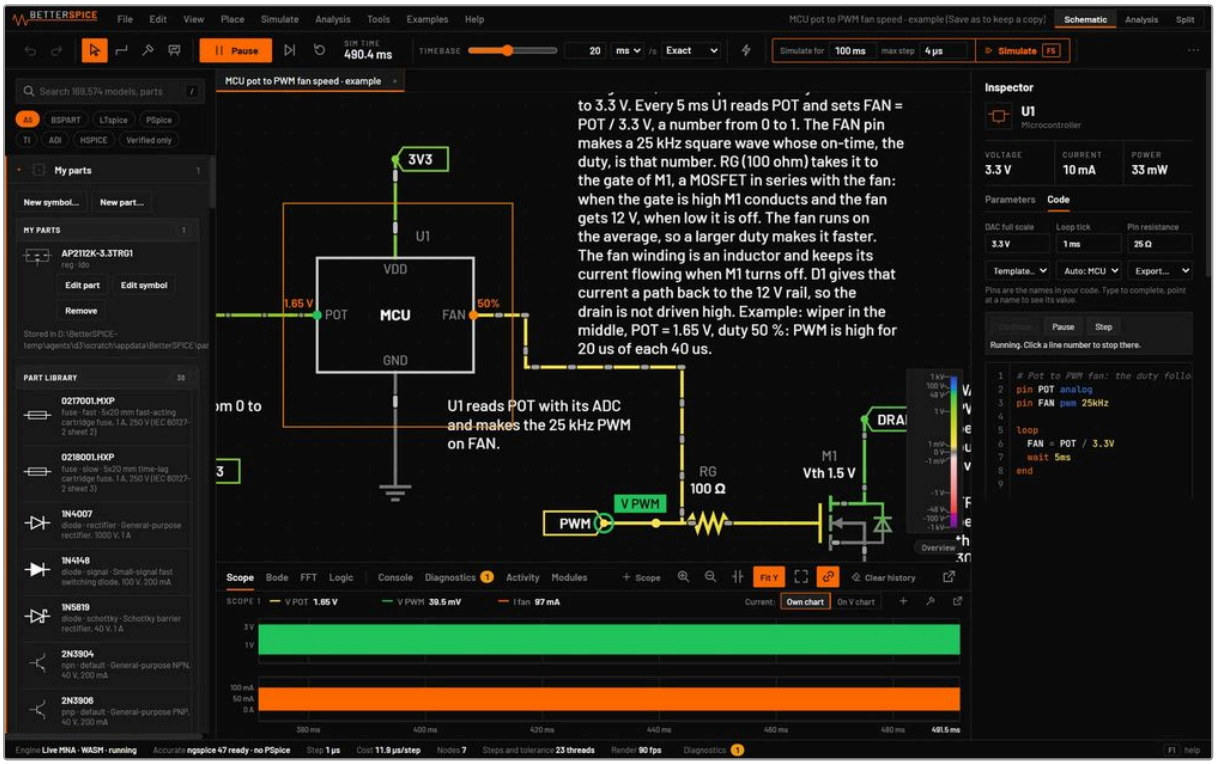


Figure 42.9 A running MCU: the pin dots on the symbol and the Pin map under the code.

The **Pin map** under the editor lists each pin with its chip pin, its role and its value now. Its **Scope** button adds a probe on the pin and its **Logic** button adds a logic analyzer channel at half the supply. Clicking a pin name jumps to its line in the code.

42.21 Debugging: breakpoints, Step and Variables

Click a line number in the Code tab gutter to set a breakpoint, shown as an orange dot. A hollow dot marks a line that holds no statement, so it never stops there. Breakpoints belong to the part, move with their lines when you add or remove lines above them, and can be undone.

When the program reaches a breakpoint, the simulation stops at that instant, the MCU is selected, its Code tab opens, the line is highlighted, the bar says *Paused at line 8, in when U gets, at 127.2 ms* and the Console gets the same line. **Step** runs the next statement of this MCU. Across a **wait** the circuit runs as fast as it can until the program gets there, and after 4 seconds without a statement it stops and says the program is waiting for a time, a pin or a byte. **Continue** runs to the next breakpoint and then plays the live view. **Pause** stops at the next statement this MCU runs.

The **Variables** panel under the editor lists variables (the ones changed since the previous stop in orange), pins with their role, level, duty or ADC volts, buses with the last data and their state, and blocks (**main**, **every**, **when**) with the current line. It updates while paused and four times a second while running.

With several MCUs, each has its own breakpoints. When U2 holds the circuit, U1's bar says *U2 paused at line 8* with a **Show U2** link, and Continue or Step lets the held MCU carry on first. Stopping does not change the waveform: the rest of the instant runs after you resume, with no shift in time.

42.22 Export to Arduino or STM32

The **Export** box in the Code tab saves a program in the Arduino style as an Arduino sketch (**.ino**) or an STM32 HAL file (**main_app.c**) with the same pin names. It is a starting point, not a finished firmware. Board pin numbers the chip does not give, the PWM frequency, the ADC and the timers are marked **TODO** where the chip needs a choice. A program in the line style is refused with a sentence that says so. The output has been read by eye and has not been compiled.

42.23 Templates and examples

The **Template...** list on the Code tab fills the code box with a ready program. Wire the pins as the first comment line says.

TEMPLATE	WHAT IT DOES
Blink	Toggles an LED every 500 ms.
Button to LED	A push button to ground on BTN with the internal pull-up lights an LED.
Pot to PWM fan	The ADC reading of a pot sets a 25 kHz PWM duty.
Read a sensor and print it	Prints an analog sensor in volts and counts every 100 ms.
I2C OLED text	Starts an SSD1306 at 0x3C and writes HELLO. Needs the pull-ups.
SPI DAC sweep	Sweeps an SPI digital potentiometer wired as a DAC.
Two MCUs on UART	The sender. The receiver is in the comments, to paste into the second MCU.
Two MCUs on CAN	Node A sends the button state. Node B's code is in the comments.

Seven circuits in **Examples › Digital control** run these programs with the parts around them:

EXAMPLE	SHOWS
MCU blink	The smallest program. R1 limits the LED current.
MCU button to LED	A switch to ground with the internal pull-up. Delete **pullup** to see the floating warning.
MCU pot to PWM fan	ADC to 25 kHz PWM to a logic-level MOSFET and a 12 V fan with a flyback diode.
Two MCUs over UART	U1 sends its pot as a byte at 9600 baud. U2 sets an LED brightness and prints the value.
MCU writes text to an I2C OLED	The SSD1306 start-up and the text HELLO. R1 and R2 are the pull-ups.
Two MCUs on a CAN bus	Two MCUs through 3V3 transceivers, terminations, a button and an LED, frames acknowledged.
MCU reads an I2C real-time clock	Starts a DS1307-style RTC at 12:30:00 and prints the time every second.

42.24 Parameters

The part's own settings, set in the inspector's **Parameters** (the first three also on the Code tab), or in **All parameters**.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
DAC full scale (supply)	**vdd**	V	3.3	> 0	Default, Code tab, part file	The supply that the logic levels, the ADC and the DAC are measured against. It's the DAC full scale.
Loop tick	**tick**	s	1 ms	> 0	Default, Code tab, part file	How long a loop pass that waits for nothing lasts.
Pin resistance	**rout**	Ω	25	> 0	Default, Code tab, part file	Output resistance of a push-pull pin.
Edge time	**tr**	s	10 ns	≥ 0	Default, file	Output rise and fall time.
Pull resistance	**r_pull**	Ω	40 kΩ	> 0	Default, file	The internal pull-up or pull-down.
DAC output resistance	**rdac**	Ω	100	> 0	Default, file	
Pin current warning	**imax**	A	25 mA	> 0	Default, file	Above this for 10 µs: **W_MCU_PIN**.
Brown-out voltage	**vbor**	V	1.8	> 0	Default, file	Below it the program stops.
Supply current	**idd**	A	10 mA	≥ 0	Default, file	Drawn from VDD to GND.
Program	**code**	text	empty		Code tab	The program, in the MCU language.

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

42.25 What is not emulated

Real microcontrollers have these. The model does not:

NOT EMULATED	INSTEAD
Watchdog, sleep modes, DMA	Use **every** and **wait**.

NOT EMULATED	INSTEAD
The RTC calendar inside the MCU	Use an RTC chip on I²C.
Input capture, quadrature encoder mode	Use **when PIN changes** and count in a variable.
ADC triggered by PWM	Sample in an **every** block.
USB, Ethernet	Not available.
I²C and SPI target (slave) mode	The MCU is always the master.
CAN arbitration between senders that start together, remote and extended frames	Standard data frames only.
UART parity and 2 stop bits, SPI modes 1 to 3, I²C clock stretching	Fixed at 8N1 and mode 0.

NOTE **Simple code, real pins.** The code is simpler than real firmware on purpose. The pins are not simplified. A missing pull-up, a floating input or an overloaded pin causes the same trouble here as on a bench, and a warning says what to add.

43 Transmission lines, PCB traces and cables

43.1 The two parts 396
43.2 The geometry fields 396
43.3 The formulas 398
43.4 Reflections 400
43.5 Simulation 400

A transmission line carries a wave with a delay, so reflections, ringing and termination effects appear as on a real board or cable. BetterSPICE computes the line's impedance, delay and loss from its geometry, from a PCB trace to a coax cable, and simulates it with the same method of characteristics as ngspice's **T** element, with skin and dielectric loss.

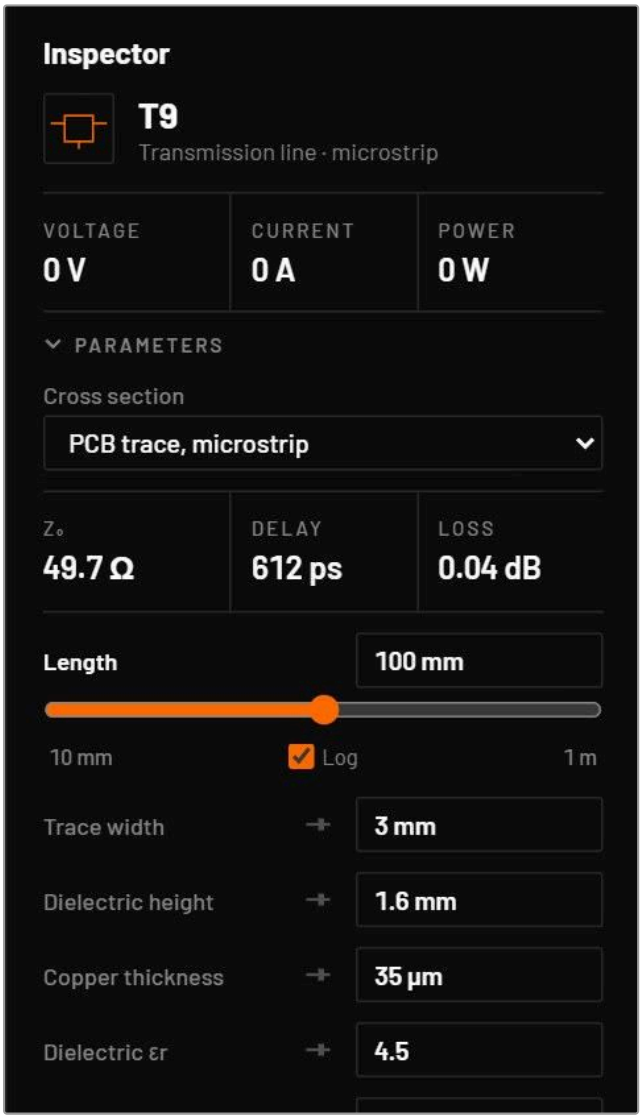


Figure 43.1 A microstrip: cross section, geometry and the computed Z0, delay and loss.

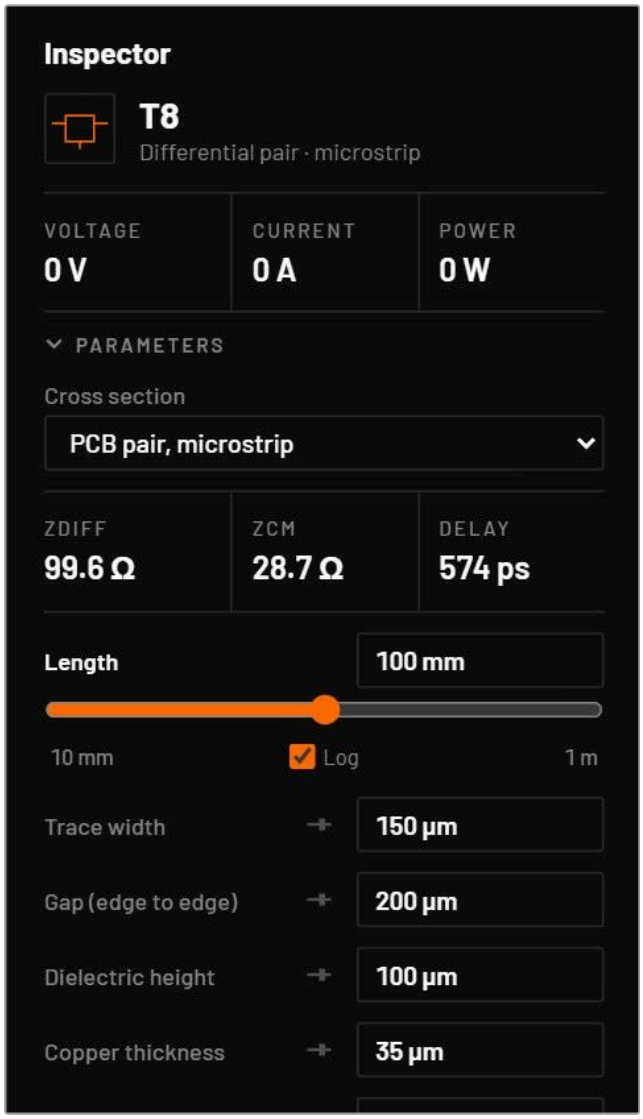


Figure 43.2 A differential microstrip pair: Zdiff, Zcm and delay.

43.1 The two parts

PART	TYPE	PINS	CROSS SECTIONS
Transmission line	**tline** (T)	A+, A-, B+, B-. A- and B- are the reference (return) conductor of each end.	ideal (Z0, delay), microstrip, stripline, cpwg (coplanar waveguide with ground), wire (over ground), pair, coax, twisted
Differential pair	**tline_diff** (T)	A1, A2, B1, B2, refA, refB	microstrip, stripline, twisted (over ground), wires (parallel, over ground), ideal (Zodd, Zeven)

Place them from the library's Transmission lines family or **Place** › **Transmission line**. The cross section picker in the inspector changes the geometry. Changing it resets the geometry fields to that section's defaults but keeps the length, the loss fit frequency, the sections and the reference tie.

43.2 The geometry fields

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Length	**len**	m	ideal 1, PCB 0.1 (cpwg 0.05), cables 1	> 0	Default, inspector, part file	Every section.
Impedance Z0	**z0**	Ω	50	> 0	Default, inspector, part file	Ideal.
Velocity factor	**vf**		0.66 (pair 0.5)	0 to 1	Default, inspector, part file	Ideal.
Delay	**td**	s	0 (from length)	≥ 0	Default, inspector, part file	Ideal. Overrides vf.
Series R / shunt G per m	**r, g**	Ω/m, S/m	0	≥ 0	Default, inspector, part file	Ideal.
Odd / even-mode Z0	**z0o, z0e**	Ω	50, 70	> 0	Default, inspector, part file	Ideal pair. Zdiff = 2 Zodd, Zcm = Zeven / 2.
Trace width	**w**	m	microstrip 3 mm, stripline 0.24 mm, cpwg 1 mm, pairs 0.15 mm	> 0	Default, inspector, part file	

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Dielectric height	**h**	m	microstrip 1.6 mm, stripline 0.3 mm to each plane, cpwg 0.8 mm, wire 5 mm (centre above the plane)	> 0	Default, inspector, part file	
Gap or spacing	**s**	m	cpwg 0.2 mm to ground, pair 6 mm centre to centre, PCB pairs 0.2 mm edge to edge	> 0	Default, inspector, part file	
Copper thickness	**t**	m	35 µm (diff stripline 18 µm)	≥ 0	Inspector, copper weight picker	0 uses zero-thickness formulas and no conductor loss. 1 oz = 34.79 µm.
Dielectric εr	**er**		FR-4 4.5 (stripline 4.2), coax 2.25, twisted 2.3, air 1	1 to 300	Default, inspector, part file	
Loss tangent	**tand**		PCB 0.02, coax and twisted 2 x 10^{-4}, wires 0	0 to 1	Default, inspector, part file	
Wire diameter	**d**	m	wire and pair 1 mm, coax inner 0.81 mm, twisted 0.511 mm (AWG 24)	> 0	Inspector, AWG and mm^2 pickers	
Insulation	**ins**	m	twisted 0.2 mm, others 0	≥ 0	Default, inspector, part file	
Effective εr	**ereff**		twisted 2.0, others estimated	0 to 300	Default, inspector, part file	0 estimates it from the insulation.
Dielectric diameter	**dout**	m	2.95 mm	> d	Default, inspector, part file	Coax.
Shield thickness	**tsh**	m	0.15 mm	≥ 0	Default, inspector, part file	Coax braid resistance.
Twists per m	**twist**	1/m	30	≥ 0	Default, inspector, part file	Twisted pair.

PARAMETER	KEY	UNIT	DEFAULT	RANGE	VALUE COMES FROM	WHAT IT DOES
Loss fit frequency	**floss**	Hz	100 MHz	> 0	Default, inspector, part file	Where the transient loss is fitted, and where the calculator reports loss.
Sections	**nseg**		0 (automatic)	0 to 64	Default, inspector, part file	Lossy lines are split into up to 16 sections automatically.
Reference tie	**rref**	Ω	1 mΩ	≥ 0	Default, inspector, part file	Ties A- to B-. 0 isolates the two ends as in SPICE.
Resistivity	**rho**	Ω·m	1.72×10^{-8} (copper)	> 0	File or All parameters	

Key: the name in the circuit file, in a parameter step (**R1.r**) and for AI agents. Range: a value outside it is refused with **E_PARAM**. Value comes from: where you can set it. The All parameters tab and agents can set every parameter.

43.3 The formulas

CROSS SECTION	METHOD
Microstrip	Hammerstad and Jensen with thickness correction. 3 mm on 1.6 mm FR-4 gives about 50 Ω.
Stripline	Wheeler with thickness correction, centred trace.
Coplanar waveguide	Conformal mapping, conductor-backed, zero thickness.
Wire over ground	60 acosh(2h / d) Ω in air, with the insulation's effect.
Pair, twisted pair	120 acosh(s / d) Ω in air. Twisted defaults give about 100 Ω and a velocity factor of 0.705.
Coax	60 / √εr · ln(dout / d). The defaults are RG-58: 50 Ω, velocity factor 0.667.
Differential microstrip	Kirschning and Jansen.
Differential stripline	Cohn.

Conductor loss has a DC resistance and a skin term that grows with √f. Dielectric loss grows with frequency through the loss tangent. The inspector's **Computed** block shows Z0 (or Zdiff, Zodd, Zeven and Zcm), εeff, velocity factor, delay per metre and total, L, C and R per metre, and loss in dB at the fit frequency, with warnings when a formula is outside its fitted range.

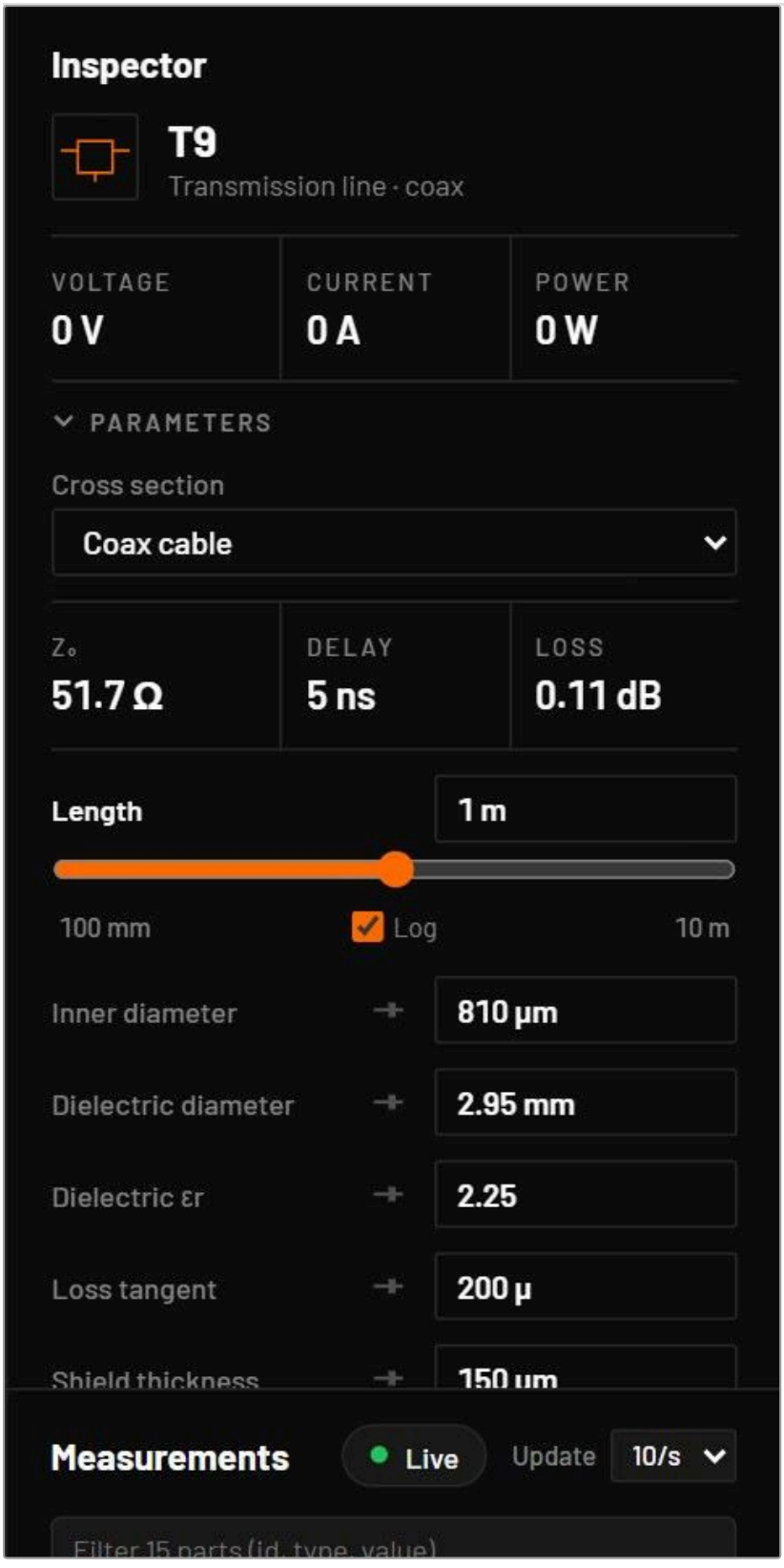


Figure 43.3 A coax cable: the defaults are RG-58, about 50 Ω and 5 ns per metre.

43.4 Reflections

FAR-END TERMINATION	WHAT RETURNS TO THE SOURCE AFTER THE ROUND TRIP
Open	The step doubles.
Short	The step inverts back to zero.
Resistor ZL	A reflection of (ZL - Z0) / (ZL + Z0).
Matched (ZL = Z0)	No reflection.

TRY IT

See a reflection

1. Open **Transmission lines**, the open-end example, or place a pulse source with 50 Ω in series, a 1 m coax and nothing at the far end.
2. Probe both ends and simulate 50 ns with a 50 ps maximum step.

YOU SHOULD SEE The near end steps to half, the far end jumps to the full value 5 ns later, and the near end reaches the full value after 10 ns. Put 50 Ω at the far end and the near end steps once to half and stays.

43.5 Simulation

- Transient: the exact method of characteristics, as ngspice's T element. Arriving edges are breakpoints, so they aren't smeared. The timestep is limited to the line delay only while waves are travelling.
- Loss: the line is split into sections with lumped resistance, skin cells and dielectric cells fitted at floss, so the DC resistance and the loss at floss are exact.
- AC: the exact lossy two-port at every frequency.
- DC: the line is a wire with its resistance.
- A line shorter than about 0.2 mm (under 1 ps of delay) acts as a wire and doesn't slow the simulation.
- Exported to ngspice as T, LTRA or a ladder of R, L, C and T elements, so Simulate and the netlist export include it.

Command line: **bspice tline-calc microstrip w=3m h=1.6m er=4.5 len=0.1** prints the same numbers, and **bspice tline-calc board.bsc —part T1** computes a line from a circuit. **3m** is 3 mm (milli).

44 The model catalogue

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The library holds 169,551 models. Every one was run before it was listed, and a model that cannot run in any engine isn't in the app.

44.1 Where the models come from

SOURCE	WHAT IT'S	MODELS
Vendor downloads (**library/raw**)	Model files from manufacturers' websites (TI, Analog Devices, Infineon, Vishay, Murata, Würth, Rohm, Nexperia, onsemi and many more) and curated community collections, each folder with a SOURCE.md naming where and when it came from.	246,841
Vendor fixes (**library/raw-fix**)	Newer or corrected files fetched from vendor sites to replace models that didn't run, with the URL, date, licence and checksum of every file.	2,397
KiCad Spice Library	The KiCad community collection of vendor models.	36,471
LTspice library	The models of your LTspice installation, read from **%LOCALAPPDATA%\LTspice\lib**.	8,159
BetterSPICE part files	Parts made with the Part Wizard, in **parts/library** and My parts.	

Identical definitions found in several places are listed once, keeping the vendor's own copy first. The vendor model files themselves aren't part of the installer: the library lists them, and Simulate needs the files, so run from a folder that has the model library or point **BSPICE_MODELS** at it (**Environment variables and files**, p. 673). A file a model includes is looked for next to it, in its folder and collection, in LTspice's standard libraries and in BetterSPICE's own generic library.

44.2 How every model is checked

1 **Parse.** The file is read in any of the usual encodings, and each **.model** or **.subckt** becomes an entry with its part number, maker, format (PSpice, LTspice, HSPICE or generic SPICE), pins and kind.

2. **Classify.** The kind (diode, Zener, Schottky, LED, NPN, PNP, N or P MOSFET, JFET, op-amp, comparator, regulator, reference, timer, logic, other) comes from the card type, the part number, the pin names and the vendor's comments. Pins win over names: a "MOSFET" with VDD and VOUT pins is an IC.
3. **Extract.** The definition is cut out with everything it uses, so it runs on its own.
4. **Run in a test circuit for its kind** in ngspice, first exactly as the vendor wrote it, then converted to ngspice syntax if that fails.
5. **Check the behaviour.** Running isn't enough: a MOSFET must switch, an op-amp must follow as a buffer, a regulator must regulate. If the named pin order doesn't work, BetterSPICE searches for the pins electrically.
6. **Fit the live model.** The measurements give the parameters the live engine uses for that part.

44.3 The test circuits

KIND	TEST	WHAT IS MEASURED
Diode	Forward sweep 0 to 5 V, reverse sweep past the breakdown	Vf at 1 mA, 10 mA, 100 mA and 1 A, reverse current at 5 V, breakdown at 1 mA
BJT	Gummel plot at Vce = 2 V, output curve at Ib = 100 µA	Vbe at 1 mA, hFE at 1 mA and 10 mA, Early voltage
MOSFET	Transfer and output curves at 5 or 10 V, both polarities, with 10, 15 and 20 V gate drive for power parts	Threshold, maximum current, Rds(on)
JFET	Transfer at Vds = 10 V	Idss, Vgs(off)
Op-amp	Unity buffer at ±5, ±15, ±2.5 V and single 5 V, open loop, step	Offset, supply current, swing, gain, gain-bandwidth, phase margin, output impedance, slew rate
Comparator	Threshold sweep and step with a pull-up	Threshold, output levels, delay
Regulator	Line and load sweeps, with enables tied active	Output voltage, dropout, line regulation, supply current, output resistance
Reference	Shunt or series sweep	Voltage, dynamic resistance or line regulation
Logic	Inputs driven with a binary count, outputs pulled up	Levels, toggling, delay, truth table for named gates
Timer	555 astable at a known frequency	Frequency within a factor of two
Other	Every pin to ground through 1 MΩ, operating point	That it runs

Runs that do not converge are retried with gentler solver settings. Discrete models (**.model** cards) are also run in BetterSPICE's own engine and compared point by point with ngspice.

44.4 How models are filed

The catalogue files each model under the kind of part it is. Zener and TVS diodes are filed as Zeners even when their subcircuit holds only plain diodes. In the library, the TVS families (SMAJ, SMBJ, P6KE, 1.5KE, SMF, TPSMx, Würth WE-TVS and others) are listed under **Protection › TVS**, ESD diodes (ESDxx, PESD) under **Protection › ESD**, and the rest under **Diodes › Zener**. Tantalum, polymer and niobium oxide capacitor models (AVX TAJ, TPS, TCJ, NOJ) are listed under **Passives › Capacitors** and not as diodes. Power MOSFETs whose vendor model calls an inner subcircuit (Infineon OptiMOS, CoolMOS and CoolSiC) are listed under **Transistors › MOSFET**.

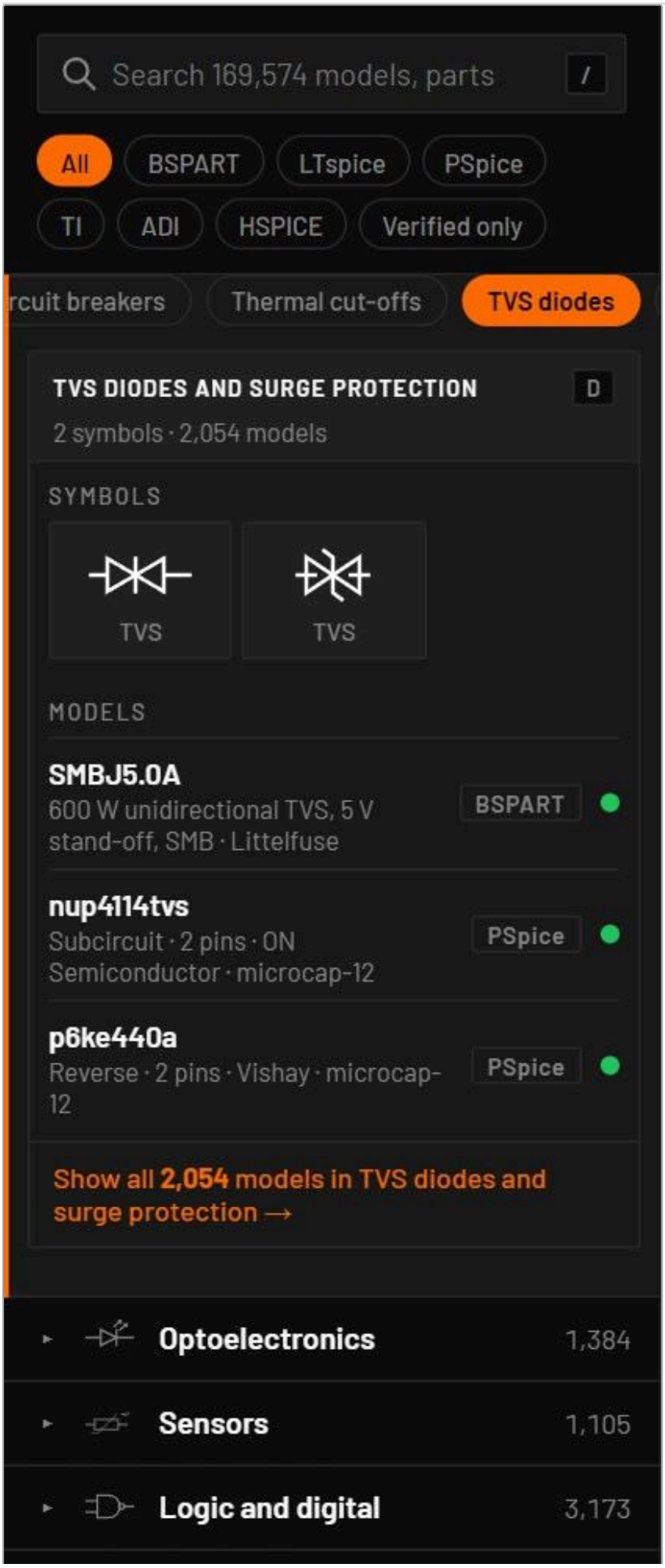

Search 169,574 models, parts
/
All
BSPART
LTspice
PSpice
TI
ADI
HSPICE
Verified only
rcuit breakers
Thermal cut-offs
TVS diodes
TVS DIODES AND SURGE PROTECTION
D
2 symbols · 2,054 models
SYMBOLS
TVS
TVS
MODELS
SMBJ5.0A
600 W unidirectional TVS, 5 V stand-off, SMB · Littelfuse
BSPART
nup4114tvs
Subcircuit · 2 pins · ON Semiconductor · microcap-12
PSpice
p6ke440a
Reverse · 2 pins · Vishay · microcap-12
PSpice
Show all 2,054 models in TVS diodes and surge protection →
Optoelectronics
1,384
Sensors
1,105
Logic and digital
3,173



Figure 44.1 The Protection family of the library, with its TVS and ESD groups.

44.5 Status

STATUS	DOT IN THE LIBRARY	MEANING	MODELS
Works	green	Runs in ngspice exactly as the vendor wrote it.	150,546
Converted	amber	Runs after conversion to ngspice syntax. Simulate runs the converted text.	15,832
Verified in PSpice	green	Cadence-encrypted, runs in PSpice for TI. Simulate runs it in PSpice.	3,084
Replaced	red, with "replaced by"	Doesn't run, but a working model of the same part stands in for it.	33

A model whose file has a problem the catalogue check found, such as a missing include, shows a red dot with the reason. Fit classes in the model dialog: **exact** (the live engine uses the vendor card with ngspice's equations), **approx** (a behavioural fit from the measurements, with its error), **accurate-only** (Simulate only).

44.6 Dialects and conversion

Vendor models are written for PSpice, LTspice, HSPICE, TINA and Micro-Cap. Each is tried as written first. If ngspice rejects it, BetterSPICE converts it to native ngspice syntax, one definition at a time, and records which rules it used. Some of the rules:

CONSTRUCT	BECOMES
HSPICE **'expr'**, nested braces	ngspice **{expr}**
PSpice **IF**, **LIMIT**, **PWR**, **PWRS**, **STP**, **&**, **|**	Ternaries, min/max, pow with the sign kept, logical operators
LTspice **uplim**, **dnlim**, **buf**, **inv**, **uramp**, **table()**	Equivalent expressions, a clamped pwl() for tables
E and G sources with **VALUE**, **TABLE**, **LAPLACE**	B-sources, clamped tables, an exact state-space network for rational Laplace functions
PSpice voltage and current switches	A B-source with PSpice's switch law
LTspice Rser, Lser, Rpar, Cpar	Explicit elements
PSpice U digital devices, LTspice A devices	XSPICE digital primitives with interface bridges
Vendor values ngspice rejects (BV = 0, NSUB = 0, division by a zero parameter)	Repaired, each repair named

When Simulate has to use the converted text, it says so in a warning. Constructs with no ngspice equivalent (for example a PSpice Chebyshev filter or a delay in a Laplace function) make the model fail with that reason.

44.7 PSpice for encrypted models

Many Texas Instruments models are encrypted by Cadence, readable only by PSpice. BetterSPICE never decrypts them. On the desktop, with PSpice for TI installed, the catalogue check ran each one in PSpice, hidden, through the same test circuits, and fitted the live simulation from the results. Simulate runs a circuit with such a model in PSpice (**PSpice for encrypted models**, p. 224). Models encrypted for other simulators (LTspice encrypted files, HSPICE **.protect**) cannot run in either engine.

44.8 Replacements

A model that doesn't run, but whose part exists elsewhere in a form that does, is replaced: the library row says "replaced by *X* from *Y*" and placing it places the working one. Same part means the same part number (ignoring case, spaces, dashes and a package suffix), the same device class and compatible pins. Vendor downloads rank above other libraries, and models that work as written rank above converted ones.

44.9 Retired models

A model that doesn't run in ngspice, doesn't pass in PSpice and has no working replacement is retired after every fix has been tried: it's removed from the app and recorded in **library/broken**. The last run retired 3,094 models.

FILE	WHAT IT HOLDS
library/broken/README.md	Counts per kind, the main causes and examples.
library/broken/index.csv	One row per retired model: id, part number, kind, maker, source, file, line, status, reason, and what was tried.
library/broken/catalog/	The full records, so a rebuild can restore them.
library/broken/files/	Copies of the model files. The originals are never moved or deleted.

What was tried is listed per model: the dependency search, the conversion, running the tests again with every current fix, PSpice for encrypted models, the replacement search and the vendor download. Every rebuild of the catalogue first puts the retired models back and judges them again, so a model that a later fix makes runnable returns to the library by itself.

44.10 Commands for the catalogue

COMMAND	WHAT IT DOES
bspice models show <part or id>	The catalogue entry, its status with the reason, and its live-view parameters.
bspice models stats —md	Counts per kind and status.
bspice models convert <file> <name>	The ngspice-native text of one model, with the rules used.
bspice models validate —mpn <part> —force	Runs one model's tests again.
bspice models check	Checks the whole catalogue for missing files, definitions and includes.
python tools/model-index/rebuild.py —retire	Rebuilds the catalogue from the sources, tests everything that changed, and retires what still fails.

TRY IT

Find out why a model was replaced

1. Search the library for the part. The row says "replaced by …".
2. Run **bspice models show <part number>** in a terminal.

YOU SHOULD SEE The JSON shows the status, the reason with the ngspice message and the vendor file and line, and the replacement it points to.

45 The model dialog

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Every part can carry a model: the description of how it behaves, which the engines simulate. The model dialog finds, fits and edits models. Open it by double-clicking the part, with Ctrl + M, the right-click menu, or **Assign model...** in the inspector. Ctrl + Shift + M opens it on the Quick model tab, and **All N parameters** in the inspector on the All parameters tab.

The header shows the part, its type and variant, and its model. The three tabs are **Library**, **Quick model** (for part kinds that have one) and **All parameters**. All three change the same model, so switching tabs never loses a value. **Done**, Esc or a click outside closes it.

45.1 Library tab

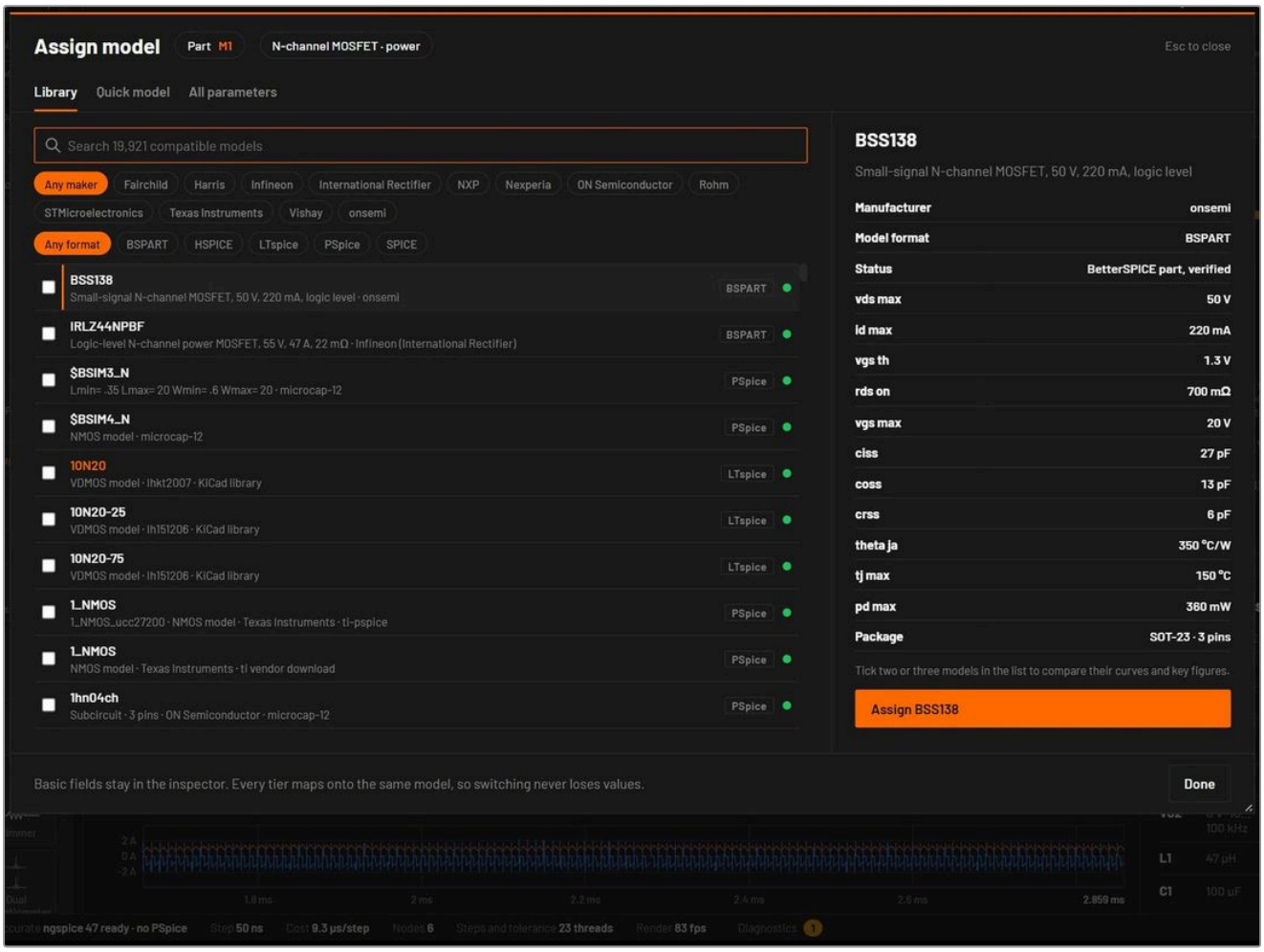


Figure 45.1 Assign model, Library tab, for an N-channel MOSFET.

- The search box searches the models that fit this part: the same device type. A generic IC box accepts any vendor subcircuit. Every word must match.
- Chips filter by maker (**Any maker** and up to 12 makers) and by format (**Any format**, SPICE, LTspice, PSpice, HSPICE, BSPART).
- The list puts BetterSPICE part files first, then working vendor models, then encrypted ones. The present model is marked **· current**.
- Click a row to see it on the right. Double-click to assign it and close.

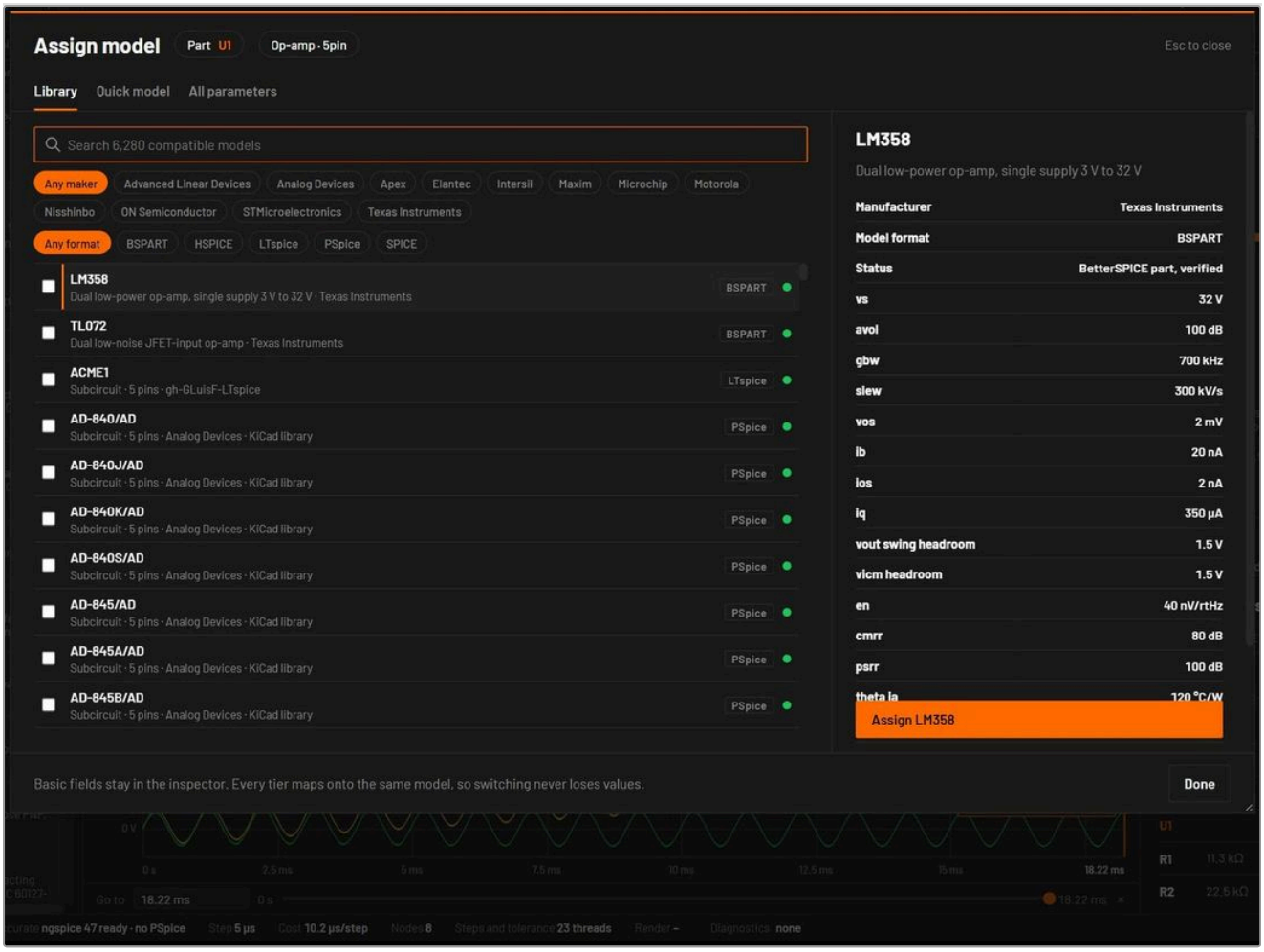


Figure 45.2 A vendor op-amp selected in the Library tab: maker, format, status, pins and the Live view line.

The preview on the right shows the model name and description, the manufacturer, the format, the status, the pins of a subcircuit, the file, and for part files the electrical, noise and thermal values and the package. The **Live view** line says how the live engine will treat it:

LIVE VIEW LINE	MEANING
Vendor model card, exact	A discrete model. The live engine uses the same equations as ngspice.
Fitted from the vendor model	A subcircuit whose live parameters were measured by running the vendor model.
Live view: fitted from PSpice (approximate)	A Cadence-encrypted model, measured in PSpice. Simulate runs the vendor model in PSpice.
No fit: left out of the live simulation	Simulate only. The live simulation treats the part as open.
No mapping: generic values in the live simulation	The live simulation uses typical values. Simulate uses the vendor card.

Assign is one undo step. It sets the model, changes the symbol variant if the model needs other pins, sets the live parameters and the pin map, and stores the file reference that Simulate loads. A message confirms it, with a warning when something needs attention:

- *"its N pins (…) do not match this op-amp: Simulate may wire it wrongly. Place it from the library to get its own pins."*
- *"encrypted: Simulate cannot run it"*, for models no engine can read.
- For a model with a working stand-in, the stand-in is assigned and the message says so.

When nothing fits, the list says *"No compatible model … Use the Quick model tab to build one from datasheet values."*

45.2 Compare models before you assign one

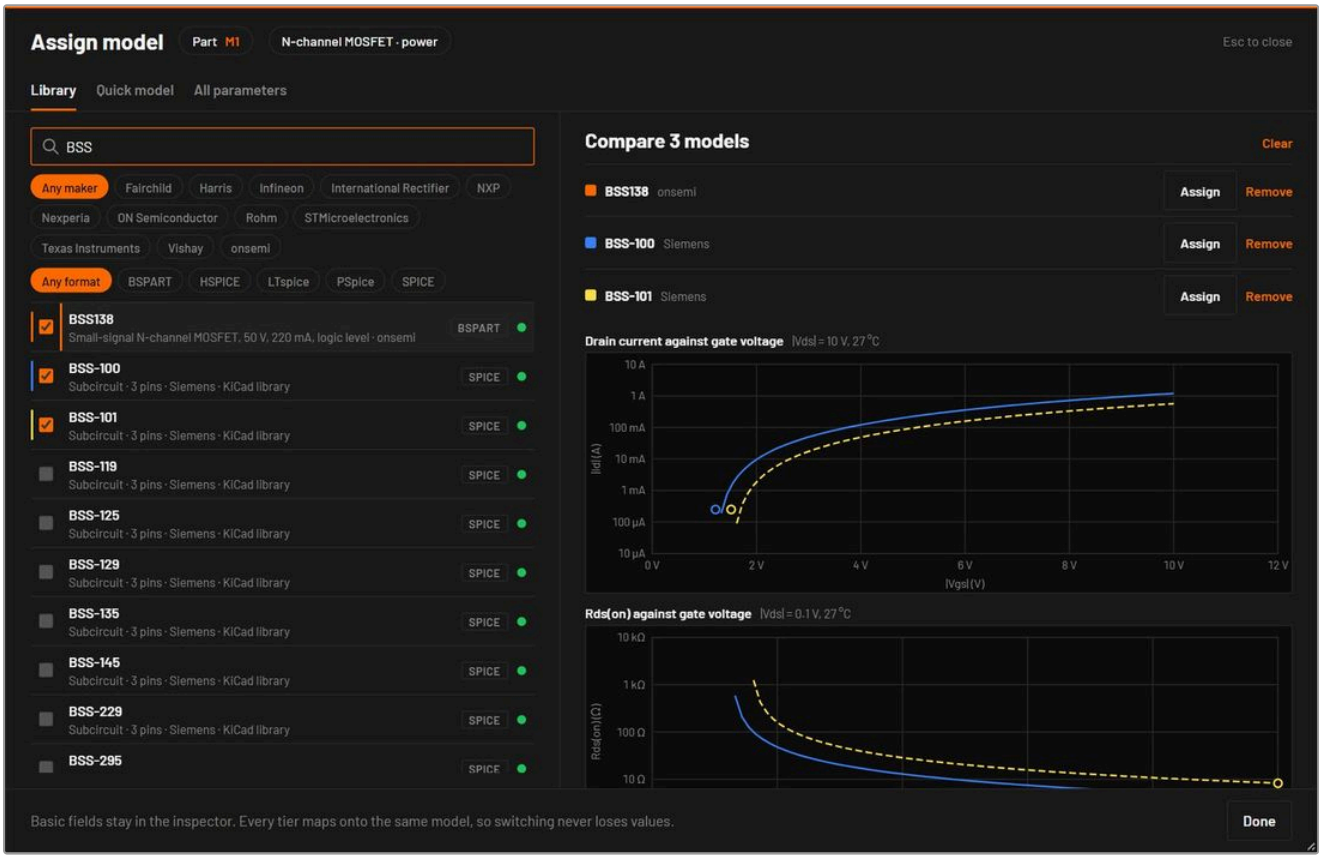


Figure 45.3 The Library tab with three MOSFET models ticked: their curves in one colour each, and the key figures side by side.

Each row of the Library tab has a tick box on its left. Tick two or three models and the right side becomes **Compare N models**:

- **Curves**, one colour per model: forward current against forward voltage for diodes, Zeners, Schottkys and LEDs, drain current against gate voltage and Rds(on) against gate voltage for MOSFETs, and current gain against collector current for BJTs.
- **Lines** are the live-view model of each part, drawn from its fitted parameters with the SPICE device equations. **Dots** are the catalogue's bench results, measured on the vendor model itself in ngspice. Where the two agree, the live view behaves like the vendor model. A model with no

fitted parameters shows its dots only, and a note under the chart says so. A MOSFET card above level 1 has no square-law line.

- **Key figures** side by side, with the condition of each row under its name (Vf at 1 mA, hFE at 10 mA and so on).
- **Assign** on a model's line assigns it. **Remove** takes a model out of the comparison and **Clear** ends it. A fourth tick box stays greyed until you remove one.

45.3 Key figures of a vendor model

A part with a vendor model has a **Key figures** section in the inspector, under **Model**. The same list is in the model dialog, under the picked model's name, and on a card that opens when the pointer rests on a library row for about half a second. It shows the figures that matter for the kind of part, with units.

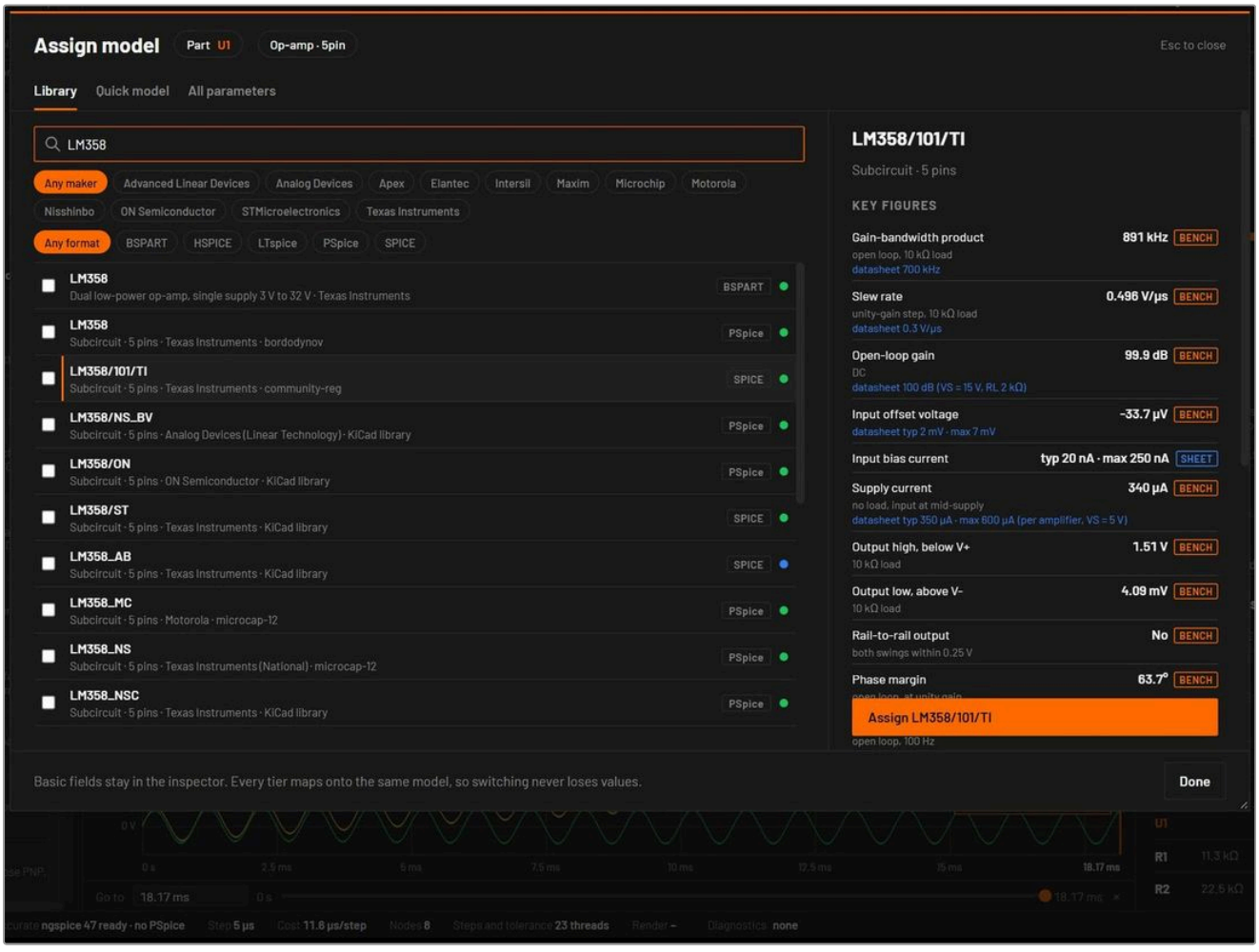


Figure 45.4 The model dialog with the LM358 picked: its key figures, each with a mark that says where the number comes from.

PART	FIGURES
Op-amp	Gain-bandwidth, slew rate, open-loop gain, input offset, supply current, how far the output stays from each rail, rail-to-rail output (yes or no), phase margin, output impedance and the supply it was measured on.
Comparator	Propagation delay, input offset against the reference, output high and low, supply current.
Regulator, reference	Output voltage, dropout at the load it was measured with, quiescent current, line and load regulation. For a reference: voltage, dynamic resistance or line regulation, input needed.
MOSFET, BJT	MOSFET: gate threshold and $R_{DS(on)}$ at V_{GS} = 10 V. BJT: h_{FE} at 1 mA, 10 mA and 1 A, V_{BE}, $V_{CE(sat)}$ and the Early voltage.
Diode, Zener, Schottky, LED, JFET	V_F at 1 mA to 1 A, leakage, breakdown or Zener voltage, C_{j0} and t_t where the model card has them. JFET: I_{DSS} and $V_{GS(off)}$.
Timer, logic	Frequency, duty, delay and a truth-table check.

Each row has a mark that says where the number comes from.

MARK	MEANING
bench	Measured on the vendor model by BetterSPICE's test circuits (**bspice models validate**) and stored with the catalog.
measured	The same bench, run now in the desktop app because the catalog had no stored result.
fit	From the fitted live-view model.
card	A parameter of the vendor model card, as written.
sheet	From the maker's datasheet.

Where the datasheet table has the same quantity, it is printed under the model's own number (*datasheet typ 2 mV, max 7 mV*), so you can see how far the model is from the sheet. The footer lists what the bench does not measure, such as noise, PSRR and hysteresis. Nothing is guessed to fill a gap. The desktop app measures a model on demand when the catalog has no result for it, in a separate process, so the window stays usable. The browser build shows what the catalog stores. An encrypted model shows the datasheet figures where the table has them and says that it is encrypted.

Dropout, quiescent current and regulation are measured at the load and input stated in the row (10 mA at 5 V, input 3 V above the output), not at the datasheet's 1 A. An adjustable regulator is measured with a divider that sets about 5 V, so its quiescent current is left out. From a script: **bspice models info LM358 —lines**, or the **model_info** MCP tool.

45.4 A model that differs from its own datasheet

A few vendor models are marked **≠ datasheet**: in the library list and the search results, in the Library tab of this dialog, and in the inspector next to the model name. The mark is a note, not a fault: the model is the vendor's own file, and it differs from *the same vendor's* datasheet for that part (a Diotec model is only ever compared with Diotec's sheet; another maker's sheet for the same part number can say something else). Pointing at the

mark, or opening the model in the dialog or the inspector's Model section, gives the sentence: which figure, the model's value at the sheet's own test condition, the sheet's limit or typical, and the sheet's name and revision.

A figure is listed when the model is outside the sheet's minimum or maximum by more than 10 % of the limit, or, where the sheet gives only a typical value, when the model is at least twice or at most half of it. The note never changes a run, adds no diagnostic and stops nothing. A part without a record looks as before.

To change it: **Edit a copy of this model** (below) changes the vendor's own values in a copy kept in your circuit; or pick another model (**Assign model...**), build a model from the datasheet's own numbers (the **Quick model** tab, where the part kind has one), or **Remove model** in the inspector. A part that runs an edited copy no longer shows the note: it is no longer the vendor's model.

45.5 Model text tab: edit a copy of a vendor model

For a part that has a vendor model the dialog has a **Model text** tab. **Edit a copy of this model** reads the vendor's text of the model (with the models it needs) into an editor. Change a value, for example **Vf=1.0** to **Vf=0.4** in a Diotec diode, and press **Use this copy**. The text is stored in the circuit file with the part (**modelText**), the inspector marks the part **edited copy**, and Simulate (F5) runs the copy in ngspice and says so in its warnings. The vendor's file is never written. **Apply changes** stores further edits, Ctrl+Z takes each step back, and **Use the vendor model again** drops the copy. Assigning another model or the Quick model also drops it.

The copy is plain SPICE text: the app does not check it, and a mistake shows as an ngspice error in Simulate. The live view keeps using the values it fitted to the vendor model, so it does not follow edits to the text; trust Simulate for a part with an edited copy. Reading the vendor's text needs the desktop app.

45.6 Quick model tab

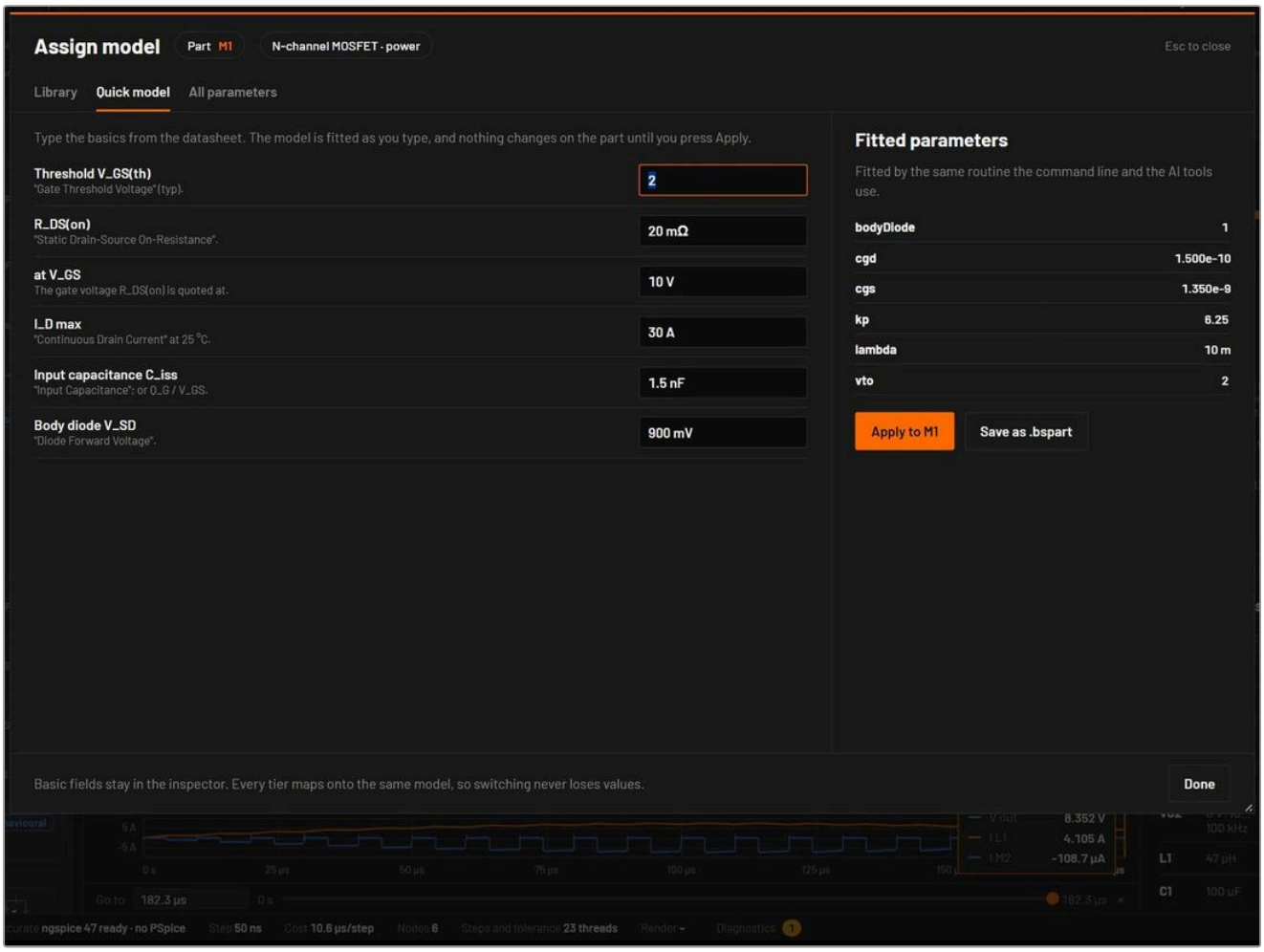


Figure 45.5 Quick model: datasheet numbers on the left, fitted parameters on the right.

Type the basics from the datasheet. The model is fitted as you type. Nothing changes on the part until you press Apply. The right side lists the fitted parameters and any notes. The fit is the same one the command line and the AI tools use.

PART	DATASHEET FIELDS (DEFAULT)	KEYS FOR BSPICE PARTS QUICK
Diode, Schottky	Forward voltage V_F (1.0 V) at forward current I_F (1 A), breakdown voltage V_BR (1000 V), reverse current I_R (5 µA), junction capacitance C_J (15 pF), reverse recovery t_rr (2 µs)	**vf, if, vbr, ir, trr, cj** (Schottky: **vf, if, vbr, cj**)
Zener	Zener voltage V_Z (5.1 V) at test current I_Z (49 mA), dynamic impedance Z_Z (7 Ω)	**vz, iz, zz**
LED	Forward voltage V_F (2.0 V) at I_F (20 mA), series resistance (2 Ω)	**vf, if, color**
NPN, PNP	Current gain h_FE (200), V_BE(on) (0.65 V) at I_C (10 mA), V_CE(sat) (0.2 V), transition frequency f_T (300 MHz)	**hfe, ic, vbe, vaf, cob, cib, ft**
N, P MOSFET	Threshold V_GS(th) (2 V), R_DS(on) (20 mΩ) at V_GS (10 V), I_D max (30 A), input capacitance C_iss (1.5 nF), body diode V_SD (0.9 V)	**vth, rds_on, vgs, ciss, crss** or **qg, id_max**

PART	DATASHEET FIELDS (DEFAULT)	KEYS FOR BSPICE PARTS QUICK
Op-amp, comparator	Gain-bandwidth (1 MHz), slew rate (0.5 V/µs, typed as **500k**), offset voltage (2 mV), output headroom to the rails (1.5 V, 0 for rail-to-rail), supply current (0.5 mA)	**gbw, slew, vos, rail, iq, avol_db, rout** (comparator: **tpd, hyst, opendrain**)
Relay	Coil voltage (5 V), coil resistance (125 Ω), pick-up voltage (3.75 V), drop-out voltage (0.5 V), contact resistance (0.1 Ω)	**v_coil, r_coil, v_pick, v_drop, r_contact**
Inductor	Inductance (10 µH), DC resistance (50 mΩ), saturation current (3 A)	**l, dcr, isat**
Switch	On resistance (10 mΩ), off resistance (1 GΩ)	**ron, roff**
TVS, varactor, JFET	Command line and AI tools only	**vbr, vc, ipp, cj, cj, vbr, vgs_off, idss**

Resistors and capacitors have no Quick model tab: type their value in the inspector. The fields start from the part's present part file where it has one. **Apply to *part*** sets the fitted values. A part that had a vendor model is renamed *model* (fitted) and no longer loads the vendor file. **Save as .bspart** writes the result as a part file (**mpn-quick.bspart**).

TRY IT

Model a MOSFET from its datasheet

1. Place an N-channel MOSFET (M) and select it.
2. Press Ctrl + Shift + M. Type V_GS(th) **1.8**, R_DS(on) **8m** at V_GS **4.5**, C_iss **2.2n**.
3. Press **Apply**.

YOU SHOULD SEE The fitted vto and kp appear on the right and in the inspector. The part now switches at about 1.8 V and conducts with 8 mΩ at 4.5 V of gate drive.

45.7 All parameters tab

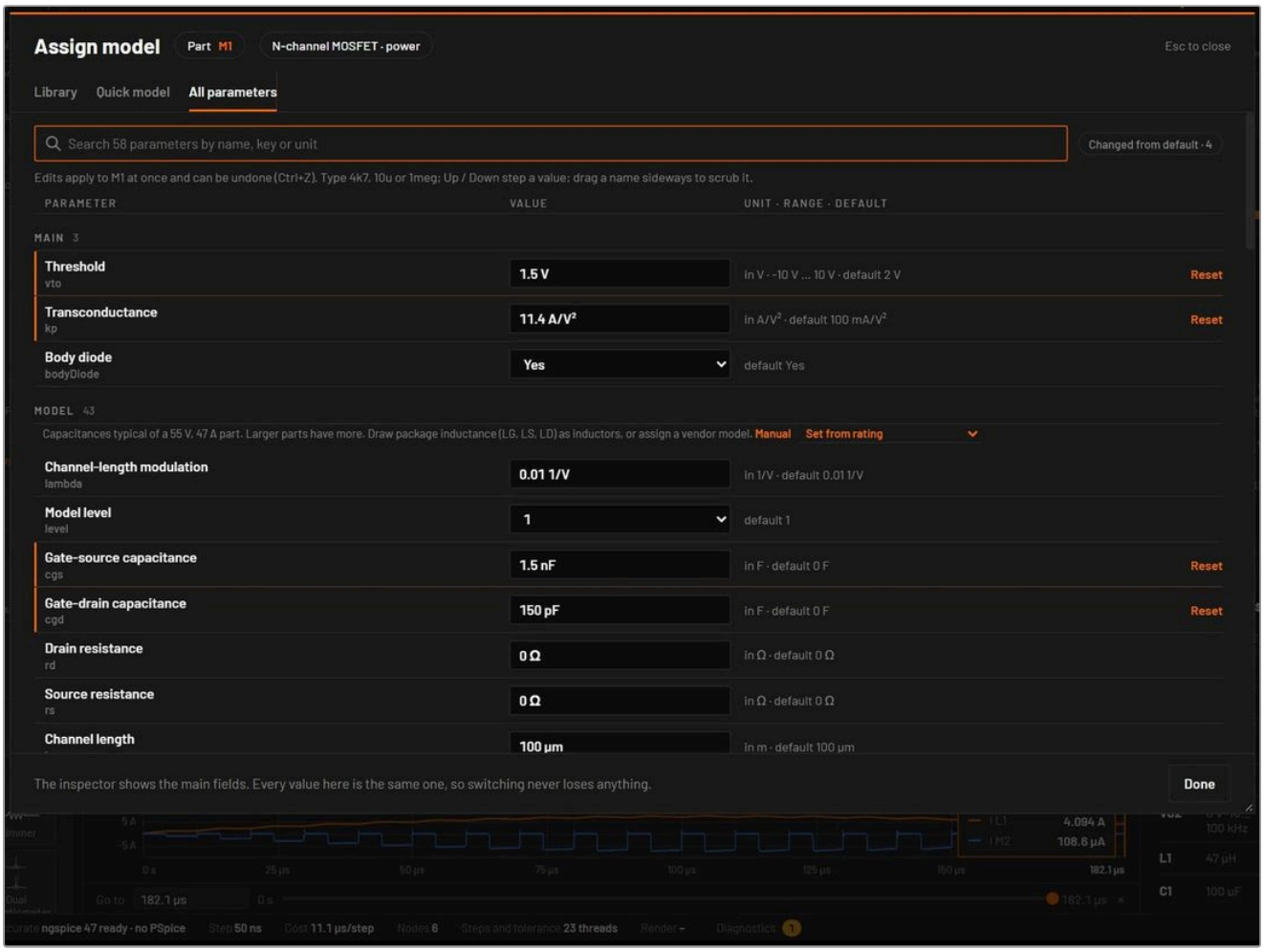


Figure 45.6 All parameters: every parameter of the part, in groups, with search.

Every parameter the part's model reads, with the value the simulation uses. The list starts with a sticky **search** box that matches the name, the key, the unit and the group (Esc clears it) and a **Changed from default** filter with its count.

GROUP	HOLDS
Main	The fields the inspector shows.
Model	The rest of the type's documented parameters. A diode shows saturation current, ideality, series resistance, breakdown, capacitances and transit time. A MOSFET its level-1, 2 or 3 or VDMOS fields. An op-amp, a regulator, a logic gate and the mixed-signal blocks show every key the engine reads, with a label and a unit.
Vendor model file	The lib, libSource, modelId and modelLine of an assigned card.
Other	Keys the part carries that no field describes.

IN EACH ROW	WHAT IT DOES
Name and key	The name in bold, the key under it. Drag the name sideways to scrub the value.
The value	The same field as in the inspector: short form while you type, Up / Down and PageUp / PageDown, the standard values list, a red line for a refused value. Choices read **No** and **Yes** or by name, not 0 and 1.
in Ω · 0.1 Ω … 10 MΩ · default 1 kΩ	The unit, the allowed range and the default the engine uses for this part. Some defaults depend on other fields: an LED's colour, a fuse's rating, a depletion MOSFET's threshold.
Reset	Shown when the value differs from the default. It removes the key, so the engine uses its own default again. An orange bar marks a changed row.

Edits apply live and are normal undo steps. Esc in a field cancels that edit, not the dialog. In a window narrower than 900 px the table has two columns. When a vendor card has a different name for a key, such as **cjo** for **cj0**, the row edits the key the part carries. The key is what a parameter step uses (**Q1.bf**) and what an AI agent sets.

45.8 Cards, variants and quick models

- **Assigning a vendor card replaces the model.** For a diode, LED, BJT, MOSFET or JFET card, the part's own model values that the card doesn't set are cleared, so the part simulates as the card says. Instance settings (colour, temperature, area, multiplier) stay. Power MOSFET cards (VDMOS) are placed as the *power* variant, with their gate-drain capacitance, gate resistance and body diode.
- **Changing the variant brings the variant's physics.** A rectifier switched to Zener gets a 5 V breakdown, and back again loses it. Only values still at the old variant's preset change. Values you set, or that a card set, are kept.
- **Quick models fit what the part reads.** A comparator gets a delay, a hysteresis and an open-collector choice, a P-channel MOSFET a negative threshold, a relay its coil and contact values, and a BJT its transit time from fT.

45.9 How models run

MODEL TYPE	LIVE SIMULATION	SIMULATE
Built-in parts	Exact device equations	The same engine with an adaptive timestep
Discrete vendor models (.model D, NPN, PNP, NMOS, PMOS, NJF, PJF)	ngspice's equations for that model, in the live engine	The same, or ngspice when the circuit also has subcircuits
Vendor subcircuits (.subckt: op-amps, regulators, current-sense amplifiers, references)	A fitted behavioural model where one exists, typical values otherwise	The vendor's subcircuit in ngspice (desktop)
Cadence-encrypted vendor models	Parameters fitted in PSpice	The vendor model in PSpice for TI (desktop with PSpice)
BetterSPICE part files	Behavioural model from the datasheet values	The part's SPICE model when the file names one, else the behavioural model

46 Part Wizard

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Tools › **Part Wizard...** (Ctrl + Shift + N), or **New part...** in My parts, turns a datasheet into a BetterSPICE part file (**.bspart**) in eight steps. Every value takes a minimum, typical and maximum, its test conditions and the datasheet page it came from. The file holds the part number, the values, the pins and package, an optional custom symbol, model parameters you tuned and an optional vendor SPICE model. **Part files (.bspart)**, p. 575 describes the file.

Progress is saved as you type. Close the wizard, go back and forth between steps or reload the app, and every field is still there. The right side always shows the file as it's being written and a **Checks** card. Fields marked * are required for simulation. Everything else improves accuracy.

BUTTON	WHAT IT DOES
The step bar	Click any step once a part type is chosen. Finished steps show a tick; a step you left with a problem shows a red mark.
Back / Next	Moves one step. Next waits for a part type (and, for Any device, the device type). Problems never block Next: the footer says how many are on this step, and nothing is lost.
Skip optional	On steps 3 to 7, jumps one step ahead.
Save to My parts	On the last step. Waits until every check passes.

46.1 Step 1: Part type

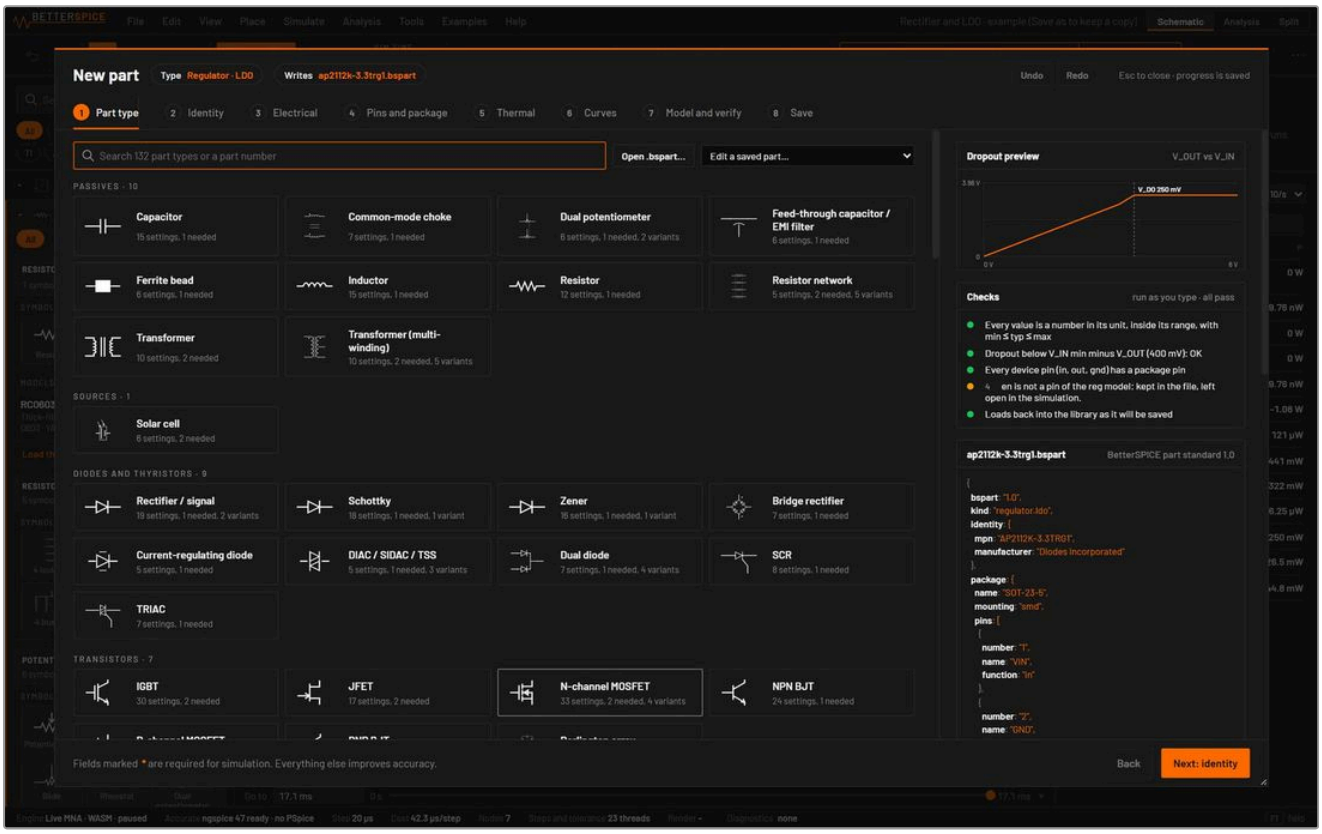


Figure 46.1 Step 1, Part type.

Choose a part type. Search by name, kind or device, or browse the types grouped by library family. Each tile shows the symbol, the name, the number of fields, how many are required and how many variants the type has. Choosing one fills the pin table with the pins the simulation needs. There are 132 part types with 1,310 fields in all. **Part templates reference**, p. 606 lists every one with its fields.

You can also type a part number in the search box, for example **TL431**. When the library knows it, a line reads *TL431 is a Voltage reference in the library* with a **Start from it** button, which fills in the type, the part number, the maker and the description for you.

CONTROL	WHAT IT DOES
Open .bspart...	Opens a part file to edit it (or to start from it). A file that doesn't read is refused with the reason and your draft stays. Saving puts the part in My parts.
Edit a saved part...	Lists My parts and the shipped part library. A My parts item is edited in place: Save replaces it, and a new part number renames it. A library part opens as a copy that saves to My parts.
Any device	In **Other**: a part of any device type the engine simulates, for the ones without a datasheet template (potentiometer, battery, flip-flop, supervisor, transmission line and more). Pick the device type below the search; the part keeps that device's own parameters (step 3).

Switching to another type keeps what you typed for the first one (switching back brings it back). The pin table follows the new type only while it is still the old type's default. A table you edited stays.

46.2 Step 2: Identity

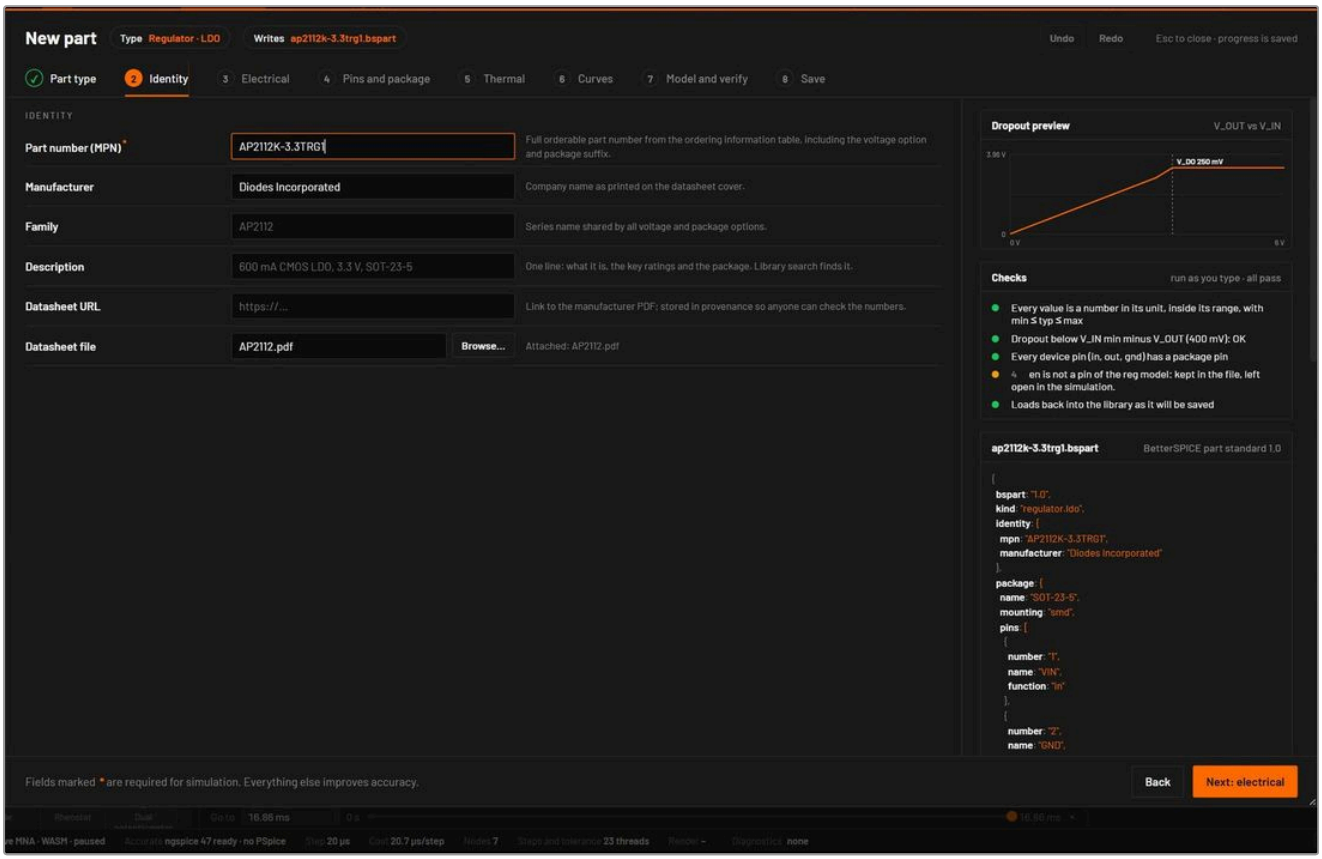


Figure 46.2 Step 2, Identity.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Part number (MPN) *	text		The full orderable part number, with the voltage option and package suffix, from the ordering table. It names the file: lower case, unsafe characters replaced by dashes. When My parts already has this number, the hint says so at once.
Manufacturer	text		The company on the datasheet cover.
Family	text		The series name shared by all options, for example AP2112.
Description	text		One line: what it is, the key ratings, the package. The library search finds it.
Datasheet URL	text		Stored in the file's provenance. A link without **https://** is flagged.
Datasheet file	a PDF		**Browse...** picks it (desktop). Only the file name is recorded. Keep the PDF next to the part file.

Type options below the identity appear for the types that have them:

OPTION	FOR	WHAT IT SETS
Variant	every type with variants (relay contact form, sensor kind, controller mode, MOSFET depletion or 4-pin, Any device)	The device variant; it decides the pins the model has.
Gate function	Logic gate	NOT, AND, OR, NAND, NOR or XOR (NAND until set).
Channel	JFET	N or P channel.
Topology	Voltage reference	Series (out, gnd) or shunt (cathode, anode, ref; TL431 style).
Colour	LED	The colour it glows in the live view.

46.3 Step 3: Electrical

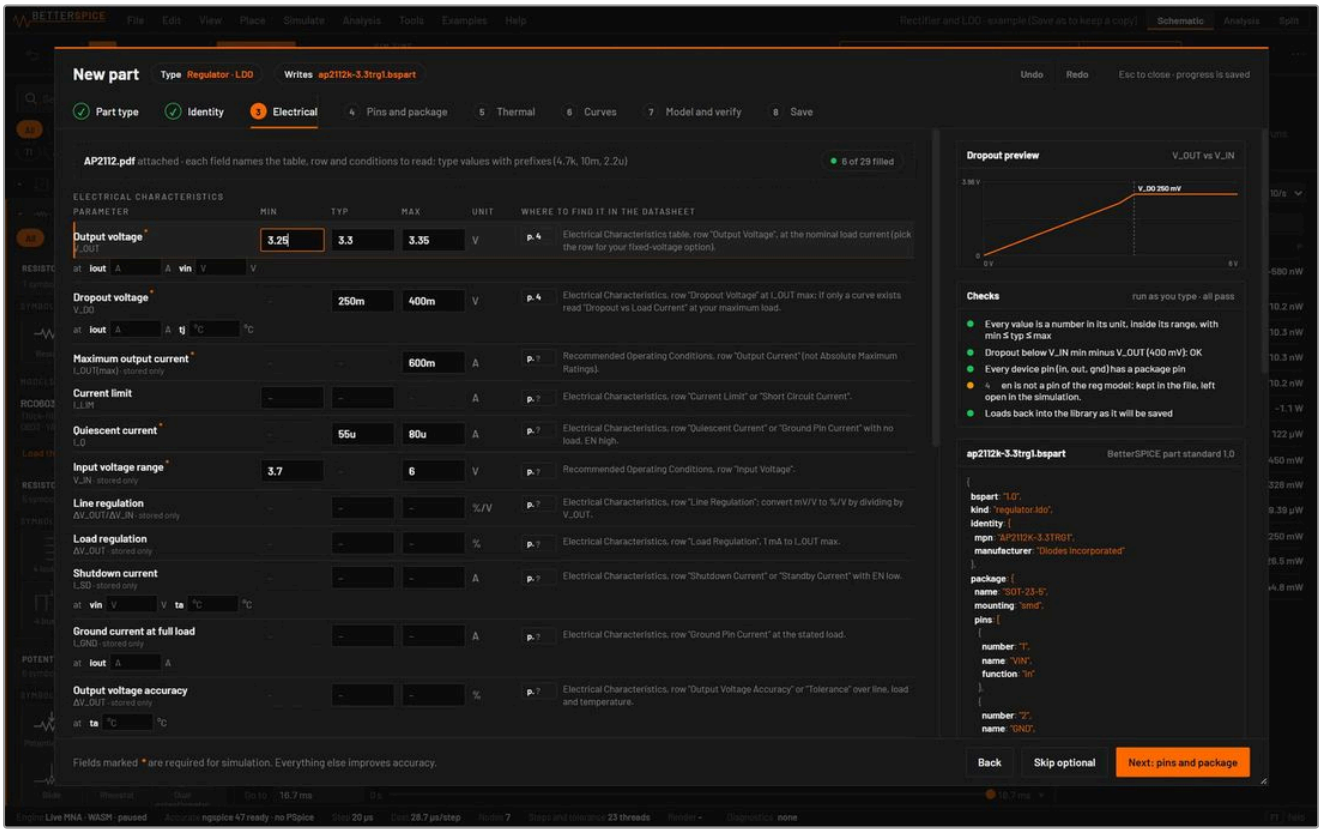


Figure 46.3 Step 3, Electrical: min, typ, max, conditions and page.

A table per group of the part type, such as Electrical characteristics and Noise and ripple. Each row has the parameter with its symbol, the **Min**, **Typ** and **Max** columns the type allows, the unit, and **Where to find it in the datasheet** with a box for the page number. Under a row with test conditions, small boxes take them: V_F *at* I_F, $R_{DS(on)}$ *at* V_{GS}. The model is fitted at those conditions, so they change the result: a MOSFET's $R_{DS(on)}$ at 4.5 V gives a different model than the same value at 10 V. A bar above the table names the attached datasheet and counts how many fields are filled.

Values take SI prefixes and may carry their unit: **250m**, **55u**, **4k7**, **2.2 µF**, **250 mV** in a volt field. A slew rate typed as **13 V/us** is converted to V/s. Every value is checked as you type, and the message stands under the field:

YOU TYPE	THE MESSAGE
abc	"abc" isn't a number (examples: 4.7k, 10m, 2.2u, 1e-3)
5 mA in an Ω field	"mA" isn't Ω; type the value in Ω (prefixes like m, µ, k are fine)
-1 for a resistance	outside 1 µΩ to 1000 TΩ (the sanity range of the part standard; check the sign and the prefix)
min 5k, typ 4k7	min, typ and max must be in increasing order (min ≤ typ ≤ max)
page **0**	datasheet page "0" must be a whole number from 1
a required field left empty	required: the live model needs this value

For an **Any device** part this step is the device's own parameter table instead: the same fields as the inspector, with the model default as the placeholder.

46.4 Step 4: Pins and package

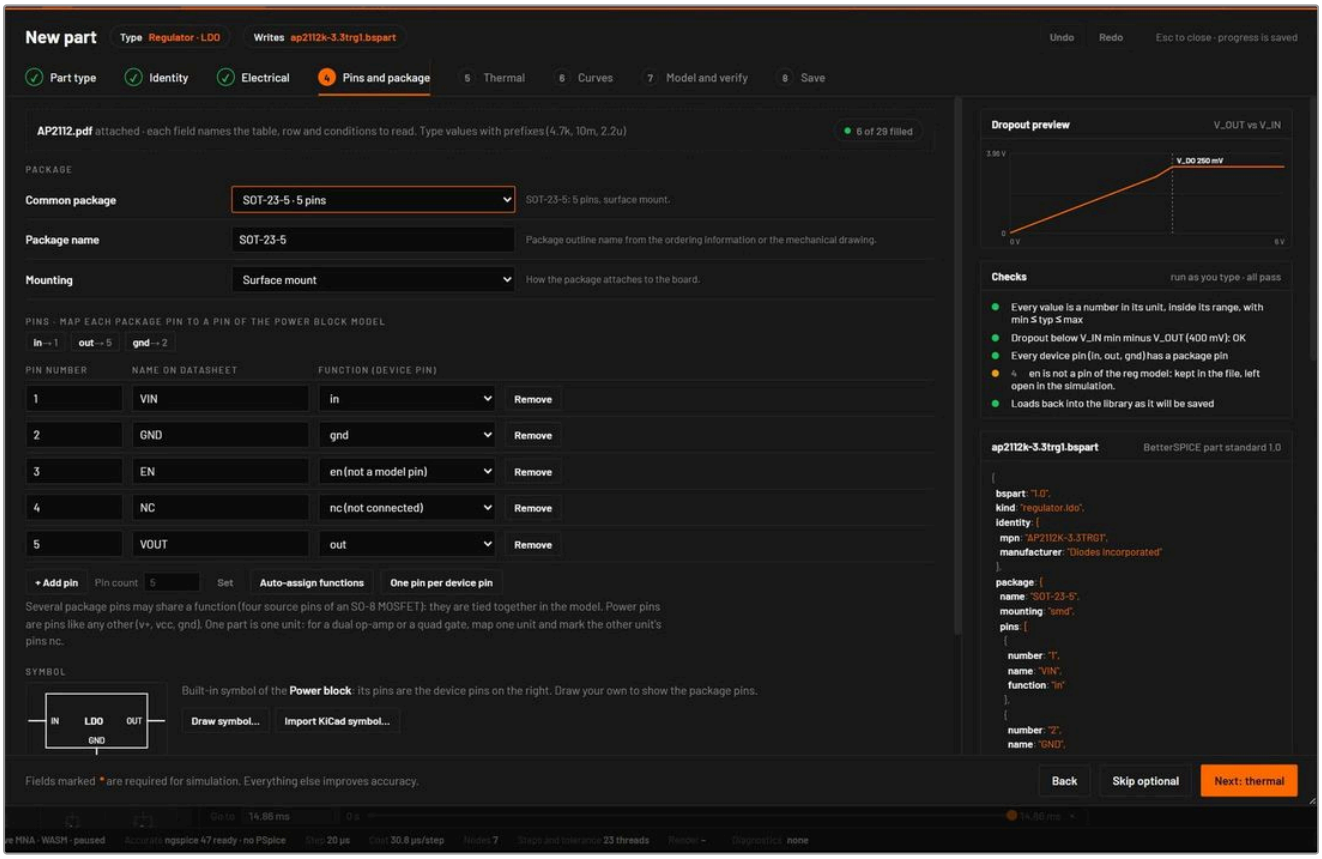


Figure 46.4 Step 4, Pins and package.

- **Common package**: SOT-23, SOT-23-5, SOT-223, SOIC-8, TSSOP, DIP-8 to DIP-40, TO-92, TO-220, DPAK, QFN-16 to QFN-48 (with the exposed pad as the last pin), LQFP, headers and more. Picking one names the package, sets the mounting and gives the pin table that many rows. Rows are never

removed silently: with more rows than the package has, a line offers **Remove the last N**.

- **Package name** and **Mounting**: surface mount, through hole, chassis (screw, panel) or module / board. Any name can be typed.
- **Device pins**: a chip per pin of the simulation model, for example *in* → *1*, *out* → *5*, *gnd* → *2*. A device pin with no package pin is red.
- **Pins**: one row per package pin with its number, its name on the datasheet and its **Function**: one of the device pins, **nc** (not connected) or **other** (kept in the file, left open in the simulation). A number used twice or left empty is flagged on its row.
- **+ Add pin** adds a row; **Pin count** and **Set** make the table exactly that long (any count up to 1024); **Auto-assign functions** fills unassigned functions from the datasheet names (VIN → in, GND → gnd, +IN → in+, NC → nc); **One pin per device pin** (press twice) starts the table again from the device.
- Several package pins may share a function, such as the four source pins of an SO-8 MOSFET: they are tied together in the model. Power pins are pins like any other (v+, vcc, gnd). One part is one unit: for a dual op-amp or a quad gate, map one unit and mark the other unit's pins nc. The checks say so when two pins share a function.

Symbol: the preview shows the symbol the part will have.

BUTTON	WHAT IT DOES
Draw symbol… / Edit symbol…	Opens the symbol editor over the wizard on the pin table (number, name, function). **Use in part** brings the symbol back attached.
Library symbol…	Attaches a symbol you saved in My parts (or one of a saved part).
Import KiCad symbol…	Reads a **.kicad_sym** library and attaches its first symbol; with several, a list picks one.
Sync symbol	Shown when the symbol and the pin table differ: renamed pins take the table's names, pins the table lacks are removed, new table pins are added (a plain box is laid out again).
Use built-in	Drops the custom symbol.

Symbol and pin table stay one list: when a symbol is attached (from the editor, the library or KiCad), the table takes its pin numbers and names and gets a row for every symbol pin it lacks. When the table was still the type's default, the functions are assigned again from the symbol's pin names.

46.5 Step 5: Thermal

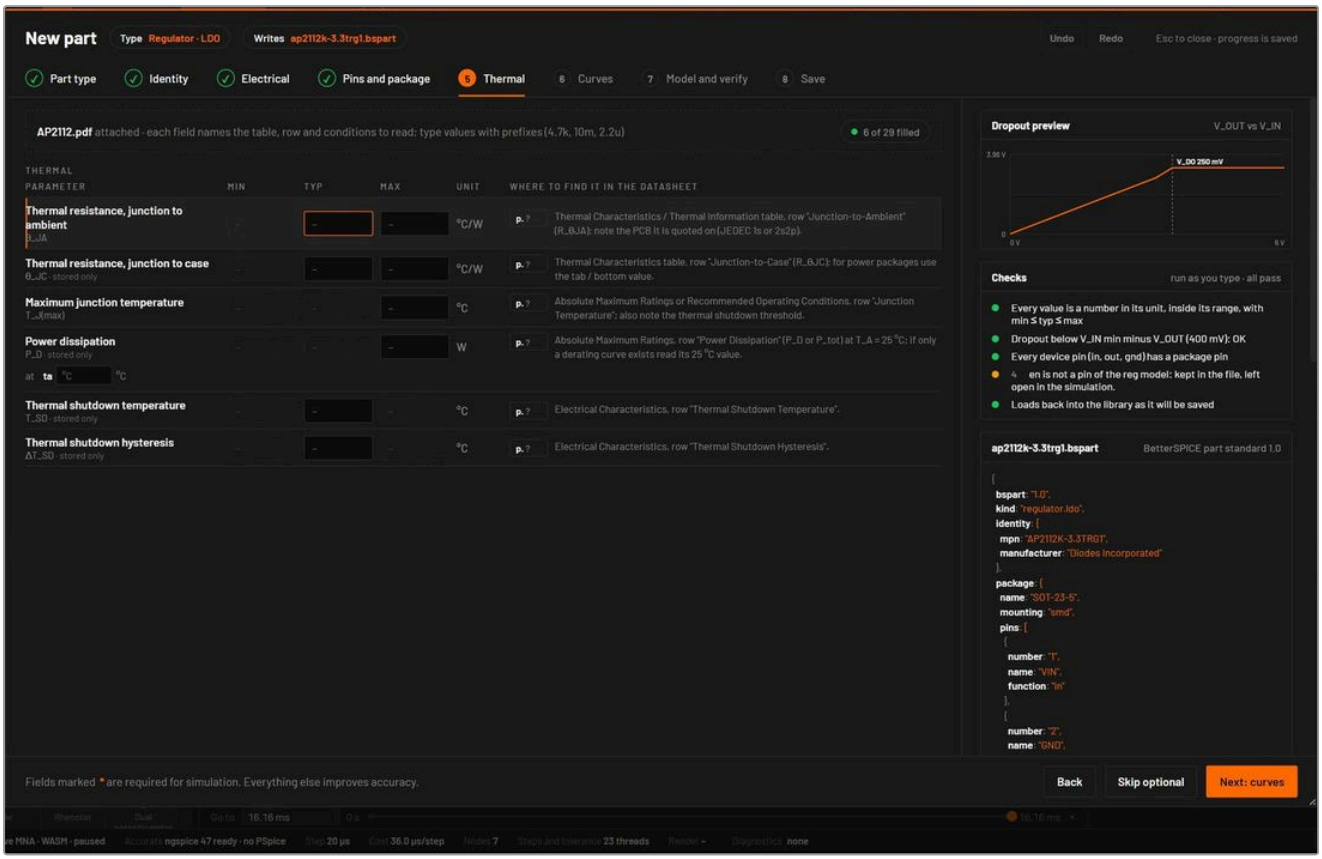


Figure 46.5 Step 5, Thermal.

The type's thermal fields, such as θJA, θJC and the maximum junction temperature, in the same table layout as step 3.

46.6 Step 6: Curves

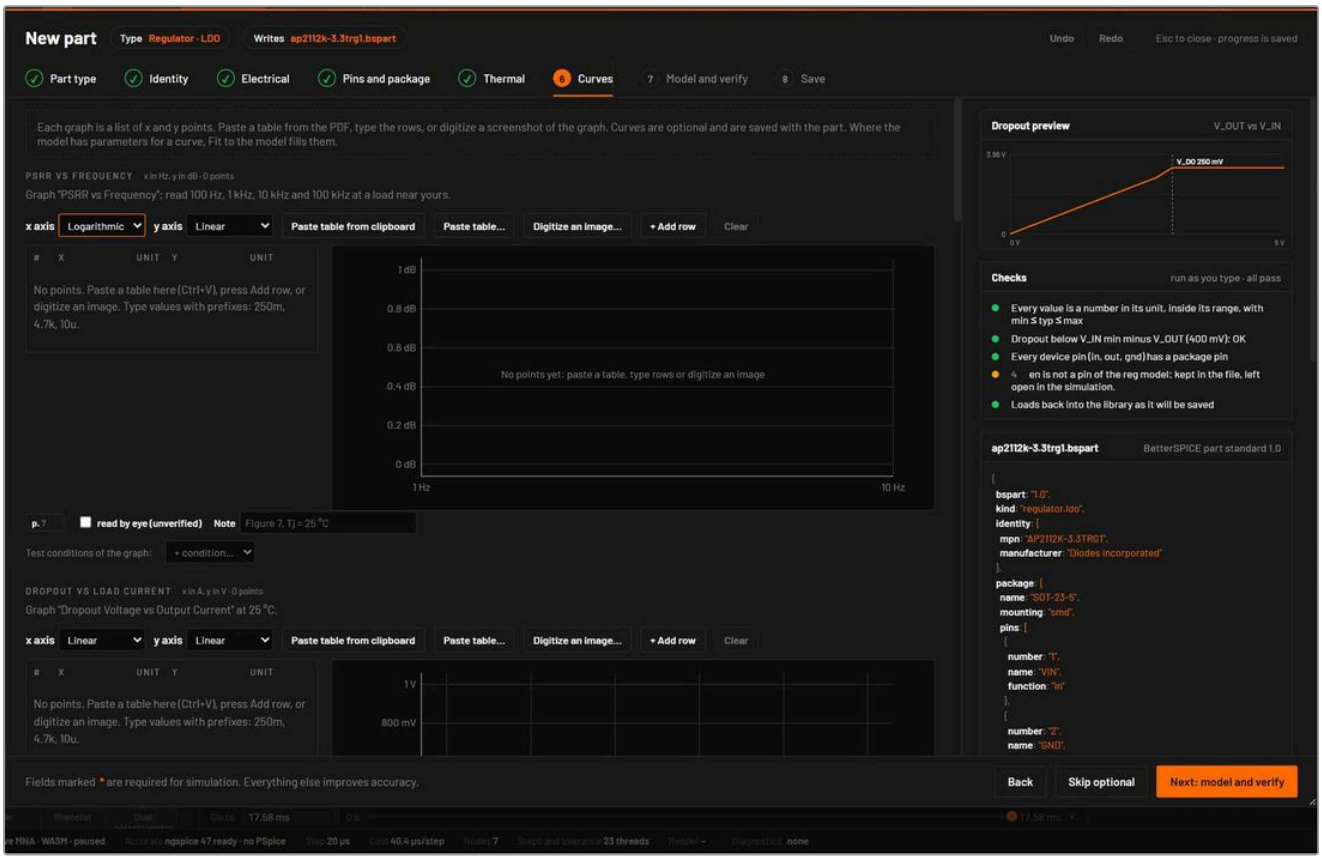


Figure 46.6 Step 6, Curves.

One editor for each graph the part type has: V_F against I_F, $R_{DS(on)}$ against gate voltage and against temperature, C_{iss}, C_{oss} and C_{rss} against V_{DS}, gate charge, open-loop gain and phase against frequency, dropout against load, PSRR, inductance against current and more. Curves are optional and are saved with the part. An editor has four ways in.

WAY IN	HOW
Type rows	In the x and y grid. The unit of each axis is next to the cell. SI prefixes (**250m**, **4.7k**, **10u**) and units (**45 mΩ**, **10 kHz**) work. A unit that does not fit the axis is an error, not a silent change.
Paste a table	Copy two columns from the PDF, a web page or a spreadsheet and press Ctrl + V on the grid, or press **Paste table from clipboard**. **Paste table...** shows how the text was read before you use it. Tabs, several spaces, semicolons and commas are understood, as are decimal commas, a header with units (**Vgs (V) Rds(on) (mΩ)** converts mΩ to Ω), units inside the cells and a table turned on its side. With more than two number columns you choose which two to use. Lines it could not read are listed.
Digitize an image	Paste a screenshot of the datasheet graph (Win + Shift + S, then Ctrl + V), drop an image file on the area, or open one. Click two known ticks on the x axis and type their values, then the same for y, saying whether each axis is linear or logarithmic. Click along the curve, or pick the curve's colour on the line and press **Trace the colour** to follow it. Remove strays with **Undo last**. **Use N points** fills the grid.
Edit the grid	Rows may be in any order. The file stores them sorted by x, and each x needs one y.

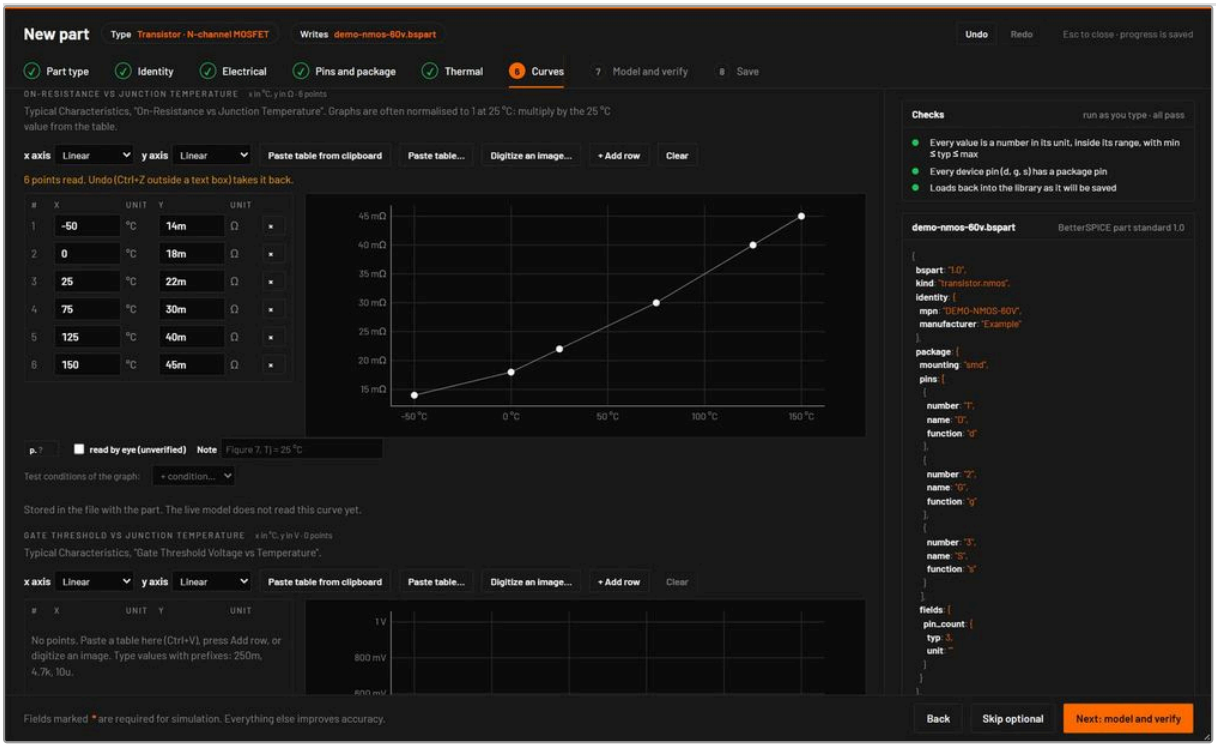


Figure 46.7 A pasted R_DS(on) against temperature table: the header's mΩ were converted to Ω and the rows sit in the grid.

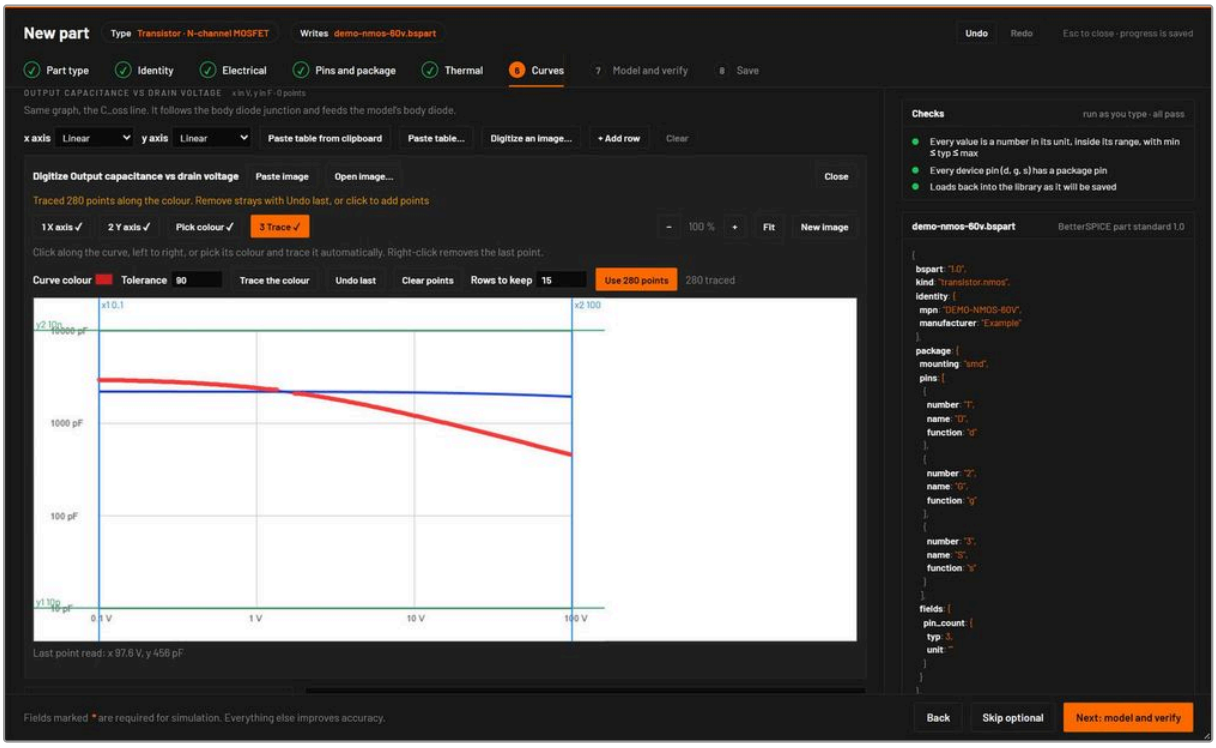


Figure 46.8 Digitizing an image of a capacitance graph. The graph here is drawn by the capture script to a known curve, so the result can be checked.

Digitized points are marked *read by eye* because a click is good to about a pixel. On a linear axis 400 pixels high that is 0.25 % of the span. On a logarithmic axis of three decades over 340 pixels it is about 2 % of the value.

Each curve has a live plot with linear or logarithmic axes, the datasheet page, a note and the test conditions under the graph. **Undo** and **Redo** in the wizard header take back and redo a pasted table or a digitized curve.

Fit to the model. For the curves the model can use, **Fit to the model** fits the model's equation to your points, shows the fitted parameters, draws the fitted curve dashed over the points and gives the error. **Apply to the model** writes the parameters into the part's model parameters, which step 7 shows. The fits are diode, LED and Schottky V_F against I_F, BJT V_{BE} against I_C, MOSFET transfer curve and $R_{DS(on)}$ against V_{GS}, MOSFET C_{oss} against V_{DS}, IGBT and JFET transfer curves, diode capacitance against reverse voltage, op-amp open-loop gain against frequency, LDO dropout against load and the Zener knee. A warning appears when the model is far from the points. The other curves are saved with the part and the live model does not read them yet, and the step says so.

46.7 Step 7: Model and verify

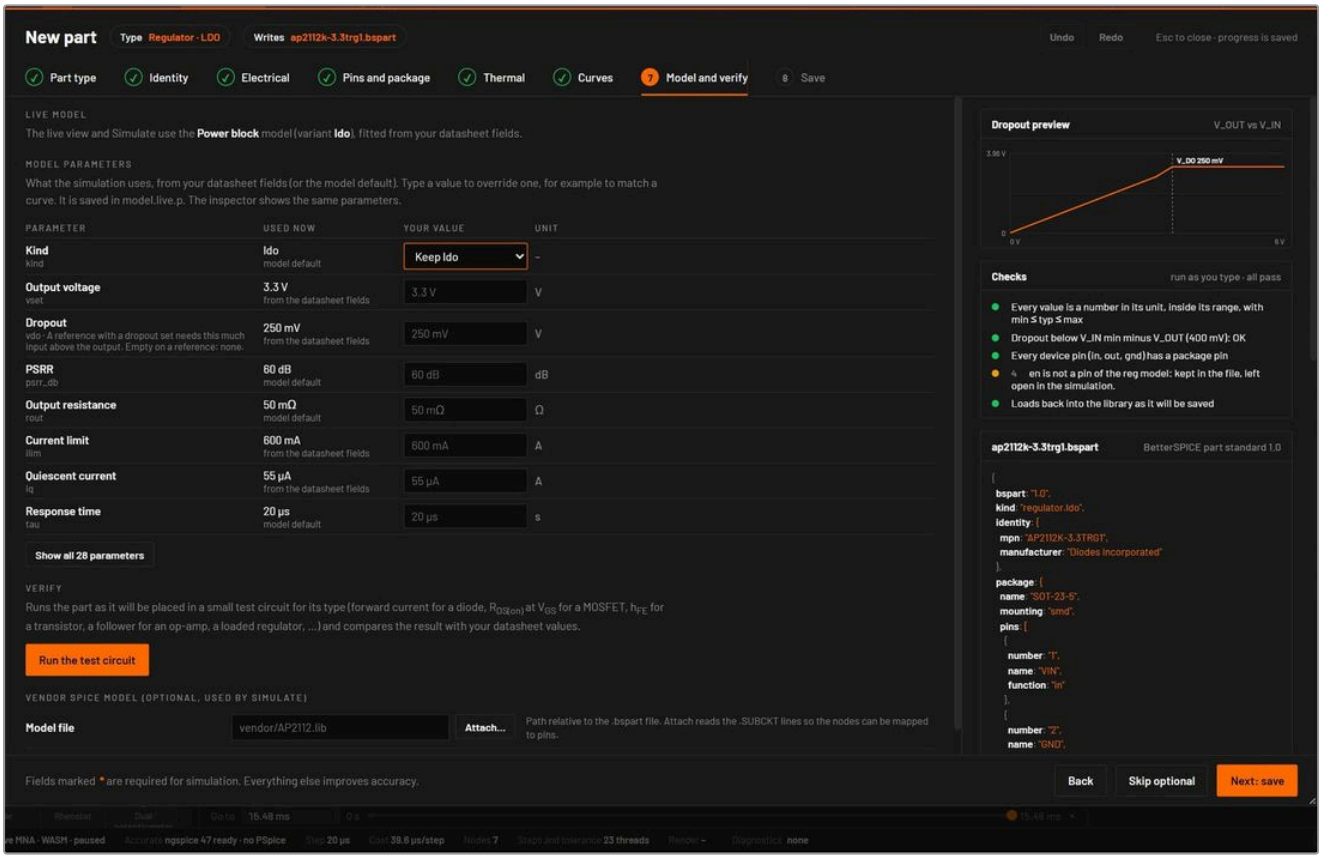


Figure 46.9 Step 7, Model and verify.

- **Live model**: names the device type and variant the part simulates as.
- **Model parameters**: the parameters of that device, the same as in the inspector. **Used now** is what the simulation uses, marked *from the datasheet fields* (fitted from your values: V_F at I_F gives the diode's saturation current, $R_{DS(on)}$ at V_{GS} and $V_{GS(th)}$ the MOSFET's transconductance, h_{FE} the transistor's gain) or *model default*. Type a

value in **Your value** to override one, for example to match a curve; it's saved in the file's **model.live.p**. **Show all N parameters** lists every one.

- **Verify**: **Run the test circuit** places the part, exactly as it will be placed from My parts, in a small test circuit for its type and compares the result with your values: forward current into a diode (V_F, and V_Z or V_{BR} in reverse), h_{FE} and V_{BE} of a transistor, $R_{DS(on)}$ and the off state of a MOSFET, I_{DSS} of a JFET, an op-amp follower, a comparator both ways, a loaded regulator, a reference. Other types are checked to load and solve with every pin tied to ground through 1 MΩ. A green line matches within the tolerance; an amber one tells you to check the field and its test condition.
- **Vendor SPICE model** (optional, used by Simulate): **Attach...** picks the model file and reads its **.SUBCKT** lines: the subcircuit (the one named like the part, else the first; a list when there are several) and its nodes. A table maps each node to a package pin, filled in by name, number or order. Also the dialect (spice3, pspice, ltspice, hspice) and whether it's encrypted (detected from the file). The path is relative to the part file.

46.8 Step 8: Save

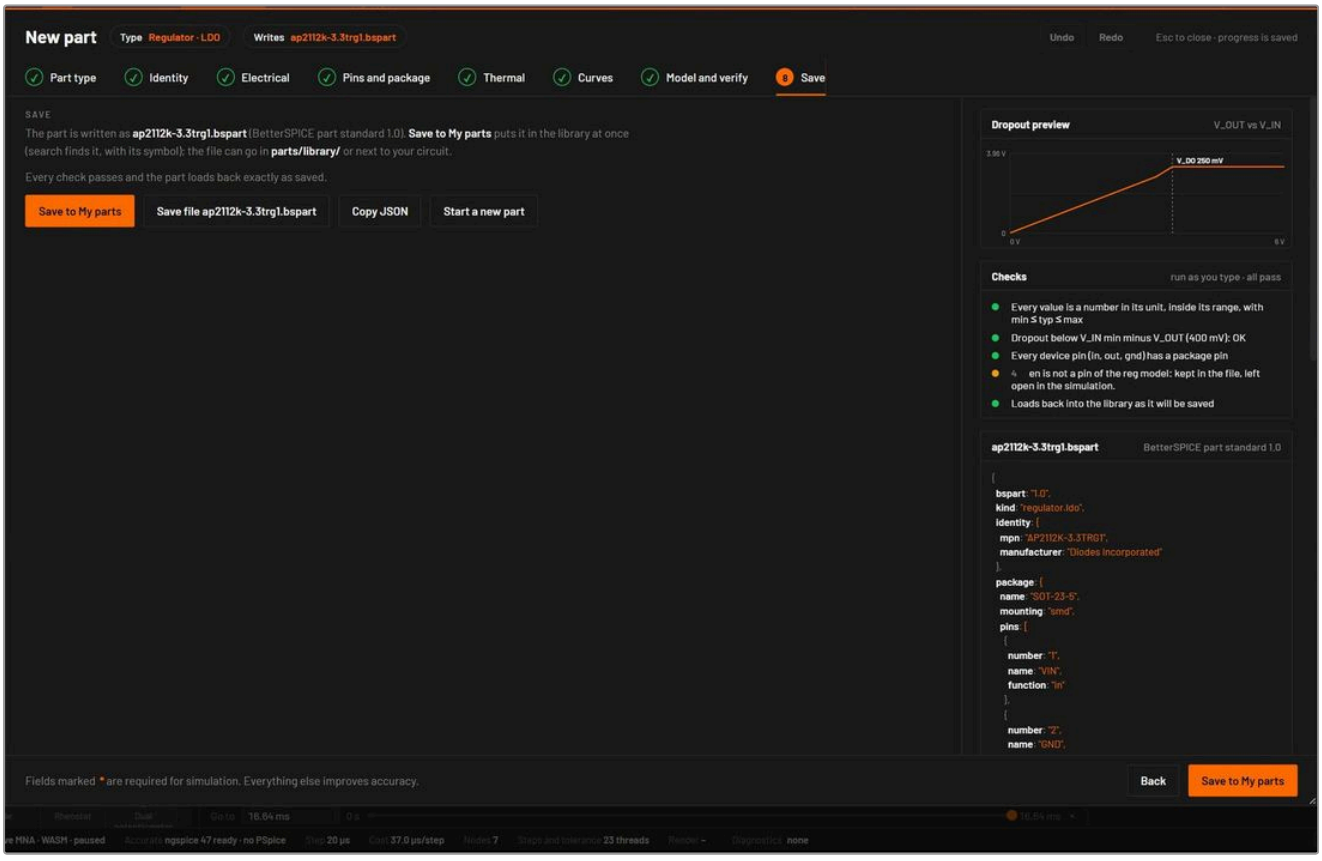


Figure 46.10 Step 8, Save.

BUTTON	WHAT IT DOES
Save to My parts	Stores the part in My parts: it's in the library at once, the library search finds it, with its symbol. The message has **Place now**. When My parts already has another part with this number, a line asks **Replace** or **Cancel** first. Editing a saved part, the button reads **Save changes to My parts**; a new part number renames the part (the old file goes).
Save file / Download	Desktop: a Save dialog. Browser: a download. With failing checks it reads **Download draft**.
Copy JSON	Copies the file text to the clipboard.
Start a new part	Press twice. Clears every field and the saved progress.

My parts takes only a part that passes every check, and the last check is the library's own load of the file: what's saved always loads back. Opening a saved part again shows every value as saved, and keys the wizard has no field for (notes, the table a value came from, aliases, a later version's sections) are written back unchanged.

46.9 The checks

KIND	CHECK
Error	Part number missing. Any device without a device type. A required field empty. A value that isn't a number, in another unit or outside the part standard's range. Min, typ and max not in order. A bad datasheet page or test condition. A pin row without a number, or a number used twice. With a custom symbol: a device pin with no package pin, or a symbol error. A SPICE node without a package pin. The file wouldn't load.
Warning	A pin without a function. A device pin with no package pin (built-in symbol). Several pins sharing one device pin. A function that isn't a pin of the model. A package whose pin count differs from the table. A symbol out of step with the pin table. For an LDO: the minimum input voltage minus the output voltage is below the dropout.
OK	Every value is a number in its unit, in range and in order. Every device pin has a package pin. The SPICE nodes are mapped. The part loads back as it will be saved.

Each check starts with its step number; click it to jump there. An LDO also shows a dropout preview: the output voltage against the input voltage.

46.10 What placing a part file does

Placing a part from My parts turns its kind into a device type, for example **regulator.ldo** into a power block of kind LDO, and sets the live parameters from the datasheet values (the typical value, or the middle of min and max). The rules are the same as in the command line's **bspice parts**. Every part type's values reach the model, a relay's coil voltage as much as a MOSFET's threshold. Parameters typed on step 6 win. A custom symbol replaces the built-in one. Extra package pins, such as several ground pins or an exposed pad, are tied to their device pin for simulation. A broken file shows its error on the library row.

TRY IT

An LDO part from a datasheet

1. Press Ctrl + Shift + N and choose **Regulator · LDO**.
2. Part number **AP2112K-3.3TRG1**, manufacturer Diodes Incorporated.
3. Output voltage min **3.234**, typ **3.3**, max **3.366**, page **4**. Dropout typ **250m** at I_{OUT} **600m**. Maximum output current **600m**. Minimum output capacitor **1u**.
4. Pick **SOT-23-5**, name the pins 1 VIN, 2 GND, 3 EN, 4 NC, 5 VOUT and press **Auto-assign functions**.
5. On step 6 press **Run the test circuit**: the output reads 3.3 V under load.
6. Press **Save to My parts**.

YOU SHOULD SEE The part appears in My parts. Placed in a circuit, it regulates to 3.3 V and drops out 250 mV below its input at full load.

TRY IT

Edit a saved part

1. In My parts, press **Edit part** on the part.
2. Change a value, or the part number to rename it.
3. Press **Save changes to My parts**.

YOU SHOULD SEE The part is replaced (or renamed) and parts you place from now on use the new values.

Command line: **bspice parts new —template ldo -o my.bspart** writes a template with TODO markers, and **bspice parts validate my.bspart** lists what's still missing (**The command line (bspice)**, p. 596).

47 Symbol editor and My parts

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Tools › **Symbol editor...** (Ctrl + Alt + B) draws a schematic symbol: pins, lines, rectangles, circles, arcs, polylines and text. It also opens from **New symbol...** and **Edit symbol** in My parts and from **Draw symbol...** / **Edit symbol...** on step 4 of the Part Wizard, over the wizard, on the part's pin table. While it's open every other shortcut is off except Esc.

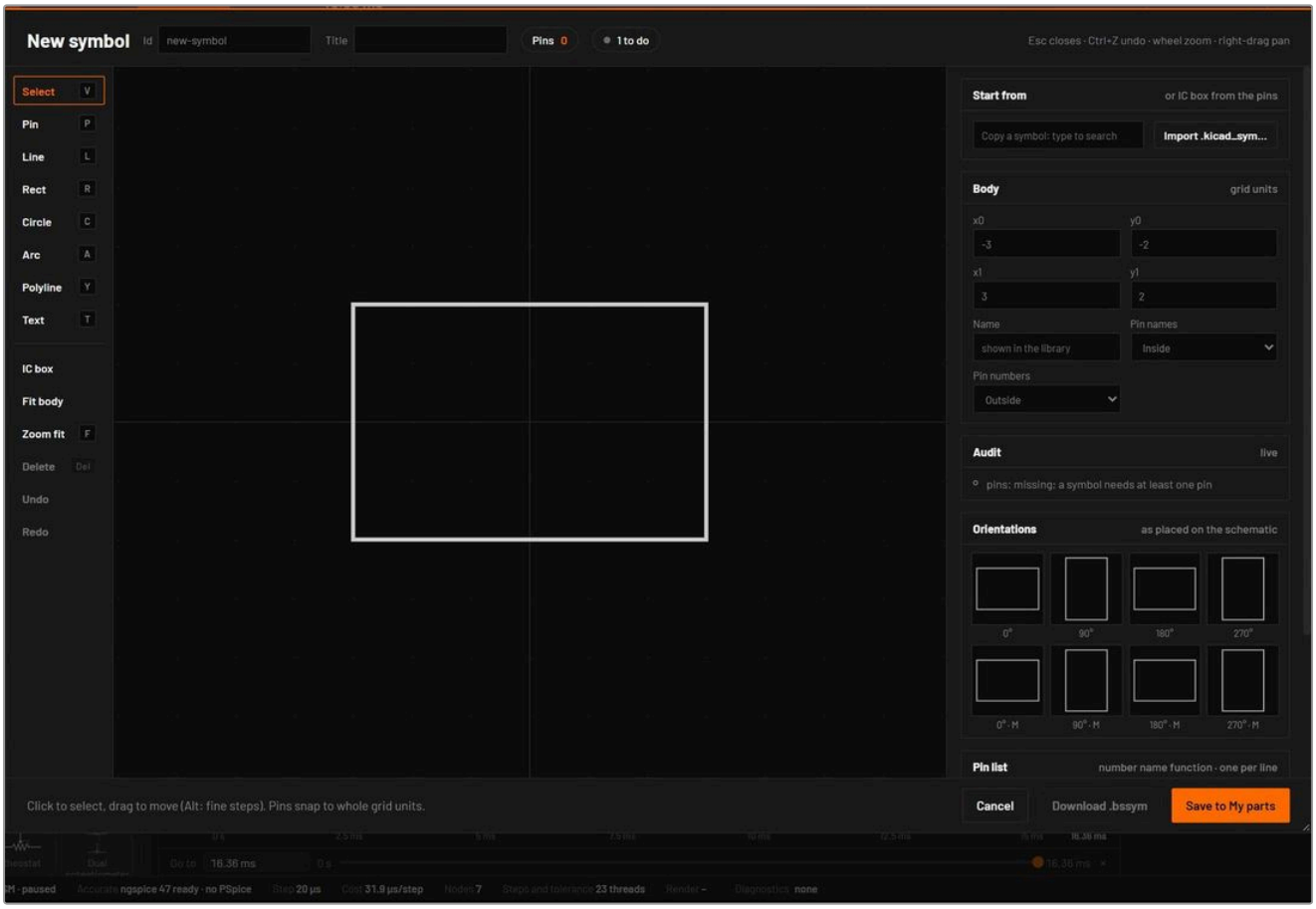


Figure 47.1 The symbol editor with the IC-box generator.

47.1 What Save does

OPENED FROM	TITLE	MAIN BUTTON	RESULT
Tools or New symbol…	New symbol	Save to My parts	A **.bssym** file in My parts
Edit symbol on a symbol	Edit symbol *id*	Save to My parts	Replaces that symbol
Edit symbol on a part	Symbol of *MPN*	Save part to My parts	The part file with its new symbol
The Part Wizard	Symbol for *MPN*	Use in part	The symbol goes into the part being made; the pin table of the wizard takes its pin numbers and names, so both stay one list

Download .bssym saves the symbol as a file. Saving is disabled while the audit lists errors.

47.2 Move pins of a placed part

Select one part, then press **Move pins…** in the **Symbol** section of the inspector, or choose **Edit** › **Move pins (edit symbol)…**. The part's symbol opens in the symbol editor, as a symbol of its own. Drag the pins to new grid points, then press **Save**. The part now uses that symbol, and the inspector says *own symbol*. An op-amp's + and – marks move with their pins. **Edit** › **Use the built-in symbol**, or the **Use the built-in symbol** link in the inspector, goes back.

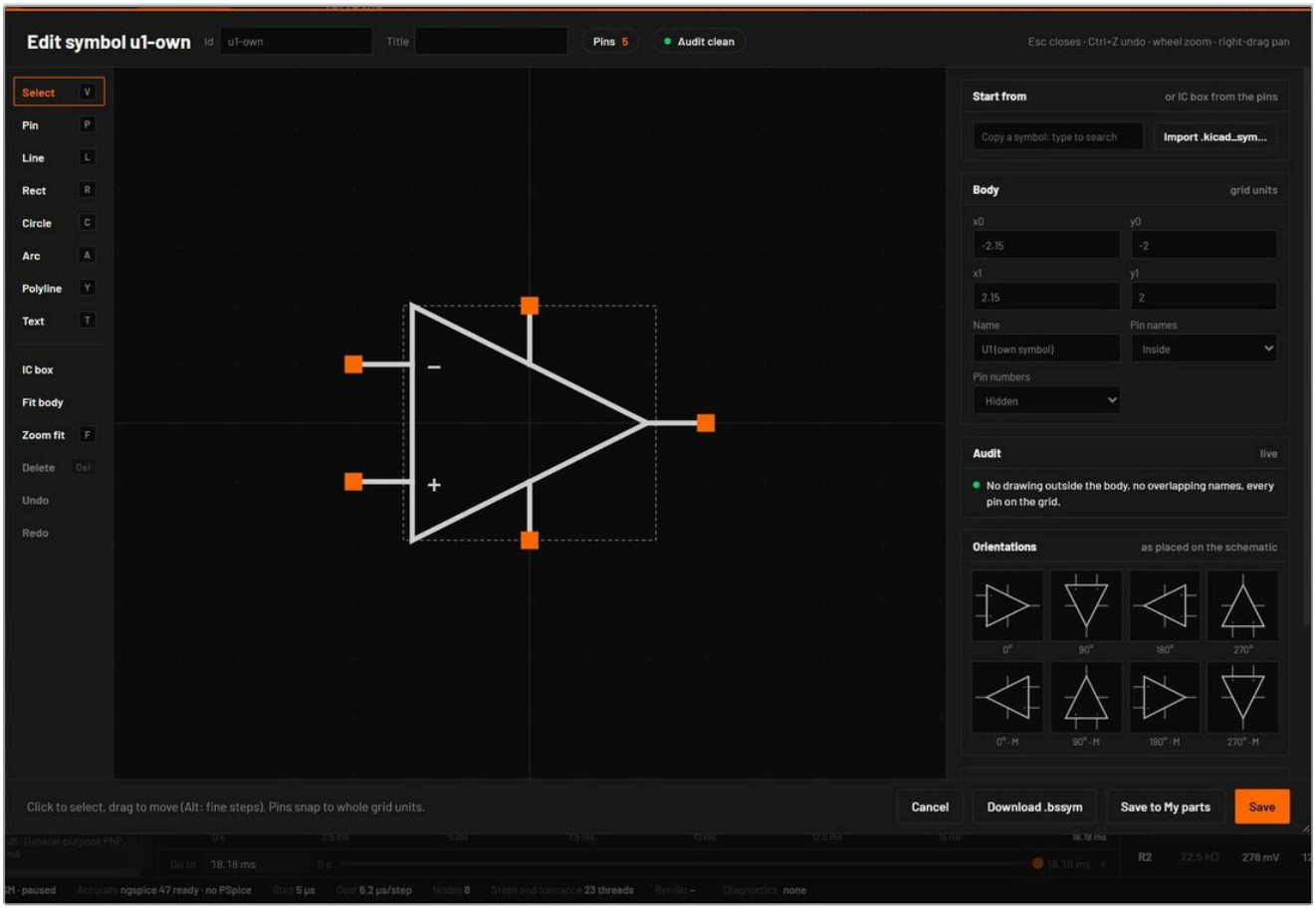


Figure 47.2 Move pins on an op-amp: its symbol in the symbol editor, with the pins ready to drag.

47.3 The layout

The header has the symbol's **Id** (lower case, cleaned as you type), its **Title** (text drawn in the body), the pin count and the audit state. The tools are on the left, the canvas in the middle on a 20 px grid, and on the right the Properties, Audit, Orientations and Pin list cards.

47.4 Start from an existing symbol

The **Start from** card has a search field. Type a name and pick a library symbol: its body, pins and drawing are copied into the editor, while the id and the title you gave stay. It's one undo step. **Import .kicad_sym...** reads a KiCad symbol library: the pins of unit 1 with their side, role and shape, and the rectangles, polylines and circles, at 1.27 mm to one grid step. The editor opens on the first symbol of the file, and the others are offered in the same search as *kicad: NAME*. A new symbol's audit reads **to do** until the first Save.

47.5 Tools

TOOL	KEY	HOW IT WORKS

TOOL	KEY	HOW IT WORKS
Select	V	Click a pin or drawing. Drag to move. Pins snap to whole grid steps and take the side they are on. Drawings snap to half steps, with Alt to tenths. Drag empty space to pan.
Pin	P	Click a grid point outside the body. The pin gets the next name and number and the side it's on.
Line, Rectangle, Circle, Arc	L, R, C, A	Drag to draw. Alt for fine steps. The radius is the drag distance.
Polyline	Y	Click points. Double-click, Enter or clicking the last point again finishes.
Text	T	Click to drop a text and return to Select.
IC box		Lays the pins out as an IC: supplies on top, grounds at the bottom, outputs right, inputs left.
Fit body		Fits the body rectangle around the pins.
Zoom fit	F	Fits the view.
Delete	Del	Removes the selected pin or drawing.
Undo / redo	Ctrl + Z / Ctrl + Y or Ctrl + Shift + Z	200 steps. Each has a button in the tool column, Redo under Undo.

The wheel zooms, right or middle drag pans. Esc cancels a drawing in progress, then returns to Select, then closes the editor. With unsaved edits, Esc or a click outside first shows a line saying so; press again within 4 seconds to discard them. **Cancel** discards at once.

47.6 Properties

SELECTED	FIELDS
A pin	**Name**, **Number**, **X**, **Y**, **Side** (left, right, top, bottom), **Role** (in, out, bidir, tristate, passive, power in, power out, open collector, open emitter, nc, unspecified), **Shape** (line, inverted, clock, inverted clock) and **Length** of the lead.
A drawing	Position, end point, radius, start and end angle for arcs, text and size, **Closed** for polylines, line width 0.5 to 4 px.
Nothing (the body)	The body corners, the name shown in the library, **Pin names** inside or hidden, **Pin numbers** outside or hidden.

47.7 Pin list

Type one pin per line as **number name function**, for example **1 VIN in**, and press **Auto-place pins** to lay them out as an IC box. A suffix **:l**, **:r**, **:t** or **:b** on the name forces a side, such as **VIN:t**. A line with only a name uses its line number. Lines starting with **#** are comments.

```
# LDO, SOT-23-5
1 VIN in
2 GND gnd
3 EN in
4 NC nc
5 VOUT out
```

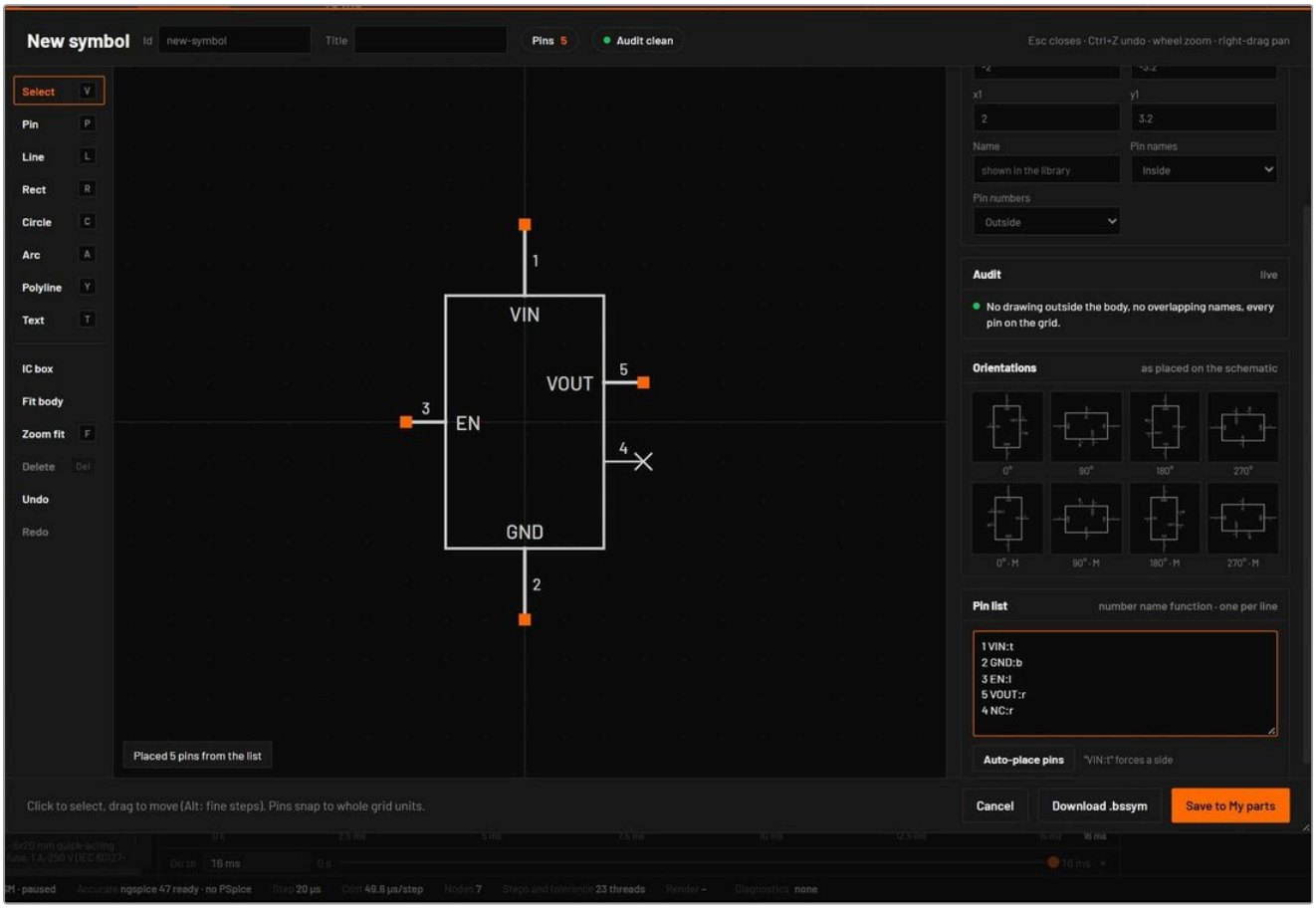


Figure 47.3 Auto-place pins: the pin list on the right laid out as an IC box.

47.8 Audit

The audit runs as you edit.

KIND	CHECKS
Errors (block saving)	An id that isn't lower-case letters, digits, dots, dashes and underscores. A body with no area. No pins. A pin with no name or number. A pin number used twice, or not on the part's package. A pin off the grid, two pins on one point, a pin not on its stated side. A polyline with one point. A circle or arc with no radius. Empty text. A filled shape (symbols are outlines). A line width outside 0 to 4.
Warnings	A pin on the body edge with no lead. A drawing outside the body. A name or text that doesn't fit in the body. Overlapping names or numbers.

Problem pins turn red or amber on the canvas. The **Orientations** card shows the symbol at 0°, 90°, 180° and 270°, mirrored and not, with text kept upright as on the schematic.

47.9 My parts



Figure 47.4 My parts in the library.

- My parts is the first family in the library. It lists what you saved from the Part Wizard and the symbol editor, what AI agents made, and files you added.
- Desktop: the files are in **%APPDATA%\BetterSPICE\parts** as **.bspart** and **.bssym**. Files you copy there appear at the next start. Browser: they are kept in the browser's storage.
- Saving a part with the number of another part in My parts asks before replacing it.
- Click a row to place it. **Edit part** opens a part in the Part Wizard: your own parts are saved back in place (a new part number renames them), a library part opens as a copy. **Edit symbol** opens the symbol editor on it. **Remove** deletes your own items after **Confirm**.
- **New part...** opens the Part Wizard on the new part you were making, or on a fresh one after an edit.
- **Part library** below lists the parts shipped with BetterSPICE. They are read only.
- A damaged file shows its error on its row and cannot be placed.

PART

VII

Design calculators

The calculator window, then each of the 17 calculators: its Simple and Advanced views, every field, result, check and warning, the library pickers, how it places and checks its circuit in the simulator, its method and sources, and worked examples.

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48 The calculator window

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The calculators design a part of a circuit from what you know, check it against its limits, and then place it in your circuit with the analysis and the measurements that check it in the simulator. There are 17, in four groups. Each has a **Simple** view, the quick calculator, and an **Advanced** view, the full design. This chapter is the window and everything the 17 share. Each calculator has its own chapter after it.

48.1 Opening a calculator

FROM	WHAT HAPPENS
Tools › **Calculators...** or Ctrl + Shift + C	Opens the picker **Find a calculator**. The key works anywhere in the app, also while the calculator window is open: the picker opens on top of it, and Esc goes back to the window. Only the Console's text box keeps the key while it has the focus.
Tools › **Calculator window**	Opens the window on the calculator you had open last. The first time it is the low pass / high pass filter.
The command palette (Ctrl + K)	One entry per calculator, *Calculator: Trace current and width* and so on. Type **calculator** to list them.
Right-click a part, **Calculate...**	Selects the part and opens the picker, which lists first the calculators that fit it, with its values filled in.

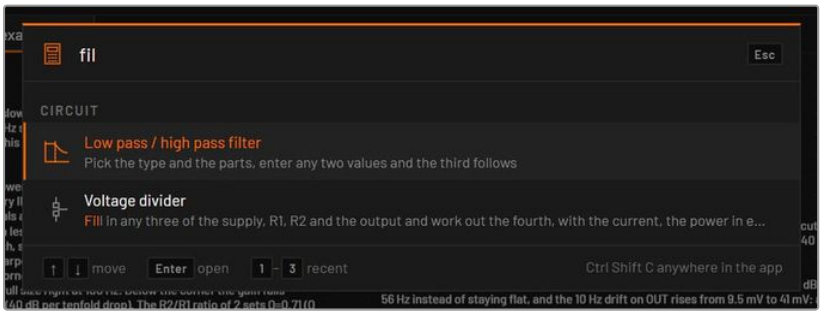


Figure 48.1 The calculator picker after typing fil.

The picker has a search box (*Find a calculator: filter, LED, via, impedance, dB...*). With the box empty it lists:

- **From your selection**, when parts or wires are selected: up to four calculators that fit them, each with the selected names and why it fits (*Fills resistance from R3*). Opening one fills in those values. Two resistors suggest the divider with R1 from the first and R2 from the second, a resistor and a capacitor an RC low pass at their cutoff, a resistor and an inductor an RL low pass, an inductor and a capacitor the LC calculator, and a selected transmission line or wire the trace impedance or the wire gauge calculator.
- **Recent**: the last three calculators you opened, newest first. 1, 2 and 3 open them from the empty box. Recent is kept between sessions.
- Every calculator, under Circuit, Parts, PCB and Units, with the first sentence of what it does.

Typing filters the list: every word you type must appear in the title, the description, the calculator's search words or the group name, in any case. Title matches come first. With nothing found it says *No calculator matches. Try "filter", "led", "via", "dB".* Up and Down move, Enter opens the highlighted calculator, Esc closes the picker, and the mouse highlights and opens as well.

48.2 The calculators

GROUP	CALCULATOR	WHAT IT WORKS OUT	CHAPTER
Circuit	**Voltage divider**	Any one of Vs, R1, R2 and Vout from the other three, or the best standard pair. Advanced: worst case over tolerance and temperature, an ADC input as the load, ratings and surge.	Voltage divider, p. 452
Circuit	**Low pass / high pass filter**	Passive RC, RL and LC ladder filters. Advanced: active Sallen-Key and MFB filters of order 1 to 8 with the op-amp, step, delay and tolerance.	Low pass and high pass filters, p. 462
Circuit	**LC resonance and Q**	Resonance, characteristic impedance, Q and bandwidth of a tank or series circuit.	LC resonance and Q, p. 469
Circuit	**Reactance**	XL and XC at a frequency, the part for a reactance, the frequency for a reactance.	Reactance, p. 474
Circuit	**Time constant**	RC and L/R time constants, the step response and the time to reach a level.	Time constant, p. 479
Circuit	**Attenuator pads**	Pi and T pads. Advanced: bridged T, minimum-loss L, unequal ports, power per resistor, tolerance and parasitics.	Attenuator pads, p. 485
Parts	**LED resistor**	Series resistor for an LED string. Advanced: corners of supply, Vf bin and temperature, current sink and CC regulator, parallel strings, PWM and light.	LED resistor and LED driver, p. 490
Parts	**Op-amp gain**	Inverting, non-inverting, difference and summing stages. Advanced: the op-amp picker, DC error budget, bandwidth, phase margin, noise and tolerance.	Op-amp gain, p. 497
Parts	**555 timer**	Astable and monostable. Advanced: the exact charge model of four chips, design from a target, corners and tolerance.	555 timer, p. 507

GROUP	CALCULATOR	WHAT IT WORKS OUT	CHAPTER
Parts	**Buck and boost stage**	Duty, inductor, capacitors and peak current. Advanced: the inductor and regulator pickers, three peak currents, losses, power stage response.	Buck and boost stage, p. 515
Parts	**Crystal load capacitors**	The two load capacitors, pulling and the gain margin of the oscillator.	Crystal load capacitors, p. 527
Parts	**Heatsink and junction**	Junction, case and heatsink temperatures. Advanced: Foster stages, interface materials, PCB copper, pulses, a shared heatsink.	Heatsink and junction, p. 533
PCB	**Trace current and width**	Width for a current and rise (IPC-2221, IPC-2152). Advanced: corners, plane and board, fusing, pulses, insert in a wire.	Trace current and width, p. 540
PCB	**Via current and parasitics**	R, L, C, current and thermal resistance of a via. Advanced: plating, stubs, arrays, return vias.	Via current and parasitics, p. 547
PCB	**Trace impedance**	Microstrip, stripline and differential pairs. Advanced: stack-up, roughness, loss, crosstalk and a TDR check.	Trace impedance, p. 553
PCB	**Wire gauge and fusing**	AWG and mm^2 wire: resistance, drop, current from a heat balance, fusing. Advanced: bundles, insulation, faults.	Wire gauge and fusing, p. 559
Units	**dB and unit converter**	dBm, dBW, dBV, dBu, volts and watts. Advanced: levels with crest factor, noise floor, an RF chain with noise figure.	dB and unit converter, p. 565

48.3 The window

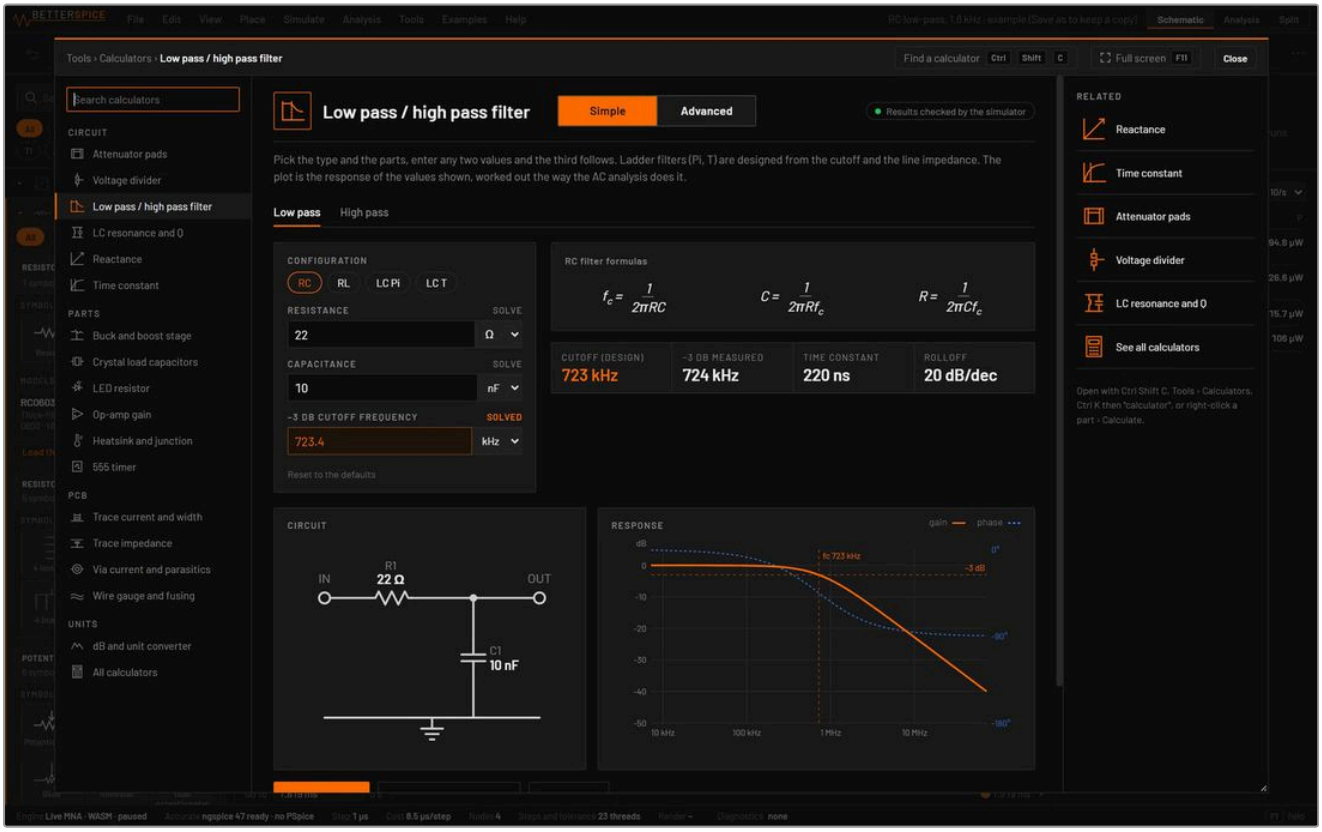


Figure 48.2 The calculator window: the list of calculators, the Simple view of the low pass filter with its inputs, formulas, result tiles and response, and the Related column.

PART OF THE WINDOW	WHAT IT HOLDS
Top bar	Where you are (*Tools › Calculators › Voltage divider*), **Find a calculator** with its key (opens the picker), **Full screen** with F11, and **Close**.
The list on the left	A search box *Search calculators* (Enter opens the first match), the calculators under Circuit, Parts, PCB and Units (the description is the tooltip, the open one is highlighted), and **All calculators** at the end.
The middle	The calculator, in its Simple or Advanced view. Its title row holds a large icon, the title, the **Simple | Advanced** switch, and on the right the chip *Results checked by the simulator* (Simple, when a button places a circuit and runs it) or the Advanced view's own choices (stage, pad, mount and so on).
Related on the right	The calculators that go with this one, **See all calculators**, and the ways to open the window. Hidden in full screen and in a window narrower than 1400 px.
All calculators	An overview page: each group with a card per calculator (icon, title, what it does). Click a card to open it.

The window is 1480 × 920 px when the app window allows it. Narrower than 1100 px the inputs and the results stack, and narrower than 820 px the list is hidden. Esc, **Close** or a click on the dark background closes it. Opening another calculator scrolls back to the top.

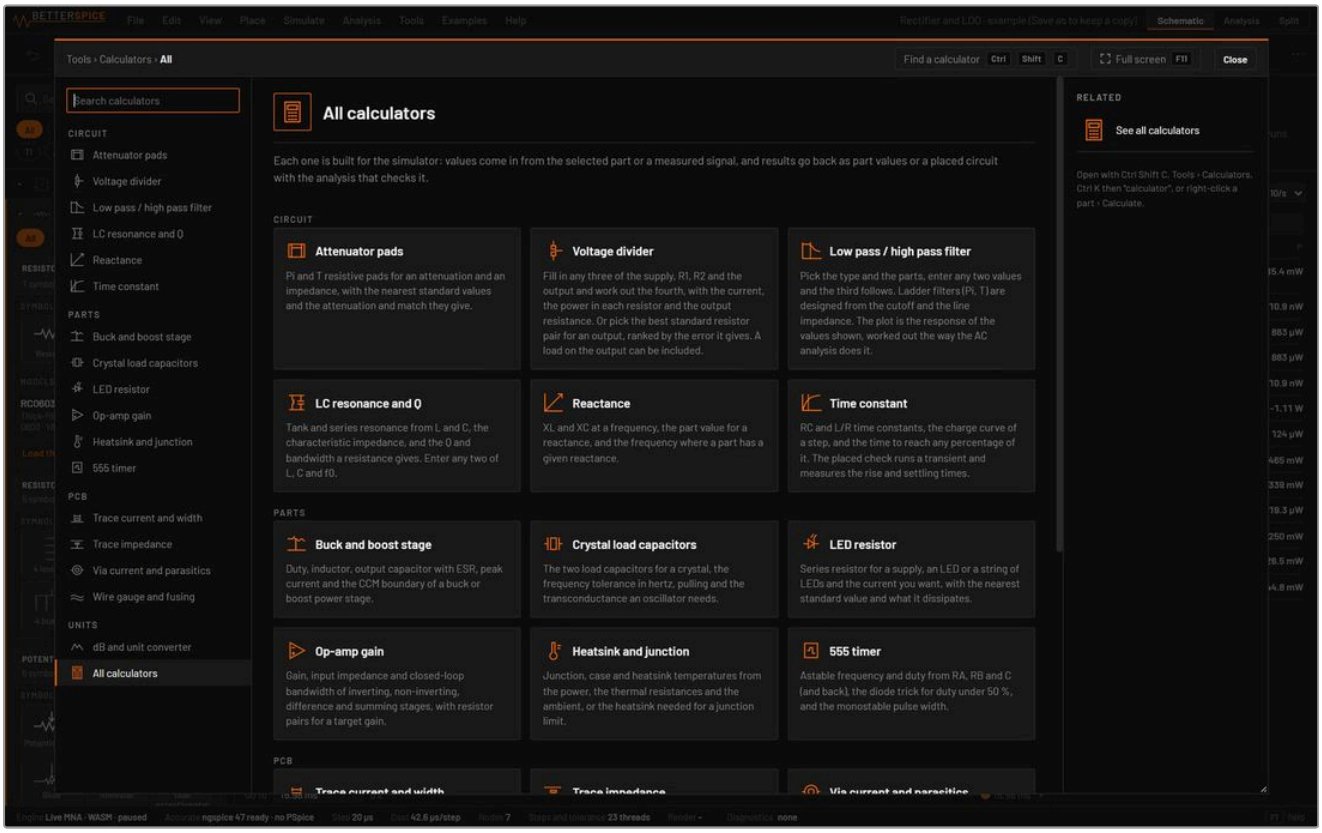


Figure 48.3 All calculators: the overview page with a card per calculator in its group.

48.4 Simple and Advanced

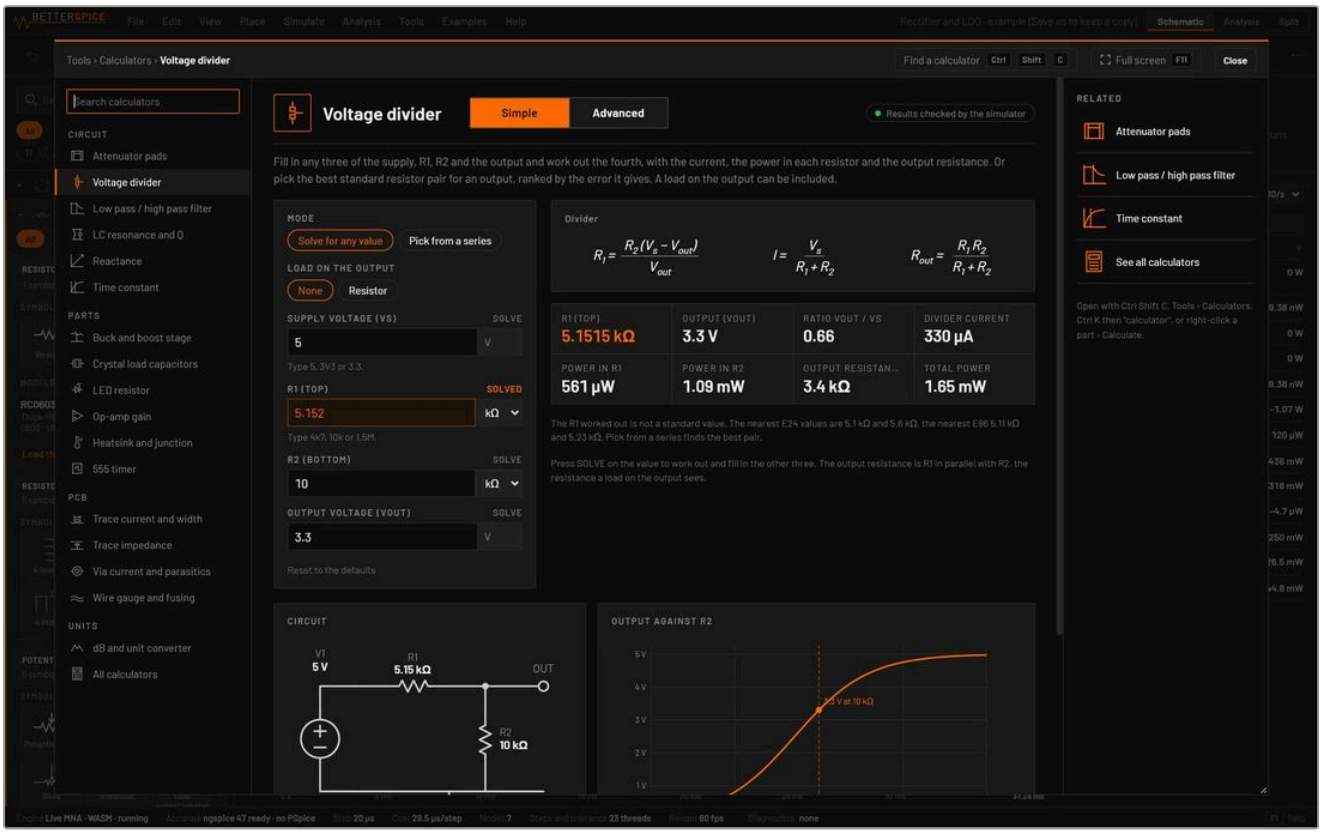


Figure 48.4 The Simple | Advanced switch beside the title, here on the Simple view of the voltage divider.

- Two large buttons beside the title switch the view: **Simple** (*Today's calculator: the main values and one result set*) and **Advanced** (*Corners, checks, parts, plots and the library pickers*). All 17 calculators have both.
- The window remembers the view of each calculator, also after a restart.
- A value typed in one view is the same in the other at once: the supply of the divider, the width of a trace, the cutoff of a filter. A field that is the **SOLVED** one is not overwritten by an edit in the other view. The first time the Advanced view opens, it takes only the Simple values you changed. A Simple value left at its default does not replace the Advanced default, and the two views start from different examples: the Simple trace is 3 A at a 10 °C rise, the Advanced one 8 A at 20 °C. A quantity only one view has, such as the Simple trace's IPC method or the Advanced trace's plating, stays in that view. Each calculator's chapter lists the values the two share.
- The Simple view has a unit menu on most fields. The Advanced view shows each field in a fixed unit written after the box.
- Both views keep their values while the app runs, also when the window is closed and opened again.
- **Reset to the defaults** at the bottom of the Simple inputs clears the Simple values, their unit choices and the Advanced values of that calculator. The Advanced view has no reset button of its own.

48.5 The Simple view

The left card holds the inputs: choices first (buttons in a row, one pressed), then the fields, then **Reset to the defaults**. Some choices change the defaults of the fields: switching the buck stage to boost swaps its voltages. The right side shows the formulas as fractions, the result tiles (the main result in orange), warnings in amber and plain notes. Under them are the drawings and plots, the buttons, and the method and its source.

SOLVE. A field that can be worked out has a small **SOLVE** label above its box (*Work this value out from the others*). Press it on the value you want to find: the field becomes read-only and shows the result, the label reads **SOLVED** (*This value is worked out from the others*), and the field that was solved before keeps its last result as a typed value. One field is solved at a time. Each calculator opens with its own field solved, for example the divider's Vout and the trace's width. When a choice hides the solved field, the calculator's default field is solved instead.

Values from the circuit. A field that can read the circuit has a second small label beside its name, which says what it reads. A click copies the value in:

LABEL	WHAT IT COPIES
from R3	The value of the selected part (the first, or for the divider's R2 the second).
from R3, RMS or *from wire, RMS*	The RMS current of the selected two-pin part or wire, measured over the live view while the window is open.
from R3, peak	The peak current.
from Q1, mean	The mean power the part dissipates.

Typing values. Fields take SI prefixes and units, and the engineering forms **4k7**, **10k**, **1.5M** and **4R7**, with the unit letter as the decimal point (**3V3** is 3.3 V, **1A5** is 1.5 A):

- Prefixes: T, G, M (mega), k, m (milli), u, µ (micro), n, p, f. **meg** in any case is mega. A trailing unit (F, Hz, V, Ω, ohm) is allowed. **1e-3** works.
- A number with no unit is in the unit the field's menu shows.
- A number written with its prefix or its base unit is that value whatever the menu shows: **4k7** or **470Ω** in a field shown in kΩ is 4.7 kΩ or 470 Ω.
- A number written with one of the menu's units is in that unit, and the menu switches to it: **10mil**, **1in**, **3cm**, **1oz**, **0.25mm**. A unit that is itself a prefix letter does not count: **2m** stays 2 milli.
- Text that is not a number (**1,5**, or **3V3** in a resistor field), an emptied field or a field left as it was puts back the value it had before.
- Results follow while you type a whole number. Text that ends in a letter waits until you press Enter or leave the field. While you edit, the field's unit stays put, so **2000** in a kHz field does not jump to MHz.
- Until you pick a unit yourself, the menu shows the largest unit that fits the value. A value outside the field's range turns the field red. Nothing is clamped.

Copy values puts the title, every visible field (*R1 (top): 4.7 kΩ*, with *(solved)* on the solved one) and every result on the clipboard as text, one per line.

48.6 The Advanced view

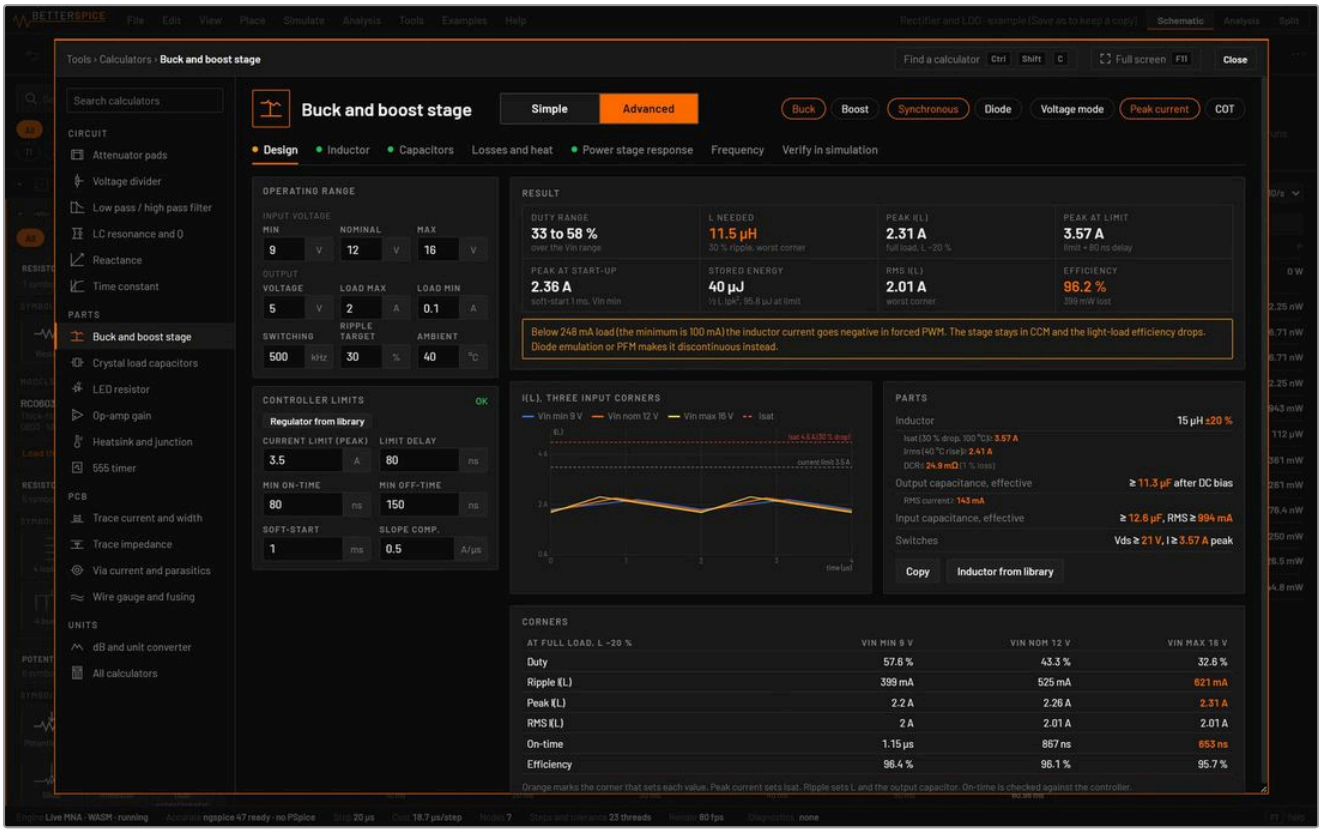


Figure 48.5 The Advanced view of the buck and boost stage in the window: the head choices, the tabs with their dots, the input groups on the left and the cards of the Design tab.

PART	WHAT IT IS
Head choices	Buttons in the title row that change the whole design: the stage (buck or boost), the pad type, the mount, the driver, and so on. Each chapter lists them.
Tabs	One tab per section, **Verify in simulation** always last. A dot on a tab says how its checks stand: green passes, amber marginal (at least one warning), red fails (at least one failing check). A tab without checks has no dot.
Input groups	On the left, the groups that belong to the tab shown. Click a group's title to fold it. A badge beside the title sums the group up (*Met*, *needs 214 kHz*, *2 × 3*).
Number fields	Each in a fixed unit written after the box. A plain number is in that unit, and a comma works as the decimal point (**1,5**). A number with a prefix (**4.7k**, **470n**, **10uH**) is in the base unit. Enter or leaving the field takes the value, Esc drops the edit. A value outside the range turns red.
SOLVED and **PART**	A field marked SOLVED is worked out from the others. A field marked PART comes from a part picked from the library. Both are read-only.
Result tiles	Four to a row: the label, the value (orange for the main result, amber or red when a limit is near or passed) and a short line under it.

PART	WHAT IT IS
Checks	One row per check: a green tick (passes), an amber triangle (marginal), a red cross (fails) or a blue circle (a note), what is checked, the value and its limit, and the margin. The card title says *Passes*, *Marginal* or *Fails* for the worst row. Each chapter gives every check with its limits.
Warnings	Each gives the fact, the number and the fix: *Use R ≥ 330 Ω (10 % margin) or a current sink.*
Parts lists	What to order: the label on the left, the value on the right, the figures that matter in orange. **Copy** copies it as a line of text.
Tables and plots	Tables have a highlighted row (the chosen pair, the worst corner). Plots draw the curves with a legend line, dashed for a second case, limit lines in red, bands for a spread and markers at the working point.
Source tags	A small label after a figure says where it comes from: **model** (green, read from the vendor SPICE model), **datasheet** (blue), **header** (purple, from the model file's header, its description or the case code) and **est.** (amber, an estimate). A figure the catalogue doesn't have shows *not in catalog* and is never guessed.

48.7 Full screen

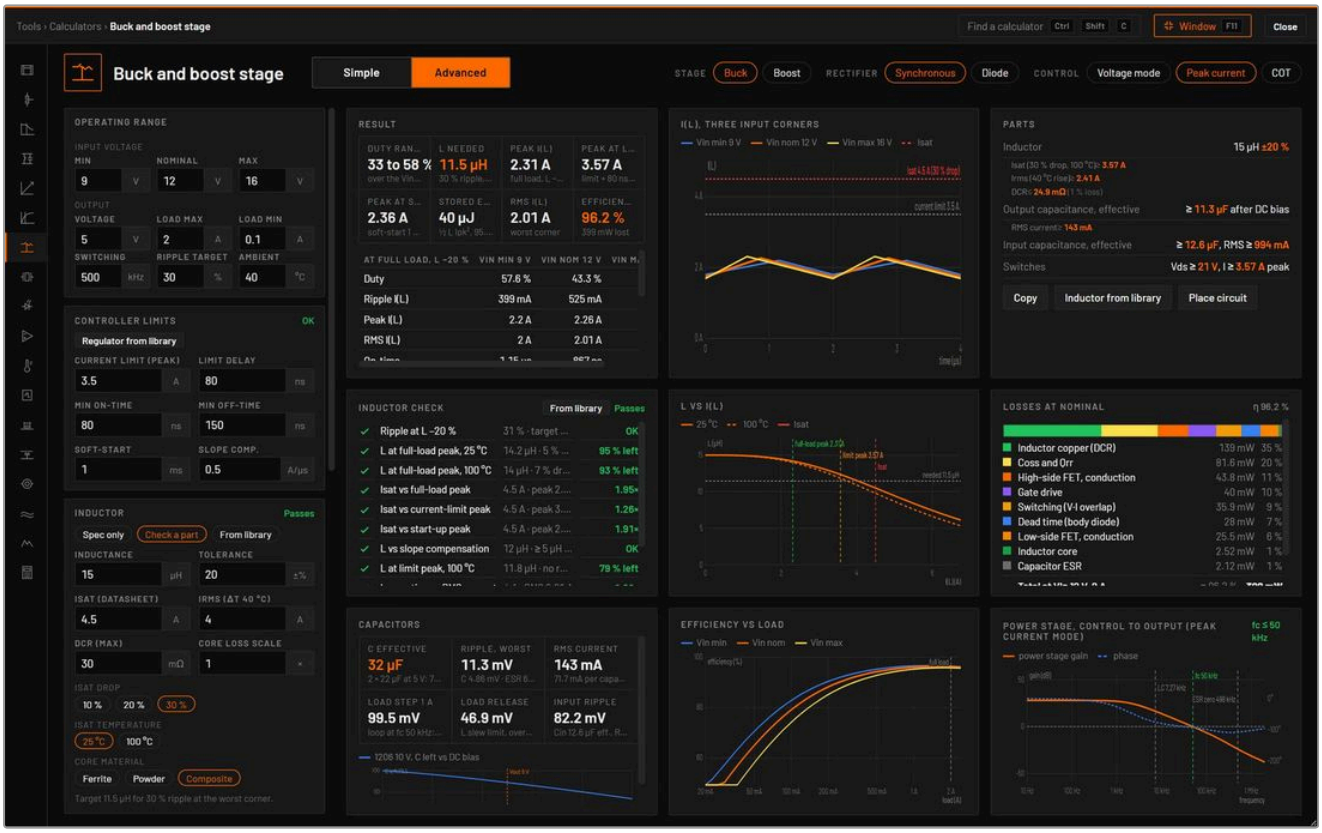


Figure 48.6 The buck and boost stage in full screen: every input group in the left column and every card of the Advanced view at once.

- F11 or **Full screen** in the top bar gives the calculator window the whole app window, with an orange line along the top. The button then reads **Window**. F11 or **Window** goes back. The choice is kept after a restart. Esc and **Close** close the whole window.
- The list of calculators folds to a column of icons (the description is the tooltip) and the Related column goes.

- The Advanced view has no tabs: every input group is in one column on the left, and every card in a grid of three columns that fills the screen with no page scroll. A card with more rows scrolls inside, a plot fills its card, the head choices show their labels, and the Verify table puts its Method column in a note under it.
- Buttons that sit on the Verify tab in the window are also on a card in full screen, so every circuit can be placed from there.
- The Simple view is the same, wider.

48.8 Parts from the library

Three Advanced views pick real parts from the model library: the inductor and the regulator of the **buck and boost stage**, p. 515, and the op-amp of the **op-amp gain**, p. 497 stage. The picker takes the place of the tabs, inputs and cards while it is open, and the title row with the switch stays. It has:

- A head with **‹ Back** (to the tabs), the title (*Inductor from library*, *Regulator from library*, *Op-amp from library*), what the design needs, and the choice of how to rank.
- Filters on the left, set from the design when the picker opens.
- The ranked table: each row is the whole design worked out with that part.
- The sheet of the selected part, with the source of every figure.
- **Use this part**, which fills the calculator's fields with the part's figures (marked **PART**) and runs every check again, and **Place with this model**, which places the vendor part with its own model.

Each picker's filters, ranking and columns are in its calculator's chapter.

48.9 Placing the circuit and checking it

The buttons that place a circuit work the same in every calculator, in both views:

- The circuit is drawn with library symbols and wires, with its source, labels and probes, at a free spot near the middle of the view, at least three grid squares from anything already there. With no room, it goes to the right of the circuit and the view moves to it.
- Names already in use are changed: V1 becomes V2, R_LED becomes R_LED2, OUT becomes OUT2, the probe *V out* becomes *V out2*. The change follows into the probes, the analysis source, the measurement signals (V(OUT) becomes V(OUT2)) and the note the button shows.
- Everything is one undo step, named after the calculator and the button: the parts, wires, labels and probes, the analysis setup, and the measurements (a measurement of the same name is replaced, the others stay). One Ctrl+Z removes it all.
- The window closes, the new parts are selected, and the view changes to the one the button asks for: the split view of schematic and Analysis

when an analysis runs, or the live view. A message says what was placed or set (*Placed V1, R1, C1.*) or gives the button's own note, for example *OUT must read 2.4898 V.*

- The analysis is stored where the Analysis view keeps it, merged over what the circuit had: transient, AC sweep, DC sweep, operating point, tolerance (worst case or Monte Carlo) and noise. Then it runs and the plot fits the result. In a circuit that already had probes, the calculator's probes get a scope of their own and the other probes are hidden from the Analysis plot (not deleted).
- The measurements carry the calculator's own numbers as their limits, so the Measurements list marks each one **PASS** or **FAIL** and its header shows **All pass** when every one passes.
- **Apply to the selected …** writes the result into the selected parts as one undo step (*Set R3 to 4.7 kΩ.*).
- A button runs one placement at a time and is greyed while it works. If nothing can be placed it says *Nothing to do with these values.*, and an edit the circuit refuses says why.

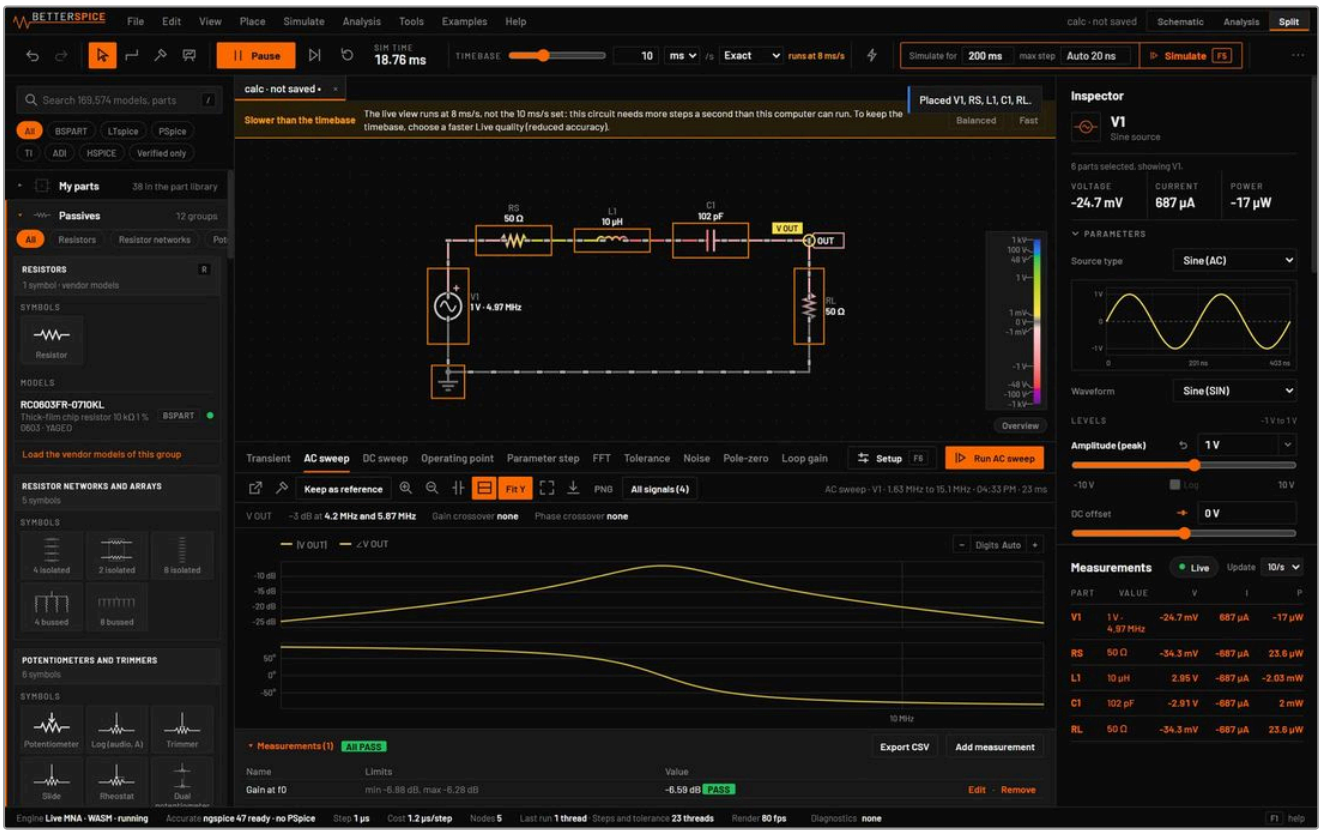


Figure 48.7 Place circuit and run AC from the LC calculator's Verify in simulation tab: the circuit placed, the AC sweep run, and the measurement Gain at f0 marked PASS against the calculator's limits.

Verify in simulation, the last tab of every Advanced view, holds a table *Calculator vs simulation*: each check, the calculator's value, the analysis and measurement that check it, and the limit. A row the simulator cannot check

says *not simulated* and why (the engine has no photometric model for an LED's light, for example). Under the table are the buttons that place each check's circuit and run it.

48.10 When a calculator cannot work the values out

YOU SEE	WHAT IT MEANS
"These values give no result (…). Check them: a zero, a negative or a very large value is outside what this calculator can work out."	A Simple calculator found no result. No tiles are shown.
"Some results are not defined for these values. Check zero, negative or very large inputs."	Some results are shown as –. The calculator never shows NaN or infinity.
"The Advanced view cannot work these values out (…). Change a value or reset the Advanced values."	The Advanced view met values it cannot handle. The window stays open. **reset the Advanced values** puts that calculator's Advanced values back to its defaults, and changing a value in the Simple view tries again.
"This calculator cannot work these values out (…). Change a value or reset the values."	The same for the Simple view. **reset the values** is Reset to the defaults.
"The Advanced view could not load: …"	The Advanced view's code did not load. Close and open the window again.

48.11 Keys in the calculator window

KEY	WHAT IT DOES
Ctrl + Shift + C	The picker, on top of the window. Esc comes back.
F11	Full screen on or off.
Esc	Closes the window (in the picker: back to the window). In an Advanced number field it drops the edit.
Enter	In a field: takes the value. In the list search: opens the first match. Elsewhere: presses the orange button.
Tab / Shift + Tab	Moves through the window. The focus stays inside it.
Up / Down, 1 to 3	In the picker: move, and open a Recent calculator.
Ctrl + K	The command palette, with every calculator.

NOTE **Estimates and checks** A calculator gives a design from equations and published data, and says which. The placed circuit and its analysis are the check: where the simulator and the calculator disagree, read the reason in the Verify table, and trust the simulator for the circuit as drawn.

49 Voltage divider

49.1 The voltage divider 453
49.2 Advanced: a divider into an ADC 456

Two resistors that give a fraction of a voltage: a feedback divider, a reference, a battery or mains monitor into an ADC. The Simple view works out any one of the supply, R1, R2 and the output from the other three, or picks the best standard pair. The Advanced view designs the divider for an ADC input over tolerance, tempco and temperature, with its ratings and a surge. Group Circuit. Search words include divider, ratio, feedback, e24, e96, vout, r1 and r2.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

49.1 The voltage divider

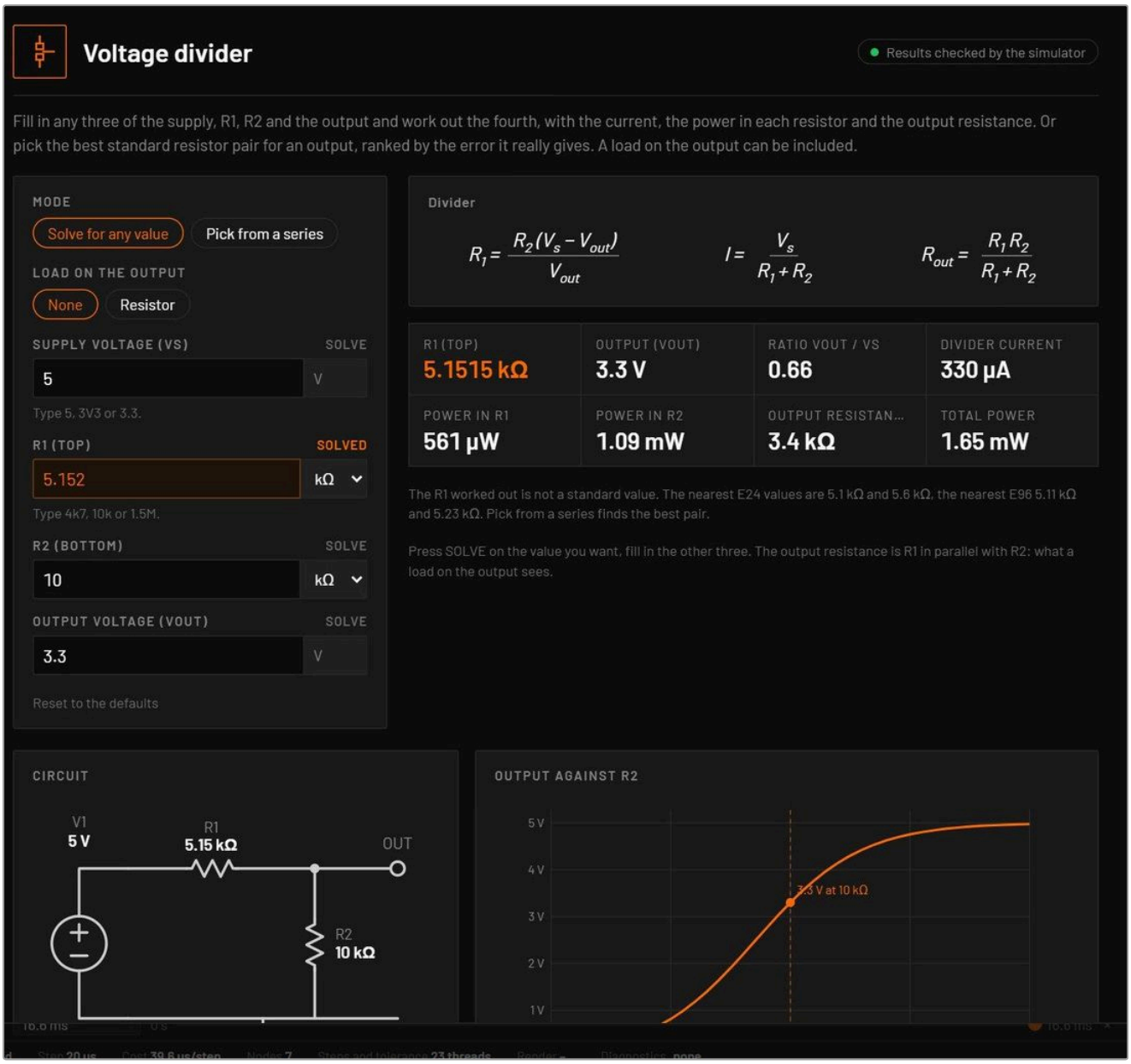


Figure 49.1 The voltage divider solving R1: 5 V, R2 10 kΩ and Vout 3.3 V give R1 5.1515 kΩ, with the nearest E24 and E96 values, the formulas, the circuit and the output against R2.

CHOICE	OPTIONS	WHAT IT DOES
Mode	**Solve for any value** (default), Pick from a series	Solve: fill in three of Vs, R1, R2 and Vout and press SOLVE on the fourth. Pick: the best pairs of a series for an output, ranked by the error they give.
Series	E12, **E24**, E96	Pick mode only.
Load on the output	**None**, Resistor	Resistor adds a load across R2 (R2′ = R2 ‖ RL) in either mode. It counts in every result.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Supply voltage (Vs)	V	5	SOLVE. Type 5, 3V3 or 3.3.

FIELD	UNIT	DEFAULT	WHAT IT DOES
R1 (top)	Ω, kΩ, MΩ	4.7 kΩ	SOLVE. Reads the first selected resistor.
R2 (bottom)	Ω, kΩ, MΩ	9.1 kΩ	SOLVE. Reads the second selected resistor.
Output voltage (Vout)	V	3.2971 (solved)	SOLVE, solved when the calculator opens.
Input voltage, Output voltage	V	5, 3.3	Pick mode.
Total resistance, about	Ω, kΩ, MΩ	10 kΩ	Pick mode. Sets the current: pairs within half a decade of it are listed.
Load	Ω, kΩ, MΩ	100 kΩ	With Load on the output = Resistor.

The formulas: Vout = Vs R2′ / (R1 + R2′), I = Vs / (R1 + R2′), Rout = R1 R2 / (R1 + R2). With a load, R2′ = R2 RL / (R2 + RL). When Vs, R1 or R2 is solved, its own formula is shown: Vs = Vout (R1 + R2′) / R2′, R1 = R2′ (Vs – Vout) / Vout, R2′ = R1 Vout / (Vs – Vout), and with a load R2 = R2′ RL / (RL – R2′).

RESULT	WHAT IT IS
Input (Vs), R1 (top) or R2 (bottom)	The solved value, five digits, first and in orange.
Output (Vout)	With the load, if any.
Ratio Vout / Vs	
Divider current	Vs / (R1 + R2′).
Power in R1, Power in R2	I^2 R1 and $Vout^2$ / R2.
Output resistance	R1 ‖ R2, the resistance a load on the output sees (without the load).
Power in the load, Output with no load	With a load: $Vout^2$ / RL, and Vs R2 / (R1 + R2).
Total power	Vs × I.
Pick mode	R1 (top) and R2 (bottom) of the best pair, Output, Error (signed, %), Divider current, Divider power, and a table **Best E24 pairs** (R1, R2, Output, Error, Current, Power) with the best row marked.

A solved R1 or R2 that is not a standard value gets a note: *"The R1 worked out is not a standard value. The nearest E24 values are 5.1 kΩ and 5.6 kΩ, the nearest E96 5.11 kΩ and 5.23 kΩ. Pick from a series finds the best pair."* The plot **Output against R2** (log R2, two decades around it) marks the working point. Pick mode searches every R2 of the series from a hundredth of the total to 3.2 times it, takes the two standard values around the exact R1, keeps pairs within half a decade of the total, works out each with the load, and lists the ten with the smallest error (equal errors: the total nearer the one asked first).

MESSAGE	WHEN IT SHOWS
"The load of 10 kΩ is close to the divider resistance (13.7 kΩ), so the output moves with it. A lower total resistance or a buffer keeps it steady."	A load under 10 × (R1 + R2).
"The input voltage (Vs) cannot be negative. Keep the supply positive and swap the resistors if the polarity is the other way."	A negative value. Also for R1, R2 and Vout.

MESSAGE	WHEN IT SHOWS
"R1 cannot be zero: a resistor of zero ohms is a wire."	R1 or R2 is 0.
"Vout (6 V) is above Vs (5 V). A divider only gives an output below its input."	Vout above Vs.
"Vout equals Vs. That needs R1 at zero ohms (a wire) or R2 open, so there is no divider to size."	Vout equal to Vs.
"The output voltage has to be above zero to work a resistor out from it. At zero volts R2 would have to be a short."	Vout at 0 while solving a resistor.
"With R1 = 4.7 kΩ and a load of 1 kΩ the output cannot reach 3.3 V. The most it gives is … with R2 open. Raise the load, lower R1 or ask for a lower output."	Solving R2 with a load that cannot give the output.
"The … is not a number. / The load has to be above zero ohms. / The input voltage has to be above zero."	The other impossible inputs.

An impossible input shows one message and no tiles, and no buttons.

BUTTON	WHAT IT DOES
Place and run live	V1 at Vs, R1, R2 and the load if any, OUT probed, in the live view. *The live view shows 3.2971 V on OUT.*
Place and check the operating point	The same circuit and an operating point. Measurement *Divider output*, V(OUT), within ±0.1 % of the calculator.
Apply to selected resistors (R3 top, R4 bottom)	With two resistors selected: R1 into the first, R2 into the second.

With two resistors selected, the picker offers the divider with their ratio, and it opens in Solve mode with R1 from the first and R2 from the second. Standard values are from IEC 60063.

TRY IT

The textbook divider and a 3.3 V output

1. Open the voltage divider (Ctrl + Shift + C, type **divider**) and press **Reset to the defaults**.
2. Read the tiles: Vs 5 V, R1 4.7 kΩ, R2 9.1 kΩ.
3. Press **SOLVE** on R1, then type Vs **5**, R2 **10k** and Vout **3V3**.

YOU SHOULD SEE First: Output (Vout) 3.2971 V, ratio 0.65942, current 362 µA, 617 µW in R1, 1.19 mW in R2, output resistance 3.1 kΩ, 1.81 mW in all. Then: R1 5.1515 kΩ, 330 µA, and the note naming 5.1 kΩ and 5.6 kΩ (E24) and 5.11 kΩ and 5.23 kΩ (E96).

TRY IT

Pick a pair, then load it

1. Set **Mode** to **Pick from a series**: 5 V to 3.3 V, about 10 kΩ, E24.
2. Set **Load on the output** to **Resistor** and type **10k**.

YOU SHOULD SEE The best E24 pair is 4.7 kΩ over 9.1 kΩ: 3.2971 V, −0.088 %. With the 10 kΩ load it becomes 2.7 kΩ over 11 kΩ (3.2993 V, −0.020 %, 630 µA) and the amber warning says the load is close to the divider resistance.

49.2 Advanced: a divider into an ADC

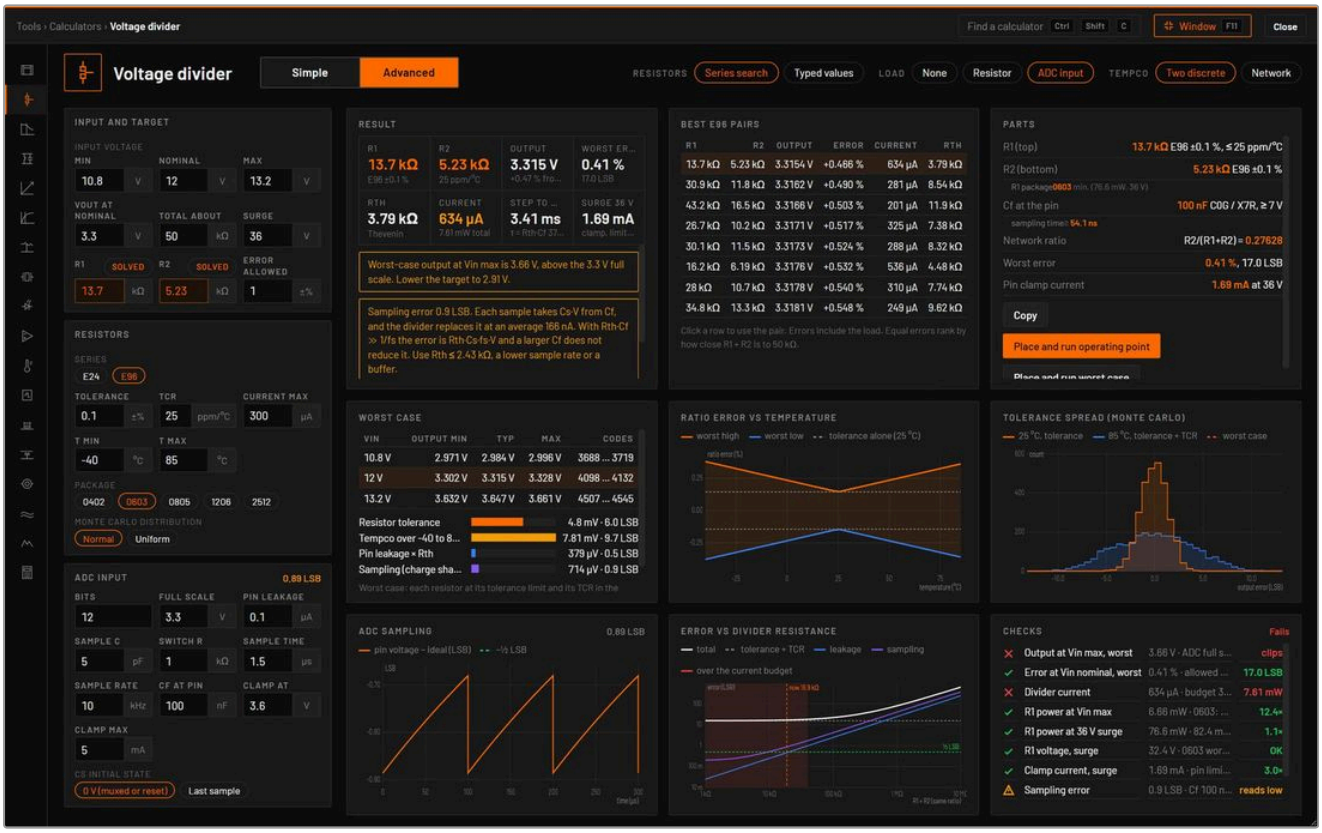


Figure 49.2 The voltage divider's Advanced view in full screen: 12 V to 2.5 V into a 12-bit ADC, the best E96 pairs, the parts, the worst case, the ratio error against temperature, the Monte Carlo, the ADC sampling and the checks.

CHOICE	OPTIONS	WHAT IT DOES
Resistors	**Series search**, Typed values	Series search sets R1 and R2 from the best pair (marked SOLVED). Typing in R1 or R2 switches to Typed values.
Load	None, Resistor, **ADC input**	What the output drives. None: an ideal voltmeter. ADC input: pin leakage, the sampling capacitor and the clamp diode.
Tempco	**Two discrete**, Network	Two resistors with their own tolerance and TCR, or a matched network with a ratio tolerance and tracking.

TAB	ITS DOT	CARDS
Design	The worst check.	Result, Best E96 pairs, Parts, Checks.
Accuracy	Green when the worst error is within the error allowed, else amber.	Worst case, Ratio error vs temperature, Tolerance spread (Monte Carlo).
ADC input	With an ADC load: green when the sampling and the leakage error are each within ½ LSB, else amber.	ADC sampling, Error vs divider resistance, Checks.
Verify in simulation	None.	Calculator vs simulation and the buttons.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Input voltage Min / Nominal / Max	V	10.8 / 12 / 13.2	Group *Input and target*. The output corners are worked out at all three.
Vout at nominal	V	2.5	
Total about	kΩ	50	The R1 + R2 the series search aims for.
Surge	V	36	A transient on the input, for the clamp and R1 checks.
R1, R2	kΩ	39.2, 10.2 typed (SOLVED from the search)	
Error allowed	±%	1	Of the output.
Series		E24, **E96**	Group *Resistors*.
Tolerance (Ratio tol for a network)	±%	0.1	
TCR (Tracking for a network)	ppm/°C	25 (5)	
Current max	µA	300	The current budget.
T min, T max	°C	–40, 85	
Package		0402, **0603**, 0805, 1206, 2512	Rating at 70 °C and working voltage: 0402 63 mW 50 V, 0603 100 mW 75 V, 0805 125 mW 150 V, 1206 250 mW 200 V, 2512 1 W 500 V. Derated linearly to 0 at 155 °C.
Monte Carlo distribution		**Normal**, Uniform	
Bits, Full scale	, V	12, 3.3	Group *ADC input*. Its badge is the sampling error in LSB, green at ½ LSB or less.
Pin leakage	µA	0.1	
Sample C, Switch R	pF, kΩ	5, 1	The ADC's sampling capacitor Cs and switch Rsw.
Sample time, Sample rate	µs, kHz	1.5, 10	tacq and fs.
Cf at pin	nF	100	A capacitor at the pin. 0 for none.
Clamp at, Clamp max	V, mA	3.6, 5	The pin's clamp diode and its injection limit.
Cs initial state		**0 V (muxed or reset)**, Last sample	A multiplexed or reset input starts each sample from 0 V.
Load	kΩ	1000	Group *Load resistor*, with Load = Resistor.

How it works it out. The series search tries every R2 of the series from a fortieth of the total to 1.2 times it with the two standard R1 around the exact value, keeps pairs within half a decade of the total, includes a resistor load (not the ADC), and lists the eight with the smallest error. Click a row to use the pair. The ratio is $k = R2' / (R1 + R2')$, the source resistance $Rth = R1 \parallel R2 \parallel RL$, and 1 LSB = full scale / 2^{bits}.

- **Worst case**: two discrete resistors at all 2^4 corners of their tolerance and TCR, a network with R2 at its ratio tolerance and tracking, at 25 °C, T min and T max. The output corners at Vin min, nominal and max add the leakage drop (Ileak × Rth) and the sampling error, and give the ADC codes.
- **Worst error** is the sum of the tolerance, tempco, leakage and sampling errors, each at its worst. It is not a root-sum-square.
- **Sampling**: with no Cf, Cs charges through Rth + Rsw for tacq, and the error is $V\, e^{-tacq / ((Rth + Rsw)\, Cs)}$. With Cf, each sample takes charge from Cf and the divider tops it up: the steady state of charge sharing at the sample rate (when Rth Cf is much longer than 1/fs the error is Rth Cs fs V, and a larger Cf does not lower it). The largest Rth for direct sampling is tacq / (Cs (bits + 1) ln 2) – Rsw.
- **Monte Carlo**: 3000 seeded draws at 25 °C (tolerance) and at T max (tolerance and TCR), shown as two histograms in LSB.
- **Ratings**: the power in R1 at Vin max and at the surge against the package rating at T max, the surge voltage against its working voltage, and the clamp current at the surge (Vsurge × k – Vclamp) / Rth. The smallest package that covers both is named.

RESULT	WHAT IT IS
R1, R2	The pair, with series, tolerance and TCR (or tracking).
Output	At the nominal input, and how far from the target.
Worst error	% of the output and in LSB. Amber above the error allowed.
Rth	The resistance the ADC pin sees.
Current	With the total power. Amber above the budget.
Step to ½ LSB, or Sample settles	ADC with Cf: τ = Rth Cf and the time to settle to ½ LSB after a step. Without Cf: the time Cs needs. Other loads: R1 power and its rating.
Surge 36 V	The clamp current (red above the pin limit), or the pin voltage.

The **Parts** card lists R1 and R2 with series, tolerance and TCR, the R1 package with its power and surge rating, Cf (C0G or X7R, at least twice the full scale), the ADC sampling time to set, the network ratio to five decimals, the worst error and the clamp current, with **Copy**. The plots: **Ratio error vs temperature** (worst high, worst low, tolerance alone at 25 °C, the allowed error in red), **Tolerance spread**, **ADC sampling** (the charge error against time, or the pin voltage over three samples with Cf) and **Error vs divider resistance** (each error against R1 + R2 at the same ratio from 1 kΩ to 10 MΩ, with the current budget as a red band and the present total marked).

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Output at Vin max, worst	The highest output · ADC full scale	At least 2 % of full scale spare	0 to 2 % spare	Clips
Error at Vin nominal, worst	% · allowed, with LSB	Within the allowed error	Up to 1.25 × it	More
Divider current	A · budget	Within the budget	Up to 1.1 × it	More
R1 power at Vin max	W · package rating at T max	Half the rating or less	Up to the rating	Over
R1 power at the surge	W · rating	Within the rating	Up to 2 × it	More
R1 voltage, surge	V · working voltage	Rating ≥ 1.25 × it	Up to the rating	Over
Clamp current, surge (ADC)	A · pin limit	No clamping, or half the limit	Up to the limit	Over
Sampling error (ADC)	LSB	½ LSB or less	Up to 2 LSB	More
Leakage error (ADC)	LSB · Ileak × Rth	½ LSB or less	Up to 2 LSB	More
Cs settling through Rsw (with Cf)	time · tacq	tacq ≥ 1.2 × it	tacq ≥ it	Shorter
Rth, direct sampling (no Cf)	Rth · its maximum	Within it	Up to 2 × it	More: add Cf
Load vs divider (resistor load)	RL · R1 ‖ R2	10 × or more	3 × to 10 ×	Less

MESSAGE	WHEN IT SHOWS
"Worst-case output at Vin max is 3.54 V, above the 3.3 V full scale. Lower the target to 2.92 V."	The highest output clips.
"Sampling error 1.8 LSB. Each sample takes Cs·V from Cf, and the divider replaces it at an average 125 nA. With Rth·Cf ≫ 1/fs the error is Rth·Cs·fs·V and a larger Cf does not reduce it. Use Rth ≤ 3.23 kΩ, a lower sample rate or a buffer."	Sampling error above ½ LSB with Cf.
"Without Cf, Rth 84.3 kΩ does not settle Cs 5 pF within 1.5 µs. Rth ≤ 32.3 kΩ is required. Add Cf (10 nF to 100 nF) or lengthen the sampling time."	The same without Cf.
"Pin leakage 100 nA through 10.9 kΩ shifts the reading by 1.3 LSB. Lower the divider resistance or add a buffer."	Leakage above ½ LSB.
"A 36 V surge drives … into the pin clamp diode, limit 5 mA. Raise R1, or add a series resistor and an external clamp."	Clamp current above the limit.
"R1 dissipates … at …, above the 0603 rating of … at 85 °C. Use a larger package or check the pulse rating."	R1 over its rating.
"Divider current … exceeds the 300 µA budget. Use R1 + R2 ≥ …. Leakage and sampling error rise with it."	Over the current budget.
"No pair for … from …. The output must be below the input. Typed values shown."	The series search finds nothing.

Verify in simulation checks *Output at Vin nominal* (operating point, V(OUT), with the pin leakage placed, ±0.1 %), *Worst high at T max* (a worst-case tolerance run of the operating point with tol and tc1 on R1 and R2 in the direction that raises the output, at T max: every corner inside), and for an

ADC the *Sampled value* (a transient with the ADC's switch and Cs at the sample rate, V(CS) at the end of the last sample, ±10 % of the dip). *Output over Vin* is calculator only: the operating point checks the ratio.

BUTTON	WHAT IT DOES
Place and run operating point	V1 at the nominal input, R1, R2, the load or Cf, and for an ADC a current source for the pin leakage. Measurement *Divider output* within ±0.1 % of the nominal output minus the leakage drop.
Place and run worst case	The same with tol and tc1 on R1 and R2 (network: R2 carries the ratio tolerance and tracking), temp at T max, then a worst-case tolerance run of 200 runs (seed 1). Measurement *Divider output at 85 °C, worst case* between the lowest and highest corners.
Place and run sampling	ADC only: the sampling switch SW_S (Rsw), Cs, a switch that empties Cs between samples and a pulse source at the sample rate, run until the steady state (up to 400 samples). Measurement *Sampled value (on Cs)*.
Place circuit	The divider with its source and load, OUT probed, no analysis.
Apply to selection	With two resistors selected: R1 to the first, R2 to the second.

The Monte Carlo histograms stay calculator only: the worst case bounds them.

SIMPLE	ADVANCED
Supply voltage (Vs), or Input voltage	Input voltage Nominal (Min and Max follow at ±10 % until you type them)
Output voltage (Vout)	Vout at nominal
R1, R2, Load, Total resistance	R1, R2, load R, Total about
Mode Pick from a series	Resistors Series search

TRY IT

12 V into a 12-bit ADC

1. Open the voltage divider and press **Advanced**. The defaults: 10.8 to 13.2 V in, 2.5 V out, E96, 0.1 %, 25 ppm/°C, a 12-bit 3.3 V ADC with 100 nF at the pin.
2. Read the **Best E96 pairs** and the tiles, then the **Checks**.

YOU SHOULD SEE The best pair is 52.3 kΩ over 13.7 kΩ: 2.4909 V, −0.364 %, 182 µA. Worst error 0.52 % (16.0 LSB), Rth 10.9 kΩ, step to ½ LSB 9.78 ms (τ 1.09 ms), and 360 µA into the clamp at the 36 V surge. Two checks are amber: *Sampling error 1.8 LSB* and *Leakage error 1.3 LSB*, with the warnings that say to use Rth ≤ 3.23 kΩ or a buffer. **Place and run operating point** passes with OUT at 2.4898 V.

TRY IT

A divider that clips

1. Type Vout at nominal **3.2**, Total about **200**, Current max **50**, Surge **60**, and Cf at pin **0**.

YOU SHOULD SEE Five checks fail: the output at Vin max reaches 3.54 V and clips, the error is 3.62 % (143.8 LSB), the sampling error is 118 LSB, the leakage 10.5 LSB, and Rth 84.3 kΩ is over the 32.3 kΩ for direct sampling. The warnings say to lower the target to 2.92 V and to add Cf.

Sources. IEC 60063 values. The ADC sampling follows Microchip's ADC application notes, and the charge-sharing steady state reduces to Rth Cs fs V. The tests check the best E96 pair against a search of every E96 pair, the worst case against the 2^4-corner closed form, and the placed circuits against bspice's operating point, worst case and sampling runs.

50 Low pass and high pass filters

50.1 Simple: passive filters 462
50.2 Advanced: active filters 464

The Simple view designs passive filters: an RC or RL section, or an LC ladder (Pi or T) of order 2 to 7 between a source and a load of the line impedance. The Advanced view designs active filters: unity-gain Sallen-Key or multiple-feedback (MFB) sections of order 1 to 8, Butterworth, Bessel or Chebyshev, with standard parts, a real op-amp, the step, the group delay and the tolerance. Group Circuit. Search words include filter, low pass, high pass, rc, rl, lc, butterworth, chebyshev, cutoff, bode, pi, t and ladder.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

50.1 Simple: passive filters

The picture of the window in **The window**, p. 443 shows this view with the RC low pass.

CHOICE	OPTIONS	WHAT IT DOES
Pass	**Low pass**, High pass	
Configuration	**RC**, RL, LC Pi, LC T	RC low pass is R in series, C to ground (high pass: C in series, R to ground). RL low pass is L in series, R to ground (high pass: R in series, L to ground). A Pi ladder starts with a shunt part, a T ladder with a series part.
Response	**Butterworth**, Chebyshev 0.5 dB	Ladders only.
Order	2 to 7, **3**	Ladders only.
Part values	**Exact**, Nearest E12, Nearest E24	Ladders only. Each part rounded to the nearest of the series.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Resistance	Ω, kΩ, MΩ	22 Ω	RC and RL. SOLVE. Reads a selected resistor.
Capacitance	pF, nF, µF	10 nF	RC. SOLVE. Reads a selected capacitor.
Inductance	nH, µH, mH	10 µH	RL. SOLVE. Reads a selected inductor.
–3 dB cutoff frequency	Hz, kHz, MHz	723.4 kHz (solved)	RC and RL. SOLVE, solved when the calculator opens.
Cutoff frequency	Hz, kHz, MHz	10 MHz	Ladders.
Line impedance	Ω	50	Ladders: the source and load resistance.

The formulas: RC fc = 1 / (2πRC), RL fc = R / (2πL), and their inverses for the solved part. A ladder uses the prototype values g_k (shown under the formula, *g = 1.0000, 2.0000, 1.0000*): low pass $C_k = g_k / (2\pi\ fc\ Z0)$ and $L_k = g_k\ Z0 / (2\pi\ fc)$, high pass $C_k = 1 / (2\pi\ fc\ Z0\ g_k)$ and $L_k = Z0 / (2\pi\ fc\ g_k)$. The load is $Z0\ g_{n+1}$ after a shunt part and $Z0 / g_{n+1}$ after a series one.

RESULT	WHAT IT IS
Cutoff (design)	The cutoff of the fields (orange).
–3 dB measured	The –3 dB point of the parts as shown, found on the AC response the way the AC analysis works it out (a two-port product of the parts, bisected from a passband point at fc/100 for a low pass or 100 fc for a high pass). With E12 or E24 values it moves from the design.
Time constant, Rolloff	RC and RL: RC or L/R, and 20 dB/dec.
Rolloff, Load	Ladders: 20 dB/dec per part, and the load resistance.

Ladders also show the table **Part values** (Part, Where, Value: RS, each part as shunt or series, RL). The **Response** plot runs from fc/100 to 100 fc (floor –50 dB, or –80 dB for more than two parts), normalised to the passband, with markers at fc and at the measured –3 dB point when they differ by more than 1 %.

MESSAGE	WHEN IT SHOWS
"The cutoff of a Chebyshev filter is the edge of its 0.5 dB ripple band. The gain is 3 dB down at 11.3 MHz."	A Chebyshev ladder (a note).
"An even-order Chebyshev filter needs a load of 99.2 Ω for the response shown."	Even order (a note).
"With E12 values the –3 dB point moves 1.8 % from the exact design."	E12 or E24 values (a note).
"Enter positive values to get a cutoff."	A zero or negative part.

BUTTON	WHAT IT DOES
Place as circuit	V1 (sine, 1 V at fc), the filter with RS and RL for a ladder, probes IN and OUT.
Place and run AC analysis	The same and an AC sweep of V1 at 100 points per decade (200 above three parts) from the passband point to where the response is about 100 dB down. Measurements: a low pass gets *Filter -3 dB* (bw3db of V(OUT)) within ±1 % of the measured –3 dB point, a high pass *Filter gain at -3 dB point*, and both *Filter passband gain* within ±0.1 dB.
Apply to selected parts	With one selected part of each kind the filter needs: their r, l and c.

TRY IT

An RC low pass and a third-order ladder

1. Open the filter calculator: RC low pass, 22 Ω, 10 nF.
2. Set **Configuration** to **LC Pi**: Butterworth, order 3, 10 MHz, 50 Ω, Exact.

YOU SHOULD SEE RC: cutoff 723 kHz (–3 dB measured 724 kHz), time constant 220 ns. Pi: g = 1, 2, 1, so RS 50 Ω, C1 318 pF to ground, L1 1.59 µH in series, C2 318 pF to ground, RL 50 Ω, 60 dB/dec. **Place and run AC analysis** passes: the passband sits at –6.02 dB because the matched source halves the voltage.

50.2 Advanced: active filters

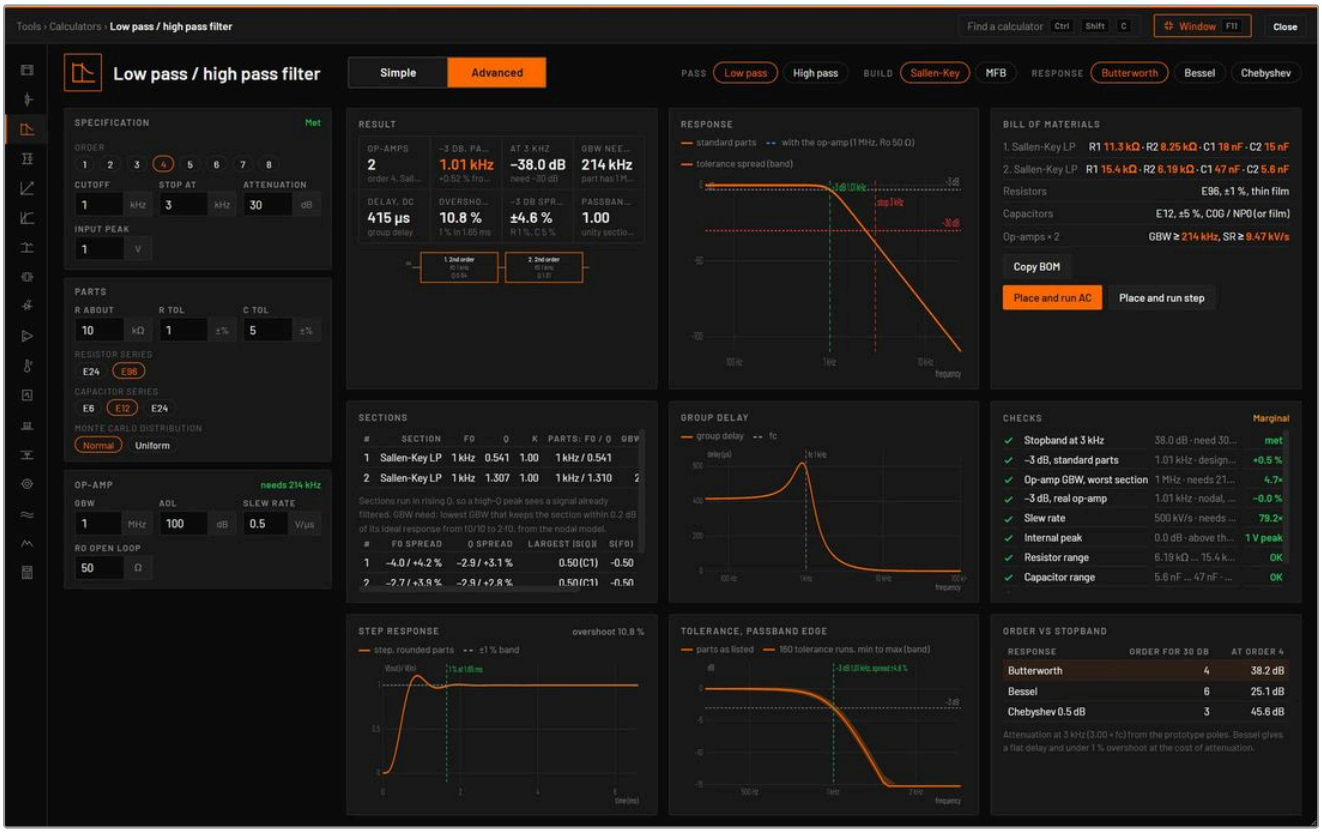


Figure 50.1 The filter's Advanced view in full screen: a fourth-order Butterworth low pass at 1 kHz in two Sallen-Key sections, with the response, the bill of materials, the sections, the group delay, the step response, the tolerance and the order each family needs.

CHOICE	OPTIONS	WHAT IT DOES
Pass	**Low pass**, High pass	Also moves Stop at: at or below fc/3 for a high pass, at or above 3 fc for a low pass.
Build	**Sallen-Key**, MFB	Unity-gain Sallen-Key, or multiple feedback (inverting, with gain).
Response	**Butterworth**, Bessel, Chebyshev	Bessel normalised to –3 dB at the cutoff. Chebyshev with any ripple.

TAB	ITS DOT	CARDS
Design	The worst check.	Result (tiles and the section blocks), Response, Bill of materials, Checks.
Sections	Green when the op-amp's GBW covers the worst section, else amber.	Sections, Tolerance per section, Order vs stopband.
Delay and step	None.	Group delay, Step response.
Tolerance	Green when the –3 dB spread is under 3 %, else amber.	Tolerance, passband edge, Tolerance per section.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Order		1 to 8, **4**	Group *Specification*. Its badge says *Met* (green) or *Not met* (red) for the stopband.
Cutoff	kHz	1	
Stop at, Attenuation	kHz, dB	3, 30	The attenuation needed at the stop frequency.
Ripple, Cutoff at	dB	0.5, **Ripple edge** or –3 dB	Chebyshev only.
Gain	V/V	1	MFB only: the passband gain, put on the first second-order section.
Input peak	V	1	For the slew rate and the internal peak.
R about	kΩ	10	Group *Parts*: the impedance level the capacitors are scaled to.
R tol, C tol	±%	1, 5	
Resistor series, Capacitor series		**E96** (or E24), **E12** (or E6, E24)	
Monte Carlo distribution		**Normal**, Uniform	
GBW, Aol, Slew rate, Ro open loop	MHz, dB, V/µs, Ω	1, 100, 0.5, 50	Group *Op-amp*. Its badge says the GBW needed, green when the part has it.

How it works it out. The prototype poles come from Williams and Taylor (Bessel from the reverse Bessel polynomial). The sections run in rising Q, first-order first. The capacitors are picked first from their series, then the resistors from the section equations of TI SLOA024 and SLOA049 and rounded to theirs, and f0, Q and gain are worked out again from the rounded parts. The section types: Sallen-Key LP, MFB LP, Sallen-Key HP, MFB HP, and for a first-order section RC + buffer, CR + buffer, Inverting RC or Inverting CR. With the real op-amp (GBW, Aol, Ro) the whole chain is solved by nodal analysis, so each section loads the one before it. The GBW a section needs is the lowest that keeps it within 0.2 dB of its ideal response from f0/10 to 2 f0. The step is integrated with fourth-order Runge-Kutta on ideal sections. The Monte Carlo runs 160 builds for the band and the histograms.

RESULT	WHAT IT IS
Op-amps	How many, with the order and the build.

RESULT	WHAT IT IS
–3 dB, parts	The cutoff of the rounded parts and how far from the design.
At 3 kHz	The attenuation at the stop frequency against the need. Red when not met.
GBW needed	For the worst section, and what the op-amp has. Amber when it is short.
Delay, DC (low pass) or Ripple (high pass)	The group delay at DC, or the rise above unity.
Overshoot	Of the step, and the time to settle to 1 %.
–3 dB spread	From the Monte Carlo of the part tolerances. Amber above 8 %.
Passband gain	The product of the section gains.

Under the tiles a block per section shows its order, f0 and Q (amber when its GBW is short). The **Bill of materials** lists each section's R and C values, the resistor and capacitor kind (thin film, C0G or film), and the op-amps with the GBW and slew rate to look for, with **Copy BOM**. **Sections** is a table of f0, Q and K designed and as built with the GBW each needs and its peak. **Tolerance per section** gives the f0 and Q spread and the sensitivities ($S(Q, x) = (\Delta Q/Q) / (\Delta x/x)$). **Order vs stopband** gives the order each family needs for the attenuation and what the present order gives.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Stopband at 3 kHz	dB · need	Reached	Within 10 %	Less: the order needed is named
–3 dB, standard parts	frequency · design	Within 2 %	Within 5 %	More
Op-amp GBW, worst section	GBW · need	GBW ≥ need	Half the need or more	Less
–3 dB, real op-amp	nodal, real GBW	Within 2 % of the parts	Within 5 %	More
Slew rate	SR · 2π f0 Vpk × peak gain	1.5 × or more	1 × to 1.5 ×	Less
Internal peak	dB above the passband	Under 3 dB	Under 6 dB	More
Resistor range	min … max · 1 kΩ to 1 MΩ	Inside	Outside	
Capacitor range	min … max · C0G up to about 100 nF	100 pF to 100 nF	Outside	
–3 dB spread	± % · R and C tolerance, 160 runs	Under 3 %	Under 8 %	More
Highest section Q	Q	Under 3	Under 8	More

MESSAGE	WHEN IT SHOWS
"28.4 dB at 3 kHz, 30 dB required. Order needed: Bessel 6, Butterworth 4, Chebyshev 0.5 dB 3."	The stopband is not met.
"Section 2 (f0 4.68 kHz, Q 1.71) needs GBW ≥ 837 kHz to stay within 0.2 dB. With 100 kHz its response shifts. Use a faster op-amp."	A section's GBW is short.
"Above about 50 kHz the op-amp roll-off cuts the high pass. The response is a band pass."	A Sallen-Key high pass with GBW under 100 × fc.
"Sallen-Key sections are unity gain (lowest sensitivity). For gain, add a stage or use MFB."	Gain other than 1 with Sallen-Key.
"Even-order Chebyshev with unity DC gain: the passband rises to +0.5 dB."	An even-order Chebyshev.
"A section output peaks … dB above the passband. A 1 V input reaches … inside the chain. Check it against the op-amp swing."	An internal peak over 3 dB.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
–3 dB point	AC: bw3db of V(OUT) (low pass), or the gain at the –3 dB frequency (high pass)	±1 %, or ±0.15 dB
Passband gain	AC: gain at fc/100 (low pass) or 100 fc	±0.1 dB
Stopband	AC: gain at the stop frequency	±0.5 dB
Step overshoot, Settling to 1 %	Transient with a 1 V step (low pass)	±1 point, ±5 %
Step undershoot	Transient, the extreme of V(OUT) after the edge (high pass)	±3 % of the gain
–3 dB spread	Monte Carlo: 200 AC runs with tol on every R and C	Inside the calculator's band

BUTTON	WHAT IT DOES
Place and run AC	Source V_FL, each section an op-amp with the typed GBW, Aol and Ro and its R and C (R1_1, C2_2, U_1 …), IN and OUT probed, and an AC sweep at 100 points per decade.
Place and run step	The same chain with a 1 V step and a transient.
Place and run Monte Carlo	tol and the distribution on every R and C, then a Monte Carlo of 200 AC runs (seed 1).
Place circuit	The chain only.

The group delay and the sensitivities stay calculator only. The simulated chain uses the typed op-amp, the calculator's step uses ideal ones.

SIMPLE	ADVANCED
–3 dB cutoff frequency, or Cutoff frequency	Cutoff
Pass	Pass
Response (Butterworth, Chebyshev)	Response

TRY IT

A fourth-order Butterworth low pass

1. Open the filter calculator and press **Advanced**: low pass, Sallen-Key, Butterworth, order 4, 1 kHz, stop 3 kHz at 30 dB, GBW 1 MHz.
2. Look at the **Sections** tab.

YOU SHOULD SEE Two sections at 1 kHz: Q 0.541 with 11.3 kΩ, 8.25 kΩ, 18 nF, 15 nF (needs 35 kHz GBW), and Q 1.307 with 15.4 kΩ, 6.19 kΩ, 47 nF, 5.6 nF (needs 214 kHz). The tiles: −3 dB at 1.01 kHz (+0.5 %), −38.0 dB at 3 kHz, delay 415 µs, overshoot 10.8 % (1 % in 1.65 ms), spread ±4.6 % (amber: C at 5 %). Bessel would need order 6 for the 30 dB, Chebyshev 0.5 dB order 3.

TRY IT

An op-amp that is too slow

1. Set high pass, Chebyshev, order 3, cutoff 5 kHz, stop 1 kHz, GBW 0.1 MHz and Gain 2.

YOU SHOULD SEE The check *Op-amp GBW, worst section* fails at 0.1 ×: section 2 needs 837 kHz. The warnings say the high pass becomes a band pass above about 50 kHz, and that Sallen-Key sections are unity gain.

Sources. Matthaei, Young and Jones, *Microwave Filters* (1964), for the ladder prototypes. Williams and Taylor and TI SLOA024 and SLOA049 for the active sections. The tests check the Q and frequency factors against the SLOA049 tables, the order for 30 dB against the closed forms, the GBW need against about 100 Q^3 f0, and the placed chains against bspice's AC, step and Monte Carlo runs.

51 LC resonance and Q

51.1 Simple: f0, Z0 and Q 469
51.2 Advanced: real parts 470

Resonance of an inductor and a capacitor: a tank in an oscillator or a filter, a series trap, a matching network. The Simple view gives f0, the characteristic impedance, Q and the bandwidth. The Advanced view uses real parts (the inductor's Q, DCR and self-resonance, the capacitor's loss and ESL, the board stray), the source and load, the tolerance and temperature, and the stress at resonance. Group Circuit. Search words include lc, resonance, tank, q, bandwidth, characteristic impedance and f0.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

51.1 Simple: f0, Z0 and Q

CHOICE	OPTIONS	WHAT IT DOES
Circuit	**Series**, Parallel tank	Series: the output is taken across R, a band pass that peaks at f0. Parallel tank: fed through R, which sets its Q.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Inductance	nH, µH, mH	10 µH	SOLVE. Reads a selected inductor.
Capacitance	pF, nF, µF	100 pF	SOLVE. Reads a selected capacitor.
Resonant frequency	Hz, kHz, MHz	5.033 MHz (solved)	SOLVE, solved when the calculator opens.
Resistance	Ω, kΩ	10 Ω	In series with L and C, or feeding the tank. Reads a selected resistor.

f0 = 1 / 2π√(LC), Z0 = √(L/C), Q = Z0/R (series) or R/Z0 (tank), BW = f0/Q, and L or C from f0 and the other.

RESULT	WHAT IT IS
Resonance f0	Orange.
Characteristic Z0	
Q	
Bandwidth (–3 dB)	

"Q is 0.032, below 0.5: the circuit is overdamped and shows no peak." warns when Q is under 0.5. The **Response** plot is the circuit's own transfer around f0 with f0 and the –3 dB edges marked.

BUTTON	WHAT IT DOES
Place as circuit	V1 (1 V at f0), L1, C1 and R1 as series or tank, IN and OUT probed.
Place and run AC analysis	The same and an AC sweep at 200 points per decade. *Resonance gain at f0* within ±0.05 dB of 0 dB and *Resonance phase at f0* within ±1°.
Apply to selected parts	With an inductor and a capacitor selected: l and c.

TRY IT

10 µH and 100 pF

1. Open LC resonance and Q (type **lc**): series, 10 µH, 100 pF, 10 Ω.
2. Press **Place and run AC analysis**.

YOU SHOULD SEE f0 5.03 MHz, Z0 316 Ω, Q 31.6, bandwidth 159 kHz. The AC run reads 0 dB and 0° at f0 and both pass.

51.2 Advanced: real parts

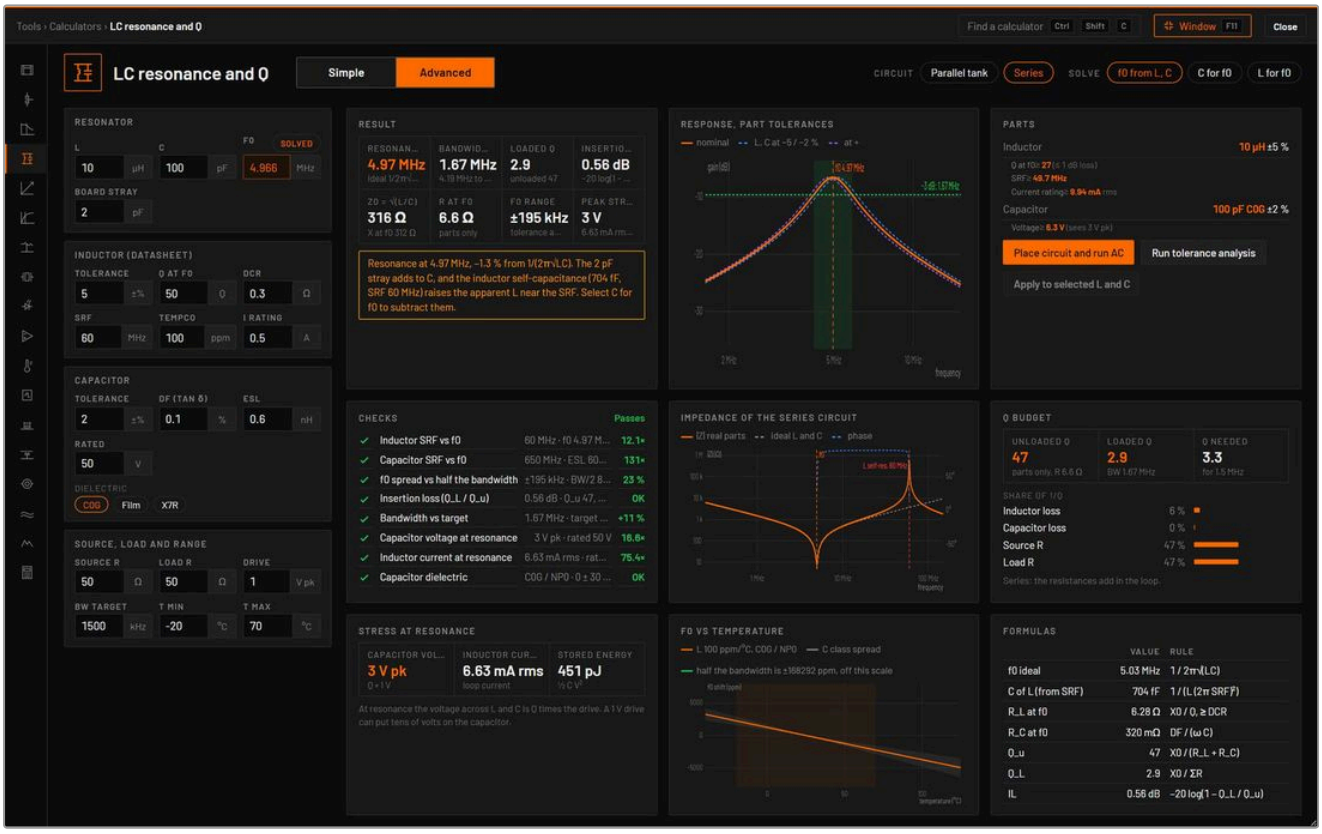


Figure 51.1 LC resonance and Q, Advanced, in full screen: the series circuit with real parts, the response with the part tolerances, the parts, the checks, the impedance with the self-resonance, the Q budget, the stress and f0 against temperature.

CHOICE	OPTIONS	WHAT IT DOES
Circuit	Parallel tank, **Series**	Loads that circuit's source, load and band: series 50 Ω and 50 Ω for 1.5 MHz, parallel 10 kΩ and 10 kΩ for 300 kHz.
Solve	**f0 from L, C**, C for f0, L for f0	C or L is then SOLVED, worked out with the strays subtracted and rounded to E24 (C) or E12 (L).

TAB	ITS DOT	CARDS
Design	Amber with a warning.	Result, Response with part tolerances, Parts.
Q and bandwidth	The insertion loss, bandwidth and spread checks.	Q budget, f0 vs temperature, Checks.
Parts and stress	The SRF, voltage, current and dielectric checks.	Impedance of the tank, Stress at resonance, Formulas.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
L, C, f0, Board stray	µH, pF, MHz, pF	10, 100, 5, 2	Group *Resonator*.
Tolerance, Q at f0, DCR, SRF, Tempco, I rating	±%, , Ω, MHz, ppm, A	5, 50, 0.3, 60, 100, 0.5	Group *Inductor (datasheet)*.
Tolerance, DF (tan δ), ESL, Rated, Dielectric	±%, %, nH, V	2, 0.1, 0.6, 50, **C0G**	Group *Capacitor*. Film and X7R too.
Source R, Load R, Drive, BW target	Ω (kΩ for a tank), V pk, kHz	50, 50, 1, 1500	Group *Source, load and range*.
T min, T max	°C	–20, 70	

How it works it out. The inductor is $(R_{ac} + j\omega L)$ in parallel with its self-capacitance $Cp = 1 / (L (2\pi\ SRF)^2)$, with $R_{ac} = X / Q$ at f0, growing as $\sqrt{f}$ and never below the DCR. The capacitor is $DF/(\omega C) + j\omega ESL + 1/(j\omega C)$. The stray sits across the tank. The resonance of the real tank is the peak (tank) or minimum (series) of |Z|, found numerically, and so are the –3 dB edges. Unloaded $Q = X0 / (R_L + R_C)$, $Rp = Q\ X0$, loaded Q from Rp, the source and the load, insertion loss $-20 \log(1 - Q_L/Q_u)$ (Zverev).

RESULT	WHAT IT IS
Resonance	Of the real parts, and the ideal $1/2\pi\sqrt{LC}$.
Bandwidth	With its edges.
Loaded Q	And the unloaded Q.
Insertion loss	$-20 \log(1 - Q_L/Q_u)$.
Z0 = √(L/C), R or Rp at f0	
f0 range	Over tolerance and temperature. Amber above a quarter of the bandwidth.
Peak stress	The capacitor voltage and the current in L.

The **Parts** card asks for the inductor's Q for under 1 dB loss, an SRF of at least 10 × f0, a current rating of 1.5 × the RMS, a C0G capacitor and twice the peak voltage, and a trimmer when the spread is wide. When C or L is solved, a

table shows the standard values around it with their f0 and error. **Q budget** shows each loss's share of 1/Q (inductor, capacitor, source, load).

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Inductor SRF vs f0	SRF · f0	10 × or more	3 × or more	Less
Capacitor SRF vs f0	$1/2\pi\sqrt{(ESL\ C)} \cdot f0$	10 × or more	3 × or more	Less
f0 spread vs half the bandwidth	±spread · BW/2	Under BW/4	Under BW/2	More
Insertion loss (Q_L / Q_u)	dB	1 dB or less	3 dB or less	More
Bandwidth vs target	%	Within ±20 %	Within ±50 %	More
Capacitor voltage at resonance	V pk · rated	2 × margin	1.2 × margin	Less
Inductor current at resonance	I rms · rated	1.5 × margin	Within it	Over
Capacitor dielectric	C0G, film, X7R	C0G or film		X7R: not for tanks

MESSAGE	WHEN IT SHOWS
"Resonance at 4.97 MHz, −1.3 % from 1/(2π√LC). The 2 pF stray adds to C, and the inductor self-capacitance (704 fF, SRF 60 MHz) raises the apparent L near the SRF. Select C for f0 to subtract them."	The real f0 is more than 1 % from the ideal.
"Tolerance and temperature move f0 by ±..., ... % of half the bandwidth. Use ±1 % C0G and a ±2 % inductor, add a ±... trimmer or widen the band."	Spread over a quarter of the band.
"Loaded Q ... is ... % of the unloaded Q ..., so ... dB is lost in the parts. An inductor with Q ≥ ... at f0 brings the loss under 1 dB."	Insertion loss over 1 dB.
"Inductor SRF 6 MHz is close to f0, where L and Q differ from the datasheet table. Use a part with SRF ≥ 10 × f0."	SRF under 3 × f0.
"Capacitor voltage at resonance is ... peak (Q times the drive). Use a ... V part."	Over the rating with margin.
"The inductor self-capacitance and the stray resonate with L below this frequency. Use a smaller L."	Solving C finds none.
"The target is above the inductor self-resonance, so no L value fits. Use a part with a higher SRF."	Solving L finds none.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Gain at f0	AC around f0 with the real parts (L1 dcr and srf, C1 esr and esl)	±0.3 dB
Resonance, −3 dB bandwidth	Read from the AC plot	
f0 spread	Tolerance analysis: 100 Monte Carlo runs of L and C, gain at the nominal f0 inside the −3 dB band	The yield

BUTTON	WHAT IT DOES
Place circuit and run AC	V1 at the drive, RS, the tank or series L1 and C1 with their losses (and a separate stray for a tank), RL, and an AC sweep at 200 points per decade.
Run tolerance analysis	tol on L and C and a Monte Carlo of 100 AC runs.
Apply to selected L and C	Their values.

SIMPLE	ADVANCED
Inductance, Capacitance, Resonant frequency	L, C, f0
Circuit	Circuit

TRY IT

The real 10 µH and 100 pF

1. Open LC resonance and Q, press **Advanced**: series, inductor Q 50, SRF 60 MHz, C0G, 2 pF stray, 50 Ω source and load.

YOU SHOULD SEE The resonance is at 4.97 MHz, 1.3 % under the ideal 5.03 MHz, and the warning says the stray and the inductor's self-capacitance pull it. Bandwidth 1.67 MHz (4.19 to 5.87 MHz), loaded Q 2.9 against 47 unloaded, 0.56 dB insertion loss, f0 range ±195 kHz. All eight checks pass. Set Solve to **C for f0** at 5 MHz: exact 99.32 pF, E24 100 pF (−0.68 %).

Sources. Textbook second-order resonance (Hayt and Kemmerly), and Zverev, *Handbook of Filter Synthesis*, for the insertion loss. The tests check f0, the series and tank bandwidths, the pull of the self-capacitance and stray (−1.3 %), the insertion loss, and the placed circuits' gain and tolerance yield against bspice.

52 Reactance

52.1 Simple: XL and XC 474
52.2 Advanced: the real part 475

The reactance of an inductor or a capacitor at a frequency, the part for a reactance, or the frequency where a part has it. The Advanced view uses the real part: a capacitor's ESR, ESL and mounting inductance, its DC bias, parallel parts and their anti-resonance against a target impedance, or an inductor's winding capacitance and loss. Group Circuit. Search words include reactance, xl, xc, impedance and admittance.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

52.1 Simple: XL and XC

CHOICE	OPTIONS	WHAT IT DOES
Part	**Inductor**, Capacitor	

FIELD	UNIT	DEFAULT	WHAT IT DOES
Frequency	Hz, kHz, MHz	1 MHz	SOLVE.
Inductance	nH, µH, mH	10 µH	SOLVE. Reads a selected inductor.
Capacitance	pF, nF, µF	100 nF	SOLVE. Reads a selected capacitor.
Reactance	Ω, kΩ, MΩ	62.83 Ω (solved)	SOLVE, solved when the calculator opens.

XL = 2πfL, XC = 1 / 2πfC, and their inverses for the part and the frequency.

RESULT	WHAT IT IS
Reactance XL (or XC)	Orange.
Frequency, Inductance (or Capacitance)	
Admittance	1/X in siemens.

A note says that an inductor's reactance doubles each time the frequency doubles, and a capacitor's halves. The plot **Reactance against frequency** runs two decades each way, and the sketch shows the check circuit: a resistor equal to X in front of the part.

BUTTON	WHAT IT DOES
Place the check and run AC analysis	V1, R1 = X in series, L1 or C1 to ground, an AC sweep. Where the reactance equals R the output is 3.01 dB down: *Reactance check gain* within ±0.05 dB of −3.01 dB and *Reactance check phase* within ±0.5° of +45° (inductor) or −45° (capacitor).
Apply to selected part	L or C into the selected part.

TRY IT

10 µH and 100 nF at 1 MHz

1. Open Reactance (type **reactance**): inductor, 1 MHz, 10 µH.
2. Switch Part to Capacitor, 100 nF.

YOU SHOULD SEE XL 62.8 Ω (15.9 mS). XC 1.59 Ω (628 mS). The placed check reads −3.01 dB and ±45° at 1 MHz.

52.2 Advanced: the real part

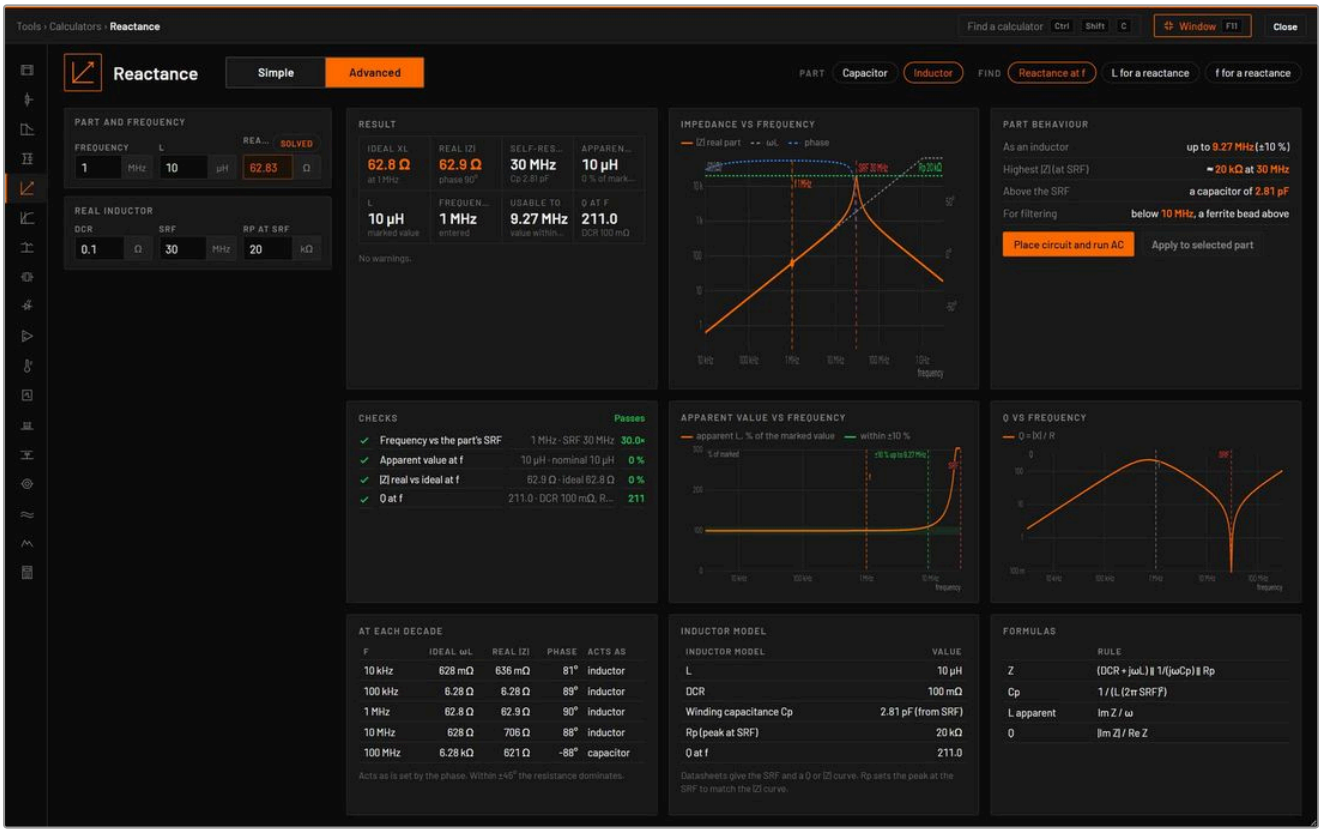


Figure 52.1 Reactance, Advanced, in full screen: a 10 µH inductor at 1 MHz with its self-resonance, the impedance against frequency, the apparent value, Q, the checks, the table at each decade and the inductor model.

CHOICE	OPTIONS	WHAT IT DOES
Part	Capacitor, **Inductor**	
Find	**Reactance at f**, C (L) for a reactance, f for a reactance	The found value is SOLVED.

TAB	ITS DOT	CARDS
Impedance	The SRF and real-vs-ideal checks.	Result, Impedance vs frequency, Part behaviour.
Real part: value and Q	The apparent value, DC bias and Q checks.	Apparent value vs frequency, Q vs frequency, Checks, At each decade.
Parallel parts	The target and anti-resonance checks.	Parallel capacitors and the target, ESL by case (inductor: Inductor model).
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Frequency, C or L, Reactance	MHz, nF or µH, Ω	1, 100 or 10, 1.5915	Group *Part and frequency*.
Case (sets the ESL)		0402, **0603**, 0805, 1206, Radial	Group *Real capacitor*. Typical ESL from vendor impedance data: 0402 0.4 nH, 0603 0.6 nH, 0805 0.8 nH, 1206 1.1 nH, radial 5 nH.
ESR, ESL, Mounting L	mΩ, nH, nH	20, 0.6, 0.5	The mounting (pads, vias, trace) is often larger than the part's ESL.
In parallel, Rated, DC bias	×, V, V	1, 16, 3.3	
Dielectric		C0G, **X7R**	X7R loses capacitance with DC bias.
DCR, SRF, Rp at SRF	Ω, MHz, kΩ	0.1, 30, 20	Group *Real inductor*. Rp sets the height of the peak at the SRF.
Second capacitor		None, **Add a second value**	Group *Second capacitor and target*: C2 1 nF, ESR 150 mΩ, ESL 0.4 nH, Target |Z| 2 Ω.

How it works it out. A real capacitor is ESR + jω(ESL + mounting) + 1/(jωC_{eff}), with C_{eff} after the DC bias and n parts in parallel (ESL/n, ESR/n), SRF = 1 / 2π√(ESL C). A real inductor is (DCR + jωL) ‖ 1/(jωCp) ‖ Rp, Cp = 1 / (L (2π SRF)^2). The apparent value is what a meter at f reads: C = −1/(ω Im Z), L = Im Z / ω. Two capacitors in parallel make an anti-resonance between their SRFs, where the larger one is already inductive.

RESULT	WHAT IT IS
Ideal XC or XL	At f.
Real |Z|	With its phase.
Self-resonance	With the ESL (with mounting) or Cp.
Apparent C or L	As % of one part's marked value, or *turned* past the SRF.
C or L, Frequency	Solved, or as entered (with C after DC bias).
Usable to	Where the apparent value is 10 % off.
Q at f	|Im Z| / Re Z.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Frequency vs the part's SRF	f · SRF	Under 0.3 × SRF	Under the SRF	Past it: inductive or capacitive
Apparent value at f	% of marked	Within ±10 %	Within ±30 %	More

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
|Z| real vs ideal at f	%	Within 10 %	Within 33 %	More
C left at the DC bias	X7R: %	80 % or more	50 % or more	Less
|Z| at f vs target	capacitor	Within the target	Up to 1.43 × it	More
Anti-resonance peak	peak · target	Within it	Up to 2 × it	More
Q at f	(information)			

MESSAGE	WHEN IT SHOWS
"At 100 MHz the capacitor is above its self-resonance (24.9 MHz) and acts as an inductor of 1.1 nH. A smaller case, a smaller value or more parts in parallel (ESL / n) raise the SRF."	f past the SRF (an inductor: *acts as a capacitor of 2.81 pF. Use a part with a higher SRF*).
"At … the part is … off its marked value because the ESL cancels part of the reactance near the SRF (…). The ideal formula holds below …."	Between 0.3 × and 1 × the SRF.
"12 V DC bias leaves 37 % of the 100 nF (0603 X7R 16 V), 37.2 nF effective. Use a higher voltage rating or a larger case."	Less than 80 % left.
"Anti-resonance at 113 MHz: 3.53 Ω, 1.8 × the target. Between the two SRFs the large capacitor is inductive and the small one capacitive. Add a middle value (10 nF), more of the same value or lower-ESL parts. Some ESR damps the peak."	The peak is over the target.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
|Z| at f (dB re 1 Ω)	AC: a 1 A AC current into the part, so the gain in dB is 20 log |Z|	±0.3 dB
Phase of Z at f	AC, the same	±3°
Self-resonance, Anti-resonance peak	Read from the AC plot	

BUTTON	WHAT IT DOES
Place circuit and run AC	I1 (1 A AC) into each part: a capacitor with its mounting inductor LM1, C1 with C_{eff}, esr and esl, the second capacitor beside it, or L1 with dcr, srf and rp, a 1 GΩ DC path, OUT probed, 200 points per decade.
Apply to selected part	C or L into the selected part.

SIMPLE	ADVANCED
Part, Frequency, Inductance or Capacitance, Reactance	Part, Frequency, L or C, Reactance

TRY IT

A 100 nF decoupling capacitor and a 1 nF beside it

1. Press **Advanced**, set Part to **Capacitor**: 100 nF 0603 X7R 16 V at 3.3 V, with a 1 nF second capacitor and a 2 Ω target.

YOU SHOULD SEE C after DC bias is 87.5 nF. At 1 MHz |Z| is 1.81 Ω (ideal 1.59 Ω), and the part self-resonates at 16.2 MHz with 1.1 nH including mounting, so it reads 87.8 nF (–12 %, amber). The pair anti-resonates at 113 MHz with 3.53 Ω, 1.8 × the target: the warning suggests a 10 nF middle value. At 100 MHz with 12 V on it the capacitor is an inductor and holds 37 % of its value: both checks fail.

Sources. Ideal reactance. Murata, KEMET and TDK impedance data (SimSurfing, K-SIM, SEAT) for the ESL by case and the anti-resonance, and Novak on power distribution networks. The tests check XL, XC, a 100 nF 0603 X7R at 3.3 V self-resonating at 16.2 MHz, the 112.5 MHz anti-resonance of 100 nF and 1 nF, and the placed parts' |Z| and phase against bspice.

53 Time constant

53.1 Simple: τ = RC or L/R 479
53.2 Advanced: the real step 480

How fast a first-order circuit follows a step: an RC charging or discharging, or a coil's current through its resistance. The Simple view gives the time constant and the time to any level. The Advanced view uses the real capacitor (DC bias of an X7R, leakage, the source resistance), settling to N bits, the delay to a logic threshold, and for a relay or solenoid coil the release time with a diode, zener or resistor clamp. Group Circuit. Search words include time constant, tau, rc, rl, charge, rise time, settling and delay.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

53.1 Simple: τ = RC or L/R

CHOICE	OPTIONS	WHAT IT DOES
Circuit	**RC**, L / R	

FIELD	UNIT	DEFAULT	WHAT IT DOES
Resistance	Ω, kΩ, MΩ	10 kΩ	SOLVE. Reads a selected resistor.
Capacitance	pF, nF, µF	100 nF	RC. SOLVE. Reads a selected capacitor.
Inductance	µH, mH, H	10 mH	L / R. SOLVE. Reads a selected inductor.
Time constant	ns, µs, ms, s	1 ms (solved)	SOLVE, solved when the calculator opens.
Time to reach	%	90	0 to 100.
Step	V	5	Only for the drawing and the placed source.

τ = RC or τ = L/R, $v(t) = V(1 - e^{-t/\tau})$, the time to a level $t_p = -\tau \ln(1 - p)$, the 10 to 90 % rise τ ln 9 and the 2 % settling τ ln 50.

RESULT	WHAT IT IS
Time constant	Orange.
Time to 90 %	For the level typed.
Rise time 10 to 90 %, Settling to 2 %	

A note says that after one τ the capacitor voltage (or the current) is at 63.2 % of the step, and after 5 τ at 99.3 %. The plot **Charge curve, % of the step** (or **Current, % of the final value**) runs from 0 to 6 τ with τ and the level marked.

BUTTON	WHAT IT DOES
Place and run transient	A pulse source V1 (0 to the step, edges of τ/10000), R1 and C1 (or L1 and R1), IN and OUT probed, a transient of 10 τ. *Rise time 10 to 90 %* and *Settling to 2 %* within ±1 % of τ ln 9 and τ ln 50.
Place as circuit	The same with no analysis.
Apply to selected parts	With a resistor and a capacitor (or inductor) selected: their values.

TRY IT

10 kΩ and 100 nF

1. Open the time constant (type **tau**): RC, 10 kΩ, 100 nF.
2. Press **Place and run transient**.

YOU SHOULD SEE τ = 1 ms, 90 % at 2.3 ms, rise 2.2 ms, settling to 2 % 3.91 ms. Both measurements pass. A selected resistor and capacitor in the picker open it with their τ.

53.2 Advanced: the real step

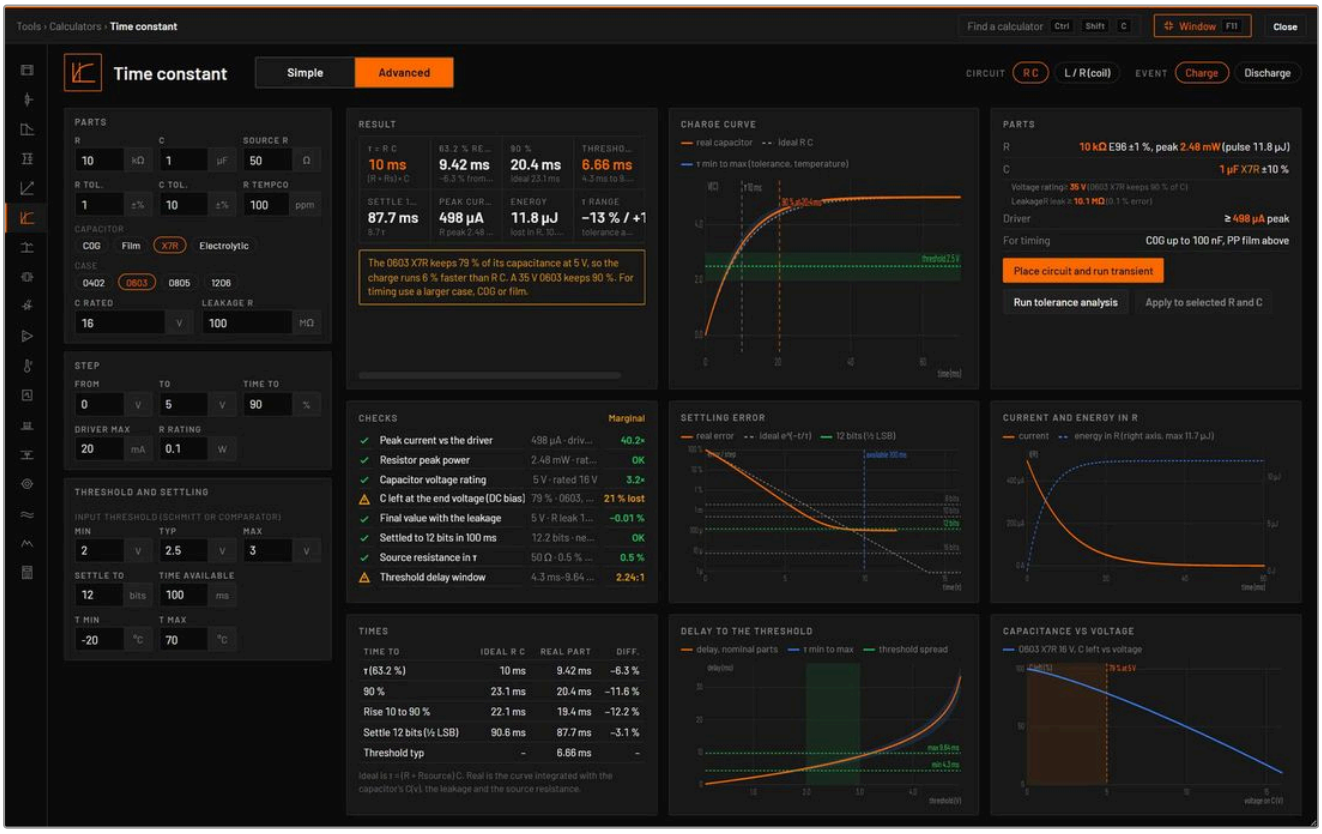


Figure 53.1 The time constant's Advanced view in full screen: 10 kΩ into a 1 µF 0603 X7R, with the real charge curve against the ideal one, the times table, the settling error, the delay to the threshold, the parts and the checks.

CHOICE	OPTIONS	WHAT IT DOES
Circuit	**R C**, L / R (coil)	
Event	**Charge**, Discharge	R C.
Turn-off clamp	**Diode**, Diode + zener, Resistor	L / R: what takes the coil current when the switch opens.

TAB	ITS DOT	CARDS
Step response	R C: amber with a warning.	Result, Charge curve (or Discharge curve), Times (coil: Coil current on and off, Clamps compared).
Settling and thresholds	The settling and threshold checks (coil: release and pick-up).	Settling error, Delay to the threshold, Checks (coil: Current after switch-off for each clamp, Coil current vs temperature).
Parts and stress	The stress checks.	Parts, Current and energy in R, Capacitance vs voltage (coil: Parts, Switch voltage at turn-off, Times).
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
R, C, Source R	kΩ, µF, Ω	10, 1, 50	Group *Parts* (R C).
R tol., C tol., R tempco	±%, ±%, ppm	1, 10, 100	
Capacitor		C0G, Film, **X7R**, Electrolytic	X7R adds Case (0402, **0603**, 0805, 1206) for its DC bias. C0G 0 ± 30 ppm/°C, PP film −200 ppm/°C, X7R ±15 % over temperature, electrolytic −20 / +10 %.
C rated, Leakage R	V, MΩ	16, 100	
From, To, Time to	V, V, %	0, 5, 90	Group *Step*.
Driver max, R rating	mA, W	20, 0.1	
Threshold Min / Typ / Max	V	2 / 2.5 / 3	Group *Threshold and settling*: a Schmitt or comparator input.
Settle to, Time available	bits, ms	12, 100	
T min, T max	°C	−20, 70	
Inductance, L tolerance, Coil resistance, Series R	mH, ±%, Ω, Ω	500, 15, 400, 0	Group *Coil* (L / R).
Supply, Diode drop, Zener, Clamp resistor	V, V, V, Ω	12, 0.8, 24, 1000	Group *Drive and clamp*.
Pick-up current, Release current, Release time max, Switch rating	%, %, ms, V	75, 10, 5, 40	Group *Target*.

How it works it out. The RC step is integrated (fourth-order Runge-Kutta, 2400 steps over 12 τ) with the capacitor's C(v), its leakage and the source resistance, against the ideal $1 - e^{-t/\tau}$. An X7R keeps $1 - f\,(V/Vr)^{1.25}$ of its value (f is 0.95 for 0402, 0.9 for 0603, 0.8 for 0805, 0.65 for 1206), a smooth stand-in for vendor curves. Settling to N bits is |error| ≤ ½ LSB, ideally $\tau \ln 2^{N+1}$. The energy lost in R is ½ C ΔV^2 for a linear C whatever R is. For a coil τ = L / (R +

DCR), and at turn-off the clamp forces L di/dt = –(iR + Vc), so the switch sees the supply plus the clamp voltage. The τ range takes the corners of tolerance and temperature.

RESULT	WHAT IT IS
τ = R C	(R + source R) C.
63.2 % real	When the real capacitor reaches 63.2 %, and how far from RC.
90 %	Real, and ideal.
Threshold delay	At the typical threshold, and from the lowest threshold on the fastest curve to the highest on the slowest.
Settle 12 bits	Real time to ½ LSB, in τ.
Peak current, Energy, τ range	The current at t = 0 and its power in R, the energy lost and stored, the τ spread.
Coil: τ, Final current, Release time, Switch peak, Stored energy, Pick-up time, Coil hot, τ range	The coil current hot uses copper's +0.393 %/°C.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Peak current vs the driver	I · driver max	1.2 × margin	Within it	Over
Resistor peak power	I^2R · rating	Within it	Over: read its pulse curve	
Capacitor voltage rating	V · rated	1.5 × margin	Within it	Over
C left at the end voltage (DC bias)	X7R: % left	90 % or more	70 % or more	Less
Final value with the leakage	% short of the step	Under 0.1 %	Under 1 %	More
Settled to 12 bits in 100 ms	bits · time needed	All the bits	85 % of them	Fewer: short
Source resistance in τ	% of R	Under 5 %	Under 12.5 %	More
Threshold delay window	min to max	Ratio 1.67:1 or less	Up to 2.86:1	More
Switch voltage at turn-off (coil)	V · rating	1.25 × margin	Within it	Over
Release time (coil)	time · the need	Within it	Up to 1.25 × it	Slow
Coil current hot vs pick-up	I hot · pick-up	1.1 × margin	Equal	Less
Energy into the clamp, Inductance tolerance on τ	(information)			

MESSAGE	WHEN IT SHOWS
"The 0603 X7R keeps 79 % of its capacitance at 5 V, so the charge runs 6 % faster than R C. A 35 V 0603 keeps 90 %. For timing use a larger case, C0G or film."	An X7R losing more than 10 %.
"Peak current 133 mA at t = 0 is above the 20 mA driver limit, so the start of the curve is current-limited. Raise R to 1 kΩ or more."	Over the driver.
"11.7 bits in 100 ms. 12 bits need 108 ms (10.7 τ). Lower R or C, or lengthen the acquisition time."	Not settled in time. When the curve never settles within 12 τ the time reads –.

MESSAGE	WHEN IT SHOWS
"R and the leakage resistance form a divider and the charge ends … % short of the step. Use a capacitor with a higher insulation resistance."	Leakage over 0.1 %.
"Electrolytics leak and drift with temperature and age. A time constant on one is ±20 % at best."	Electrolytic chosen.
"Diode clamp: switch at 12.8 V, release 2.32 ms. A slow release makes the contacts arc longer. A 24 V zener in series cuts the release to 434 µs with 36.8 V on the switch."	Coil with a diode clamp.
"At 70 °C the copper coil resistance is … % higher and the current drops to …, close to the pick-up current. Use a lower-voltage coil or a higher supply."	Coil hot near pick-up.
"Switch peak 42 V at turn-off is above the 40 V rating. Use a lower clamp voltage or a higher-rated transistor."	Over the switch rating.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Rise 10 to 90 % (Fall 90 to 10 %)	Transient of 12 τ with the real capacitor (cbias curve, rleak, tol)	±3 %
Settling to 12 bits, Final value	Not measured	
Threshold crossing	Calculator only (the threshold spread is the receiving chip's)	
Spread over tolerance	Tolerance analysis of the rise time	Inside the τ band
Switch peak at turn-off (coil)	Transient: max of V(SW) after the switch opens	±3 %

BUTTON	WHAT IT DOES
Place circuit and run transient	R C: a pulse source, RS, R1 and C1 with rleak and, for an X7R, its DC-bias curve **cbias**. Coil: the supply, L1 with dcr and dcr_tc, the clamp (D1, D1 and Z1, or RC1), a switch S1 driven to open at 6 τ, SW probed.
Run tolerance analysis	R C: tol on R and C, a Monte Carlo of 100 runs. *Rise time against the tau band* within the calculator's band.
Apply to selected R and C (R and L)	Their values.

SIMPLE	ADVANCED
Resistance, Capacitance, Inductance	R, C, Inductance
Circuit	Circuit
Time to reach	Time to

TRY IT

An RC into a logic input, on an X7R

1. Open the time constant, press **Advanced**: 10 kΩ, 1 µF 0603 X7R 16 V, 50 Ω source, 0 to 5 V, a 2 to 3 V threshold, 12 bits in 100 ms.

YOU SHOULD SEE RC is 10 ms, but the real capacitor reaches 63.2 % at 9.42 ms (−6.3 %) and 90 % at 20.4 ms against 23.1 ms ideal: the X7R keeps only 79 % of its capacitance at 5 V. The threshold is crossed at 6.66 ms, anywhere from 4.3 to 9.64 ms over the tolerances and threshold spread. 12 bits settle in 87.7 ms. Switch the capacitor to C0G and 12 bits need 108 ms: the check turns amber.

TRY IT

A relay coil and its clamp

1. Set **Circuit** to **L / R (coil)**: 0.5 H, 400 Ω, 12 V, diode clamp.
2. Compare the rows of **Clamps compared**.

YOU SHOULD SEE τ 1.25 ms, 30 mA, pick-up at 75 % after 1.73 ms. The diode releases in 2.32 ms with 12.8 V on the switch. A 24 V zener releases in 434 µs at 36.8 V. A 1 kΩ resistor takes 822 µs but puts 42 V on a 40 V switch: that check fails.

Sources. First-order step response (any circuit theory text), TI's Analog Engineer's Pocket Reference for settling to N bits, and TE Connectivity's note on relay coil suppression for the clamps. The tests check 63.2 %, ln 10, settling, the ½ CV^2 loss, an 0603 X7R at 5 V (79 %), the leakage divider, the coil turn-off against an independent integration, and the placed circuits against bspice.

54 Attenuator pads

54.1 Simple: Pi and T pads 485
54.2 Advanced: four pads and their limits 486

Resistive pads that lose a set number of decibels while matching the impedance on both sides: to tame a hot signal, isolate a mixer or a cable, or match 75 Ω to 50 Ω. The Simple view gives symmetric Pi and T pads. The Advanced view adds the bridged T and the minimum-loss L pad, unequal ports, the power in each resistor, the tolerance and the package parasitics. Group Circuit. Search words include attenuator, pad, pi pad, t pad, db, matched and 50 ohm.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

54.1 Simple: Pi and T pads

CHOICE	OPTIONS	WHAT IT DOES
Pad	**Pi pad**, T pad	
Part values	Exact, Nearest E12, **Nearest E24**, Nearest E96	Rounded to the nearest of the series.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Attenuation	dB	10	
Impedance	Ω, kΩ	50	Source and load.

With $K = 10^{dB/20}$: Pi R1 = R3 = Z (K + 1) / (K – 1) to ground and R2 = Z (K^2 – 1) / 2K in series. T R1 = R3 = Z (K – 1) / (K + 1) in series and R2 = 2ZK / (K^2 – 1) to ground.

RESULT	WHAT IT IS
R1, R3 and R2	Rounded to the series (orange).
Attenuation	What the rounded pad gives between Z and Z.
Error	Attenuation given minus asked.
Input impedance	Of the rounded pad with Z at the other end.

A table **By series** compares Exact, E12, E24 and E96 (values, attenuation, error, input Z). *"Enter an attenuation above 0 dB."* shows at 0 dB or less.

BUTTON	WHAT IT DOES
Place and run AC analysis	V1 (1 V, 1 kHz), RS = Z, the pad, RL = Z, IN and OUT probed, an AC sweep 10 Hz to 1 MHz. Measurement *Pad gain at 1 kHz* within ±0.02 dB of –(attenuation + 6.02 dB): the matched source halves the voltage.
Place as circuit	The same with no analysis.
Apply to selected resistors	With three resistors selected: R1, R2, R3.

TRY IT

A 10 dB, 50 Ω Pi pad

1. Open the attenuator pads: Pi, 10 dB, 50 Ω, E24.
2. Press **Place and run AC analysis**.

YOU SHOULD SEE R1 = R3 = 100 Ω and R2 = 68 Ω (exact 96.2 Ω and 71.2 Ω). They give 9.63 dB, an error of –0.37 dB, and 50.33 Ω in. OUT reads 15.65 dB below the source and the measurement passes.

54.2 Advanced: four pads and their limits

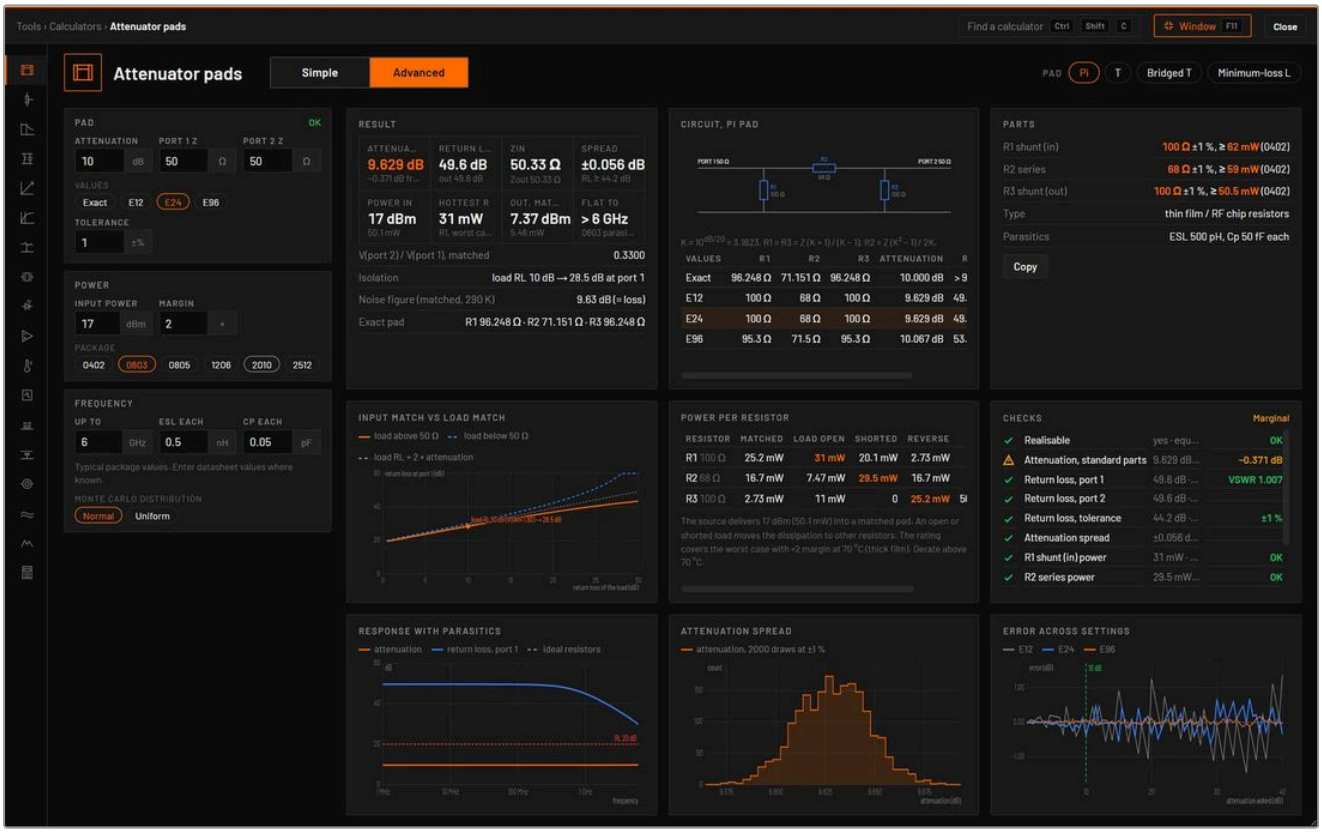


Figure 54.1 The attenuator pads' Advanced view in full screen: a 10 dB Pi pad in E24 values with its match, the power per resistor, the spread, the response with parasitics and the checks.

CHOICE	OPTIONS	WHAT IT DOES
Pad	**Pi**, T, Bridged T, Minimum-loss L	The L pad matches two impedances with the least loss: with equal ports it sets 75 Ω and 50 Ω.

TAB	ITS DOT	CARDS
Design	The worst check.	Result, Circuit, Parts, Values by series.
Power	Green when every resistor's need fits its package, else amber.	Power per resistor, Checks.
Match and tolerance	Green when the worst return loss of the Monte Carlo is 20 dB or more.	Input match vs load match, Attenuation spread, Values by series, Error across settings.
Frequency	Amber when the response drifts below the top frequency.	Response with parasitics.
Verify in simulation	None.	Calculator vs simulation.

When the pad cannot be built only Design shows, with a red dot and the reason.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Attenuation (Loss for the L pad, SOLVED)	dB	10	Group *Pad*. Its badge says *OK* or *Cannot be built*.
Port 1 Z, Port 2 Z	Ω	50, 50	The bridged T uses port 1 for both.
Values		Exact, E12, **E24**, E96	
Tolerance	±%	1	
Input power	dBm	17	Group *Power*: the source's available power into a matched pad.
Margin	×	2	On each resistor's worst power.
Package		0402, **0603**, 0805, 1206, 2010, 2512	Rating at 70 °C, ESL and Cp: 0402 63 mW, 0.4 nH, 0.03 pF … 2512 1 W, 1.5 nH, 0.2 pF.
Up to	GHz	6	Group *Frequency*: the top frequency.
ESL each, Cp each	nH, pF	0.5, 0.05	Typical package values. Enter datasheet values where known.
Monte Carlo distribution		**Normal**, Uniform	

How it works it out. Exact values from the pad's Z-parameters ($Z11 = Z1\,(1 + A^2) / (1 - A^2)$, $Z22$ likewise, $Z21 = 2A\,\sqrt{(Z1\,Z2)} / (1 - A^2)$, $A = 1/K$): T $R1 = Z11 - Z21$, $R2 = Z21$, $R3 = Z22 - Z21$, and Pi from their dual. Bridged T: $R1 = R2 = Z$, $R3 = Z\,/\,(K - 1)$, $R4 = Z\,(K - 1)$. Minimum-loss L: $Rseries = \sqrt{(Zh\,(Zh - Zl))}$ on the high side, $Rshunt = Zl\,\sqrt{(Zh\,/\,(Zh - Zl))}$, loss $20\log(\sqrt{\rho} + \sqrt{(\rho - 1)})$ with $\rho = Zh/Zl$. The rounded pad is then solved by nodal analysis for the attenuation, the return loss at both ports, the power in each resistor for a matched, open, shorted and reversed load, the response with ESL and Cp, and a Monte Carlo of 2000 draws.

RESULT	WHAT IT IS
Attenuation	Of the standard-value pad, and the difference from what was asked.
Return loss	Port 1 and port 2 (capped at 99 dB).
Zin	And Zout.
Spread	The worst attenuation change of the Monte Carlo, and the worst return loss.
Power in, Out, matched	dBm and W.
Hottest R	The worst-case power of the hottest resistor. Amber when one needs more than its package.
Flat to	The frequency where the attenuation moves 0.5 dB or the return loss drops below 20 dB, or *> 6 GHz*.

Under the tiles: the exact pad values, the voltage ratio, the isolation (a 10 dB return-loss load shows 10 dB plus twice the pad's loss at port 1) and the noise figure (equal to the loss at 290 K). **Power per resistor** is a table of the four load cases with the hottest marked and the package each needs.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Realisable	yes or no · the minimum loss	Yes		Negative resistors
Attenuation, standard parts	dB · asked	Within 0.1 dB	Within 0.5 dB	More
Return loss, port 1 and port 2	dB, with VSWR	30 dB or more	20 dB or more	Less
Return loss, tolerance	worst of 2000 runs	26 dB or more	20 dB or more	Less
Attenuation spread	± dB	Under 0.1 dB	Under 0.3 dB	More
R1 shunt (in) power, and each resistor	worst W · rating × margin	Within the rating with the margin	Within the rating	Over: the package needed
Flat to	frequency · ESL, Cp	Flat to the top	Breaks above a third of it	Lower

MESSAGE	WHEN IT SHOWS
"Minimum loss between 50 Ω and 200 Ω is 11.44 dB. 3 dB needs negative resistors. Set 11.44 dB or more, or use the minimum-loss L pad."	Unequal ports and too little loss.
"A minimum-loss L pad needs unequal port impedances. Use Pi, T or bridged T."	L pad with equal ports.
"R1, R2, R3 exceed the 0402 rating: 619 mW (> 2512 with ×2 margin), … Worst case: load open."	A resistor over its package.
"Above 4.36 GHz the 0603 ESL and Cp shift the attenuation and the match. Use a smaller package or thin-film RF resistors."	Not flat to the top frequency.
"Bridged T is symmetric. Both ports use the port 1 impedance."	Bridged T with unequal ports.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Gain of V(OUT) at 1 kHz	AC with a Z1 source and a Z2 load	±0.02 dB
Input match	AC, gain of V(IN) = 20 log |Zin / (Z1 + Zin)|	±0.05 dB
Gain of V(OUT) at the top frequency	AC to the top frequency with esl and cp on each pad resistor	±0.05 dB
Gain of V(OUT), worst case	Worst-case AC with tol on each pad resistor	Every corner inside
Power per resistor	Calculator only (V^2/R of the node voltages the AC run checks)	

BUTTON	WHAT IT DOES
Place and run AC	V_PAD behind RS = Z1, the pad, RL = Z2, IN and OUT probed, 10 Hz to 1 MHz. Measurements *Pad gain at 1 kHz* and *Pad input match*.
Place and run with parasitics	esl and cp on each pad resistor, AC from 1 MHz to the top frequency.
Place and run worst case	tol on the pad resistors, a worst-case AC of 200 runs. *Pad gain at 1 kHz, worst case* between the 2^n tolerance corners.
Place circuit	The circuit only.

SIMPLE	ADVANCED
Attenuation	Attenuation
Impedance	Port 1 Z and Port 2 Z
Pad (Pi, T)	Pad
Part values	Values

TRY IT

Where the power goes

1. Open the attenuator pads, press **Advanced**, and look at the **Power** tab: Pi, 10 dB, E24, 17 dBm, 0603.
2. Set Input power to **30** and Package to **0402**.

YOU SHOULD SEE At 17 dBm the hottest resistor is R1 with 31 mW when the load is open (25.2 mW matched). At 30 dBm every resistor fails: R1 needs 619 mW, and the warning names a 2512 as the package each needs with the ×2 margin.

Sources. Reference Data for Radio Engineers (ITT) for the Pi, T and bridged T, and the minimum-loss L pad formula. The tests check the published 50 Ω tables, the L pad 75 to 50 Ω (43.30 Ω and 86.60 Ω, 5.72 dB), the power per resistor by hand, and the placed pads against bspice's AC within 0.02 dB.

55 LED resistor and LED driver

55.1 Simple: the series resistor 490
55.2 Advanced: the LED driver 492

The current an LED string draws and the part that sets it. The Simple view sizes the series resistor from the supply, the LED's datasheet forward voltage and the current you want. The Advanced view designs the driver over the supply range, the Vf bin and the ambient: a resistor, a current sink (op-amp, MOSFET and sense resistor) or a constant-current regulator, with parallel strings, self-heating, PWM and the light it gives. Group Parts. Search words include led, resistor, series, forward voltage, current limit and indicator.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

55.1 Simple: the series resistor

CHOICE	OPTIONS	WHAT IT DOES
LED colour	**red**, orange, yellow, green, blue, white, uv, ir	Sets the LED model's emission coefficient N and series resistance Rs, as the LED part does: red, orange and yellow N 1.9 and 2 Ω, green 2.0 and 2 Ω, blue, white and UV 2.6 and 2 Ω, infrared 1.6 and 1 Ω.
Resistor series	E12, **E24**, E96	

FIELD	UNIT	DEFAULT	WHAT IT DOES
Supply voltage	V	5	Across the resistor and the LEDs together.
LED forward voltage	V	2.0	At the test current below (red about 2, green 2.1, blue and white 3.2). Reads a selected LED's vf.
LED test current	mA, A	20 mA	The current the datasheet gives the forward voltage at. Reads a selected LED's if_test.
LEDs in series		1	1 to 20 (at most 50 are worked out).
LED current	mA, A	10 mA	SOLVE. The current you want, or the current a given resistor gives.
Resistor	Ω, kΩ	330 Ω (solved)	SOLVE, solved when the calculator opens: the nearest standard value, or the resistor you have when the current is solved.

The LED is the simulator's own: IS is fitted so the Shockley law gives the datasheet Vf at the test current, and $Vf(I) = n\,Vt\,\ln(I/IS + 1) + I\,Rs$. So Vf is taken at the working current, not at the test current. $R = (Vs - N{\cdot}Vf) / I$. Solving the current finds the current where $N{\cdot}Vf(I) + I{\cdot}R = Vs$.

RESULT	WHAT IT IS

RESULT	WHAT IT IS
Standard value	The nearest value of the series, nearest in ratio (orange).
Exact value, Neighbours in E24	The exact resistor and the two standard values around it.
Current with it	The current the standard value really gives.
LED current	When the current is solved (replaces the four above).
Vf per LED	At the working current.
Resistor power, Resistor rating	I^2R, and the first of 0.1, 0.125, 0.25, 0.5, 1, 2, 3 and 5 W that is at least twice it.
LED power, Supply power	N·Vf·I and Vs·I.

The plot **LED current against voltage** draws the LED curve and the resistor's load line, with the working point marked.

MESSAGE	WHEN IT SHOWS
"Supply 1.5 V is below the string voltage 1.95 V at 10 mA. Raise the supply or use fewer LEDs in series."	The string needs more than the supply. The tiles read 0.
"Resistor 301 mW is above the 0.25 W of a quarter-watt part. Use a 1 W resistor or lower the supply."	Over 0.25 W.
"Resistor ... A 1/8 W part runs hot, use 1/4 W or larger."	Over 0.125 W.
"Current 30.2 mA is above the 20 to 30 mA of an indicator LED. Check the LED's absolute maximum current."	Over 30 mA.
"Nearest E24 value gives ..., ... % off target. Use E96 or two resistors in series."	The standard value is more than 10 % off.
"The LEDs drop over 90 % of the supply, so the current follows the supply and Vf closely. A current source holds it steadier."	Little headroom.
"At most 50 LEDs in one string."	More than 50.

BUTTON	WHAT IT DOES
Place as circuit	V_LED, R_LED and the LEDs (with the colour, vf and if_test), a probe *I LED*, in the live view.
Apply to the selected resistor	The resistor used, into the selected resistors.

TRY IT

A red LED on 5 V

1. Open the LED resistor (type **led**): 5 V, red, 2.0 V at 20 mA, one LED, 10 mA, E24.
2. Press **SOLVE** on LED current and type Resistor **330**.

YOU SHOULD SEE Standard value 300 Ω (exact 305 Ω, neighbours 300 Ω and 330 Ω), 10.2 mA with it, Vf 1.95 V at that current, 31.1 mW in the resistor (rating at least 100 mW). With 330 Ω the current is 9.27 mA.

55.2 Advanced: the LED driver

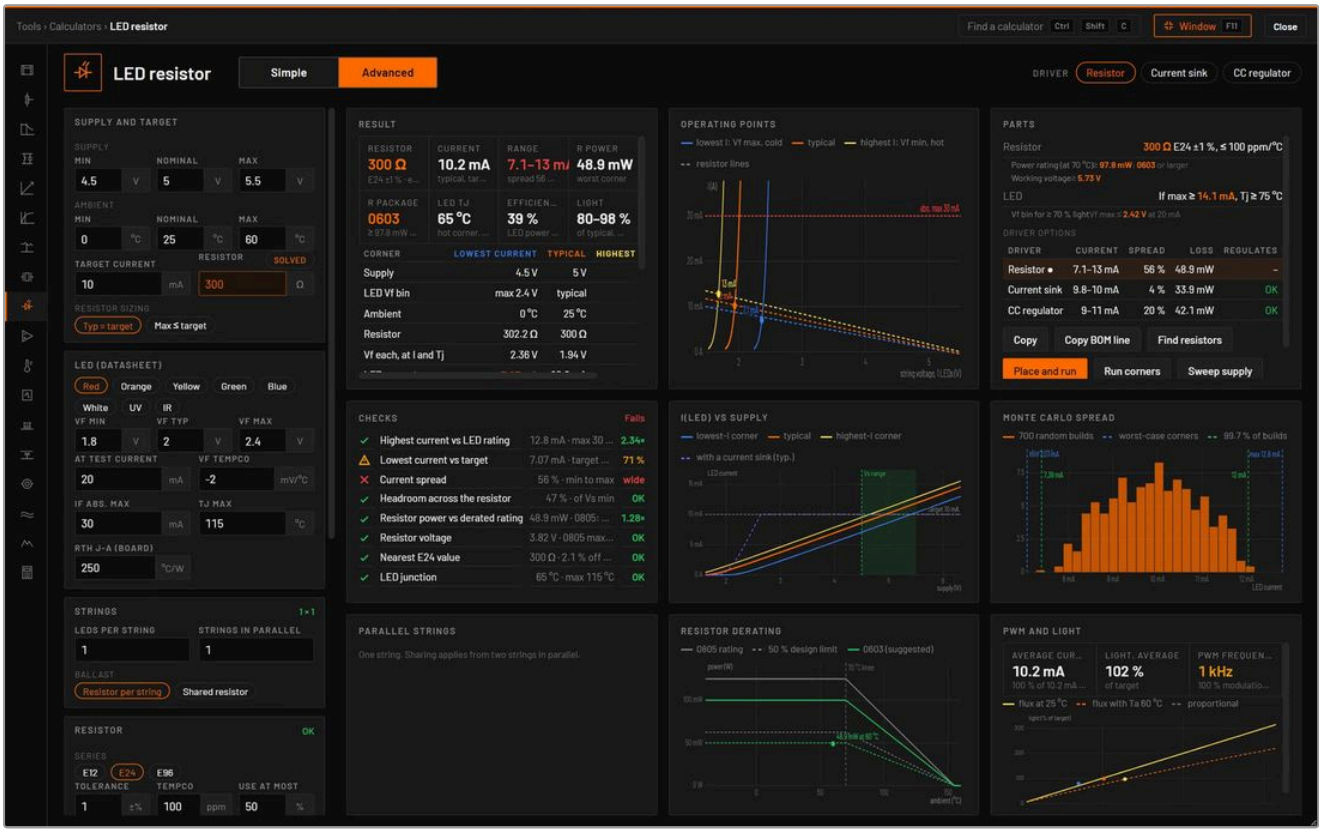


Figure 55.1 The LED driver's Advanced view in full screen: a red LED from 4.5 to 5.5 V over 0 to 60 °C, with the three corners, the operating points, the parts, the checks, the current against supply, the Monte Carlo, the strings, the derating and the light.

CHOICE	OPTIONS	WHAT IT DOES
Driver	**Resistor**, Current sink, CC regulator	Current sink: an op-amp holds a MOSFET's source at Vref across a sense resistor, I = Vref / Rs. CC regulator: a constant-current regulator with its accuracy and headroom.

TAB	ITS DOT	CARDS
Design	The worst check.	Result, Operating points, Parts, Checks.
Corners and spread	Red when the current spread is over 50 %, amber over 30 %.	Corners, Checks, I(LED) vs supply, Monte Carlo spread.
Strings	With two strings or more: red over 20 % imbalance, amber over 10 %.	Parallel strings.
Driver and parts	Resistor: red over its usable rating. Sink or regulator: red when it drops out at Vs min.	Parts, Resistor derating (or Driver loss vs supply), Checks.
PWM and light	Amber with PWM under 1250 Hz.	PWM and light.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES

FIELD	UNIT	DEFAULT	WHAT IT DOES
Supply Min / Nominal / Max	V	4.5 / 5 / 5.5	Group *Supply and target*. Min and max follow at ±10 % of the nominal until you type them.
Ambient Min / Nominal / Max	°C	0 / 25 / 60	
Target current	mA	10	
Resistor, or Sense resistor	Ω	SOLVED	The resistor driver's resistor, or the sink's sense resistor (nearest E96 to Vref / I).
Resistor sizing		**Typ = target**, Max ≤ target	Max ≤ target takes the next value up so the highest corner stays at or under the target.
Colour		Red … IR	Group *LED (datasheet)*. A colour loads typical datasheet figures: red, orange, yellow Vf 1.8 / 2.0 / 2.4 V and −2 mV/°C, green 2.8 / 3.1 / 3.5 V and −3 mV/°C, blue 2.8 / 3.0 / 3.4 V, white 2.8 / 3.0 / 3.3 V and −2.5 mV/°C.
Vf min / typ / max	V	1.8 / 2.0 / 2.4	The Vf bin of the datasheet.
At test current	mA	20	
Vf tempco	mV/°C	−2	
If abs. max, Tj max	mA, °C	30, 115	
Rth j-a (board)	°C/W	250	For self-heating: Tj = Ta + Rth × I × Vf.
LEDs per string, Strings in parallel		1, 1	Group *Strings* (badge 2 × 3). Up to 8 strings.
Ballast		**Resistor per string**, Shared resistor (Driver per string, Shared driver)	
Series, Tolerance, Tempco	, ±%, ppm	E24, 1, 100	Group *Resistor*.
Use at most	%	50	Of the derated package rating.
Package (thick film, rating at 70 °C)		0402 … 2512, **0805**	0402 62.5 mW, 0603 0.1 W, 0805 0.125 W, 1206 0.25 W, 1210 0.5 W, 2010 0.75 W, 2512 1 W. The rating falls to 0 at 155 °C.
Reference, Reference tol., Sense R tol., Min Vds, FET θJA	V, ±%, ±%, V, °C/W	0.5, 1, 1, 0.2, 250	Current sink.
Accuracy, Headroom, θJA	±%, V, °C/W	10, 1.8, 200	CC regulator.
DC or PWM, Duty, Frequency	, %, Hz	DC, 50, 1000	Group *PWM and light*.
Flux at test I, Flux exponent, Flux tempco	lm, , %/°C	7, 1.0, −0.6	Light = flux × $(I / I_{test})^{exponent}$ × (1 + tempco (Tj − 25)).

The corners. Each corner puts every limit the same way: **Lowest current** is Vs min, the Vf max bin, cold and the resistor at +tolerance. **Typical** is nominal. **Highest current** is Vs max, the Vf min bin, hot and the resistor at −tolerance. The LED is the simulator's own with the datasheet tempco added, and its junction temperature is found together with the current. A sink regulates while its headroom is at least Min Vds, else the string is

limited by what is left. A regulator scales down in proportion when it lacks headroom. The Monte Carlo draws 700 builds: supply and ambient uniform over their ranges, Vf normal inside the bin (the bin is ±3σ), the tolerances ±3σ.

RESULT	WHAT IT IS
Resistor, Sense resistor or CC regulator	The part that sets the current.
Current	Typical, and the target.
Range	Lowest to highest corner, and the spread as % of typical. Amber over 30 %, red over 50 %.
R power or Driver loss	At the worst corner (with the duty in PWM).
R package or Headroom	The smallest package whose rating covers the power and voltage, or the sink's headroom at the lowest corner.
LED Tj	At the hot corner.
Efficiency	LED power over supply power, typical.
Light	From the lowest-current corner to the highest, as % of typical, with Tj. The first number belongs to the lowest-current corner, so a hot corner can read like 96–72 %.

The **Corners** table gives supply, Vf bin, ambient, resistor, Vf at the current and Tj, current, Tj, power and brightness for each corner. **I(LED) vs supply** draws the three corners over the supply range with the other driver dashed. **Parallel strings** compares a resistor per string with a shared one for each Vf bin, and the hottest string. **Parts** gives what to order (resistor, its rating at 70 °C, working voltage, how many, the LED's If max and Tj, and the Vf bin for at least 70 % light), the table **Driver options** comparing the three drivers, and **Copy**, **Copy BOM line** and **Find resistors** (which closes the calculator and searches the library for the resistor's value).

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Highest current vs LED rating	I · If max	If max ≥ 1.1 × I	Up to If max	Over
Lowest current vs target	I · target	80 % of target or more	60 % or more	Less
Current spread	% min to max	30 % or less	50 % or less	More
Headroom across the resistor	% of Vs min	20 % or more	10 % or more	Less
Resistor power vs derated rating	W · usable rating	Within it	Up to 1.25 × it	More
Resistor voltage	V · package maximum	1.5 × margin	Within it	Over
Nearest E24 value	R · % off target	Within 5 %	Within 10 %	More
Regulates at Vs min (sink, regulator)	V · Vsat or headroom	1.5 × what it needs	What it needs	Drops out
Driver junction	°C · P × θ	Under 125 °C	Under 150 °C	More
LED junction	°C · Tj max	10 °C under it or more	Under it	Over
String current sharing	% · ballast	10 % or less	20 % or less	More
PWM flicker (IEEE 1789)	frequency	1.25 kHz or more	90 Hz or more	Less

MESSAGE	WHEN IT SHOWS

MESSAGE	WHEN IT SHOWS
"Current spread –31 % / +25 %: the resistor drops 3.06 V of 5 V. Use fewer LEDs per string, a higher supply or a current sink (4 % spread)."	A resistor driver with a spread over 50 %.
"Highest-corner current … is above the 30 mA rating. Use R ≥ … (10 % margin) or a current sink."	Over the LED's rating.
"LED Tj … (Rth … °C/W × …) is above the 115 °C limit. Add copper under the LED or lower the current."	LED too hot.
"3 LEDs need …, the supply is …. Use fewer LEDs per string or a boost driver."	The string needs more than the supply.
"Resistor 72.3 mW at 60 °C. A 0805 allows 62.5 mW at 50 % of its derated rating. Use a 1206 or two resistors in series."	Resistor over its usable rating.
"Regulator drops out at 10.8 V with the Vf max bin: current 8.96 mA. Use one LED fewer per string or a lower reference."	Sink or regulator drops out.
"Shared resistor: string currents differ by … % and the hot string runs away. Use one resistor per string."	Shared ballast over 20 % imbalance.
"PWM 1 kHz at 100 % modulation is above the IEEE 1789 low-risk line. Use ≥ 1.25 kHz (low risk) or ≥ 3 kHz (no observable effect)."	PWM under 1250 Hz.
"Nominal supply … is outside the … to … range. Set min and max around it."	Typed range does not hold the nominal.

Verify in simulation places the driver at a chosen **Corner** (Lowest current, Typical, Highest current) and compares: *LED current (op)* within 3 %, *Vf each* within 30 mV, *LED junction (rth_ja)* within 3 °C, *Resistor power* or *Driver power* within 6 %, and *Current from Vs min to max* (a DC sweep) within 4 %. *Light output* is not simulated: the engine has no photometric model. The placed LED carries the band gap eg for the datasheet tempco. From 0.8.1 the engine sets it by itself (**LED**, p. 289), and the written value keeps older engines right.

BUTTON	WHAT IT DOES
Place and run	The chosen driver at the chosen corner: V_LED, R_LED and the LEDs with colour, vf, if_test, vf_tol, rth_ja, tamb and eg, or the sink (Q_LED, R_SENSE, U_LED, V_REF), or an ideal current source for the regulator, in the split live view with a probe on the LED current.
Run corners	Three circuits side by side (_MIN, _TYP, _MAX), an operating point, and *LED current, lowest current corner* and the others within ±3 % of the calculator.
Sweep supply	A DC sweep of V_LED from 0.9 × Vs min to 1.15 × Vs max, typical corner.
Monte Carlo (200 runs)	tol on the supply, the driver parts and the LED bin, a Monte Carlo of the operating point (seed 1). *LED current* within the 99.73 % limits.
Apply to R	Resistor driver with a resistor selected: its value.

SIMPLE	ADVANCED
Supply voltage	Supply Nominal
LED forward voltage, LED test current	Vf typ, At test current
LEDs in series	LEDs per string
LED current	Target current
LED colour, Resistor series	Colour, Series

TRY IT

Why a resistor spreads, and a sink does not

1. Open the LED resistor and press **Advanced**: 5 V ±10 %, red, 10 mA, 0 to 60 °C.
2. Open **Driver and parts** and read the table **Driver options**.

YOU SHOULD SEE The resistor is 300 Ω. The current runs from 7.07 mA (4.5 V, Vf max bin, 0 °C) to 12.8 mA (5.5 V, Vf min, 60 °C, Tj 65 °C): a 56 % spread, so *Current spread* fails and the warning suggests a current sink. The table shows the sink at 9.8 to 10 mA (4 %) and the CC regulator at 9 to 11 mA (20 %). **Run corners** passes at all three corners.

56 Op-amp gain

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An op-amp gain stage. The Simple view gives the gain, the noise gain, the bandwidth and the input impedance of an inverting, non-inverting, difference or summing stage, with resistor pairs for a target gain. The Advanced view checks the whole stage with a real op-amp: output swing and input range, slew rate and flatness, phase margin with a capacitive load and the isolation resistor, the DC error budget over temperature, noise, the step response and the tolerance, and it picks the op-amp from the library's 5,872 usable models. Group Parts. Search words include op amp, operational amplifier, gain, inverting, non-inverting, difference, summing, gbw and feedback.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

56.1 Simple: gain and bandwidth

CHOICE	OPTIONS	WHAT IT DOES
Stage	**Inverting**, Non-inverting, Difference, Summing	
Resistor series	E12, **E24**, E96	Shown while Rf is solved.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Target gain	V/V	10	Shown while Rf is solved. Inverting and difference stages give 0 or more, non-inverting 1 or more.
R1	Ω, kΩ, MΩ	10 kΩ	The input resistor (non-inverting: the resistor to ground).
R2	Ω, kΩ, MΩ	10 kΩ	Summing: the second input resistor.
Rf	Ω, kΩ, MΩ	100 kΩ (solved)	SOLVE, solved when the calculator opens. In the difference stage R4 has the same value.
Gain-bandwidth product	kHz, MHz	1 MHz	Reads a selected op-amp's gbw.
Open-loop DC gain	V/V	100000	Reads a selected op-amp's gain.
Supply, plus and minus	V	15	Sets the rails of the placed circuit (at least ±3 V).

Inverting G = –Rf/R1 and Zin = R1. Non-inverting G = 1 + Rf/R1. Difference Vout = Rf/R1 (V+ – V–) with R3 = R1 and R4 = Rf, Zin = 2 R1. Summing Vout = –Rf (V1/R1 + V2/R2). The noise gain NG = 1 + Rf/R1 (summing 1 + Rf/(R1 ‖ R2)), the bandwidth fc = GBW / NG (single pole), and H(f) = G / (1 + NG/Aol(f)).

RESULT	WHAT IT IS
Gain, Gain in dB	Negative for inverting and summing (orange).
Gain from input 2	Summing.
Rf exact, Rf nearest E24	When Rf is solved: the nearest value and the gain it gives.
Noise gain, Bandwidth (–3 dB), Input impedance	Non-inverting: *the op-amp input, very high*.
DC gain error	NG / AoI.

With Rf solved, a table **Closest E24 pairs** lists the six pairs (R1 from 1 kΩ to 100 kΩ) with the smallest gain error. The **Closed-loop response** plot marks the –3 dB point and the GBW.

MESSAGE	WHEN IT SHOWS
"A non-inverting stage cannot have a gain under 1."	Target under 1 (Rf is then set equal to R1).
"A resistor under 1 kΩ loads the output hard. Scale both resistors up by the same factor."	R1 or Rf under 1 kΩ.
"A resistor over 1 MΩ adds noise and makes the input bias current matter. Scale both down."	Over 1 MΩ.
"The bandwidth is 9.01 kHz. A signal near it loses gain and shifts in phase. Use an op-amp with more gain-bandwidth."	Bandwidth under 20 kHz.
"The finite open-loop gain costs … % of the gain. Use an op-amp with more DC gain or a lower stage gain."	DC gain error over 1 %.
"R1 and R2 differ by 900 %. Input 1 is weighted –100 V/V and input 2 –10 V/V. Use equal resistors for an equal sum."	Summing with R1 and R2 more than 50 % apart.

BUTTON	WHAT IT DOES
Place and run AC	U_OA (gbw and gain from the fields) on ± rails, R1_OA and RF_OA (R3_OA, R4_OA for a difference, R2_OA and a second source for summing), a 10 kΩ load, a 1 kHz source, OUT probed, an AC sweep at 20 points per decade. *Gain* within ±0.1 dB and *Bandwidth* (bw3db) within ±10 % of fc.
Apply to the selected resistors	Sorted by name: R1, Rf (summing R1, R2, Rf).

TRY IT

A gain of 10

1. Open the op-amp gain (type **op amp**): inverting, target 10, R1 10 kΩ, GBW 1 MHz.
2. Switch Stage to **Non-inverting** and press **Place and run AC**.

YOU SHOULD SEE Inverting: –10 V/V (20 dB), Rf 100 kΩ, noise gain 11, 90.9 kHz, Zin 10 kΩ, 0.011 % gain error. Non-inverting: Rf exact 90 kΩ, nearest E24 91 kΩ (10.1 V/V), and the pair 3 kΩ and 27 kΩ gives exactly 10. The run reads 20 dB and 100 kHz and both pass.

56.2 Advanced: the real stage

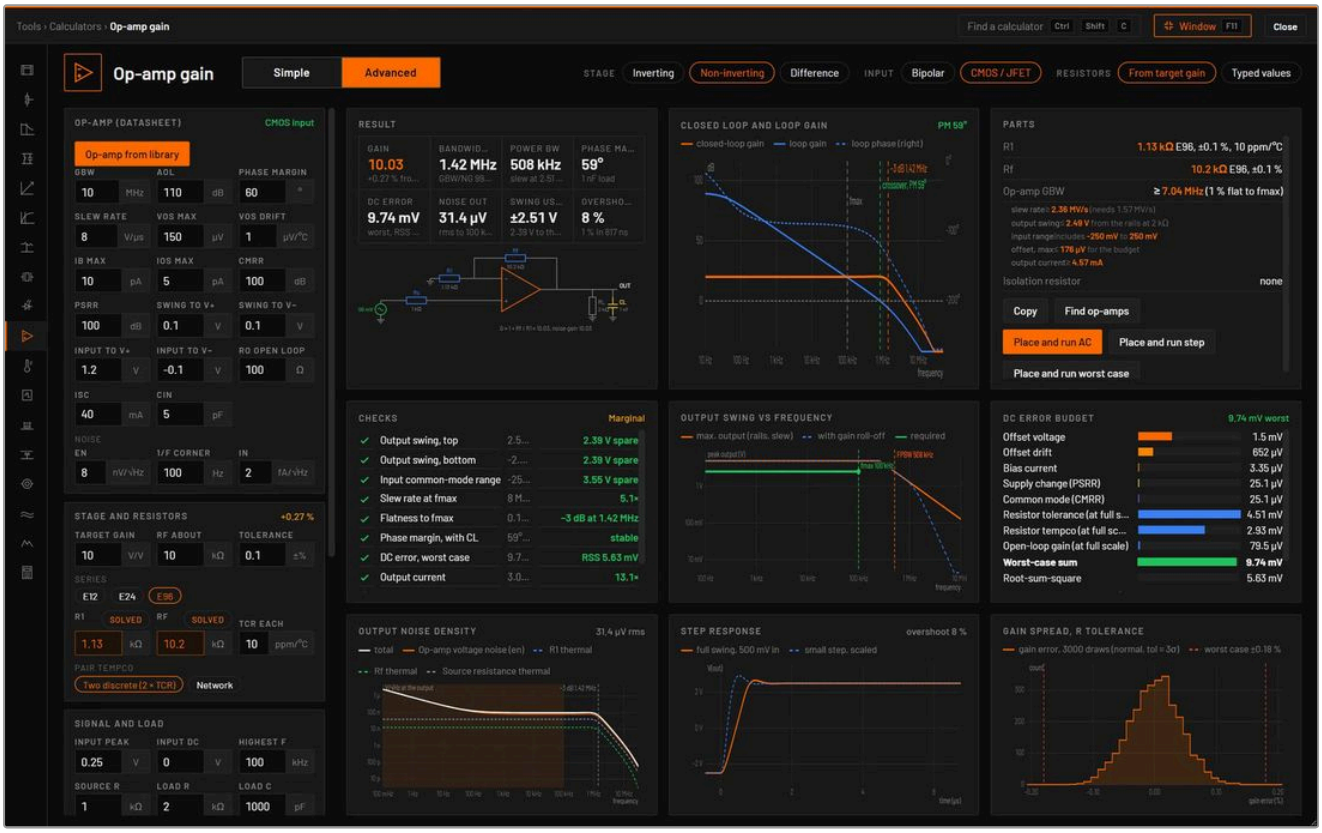


Figure 56.1 Op-amp gain, Advanced, in full screen: a non-inverting gain of 10 on ±5 V driving 2 kΩ and 1 nF, with the closed loop and loop gain, the parts, the checks, the swing against frequency, the DC error budget, the noise, the step response and the gain spread.

CHOICE	OPTIONS	WHAT IT DOES
Stage	Inverting, **Non-inverting**, Difference	The Advanced view has no summing stage: choosing Summing in the Simple view leaves the Advanced stage as it was.
Input	Bipolar, **CMOS / JFET**	How the bias current changes with temperature.
Resistors	**From target gain**, Typed values	From target gain picks R1 and Rf from the series (SOLVED). Typing R1 or Rf switches to Typed values.

TAB	ITS DOT	CARDS
Design	The worst check.	Result, Stage, Checks, Parts, Output swing vs frequency.
Bandwidth and stability	Green with a phase margin of 45° or more, amber 30° or more, else red.	Closed loop and loop gain, Step response, Stability.
DC accuracy	Green when the worst-case DC error is within the limit, else amber.	DC error budget, Gain spread.
Noise	Green with an SNR of 90 dB or more, else amber.	Output noise density, Noise by source.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES

FIELD	UNIT	DEFAULT	WHAT IT DOES
Op-amp from library			Group *Op-amp*: opens the picker. With a part chosen: its name, input type and rating, how its vendor model runs, and **Change**, **Typed values**, and **Est. max** or **Typical** for the worst case.
Target gain, Rf about, Tolerance	V/V, kΩ, ±%	10, 10, 0.1	Group *Stage and resistors*. Its badge is the gain error of the standard parts. The pair search looks for Rf within 3.2 × of Rf about.
Series		E12, E24, **E96**	
R1, Rf	kΩ	SOLVED	
TCR each, Pair tempco, Tracking	ppm/°C	10, **Two discrete (2 × TCR)** or Network, 5	
R, + input	kΩ	0	Inverting: a resistor from + to ground that cancels the bias current (0 = grounded).
Input peak, Input DC (Input CM), Highest f	V, V, kHz	0.25, 0, 100	Group *Signal and load*.
Source R, Load R, Load C, Riso, Cf across Rf	kΩ, kΩ, pF, Ω, pF	1, 2, 1000, 0, 0	With an inverting or difference stage the source resistance is part of R1.
V+, V–, Reference, Supply change	V	5, –5, 0, 0.25	Group *Supply, temperature, budget*.
T min, T max, DC error limit (out)	°C, °C, mV	–40, 85, 10	
GBW, Aol, Phase margin, Slew rate	MHz, dB, °, V/µs	10, 110, 60, 8	Group *Op-amp (datasheet)*, or *Op-amp, fields from the part* (marked PART).
Vos max, Vos drift, Ib max, Ios max	µV, µV/°C, pA, pA	150, 1, 10, 5	
CMRR, PSRR	dB	100, 100	
Swing to V+, Swing to V–, Input to V+, Input to V–	V	0.1, 0.1, 1.2, –0.1	The output's distance from each rail at the load, and the input range (here –5.1 V to 3.8 V).
Ro open loop, Isc, Cin	Ω, mA, pF	100, 40, 5	
en, 1/f corner, in	nV/√Hz, Hz, fA/√Hz	8, 100, 2	
Integrate, From, Monte Carlo distribution		**Signal band (to fmax)** or Full bandwidth, 0.1 Hz, **Normal** or Uniform	Group *Noise band*.

How it works it out. The stage is solved as a circuit (nodal analysis): the source, Rs, R1, Rf with Cf, Cin on both inputs, the op-amp as a controlled source with two poles (the dominant one at GBW/Aol and a second set by the phase margin), Ro, Riso and the load. That gives the closed-loop gain, the loop gain with its crossover and phase margin (with and without the load capacitance), the –3 dB point, the peaking, and each noise source's own

transfer. The view draws a light pass first and the full one about 20 ms later (190 points, the step, the Riso search and the Monte Carlo), so the overshoot reads … for a moment.

- **Resistors**: the series pairs with Rf within 3.2 × of Rf about, R1 = Rf/(G – 1) (non-inverting) or Rf/G – Rs, the six with the smallest error, the first used. With an inverting or difference stage the source resistance counts in R1.
- **DC error budget**, output-referred and worst case over T min to T max (ADI MT-037, MT-038, MT-068): offset, drift, bias current (a CMOS or JFET Ib doubles every 10 °C above 25 °C), PSRR, CMRR, the resistor mismatch for a difference stage, and the gain terms at full scale (tolerance, tempco, open-loop gain, Riso), as a sum and as a root-sum-square.
- **Isolation resistor**: TI SBOA418's start value, then a bisection on the circuit for the target margin (60°, or 3° under the margin without the load).
- **Noise** (ADI MT-049, MT-050): en with its 1/f corner, the current noise at each input, and the thermal noise of each resistor, each through its own transfer, integrated over the band with no 1.57 factor.
- **Gain spread**: 3000 draws of R1 and Rf. **Step**: the same circuit integrated with the slew rate and the swing limits, a small and a full step.

RESULT	WHAT IT IS
Gain	Of the standard pair, and how far from the target.
Bandwidth	–3 dB, and GBW/NG.
Power BW	Slew rate over 2π × peak. Red below the highest frequency.
Phase margin	With the load capacitance. Amber under 45°, red under 30°.
DC error	Worst case, and RSS. Amber over the limit.
Noise out	RMS over the band.
Swing used	± peak, and the room left to the limit. Red when it clips.
Overshoot	Of the small step, with the 1 % settling. *oscillates* when the loop is unstable.

The **Parts** card asks for R1 and Rf (series, tolerance, TCR), the bias-cancelling resistor or the matched R3 and R4, the op-amp's GBW (NG × fmax / 0.1425 for 1 % flatness), slew rate (1.5 × the need), output swing, input range, the largest offset the budget allows, the output current, and the isolation resistor, with **Copy** and **Find op-amps**. The **Stability** table gives the crossover, the phase margin with and without the load, the output pole Ro·CL, the input pole, the Riso start value (TI SBOA418) and the Riso for the target margin found on this circuit. The **DC error budget** shows offset terms (orange) and gain terms at full scale (blue).

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Output swing, top (and bottom)	output · limit	0.1 V spare or more	0 to 0.1 V	Clips
Input common-mode range	range · allowed	0.1 V spare or more	0 to 0.1 V	Outside
Slew rate at fmax	SR · 2π fmax Vo	1.5 × or more	1 × or more	Less
Flatness to fmax	gain change	Within 1 %	Within 10 %	More

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Phase margin, with CL	PM · CL	45° or more: stable	30° or more: rings	Less: unstable
DC error, worst case	error · allowed	Within it	Up to 1.43 × it	More
Output current	peak · Isc	2 × or more	1 × or more	Less
Gain, standard parts	gain · target	Within the tolerance	Within 1 %	More
Supply rating (library part)	rating · rails	1.05 × or more	Equal	Over rating
Noise in band	rms · SNR	90 dB or more	70 dB or more	Less

MESSAGE	WHEN IT SHOWS
"Output range –10 V to 10 V exceeds the swing –2.9 V to 2.9 V at 600 Ω. Lower the gain or the input, or use a rail-to-rail output."	The output clips.
"Input common mode … is outside the input range …. The output distorts or phase-reverses. Move the bias point or use a part whose input range includes that rail."	Outside the input range.
"A 10 V peak sine at 200 kHz needs 12.6 MV/s. The part slews 2 MV/s, so the output is slew-limited above 31.8 kHz. Use a faster part or keep the swing under 1.59 V peak."	Slew-limited.
"Phase margin 29° with 100 nF (89° without). Small-step overshoot 42 %. Riso 39 Ω between output and capacitor gives 60° (SBOA418 start value 6.11 Ω)."	Margin under 45° (or: *Raise the noise gain or reduce CL.*).
"The rails span …, above the … V rating of the part. Lower the rails or pick a part rated for them."	A library part rated below the rails.
"R1 20 Ω is below the source resistance 1 kΩ, so the source sets most of the gain. Raise Rf about to 100 kΩ or more."	Inverting with R1 under Rs. Otherwise with Rs: *Rs … is in series with R1 and sets part of the gain.*
"Bias current is a large share of the error. Add … (R1 ‖ Rf) in series with the + input to cancel Ib. Ios remains."	Bipolar input.
"A resistor above 1 MΩ adds noise, and with Cin it puts a pole near the crossover. Scale both resistors down."	
"No resistor pair for gain …. A non-inverting stage has a gain of at least 1. Typed values shown."	

56.3 The op-amp picker

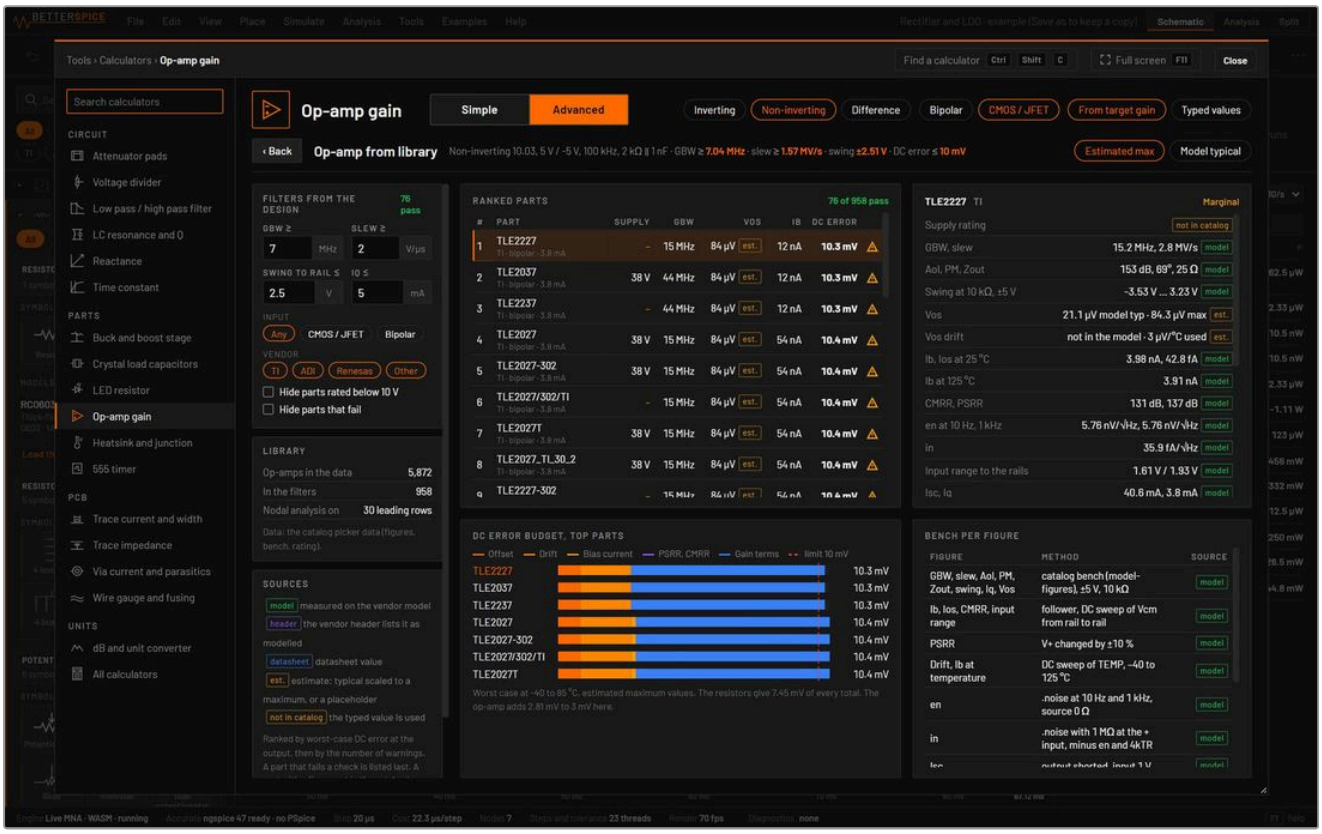


Figure 56.2 Op-amp from library for the default stage: the filters set from the design, the library counts, the ranked op-amps with their worst-case DC error, and the sheet of the selected part with the source of every figure.

Open it with **Op-amp from library**, **Find op-amps** on the Parts card, or **Change**. The head shows what the stage needs (*Non-inverting 10, 5 V / –5 V, 100 kHz, 2 kΩ ‖ 1 nF · GBW ≥ 7.04 MHz · slew ≥ 1.57 MV/s · swing ±2.51 V · DC error ≤ 10 mV*) and **Worst case from**: **Estimated max** or Model typical.

The data. The catalogue has 6,278 op-amp models. The 5,872 with a gain-bandwidth figure are in the picker: TI (with Burr-Brown and National) 2,589, ADI (with Linear Technology and Maxim) 2,302, Renesas (Intersil) 279, others 702. GBW, slew, Aol, phase margin, Zout, swing, Iq and Vos come from the catalogue's bench on each vendor model at ±5 V into 10 kΩ. 5,278 also have figures measured on the vendor model with ngspice for this picker: Ib and Ios, CMRR and the input range (a DC sweep of the common mode), PSRR (V+ changed by ±10 %), drift and Ib at temperature (a sweep from –40 to 125 °C), en at 10 Hz and 1 kHz, in, and Isc. 1,665 have a supply rating from the datasheet or ti.com page. The **Bench per figure** card lists how each figure was measured.

FIELD	UNIT	DEFAULT	WHAT IT DOES
GBW ≥	MHz	NG × fmax / 0.1425 (7 MHz here)	Group *Filters from the design*, badge the number that pass. The four numbers follow the design until you type in one.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Slew ≥	V/µs	1.25 × the need (2 V/µs here)	
Swing to rail ≤	V	the room to the rails (2.5 V here)	The part's output swing to a rail, from its ±5 V bench.
Iq ≤	mA	5	A part with no Iq passes.
Input		**Any**, CMOS / JFET, Bipolar	From the part's Ib: under 1 nA is CMOS / JFET.
Vendor		TI, ADI, Renesas, Other	
Hide parts rated below 10 V, Hide parts that fail		off	

The **Library** card counts *Op-amps in the data* (5,872), *In the filters* (958 for the default stage) and *Nodal analysis on 30 leading rows*.

How the ranking works.

1. **Filters.** Every usable part is tested against GBW, slew, Iq, vendor, swing to the rails, and the rating if that box is ticked.
2. **Closed forms on every part that passes the filters.** The part's figures replace the typed ones and the stage is worked out with the same R1 and Rf for every part: output swing, input range, slew rate, the DC error budget, output current, supply rating. A figure the catalogue doesn't have is filled, for the ranking only, with the worse of your typed value and the library's 90th percentile, and the part is listed after every part that has all its figures. A part fails when any of these checks fails.
3. **Order.** Passing parts first, then parts with every figure, then the smallest worst-case DC error at the output, then the fewest warnings.
4. **Nodal analysis on the leading 30.** The first 30 rows (and the selected one) are solved again as a circuit, which adds the phase margin with the load, the noise and the flatness, and are sorted again.

The table shows the 30 analysed rows: the part (vendor group, input type, Iq), its supply rating (red below the rails), GBW, Vos, Ib, the worst-case DC error (with a *gaps* tag when a figure was filled in) and the status. Full screen adds the slew rate, en at 1 kHz, the phase margin with the load, the output noise and how its vendor model simulates. Hovering a row names its failed or marginal checks. The 30 are a view, not a limit: every part in the filters is ranked, so narrow the filters to bring a part into the 30.

Use this part fills the op-amp fields (marked PART) from the part: GBW, Aol, phase margin, slew rate, Ro, swing and input range, Isc, en, the 1/f corner, in and the input type as measured (tag **model**), and the rating (**datasheet** or **header**). With **Estimated max** the typical model values are scaled to an estimated maximum until the catalogue holds the datasheet maxima: Vos ×

4, drift, Ib and Ios × 3, CMRR and PSRR – 10 dB (tag **est.**). A figure the model does not give gets a placeholder and a note: 3 mV offset, 3 µV/°C drift, 20 nV/√Hz noise, 80 dB PSRR. The detail card lists every figure with its source, four tiles (DC error, noise, phase margin, swing spare), **Show what is placed** and **Place with this model**. **DC error budget, top parts** compares the seven best.

> **NOTE** **Typical against maximum** Vendor models give typical values. The worst case needs the datasheet maximum, so with Estimated max the offset of a part whose model has none is a 3 mV placeholder: type the datasheet figure in the Op-amp fields to replace it.

56.4 Verify in simulation

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Gain at 1 kHz	AC, gain of V(OUT) at min(1 kHz, f3/100)	±0.1 dB
–3 dB bandwidth	AC, bw3db of V(OUT)	±3 %
Phase margin	Loop gain, broken at the output pin	±1°
Output noise	Noise from the From frequency to the band end	±5 %
Overshoot, small step	Transient: a step of 2 % of the swing	±5 points
Rise time, full swing	Transient: the full step (fall time for an inverting stage)	±15 %
Output, worst case	Worst-case operating point with tol on R1, Rf (R3, R4) and vos_max on the op-amp	Every corner inside

BUTTON	WHAT IT DOES
Place and run AC	A 5-pin op-amp carrying every datasheet value (gbw, gain, pm, slew, vos, vos_tc, ib, ios, cmrr_db, psrr_db, rail and input-range limits, rout, isc, cin, en, en_fc, inoise) on V+ and V– flags, the source behind Rs, R1 and Rf (Cf) with tol and tc1, RL and CL behind Riso, and an AC sweep at 40 points per decade. *Gain* and *Bandwidth*.
Place and run step	A small step then a full step. *Overshoot, small step* and *Rise 10-90 %, full step*.
Place and run worst case	A DC input of the peak, tol on the resistors and the offset at ±Vos max (bias currents off), a worst-case run of 200 (seed 1). *Output, worst case*.
Place circuit	The stage only.
Place with OPA197	With a library part: its vendor model instead of the datasheet values, and an AC run. Its gain follows the calculator. Its bandwidth and margin come from the vendor model's own poles.
Apply to selection	R1 to the first selected resistor, Rf to the second.

The drift, bias current, PSRR and CMRR terms of the budget stay calculator only.

SIMPLE	ADVANCED
Target gain, R1, Rf, Gain-bandwidth product	Target gain, R1, Rf, GBW (when typed)
Open-loop DC gain	Aol in dB
Supply, plus and minus	V+ and V–
Stage, Resistor series	Stage (not Summing), Series

TRY IT

Gain 10 into 1 nF, then a real op-amp

1. Open the op-amp gain and press **Advanced**: non-inverting, 10, E96 ±0.1 %, ±5 V, 250 mV peak to 100 kHz, 2 kΩ and 1 nF, GBW 10 MHz.
2. Press **Op-amp from library**, select OPA197 and press **Use this part**.

YOU SHOULD SEE R1 1.13 kΩ and Rf 10.2 kΩ give 10.03 (+0.27 %, amber against ±0.1 %). Bandwidth 1.42 MHz, phase margin 59° with 1 nF (85° without), DC error 9.74 mV worst (RSS 5.63 mV) against 10 mV, noise 31.4 µV (SNR 95 dB), overshoot 8 %. The picker has 958 parts in the filters and 76 pass. With OPA197 the margin drops to 41° (rings, Riso 160 Ω suggested) and the DC error rises to 38 mV: its model has no offset, so the 3 mV placeholder × the noise gain fails the budget until the datasheet maximum is typed.

Sources. Horowitz and Hill, *The Art of Electronics* chapter 4, ADI MT-049 and MT-050 (noise), MT-037, MT-038 and MT-068 (DC errors, difference amplifier), TI SBOA418 (isolation resistor). The tests check the single-pole stage, the noise against MT-049, a two-pole buffer's 6.4 % overshoot, the Riso search, the budget terms, the E96 pairs against every pair, the picker's gap handling, and the placed stages (AC, loop gain, noise, step, worst case, and the vendor models of OPA197, OPA2156 and OPAx211 within 0.05 dB) against bspice.

57 555 timer

57.1 Simple: the datasheet formulas 507
57.2 Advanced: four chips, exact timing 509

The 555 as an astable oscillator or a monostable one-shot. The Simple view uses the datasheet formulas. The Advanced view works the timing out exactly for four real chips (NE555, TLC555, LMC555, ICM7555), designs the parts from a target, and checks the tolerance, the drift, the chip's limits and its output. Group Parts. Search words include 555, ne555, timer, astable, monostable, oscillator, pulse, duty and one shot.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

57.1 Simple: the datasheet formulas

CHOICE	OPTIONS	WHAT IT DOES
Mode	**Astable**, Monostable	
Duty	**RA + RB (over 50 %)**, Diode across RB	Astable. A diode across RB gives a duty under 50 %.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Supply	V	5	4.5 to 18 V. Only sets the plotted levels and the placed source: the timing does not depend on it, except with the diode.
RA	Ω, kΩ, MΩ	1 kΩ	Astable. SOLVE, solved when the calculator opens: RA and RB are designed for the frequency and duty.
Diode forward voltage	V	0.7	Diode across RB. 0 gives the datasheet 0.693 RC.
RB	Ω, kΩ, MΩ	10 kΩ	Astable, shown while RA is not solved.
Frequency, Duty cycle	Hz, kHz, %	1000 Hz, 60 %	The target, while RA is solved.
R	Ω, kΩ, MΩ	10 kΩ	Monostable. SOLVE, solved when the mode opens.
Pulse width	µs, ms, s	1.1 ms	Monostable, the target while R is solved.
Timing capacitor C	pF, nF, µF	100 nF	Reads a selected capacitor.

Astable: $f = 1.44 / ((RA + 2\,RB)\,C)$, $t_{high} = 0.693\,(RA + RB)\,C$, $t_{low} = 0.693\,RB\,C$, duty = $(RA + RB) / (RA + 2\,RB)$. With the diode C charges through RA alone toward the supply less the diode drop: $t_{high} = \ln((⅔\,Vcc - Vd) / (⅓\,Vcc - Vd))\,RA\,C$, and duty = $RA / (RA + RB)$ when Vd is 0. Monostable: $t = 1.1\,R\,C$: the output goes high at the trigger and low again when the capacitor reaches ⅔ of the supply. In this view RA (or R) is the solved field, so the 555 is designed from the frequency and duty (or the width).

RESULT	WHAT IT IS
Frequency	Orange.
RA, RB	The designed resistors.
Duty cycle, Period, Output high time, Output low time	
Pulse width, Resistor, Capacitor	Monostable.
Trigger must stay low for less than	Monostable: the pulse width.

The plot shows the output and the capacitor for two periods, with ⅓ and ⅔ of the supply marked (monostable: the trigger, the capacitor and the output).

MESSAGE	WHEN IT SHOWS
"Without the diode the duty is always above 50 %. Add the diode across RB, or invert the output."	A duty at or under 50 % asked without the diode.
"The duty is close to 50 %. Make RB much larger than RA for a square wave, or add the diode across RB for 50 % with RA = RB."	Duty under 55 % without the diode.
"RA below 1 kΩ lets the discharge pin pass 10 mA while it shorts RA. Keep RA at 1 kΩ or more."	RA under 1 kΩ.
"RB below 1 kΩ is outside the datasheet range of 1 kΩ to 10 MΩ."	RB under 1 kΩ.
"RA + RB above 10 MΩ is limited by the threshold input current."	Over 10 MΩ.
"Above about 500 kHz a bipolar 555 drifts from these equations. Use a CMOS 555 and a smaller capacitor."	Over 500 kHz.
"A phase shorter than a few microseconds is limited by the 555 propagation delays, so the real frequency is lower."	A phase under 10 µs.
"R below 1 kΩ draws too much from the supply while the capacitor charges. The datasheet range for R is 1 kΩ to 10 MΩ."	Monostable R under 1 kΩ (over 10 MΩ: limited by the threshold current).
"A timing capacitor under 100 pF is dominated by stray capacitance, so the pulse is not 1.1 R C."	C under 100 pF.

BUTTON	WHAT IT DOES
Place and run a transient	U_555 with V_555 at the supply, 10 nF on CONT, a 10 kΩ load on OUT, RA_555, RB_555 and CT_555 (and D_555 across RB), or R_555, CT_555 and a trigger source for the monostable. Probes *V out*, *V C* (and *V trig*). A transient of 12 periods: *Output frequency* within ±5 % and *Output duty* within ±3 points.
Apply to the selected timing parts	The first selected resistor gets RA (or R), the second RB, the first capacitor C.

TRY IT

A 1 kHz astable

1. Open the 555 timer (type **555**): astable, 1 kHz, 60 %, 100 nF, 5 V.
2. Press **Place and run a transient**.

YOU SHOULD SEE RA 2.89 kΩ and RB 5.77 kΩ: 1 kHz, 60 %, high 600 µs, low 400 µs. The run measures the frequency and duty and both pass. With the diode at 50 % the design is RA 4.99 kΩ and RB 7.21 kΩ.

57.2 Advanced: four chips, exact timing

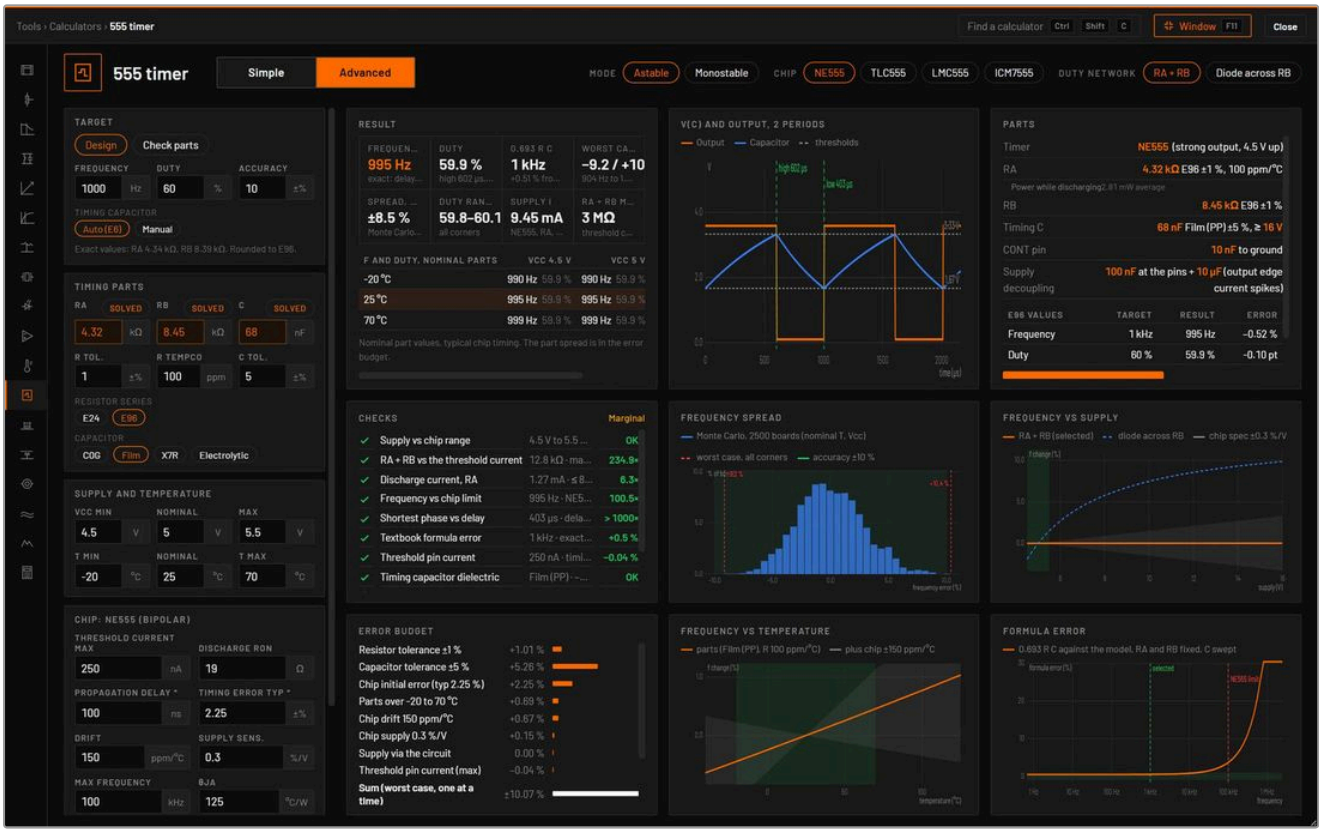


Figure 57.1 The 555's Advanced view in full screen: an NE555 designed for 1 kHz and 60 %, with the corners table, the waveforms, the parts, the checks, the spread, the frequency against supply, the error budget, against temperature and the formula error.

CHOICE	OPTIONS	WHAT IT DOES
Mode	**Astable**, Monostable	Monostable sets C to 100 nF and the chip's monostable figures.
Chip	**NE555**, TLC555, LMC555, ICM7555	Loads that chip's datasheet values into the Chip group.
Duty network	**RA + RB**, Diode across RB	Astable.

TAB	ITS DOT	CARDS
Design	Amber when there is a warning. Red when the circuit cannot oscillate.	Result (tiles, warnings and the corners table), V(C) and output, Parts.
Tolerance and drift	The state of *Worst case vs accuracy*.	Error budget, Frequency spread, Frequency vs temperature, Frequency vs supply.
Chip limits and output	The worst of the chip checks.	Checks, Output and chip power, Formula error.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Design, Check parts		**Design**	Group *Target*. Design works the parts out from the target. Check parts takes the typed parts.
Frequency, Duty, Accuracy	Hz, %, ±%	1000, 60, 10	Astable target. Monostable: Pulse width (10 ms) and Accuracy.
Timing capacitor		**Auto (E6)**, Manual	Auto picks the E6 value that brings the main resistor near 10 kΩ (bipolar) or 100 kΩ (CMOS).
RA, RB (R), C	kΩ, nF	SOLVED in Design mode	Group *Timing parts*. Typed in Check parts mode.
R tol., R tempco, C tol.	±%, ppm/°C, ±%	1, 100, 5	
Resistor series		E24, **E96**	
Capacitor		C0G, **Film**, X7R, Electrolytic	Sets the C tolerance (X7R 10 %, electrolytic 20 %). Electrolytic adds **Leakage (spec max)** in µA.
Diode drop, Drop tempco	V, mV/°C	0.65, −2	With the diode.
Vcc min / Nominal / Max	V	4.5 / 5 / 5.5	Group *Supply and temperature*.
T min / Nominal / T max	°C	−20 / 25 / 70	
Threshold current max, Discharge Ron, Propagation delay, Timing error, Drift, Supply sens., Max frequency, θJA	nA, Ω, ns, ±%, ppm/°C, %/V, kHz, °C/W	from the chip	Group *Chip*, editable. A * after a label marks a value the datasheet does not give (assumed).
Load current (high), VOH min	mA, V	10, 3.5	Group *Output and load*. Monostable adds Trigger pulse (100 µs) and Trigger period (50 ms). CMOS chips add Output R (high).

	NE555	TLC555	LMC555	ICM7555
Technology	bipolar	CMOS	CMOS	CMOS
Supply	4.5 to 16 V	2 to 15 V	1.5 to 15 V	2 to 18 V
Threshold current (max / typical)	250 nA / 30 nA	75 pA / 10 pA	10 pA	10 nA
Discharge Ron	19 Ω	6 Ω	30 Ω *	20 Ω *
Propagation delay	100 ns *	100 ns *	100 ns	100 ns *

	NE555	TLC555	LMC555	ICM7555
Timing error (astable)	2.25 % typ *	1 % typ *	9 % max	2 % typ *
Drift	150 ppm/°C	75 ppm/°C *	75 ppm/°C	150 ppm/°C *
Supply sensitivity	0.3 %/V	0.1 %/V	0.3 %/V	0.3 %/V *
Max frequency	100 kHz	1.2 MHz	3 MHz	500 kHz
Supply current	3 mA	180 µA	150 µA	40 µA
Output resistance (high)	(bipolar drop)	200 Ω	150 Ω *	150 Ω *
Max discharge current	8 mA	10 mA	10 mA	10 mA

The chip presets. * marks a value the datasheet does not give: assumed. θJA is 125 °C/W for all four.

The exact model. The thresholds are ⅔ and ⅓ of Vcc. C charges toward Vcc (Vcc – Vd with the diode) less the pin and leakage current times the charging resistance, and discharges toward the Thevenin voltage of RA against the discharge switch Ron. The propagation delay lets C overshoot both thresholds before the output turns. With Ron, the delay and the pin current at zero this is the datasheet 0.693 RC exactly (TI SLFS022K), and TI's TLC555 datasheet (SLFS043K, eq. 8) makes the same corrections. Design inverts this model and rounds the resistors to the series. The worst case takes every corner of the resistors, C, temperature, supply, the chip's error and the capacitor class at once. The Monte Carlo draws 2500 boards at nominal supply and temperature.

RESULT	WHAT IT IS
Frequency (Pulse width)	Exact, with the delays and Ron (and the diode drop).
Duty	With the high and low times.
0.693 R C (1.1 R C)	The textbook value, and how far it is from the exact one.
Worst case	All corners at once: −% / +%, and the frequency range.
Spread, 99.7 %	±3σ of the Monte Carlo.
Duty range, Supply I, RA + RB max	The duty over all corners, the supply current, and the largest RA + RB the threshold current allows.
Recovery, Max trigger rate	Monostable: 4.6 Ron C to discharge C, and 1 / (width + recovery).

The corners table gives f and duty (or the width) at Vcc min, nominal and max and at T min, nominal and T max. The **Parts** card names the timer (amber *use a CMOS part* when a bipolar one is out of its range), RA and RB with series, tolerance and tempco, the power while discharging, the timing C with its dielectric and voltage rating, the diode, 10 nF on CONT and the decoupling, and in Design mode a table of target against result. The **Error budget** moves one item at a time to its limit: resistor and capacitor tolerance, the chip's initial error, the parts over temperature, the chip's drift and supply sensitivity, the supply through the circuit, and the threshold pin current, with their sum and root-sum-square.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Supply vs chip range	Vcc range · the chip's range	Inside		Outside
RA + RB vs the threshold current	sum · max at Vcc min	2 × margin	Within it	Over
Discharge current, RA	Vmax/RA · the chip's maximum	Within it	Up to 1.25 × it	More
Frequency vs chip limit	f · max frequency	2 × margin	Within it	Over
Shortest phase vs delay	phase · delay	100 × or more	20 × or more	Less
Textbook formula error	textbook · exact	Under 1 %	Under 5 %	More
Threshold pin current (with leakage)	timing shift	Under 0.5 %	Under 2 %	More
Timing capacitor dielectric	its tempco	C0G or film	X7R or electrolytic	
Worst case vs accuracy	–a % / +b % · accuracy	Inside	Up to 1.43 × it	More: too wide
Output high at load	VOH · load and VOH min	5 % above the minimum	At the minimum	Below: low
Chip temperature	Tj · power at T max	Under 104 °C	Under 125 °C	More
Trigger width vs pulse (monostable)	trigger · pulse	Half the pulse or less	Up to the pulse	Longer: stretches
Trigger period vs pulse + recovery	period · width + recovery	1.2 × or more	Equal or more	Less: missed

MESSAGE	WHEN IT SHOWS
"Duty 40 % is below the 50 % minimum of RA + RB: C charges through both resistors while the output is high. Select Diode across RB, or design for 60 % and invert the output. The parts below are the typed RA and RB."	Design with a duty under 50 % and no diode.
"The target needs phases shorter than a few propagation delays (100 ns). Lower the frequency or use a faster CMOS part. The parts below are the typed values."	A phase too short to design.
"C settles at 1.7 V and never reaches the 3.33 V threshold: threshold-pin current plus capacitor leakage drop too much across the timing resistor. Use a smaller resistor with a larger capacitor, a CMOS 555 or a film capacitor."	It cannot oscillate (only this card shows).
"C never falls to the trigger level: RA is too small against the discharge switch resistance. Raise RA."	RA far too small.
"RA + RB = 10 MΩ is above the 3 MΩ limit set by the NE555 threshold current (up to 250 nA). Use a larger C with smaller resistors, or a CMOS 555 (pA pin currents)."	Over the threshold-current limit.
"2 MHz is above the NE555 limit of 100 kHz. The delays add to every phase. Use the LMC555 (3 MHz)."	Over the chip's frequency.
"0.693 R C is +123.9 % off here (delays 100 ns, discharge switch 19 Ω). The results above include these."	The textbook formula is more than 2 % off.
"With the diode across RB, f moves –2.3 % over the supply range and drifts with the diode drop (–2 mV/°C), because C charges toward Vcc – Vd. …"	Diode with a supply effect over 0.5 %.
"C = 100 pF is close to the pin and board capacitance (about 5 pF), which adds about 5 % to C. Use 1 nF or more with larger resistors."	C under 1 nF.

MESSAGE	WHEN IT SHOWS
"X7R drifts up to ±15 % over temperature and loses capacitance with DC bias, and the timing follows it. Use C0G up to about 100 nF and PP film above."	X7R chosen.
"Aluminium electrolytics leak (spec ..., doubling every 10 °C) and age. ..."	Electrolytic chosen.
"Tj ... °C with this load. Drive the load through a transistor."	Chip over 105 °C.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Frequency	Transient, freq of V(OUT) from the third period	±1.5 %
Duty	Transient, duty of V(OUT)	±1 point
Capacitor peak and valley	Not measured (the overshoot of the thresholds)	
Pulse width (monostable)	The duty of a period of five widths	19.7 to 20.3 %
Spread, Monte Carlo 99.7 %	Tolerance analysis: 100 Monte Carlo runs of R and C	The yield within the accuracy

BUTTON	WHAT IT DOES
Place circuit and run transient	The Simple circuit with the chip's keys on U_555: **rdis** = Ron, **iq**, **tdelay** = the propagation delay, **ithr**, and for a CMOS chip **family: cmos** and its output resistance (**555 timer**, p. 301). An electrolytic gets its leakage as **rleak**.
Run tolerance analysis	The same with tol on RA, RB and C, the transient saved, and a Monte Carlo of 100 runs (seed 1). *Output frequency* within the accuracy: the Tolerance tab shows the yield. The chip's own error and drift are not parts, and stay in the budget.
Apply to selected R and C	Resistor 1 = RA (R), resistor 2 = RB, capacitor 1 = C.

SIMPLE	ADVANCED
Frequency, Duty cycle, Pulse width	Frequency, Duty, Pulse width
RA, RB, R, Timing capacitor C	RA, RB, R, C
Mode, Duty (diode)	Mode, Duty network
Supply	Vcc nominal

TRY IT

An NE555 at 1 kHz, and why it is marginal

1. Open the 555 timer and press **Advanced**: NE555, Design, 1 kHz, 60 %, ±10 %, E96, film C.
2. Open **Tolerance and drift**.

YOU SHOULD SEE Auto C is 68 nF, RA 4.32 kΩ and RB 8.45 kΩ: 995 Hz, duty 59.9 %, and 0.693 RC is 0.51 % off the exact value. The worst case is −9.2 % / +10.4 % (904 Hz to 1.1 kHz), just outside ±10 %, so *Worst case vs accuracy* is amber. The budget shows why: the capacitor's 5 % is +5.26 %, the chip's initial error +2.25 %, the resistors +1.01 %. The Monte Carlo spread is ±8.5 %. **Place circuit and run transient** passes at 979.8 to 1009.7 Hz.

TRY IT

Past the chip's limit

1 Type Frequency **2000000**.

YOU SHOULD SEE Auto C 100 pF, RA 1.02 kΩ, RB 1.1 kΩ. Three checks fail: 2 MHz against the NE555's 100 kHz, a 201 ns phase against the 100 ns delay, and the textbook formula 123.9 % off. The warning names the LMC555 (3 MHz).

Sources. TI NE555 (SLFS022K), TLC555 (SLFS043K), LMC555 (SNAS558) and ICM7555 datasheets. The tests check the exact model against 0.693 RC and 1.1 RC, the threshold-current limit against TI's 3.4 MΩ at 5 V and 10 MΩ at 15 V, design from a target, the diode's supply effect, and the placed circuits against bspice within 1.5 to 2 %, including the 0.8.1 **tdelay**.

58 Buck and boost stage

58.1 Simple: the ideal stage 515
58.2 Advanced: the whole stage 518
58.3 The inductor picker 521
58.4 The regulator picker 523
58.5 Verify in simulation 524

The power stage of a buck (step-down) or boost (step-up) switching converter. The Simple view gives the duty, the inductor for a ripple, the peak and valley current, the output capacitor and the CCM boundary, and places an ideal-switch stage. The Advanced view designs the whole stage over the input range: three peak currents (full load, current limit, start-up), the inductor's saturation and heat, the capacitors after DC bias, every loss, the power stage response, the frequency trade, and real parts picked from the library (6,223 power inductors and 649 TI switching regulators). Group Parts. Search words include buck, boost, inductor, smps, switching, regulator, ripple, ccm, dcm and converter.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

58.1 Simple: the ideal stage

CHOICE	OPTIONS	WHAT IT DOES
Stage	**Buck**, Boost	Loads starting voltages: buck 12 V to 5 V, boost 5 V to 12 V.
Rectifier in the placed circuit	**Synchronous switch**, Diode	With a diode its forward drop enters the duty and the placed stage has a Schottky diode.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Input voltage, Output voltage	V	12, 5 (boost 5, 12)	0.5 to 1000 V.
Output current	mA, A	2 A	
Switching frequency	kHz, MHz	500 kHz	1 kHz to 20 MHz.
Inductor ripple	%	30	Peak to peak, of the average inductor current. 20 to 40 % is usual. Shown while Inductance is solved.
Inductance	nH, µH, mH	10 µH (solved)	SOLVE, solved when the calculator opens. Typed: used exactly.
Output ripple allowed	mV, V	20 mV	Peak to peak.
Capacitor ESR	mΩ, Ω	10 mΩ	
Diode forward voltage	V	0.4	Diode rectifier: the drop at the load current (a Schottky is 0.3 to 0.5 V).
Efficiency	%	100	100 for the ideal stage the placed circuit builds.

Buck: $D = (V_{out} + V_d) / (\eta V_{in} + V_d)$, $\Delta I_L = (V_{in} - V_{out}) D / (f_s L)$, $L = V_{out} (V_{in} - V_{out}) / (\Delta I_L f_s V_{in})$, $I_{pk} = I_{out} + \Delta I_L/2$, $C_{out} = \Delta I_L / (8 f_s (\Delta V - ESR \Delta I_L))$, $I_{crit} = \Delta I_L/2$. Boost: $D = (V_{out} + V_d - \eta V_{in}) / (V_{out} + V_d)$, $\Delta I_L = V_{in} D / (f_s L)$, $I_{in} = I_{out} / (1 - D)$, $I_{pk} = I_{in} + \Delta I_L/2$, $C_{out} = I_{out} D / (f_s (\Delta V - ESR I_{pk}))$, $I_{crit} = (1 - D) \Delta I_L/2$. A solved L is rounded up to the next E6 value (3 % slack) and the stage is worked out with it. The capacitor is the next E12 value up.

RESULT	WHAT IT IS
Duty cycle	Orange.
Inductance, exact and Inductance, E6	When solved (else Inductance).
Inductor ripple current, Peak inductor current, Valley inductor current	
Output capacitor, minimum and E12	*ESR too high* when the ESR alone uses up the ripple.
Output ripple with that capacitor	The capacitor current integrated over a period plus the ESR step.
Ripple, datasheet worst case sum	The two terms added.
CCM boundary (load current), Mode at this load	CCM, DCM (diode), or *CCM, I(L) < 0* (synchronous in forced PWM).
Diode average current (buck), Input current (boost)	

The plots **Inductor current** and **Switch node** show two periods.

MESSAGE	WHEN IT SHOWS
"A buck stage needs an output voltage below the input. Lower the output or raise the input."	Buck with Vout ≥ Vin (boost likewise). No results.
"Duty is 98 %, above 95 %. Controllers cannot make an off-time that short, and losses limit the step-up. Lower the step-up ratio or use two stages."	Duty over 95 %.
"ESR ripple alone is 58.3 mV, over the 20 mV allowed. Use a capacitor with lower ESR or allow more ripple."	No capacitor can meet the ripple.
"Load current 50 mA is below the CCM boundary of 3.05 A. The stage runs in discontinuous mode and the duty and ripple equations do not hold. Raise the inductance or the frequency."	Diode, below the boundary.
"Load current 50 mA is below the CCM boundary of 2.92 A. With a synchronous switch in forced PWM the inductor current goes negative to –2.87 A and the stage stays in CCM. The light-load loss stays high. Raise the inductance or the frequency, or use diode emulation."	Synchronous, below the boundary.
"Ripple current is … % of the average current. The CCM boundary is at … % of the load, so light loads drive the inductor current negative. Raise the inductance."	Ripple over 120 %.
"Ripple current is under 10 %, which needs a large inductor. 20 to 40 % is usual."	Ripple under 10 %.
"The duty includes the efficiency set above, so it is a little above the ideal ratio."	Efficiency under 100 %.

BUTTON	WHAT IT DOES
Place and run a transient	An ideal-switch stage: V_IN_PS, the switch S_HI_PS driven by a PWM source at D, S_LO_PS with an inverted PWM (or a Schottky D_PS), L_PS (starting at its average current), C_OUT_PS with its ESR (starting at Vout), R_LOAD_PS = Vout/Iout, OUT, and probes *V out*, *I L_PS*, *V sw*. A transient long enough for the start-up to ring down (12 RC, 100 to 3000 periods), measured over the last 20 periods: *Output ripple* within ±15 %, *Output mean* within ±3 % (diode −10 / +3 %), *Inductor ripple current* within ±10 %.
Apply to the selected inductor and capacitor	The L used and the E12 capacitor into the selected parts.

TRY IT

12 V to 5 V at 2 A

1. Open the buck and boost stage (type **buck**): 12 V to 5 V, 2 A, 500 kHz, 30 % ripple, 20 mV, 10 mΩ.
2. Press **Place and run a transient**.

YOU SHOULD SEE D 41.67 %, L 9.722 µH exact, 10 µH E6, ripple 583 mA, peak 2.292 A, valley 1.708 A, Cout at least 10.29 µF so 12 µF, output ripple 12.88 mV (17.99 mV as the worst-case sum), boundary 292 mA, CCM. The run measures 10.94 to 14.81 mV ripple, 4.85 to 5.15 V mean and 525 to 642 mA inductor ripple, and all pass.

58.2 Advanced: the whole stage

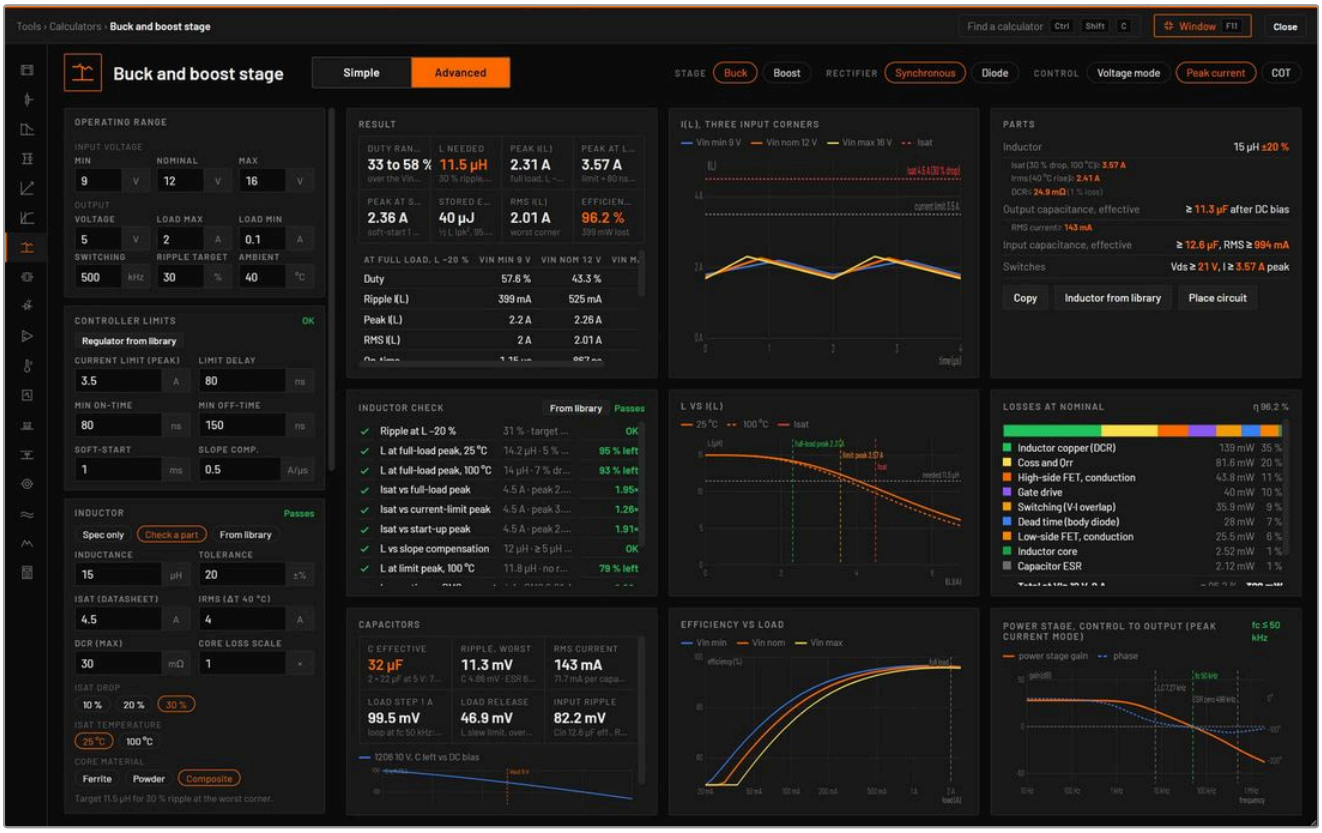


Figure 58.1 The buck and boost stage's Advanced view in full screen: the result tiles with the corners, checks and warnings, the inductor current at three input voltages, the parts, the inductor check, L against current, the losses, the capacitors, the efficiency against load and the power stage response.

CHOICE	OPTIONS	WHAT IT DOES
Stage	**Buck**, Boost	Resets the operating range, controller, inductor and capacitor groups to that stage's starting values and clears a chosen regulator. The switches stay.
Rectifier	**Synchronous**, Diode	
Control	Voltage mode, **Peak current**, COT	Sets the response model and the slope compensation check.

TAB	ITS DOT	CARDS
Design	Amber with a warning.	Result (with the corners, checks and warnings), I(L) three input corners, Parts, Corners.
Inductor	The inductor check.	Inductor check, L vs I(L), Corners, Top library parts.
Capacitors	Red when the worst ripple is over the limit.	Capacitors.
Losses and heat	None.	Losses at nominal, Efficiency vs load.
Power stage response	Green.	Power stage Bode plot and Poles and zeros.
Frequency	None.	Efficiency and inductor size vs frequency.

TAB	ITS DOT	CARDS
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Input voltage Min / Nominal / Max	V	9 / 12 / 16 (boost 3.3 / 5 / 5.5)	Group *Operating range*.
Output Voltage, Load max, Load min	V, A, A	5, 2, 0.1 (boost 12, 1, 0.05)	
Switching, Ripple target, Ambient	kHz, %, °C	500, 30, 40	
Current limit (peak), Limit delay	A, ns	3.5 (boost 6.5), 80	Group *Controller limits*. Its badge says *OK* or *1 problem* (an on-time or off-time under the minimum). **Regulator from library** is here.
Min on-time, Min off-time, Soft-start	ns, ns, ms	80, 150, 1 (boost 2)	
Slope comp.	A/µs	0.5 (boost 0.6)	Peak current control.
Inductor source		Spec only, **Check a part**, From library	Group *Inductor*. Spec only states a need, Check a part takes a datasheet part, From library opens the picker.
Inductance, Tolerance, Isat (datasheet), Irms (ΔT 40 °C), DCR (max), Core loss scale	µH, ±%, A, A, mΩ, ×	15 (boost 10), 20, 4.5 (9), 4 (7.5), 30 (20), 1	A library part fills these, marked PART.
Isat drop, Isat temperature, Core material		10, 20, **30 %**, **25 °C** or 100 °C, Ferrite, Powder, **Composite**	How the datasheet states Isat, and the core's roll-off.
C each, Count, Rated, ESR each, ESL each, Ripple max	µF, ×, V, mΩ, nH, mV	22, 2 (4), 10 (25), 20 (3), 0.4, 20 (120)	Group *Output capacitors*.
Type and size		0805, **1206** (boost 1210), 1210, Polymer	Sets the DC-bias loss.
Load step, Crossover	A, fs /	1 (0.5), 10	
C each, Count, Rated, ESR each, Type	µF, ×, V, mΩ	10 (22), 2, 25 (10), 4, 1206 (0805)	Group *Input capacitors*.
Rds(on) high side, low side, Qg, Qgd, Coss, Gate R, Gate drive, Miller plateau, Dead time, Qrr (or Diode Vf), θJA	mΩ, mΩ, nC, nC, pF, Ω, V, V, ns, nC, °C/W	18, 8, 8, 2, 300, 2.5, 5, 2.6, 20, 10 (0.4 V), 60	Group *Switches (two FETs)*, or *Switch and diode*.

How it works it out. Everything is at full load and at the three input voltages, with L at its low tolerance for the worst values. The duty includes the losses (solved together with the efficiency). L falls with current along the part's L(I) curve: a Vishay part's own tanh law ($L/L0 = \mathrm{sech}^2(I/2a)$), a power law through

datasheet points, or one rating with the core's sharpness. The L needed is taken at Vin max for a buck and near ⅔ Vout for a boost (TI SLVA372). The peak at the current limit adds the overshoot of the limit delay, the start-up peak the charge of the output capacitors in the soft-start. Losses: conduction at 1.4 × Rds(on) (about 100 °C), switching (Infineon AN 2006-07), Coss, Qrr, gate drive, dead time or the diode, copper at the DCR's temperature, a core-loss estimate, capacitor ESR. Output capacitors keep 1 – k (V/Vr)$^{1.25}$ of their value (k 0.8 for 0805, 0.65 for 1206, 0.5 for 1210, 0 for polymer). The response uses the LC pole, the ESR zero and the boost's RHP zero, crossover at min(fs/10, RHP/4), and previews the phase margin with a type II or III compensator.

RESULT	WHAT IT IS
Duty range	Over the input range.
L needed	For the ripple target at the worst corner (orange).
Peak I(L), Peak at limit, Peak at start-up	Full load with L at –tolerance, the limit plus its delay, and the soft-start at Vin min.
Stored energy (buck) or RHP zero (boost)	½ L I^2_{pk}, or the zero and the crossover it allows.
RMS I(L)	Worst corner.
Efficiency	At Vin nominal, with the total loss (orange).

The **Corners** table gives duty, input current (boost), ripple, peak, RMS, on-time and efficiency at each input voltage, the corner that sets each worst value in orange. The **Parts** card is what to buy: the inductor (E6 value, Isat at 30 % drop and 100 °C, Irms for a 40 °C rise, DCR for 1 % loss), the output and input capacitance after DC bias with their RMS current, and the switches' voltage and current, with **Copy** and **Inductor from library**. The capacitors card gives C effective, the worst ripple split into its C, ESR and ESL parts, the RMS current, the load step and release, and the input ripple, with a plot of C left against DC bias.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Ripple at L –20 %	ripple · target	Within 1.25 × target	Up to 1.56 ×	More
L at full-load peak, 25 °C (and 100 °C)	% left · drop	80 % or more	70 % or more	Less
Isat vs full-load peak	Isat / peak	1.2 × or more	1.0 × or more	Less
Isat vs current-limit peak	Isat / limit peak	1.0 × or more	0.9 × or more	Less
Isat vs start-up peak	Isat / start-up peak	1.1 × or more	1.0 × or more	Less
L vs slope compensation (peak current)	L · Vout / (2 Se)	1.1 × or more	1 × or more	Less: subharmonic
RHP zero vs crossover (boost)	RHP zero · fc	RHP/4 ≥ fs/10	Otherwise: limits fc	
L at limit peak, 100 °C	% left	60 % or more	45 % or more	Less: runaway
Irms rating vs RMS current	Irms / RMS	1.2 × or more	1.0 × or more	Less
Losses, copper + core	% of Pout	2 % or less	Up to 3.3 %	More
Temperature rise, est.	hot spot	Under 109 °C	Under 125 °C	More

MESSAGE	WHEN IT SHOWS
"On-time at Vin max is 61.6 ns, under the 80 ns minimum of the controller. The regulator skips pulses. Lower the switching frequency to 1.39 MHz or less."	On-time too short.
"Off-time … at Vin min is under the … minimum. Lower the switching frequency."	Off-time too short.
"Isat 2.5 A is below the 6.49 A peak at the current limit. Use a part with Isat ≥ 7.14 A or lower the current limit."	Isat under the limit peak.
"Below 248 mA load (the minimum is 100 mA) the inductor current goes negative in forced PWM. The stage stays in CCM and the light-load efficiency drops. Diode emulation or PFM makes it discontinuous instead."	Load min under the boundary (diode: it goes discontinuous).
"Output ripple 30.6 mV is over the 20 mV limit. The capacitors keep 84 % of their value at 3.3 V. Add capacitance or use a higher voltage rating."	Over the ripple limit.
"Duty goes above 50 % in peak current mode and the slope compensation … A/µs is under the … A/µs needed against subharmonic oscillation. Raise the slope compensation or the inductance."	Peak current mode with too little slope compensation.

58.3 The inductor picker

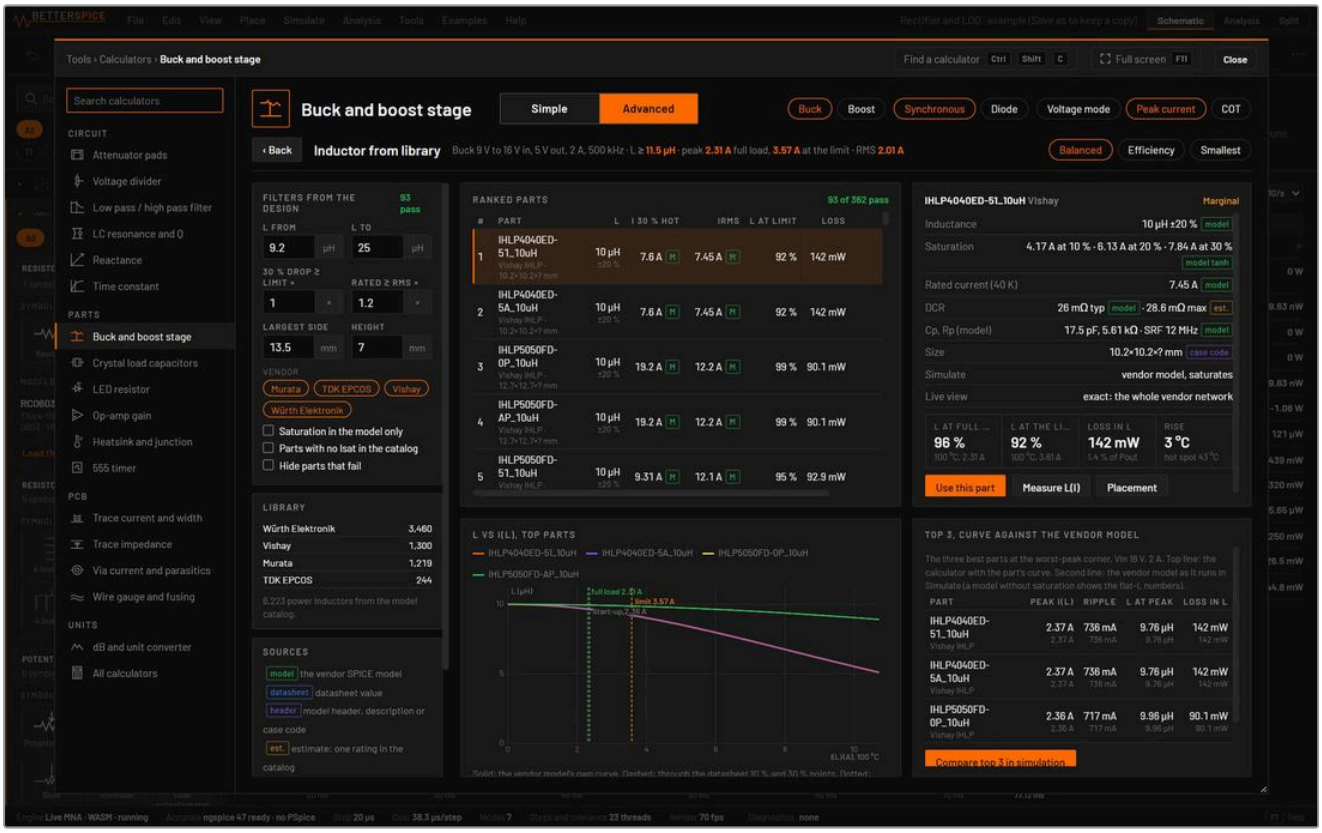


Figure 58.2 Inductor from library for the default buck: the filters set from the design, the ranked parts with their current at 30 % drop hot, the detail of the selected IHLP part, and the L against current of the top parts.

Open it with **From library** on the inductor check, **Inductor from library** on the Parts card, **Open the library picker** under Top library parts, or the inductor source **From library**. The head shows what the design needs (*Buck 9 V to 16 V*

in, 5 V out, 2 A, 500 kHz · L ≥ 11.5 µH · peak 2.31 A full load, 3.57 A at the limit · RMS 2.01 A) and **Rank for**: **Balanced**, Efficiency, Smallest.

The data is the catalogue's 6,223 power inductors with an L: Würth Elektronik 3,460, Vishay 1,300, Murata 1,219 and TDK EPCOS 244, in 213 families, from 25 nH to 10 H. 3,026 have both a saturation figure and a current rating and can be ranked. The rest are listed only with **Parts with no Isat in the catalog**. Each part's saturation comes from the vendor model (Vishay's tanh law), from datasheet 10 % and 30 % points (Würth and TDK, copied from the makers' PDFs), or from one rating (Murata's header Imax, an estimate). The DCR used is the datasheet maximum, else the typical × 1.1.

FIELD	UNIT	DEFAULT	WHAT IT DOES
L from, L to	µH	0.8 × and 2.2 × L needed	Follow the design until you type in them.
30 % drop ≥ limit ×		1.0	The part's current at 30 % drop, at 100 °C, against the peak at the current limit.
Rated ≥ RMS ×		1.2	Irms against the worst RMS.
Largest side, Height	mm	13.5, 7	A part with an unknown size passes.
Vendors		all on	
Saturation in the model only, Parts with no Isat in the catalog, Hide parts that fail		off	

Every part in the filters runs the whole design with its own L(I), tolerance, DCR and rating, and gets the full inductor check. A part fails when its 30 % current hot is under the limit peak, its Irms is under the RMS need, its L at the limit peak is under 50 %, or another check fails. Passing parts rank first, then (in Balanced and Smallest) parts with a trusted size, then by a score of loss, temperature rise, footprint and saturation margin weighted by the rank mode. A size that would store more than 8 µJ per mm^3 is marked *size implausible* (a case code read in the wrong unit). The table shows the part (family, size), L, the current at 30 % hot with its source tag, Irms, L at the limit (red under 50 %, orange under 70 %), loss and rise, and in full screen the DCR, the efficiency and how it simulates.

The **detail** card gives the part's inductance, saturation points, rating, DCR, Cp and Rp of the model, size, how Simulate and the live view run it, and four tiles (L at full load, L at the limit, loss, rise). **Use this part** puts it into the design. **Measure L(I)** places a bench: a 1 A/µs ramp through the vendor model, where V(LI) in volts reads L in µH. **Placement** shows what the part is placed as: for Würth, the fitted inductor with the datasheet saturation or the vendor model as is (which does not saturate). **L vs I(L), top parts** plots the best parts at 100 °C, and **Top 3, curve against the vendor model** compares each with its vendor model as Simulate runs it. **Compare top 3 in simulation** places the stage three times with the three vendor models and runs one transient with twelve measurements.

58.4 The regulator picker

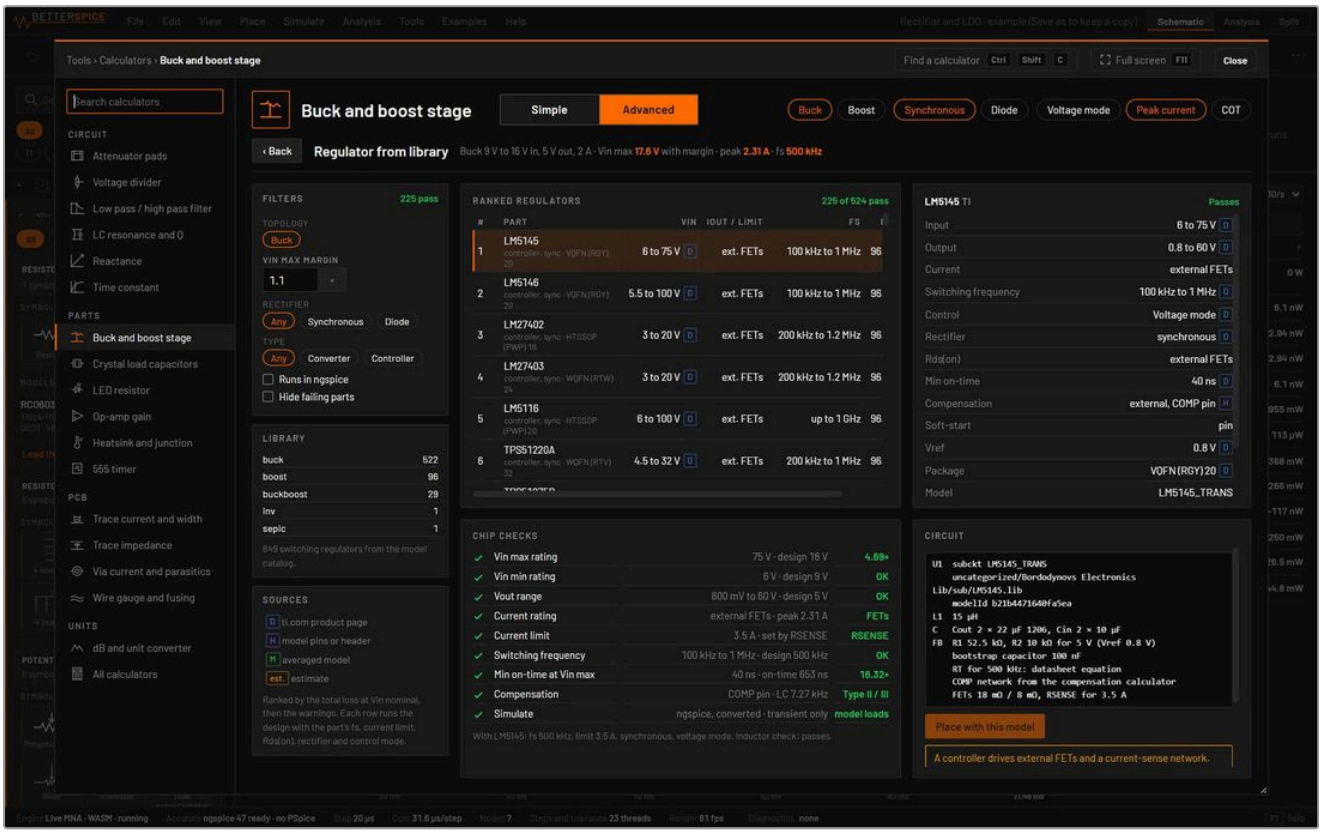


Figure 58.3 Regulator from library for the default buck: the filters, the ranked TI regulators with their efficiency in this design, the chip checks of the selected part and the circuit it would be placed with.

Regulator from library in the Controller limits group lists the catalogue's TI switching regulators with a known input range: 649 of 727 (buck 522, boost 96, buck-boost 29, inverting and SEPIC one each). The head shows the need with the input margin. Filters: the topology (from the stage), **Vin max margin** (1.1 ×), **Rectifier** (Any, Synchronous, Diode), **Type** (Any, Converter with its own switches, Controller with external FETs), **Runs in ngspice** and **Hide failing parts**. The figures come from ti.com product pages (D), the model's pins or header (H), the averaged model (M) or an estimate.

Each row runs the design with the chip's switching frequency (fixed, the nearer of two, or the design's clamped into its range), its current limit, minimum on- and off-time, rectifier, control mode and, for a converter, its Rds(on). Its checks: Vin max and min rating, Vout range, output current rating (1.2 × the load), current limit against the peak (1.2 ×), switching frequency, minimum on-time at Vin max (1.2 ×), compensation, the boost's RHP zero, and whether the model simulates. A figure the catalogue lacks is amber *datasheet*. Passing parts rank by the total loss at nominal input plus half a point per marginal check and per PSpice-only model.

Use this part sets those values in the design (shown as PART) and puts the chip in the Controller limits group with **Change part** and **Type values**. The **Circuit** card lists what it would be placed with: the model, the design's inductor and capacitors, a feedback divider (R2 10 kΩ, R1 for Vout from Vref),

bootstrap, RT, COMP network, soft-start, and a Vref field when the catalogue has none. **Place with this model** places the vendor subcircuit with that stage, pins assigned by their names (VIN, EN, GND, SW, BOOT, FB, COMP, SS, VCC and so on). It says which pins it left open, and refuses with the reason when the pin list, the feedback pin or Vref is missing, or for a controller or a multi-channel part. No analysis runs: a vendor switching model needs **Start from initial conditions** in the setup and a transient past the soft-start.

58.5 Verify in simulation



Figure 58.4 Place circuit and run at Vin max: the stage placed with its saturating inductor and DC-biased capacitor bank, the transient, and the four measurements passing.

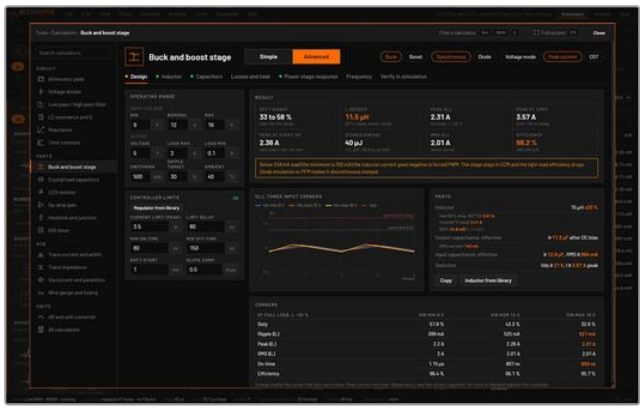


Figure 58.5 The buck's Advanced view in the window, Design tab.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Output mean	Transient, mean of V(OUT) over the last 20 periods	±3 % (diode ±6 %)
Inductor ripple	Ripple of I(L)	±10 %
Inductor peak	Max of I(L)	±5 %
Output ripple	Ripple of V(OUT)	±15 %
Duty, L at the mean current	Set by the PWM source, and the saturation given to the inductor	

The **Corner** buttons pick Vin min, nominal or max (default max). The placed stage has ideal switches with Rds(on) (or a Schottky), a body diode for the dead time, the inductor with its DCR and saturation (a typed Isat becomes the simulator's 50 % point: × 1.53 for a 30 % drop, × 2 for 20 %, × 3 for 10 %, and a library part its own eight-point **Iisat** curve), the output bank as one capacitor with ESR/n and its DC-bias curve, and the load. The duty is found so Vout is right with the conduction drops. The capacitor ESL is left out: its spike is in the Capacitors tab's ripple.

BUTTON	WHAT IT DOES
Place circuit and run	The stage at the chosen corner and a transient, with the four measurements.
Run three corners	The stage at Vin min, nominal and max one under the other (_MIN, _NOM, _MAX), one transient, twelve measurements.
Apply to selected L and C	l, dcr and isat (or lisat) into the selected inductor, c, esr and cbias into the selected capacitor.

SIMPLE	ADVANCED
Input voltage, Output voltage, Output current, Switching frequency	Vin nominal, Output voltage, Load max, Switching
Inductor ripple, Inductance (typed)	Ripple target, Inductance
Output ripple allowed, Capacitor ESR	Ripple max, ESR each × count
Diode forward voltage, Stage, Rectifier	Diode Vf, Stage, Rectifier

TRY IT

The default buck, then a library inductor

1. Open the buck and boost stage, press **Advanced**: 9 to 16 V in, 5 V, 2 A, 500 kHz, a 15 µH ±20 % composite inductor rated 4.5 A.
2. Open the **Inductor** tab and press **From library**. Select the first row and press **Use this part**.

YOU SHOULD SEE The design: duty 33 to 58 %, L needed 11.5 µH, peaks 2.31 A (full load), 3.57 A (limit), 2.36 A (start-up), efficiency 96.2 % with 399 mW lost (139 mW of it in the inductor's copper), output ripple 11.3 mV, LC pole 7.27 kHz, crossover 50 kHz, phase margin preview 72.7°. The inductor check passes. One warning: under 248 mA load the current goes negative in forced PWM. The picker lists 362 parts in the window, 93 pass, Vishay IHLP4040ED-51 10 µH first (7.6 A at 30 % hot). With it the ripple at L −20 % reads 46 %: amber, 1.53 × the target.

TRY IT

A stage that does not hold

1. Set 9 to 36 V in, 3.3 V, 3 A, 2 MHz, limit 5 A, and the inductor 2.2 µH, Isat 2.5 A, Irms 2.5 A, DCR 60 mΩ.

YOU SHOULD SEE The inductor check fails on ten rows (L falls to 36 % at the peak, Isat is 0.62 × the full-load peak, subharmonic risk, 8.2 % loss), efficiency 80 %. The warnings say the 61.6 ns on-time is under the 80 ns minimum (use 1.39 MHz or less), Isat is under the 6.49 A limit peak (use ≥ 7.14 A), and the 30.6 mV ripple is over 20 mV.

Sources. TI SLVA477 (buck) and SLVA372 (boost), SLVA057 and SLVA061 (DCM, small signal, RHP zero), SLYT670 (input capacitor), Coilcraft Doc 361 and Doc 1733 (Irms as a 40 °C rise, DCR and saturation at 100 °C), Infineon AN 2006-07 (MOSFET losses), Ridley (1991) and TI SNVA555 (slope compensation), TI LM5164 and TPS560430 (minimum on-time), Vishay's IHLP law, Erickson and Maksimovic chapter 5 (forced PWM). The tests check these

equations, the picker rows against the catalogue, and the placed stages (synchronous, diode, boost, a Vishay part near saturation, three corners, top 3) against bspice within the stated limits.

59 Crystal load capacitors

59.1 Simple: C1 = C2 for a CL 527
59.2 Advanced: margin, drive and budget 529

The two load capacitors of a Pierce crystal oscillator, as on a microcontroller's XIN and XOUT pins: the values that make the crystal run at its marked frequency, the frequency error they give, and whether the oscillator has gain enough to start. The Advanced view adds the negative resistance, the drive level, the start-up time and the whole frequency budget for UART, USB, Ethernet, BLE or an RTC, with presets for a 16 MHz AT-cut crystal and a 32.768 kHz tuning fork. Group Parts. Search words include crystal, xtal, load capacitor, oscillator, pierce, ppm, cl and quartz.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

59.1 Simple: C1 = C2 for a CL

FIELD	UNIT	DEFAULT	WHAT IT DOES
Crystal load capacitance CL	pF	18	From the crystal datasheet. Reads a selected crystal's cl.
Stray capacitance	pF	3	Pins, traces and the amplifier input. 2 to 5 pF is typical.
C1 = C2	pF	30 (solved)	The load capacitors, always the solved field.
Frequency	kHz, MHz	16 MHz	Reads a selected crystal's freq.
Tolerance	ppm	20	Plus and minus, with the stability if the datasheet adds it.
Shunt capacitance C0	pF	3	
Motional capacitance C1 of the crystal	fF	7	
ESR	Ω	40	
Amplifier gm	µA/V, mA/V	5 mA/V	From the MCU datasheet. The gain margin is gm over gm critical and must be 5 or more.

C1 = C2 = 2 (CL − Cstray), from CL = C1 C2 / (C1 + C2) + Cstray. The tolerance in hertz is f × ppm / 10^6. The pulling is Cm / (2 (C0 + CL)^2) per pF, and the critical transconductance gm_{crit} = 4 ESR (2πf)^2 (C0 + CL)^2. With the nearest E12 capacitor, the frequency error is Cm/2 (1/(C0 + CL′) − 1/(C0 + CL)): a larger CL pulls the crystal below its marked frequency.

RESULT	WHAT IT IS
C1 = C2	Exact (orange).
Nearest E12, CL with it, Error with it	The standard value, the CL it gives, and the frequency error in ppm.
Tolerance	± Hz.
Pulling	ppm per pF.
gm critical, Gain margin, gm for margin 5	The margin is gm / gm_{crit}.

MESSAGE	WHEN IT SHOWS
"The standard E12 capacitor puts the crystal 11.1 ppm below its marked frequency. Use two capacitors in parallel or tune on the board."	Error over 10 ppm.
"The stray capacitance is as large as the load capacitance, so no positive capacitor gives the wanted CL. Check the crystal CL and the board stray value (2 to 5 pF is usual)."	C1 at or under 0.
"Load capacitors under about 5 pF are dominated by the pin and trace capacitance. Treat the result as a starting point and measure the stray capacitance."	C1 under 5 pF.
"Crystals with a CL under 6 pF are very sensitive to stray capacitance."	CL under 6 pF.
"The amplifier gm of 0.5 mA/V gives a gain margin of 1.5, below the 5 that AN2867 asks for. Use a crystal with a lower ESR or CL, or an amplifier with at least 1.64 mA/V."	Margin under 5.
"A CL above 32 pF is unusual and makes start-up harder because the amplifier needs more gain."	CL over 32 pF.

The drawing shows the crystal with C1 and C2 to ground and the CL formula. There is no placed circuit: the oscillator's amplifier (a gate or transistor, its bias and drive resistor) is your choice. **Apply to the selected crystal and capacitors** (or **Apply to the selected load capacitors**) writes the nearest E12 value into each selected capacitor and CL into a selected crystal.

TRY IT

An 18 pF, 16 MHz crystal

1. Open the crystal calculator (type **crystal**): CL 18 pF, 3 pF stray, 16 MHz, ESR 40 Ω, gm 5 mA/V.

YOU SHOULD SEE C1 = C2 = 30 pF. The nearest E12 is 33 pF, which gives CL 19.5 pF and −11.1 ppm, so the amber warning suggests two capacitors in parallel. ±20 ppm is ±320 Hz, the pulling 7.94 ppm/pF, gm_{crit} 0.713 mA/V and the gain margin 7.0 ×.

59.2 Advanced: margin, drive and budget

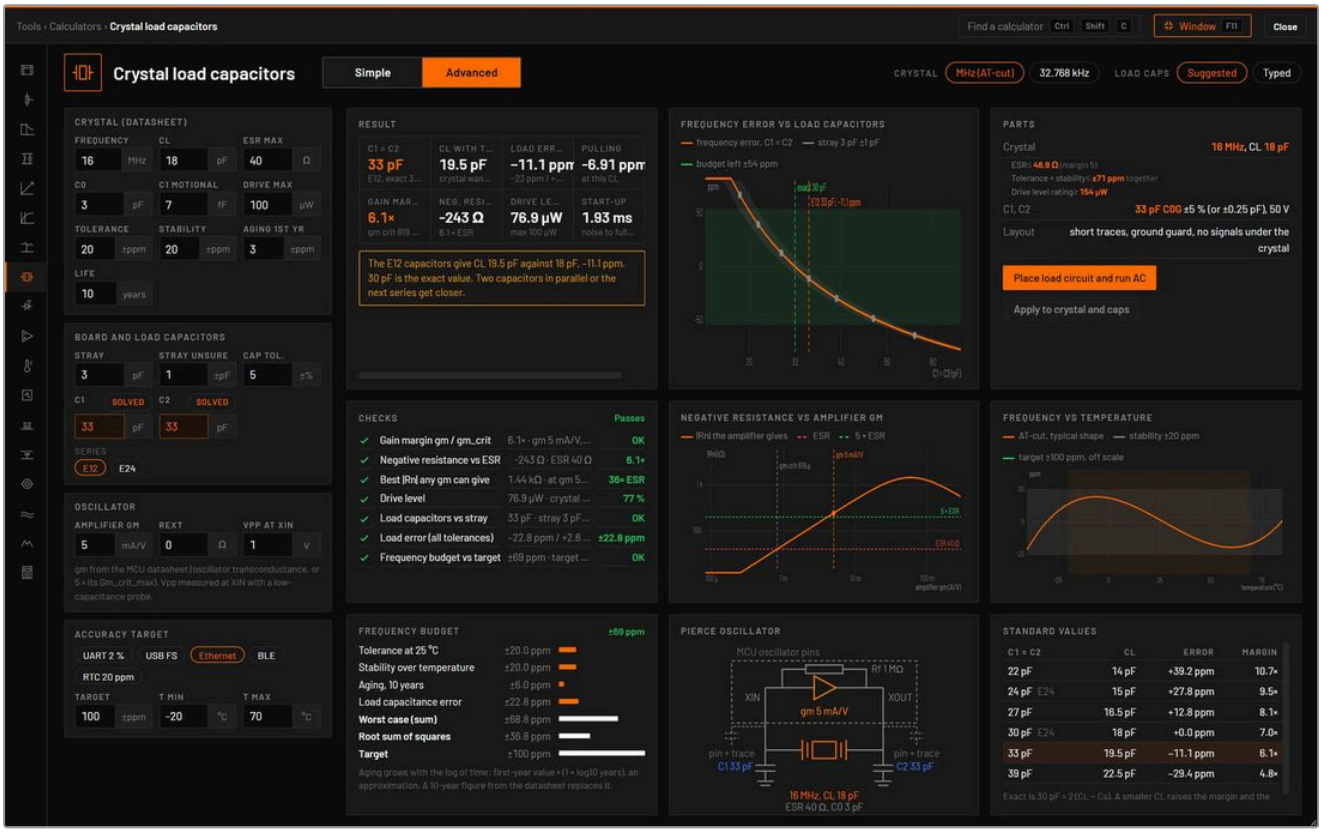


Figure 59.1 The crystal's Advanced view in full screen: a 16 MHz AT-cut crystal with E12 load capacitors, the frequency error against the capacitors, the parts, the checks, the negative resistance against gm, the frequency against temperature, the budget, the Pierce oscillator and the standard values.

CHOICE	OPTIONS	WHAT IT DOES
Crystal	**MHz (AT-cut)**, 32.768 kHz	Loads a preset: 16 MHz, CL 18 pF, ESR 40 Ω, or a tuning fork with CL 12.5 pF, ESR 50 kΩ, C0 1.2 pF, 2.5 fF, 1 µW, gm 10 µA/V, an RTC target of 20 ppm.
Load caps	**Suggested**, Typed	Suggested: the nearest value of the series to 2 (CL – Cs), SOLVED.

TAB	ITS DOT	CARDS
Load capacitors	The load and stray checks.	Result, Frequency error vs load capacitors, Standard values.
Oscillator margin and drive	The margin, negative resistance and drive checks.	Negative resistance vs amplifier gm, Pierce oscillator, Checks.
Frequency budget	The budget check.	Frequency budget, Frequency vs temperature, Parts.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Frequency, CL, ESR max, C0, C1 motional, Drive max	MHz, pF, Ω, pF, fF, µW	from the preset	Group *Crystal (datasheet)*.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Tolerance, Stability, Aging 1st yr, Life	±ppm, ±ppm, ±ppm, years	20, 20, 3, 10	The fork has no stability figure: its temperature parabola is used.
Stray, Stray unsure, Cap tol.	pF, ±pF, ±%	3, 1, 5	Group *Board and load capacitors*.
C1, C2, Series	pF	SOLVED, **E12** or E24	
Amplifier gm, Rext, Vpp at XIN	mA/V, Ω, V	5, 0, 1	Group *Oscillator*. gm from the MCU datasheet (or 5 × its Gm_crit_max). Vpp measured at XIN with a low-capacitance probe.
Accuracy target		UART 2 %, USB FS, **Ethernet**, BLE, RTC 20 ppm	Sets the target: 20 000, 2500, 100, 50 or 20 ppm.
T min, T max	°C	–20, 70	

How it works it out. f(CL) = fs (1 + Cm / (2 (C0 + CL))), the relation of the engine's crystal part. $gm_{crit} = 4\,(ESR + Rext)\,(2\pi f)^2\,(C0 + CL)^2$, margin ≥ 5 (ST AN2867). The negative resistance follows Vittoz, Degrauwe and Bitz (IEEE JSSC 1988) with C0 and the pin capacitance, and equals AN2867 at small gm. The start-up time is the growth from noise to full amplitude at the net negative resistance. The drive is $I = 2\pi f\ Vpp\ Ctot / 2\sqrt{2}$ at XIN and $DL = ESR\ I^2$ (AN2867). The budget adds tolerance, stability (for the fork its parabola, –0.034 ppm/K² typical), aging × $(1 + \log_{10}$ years), and the worst load error over the capacitor and stray tolerances.

RESULT	WHAT IT IS
C1 = C2	The series value and the exact one.
CL with them	Against what the crystal wants.
Load error	ppm, and its range with the tolerances.
Pulling	ppm/pF, negative: a larger CL lowers f.
Gain margin	With gm_{crit}. Amber under 5.
Neg. resistance	In multiples of the ESR.
Drive level	Against the maximum. Red over it.
Start-up	Noise to full amplitude, an estimate, or *never*.

The **Parts** card gives the ESR the crystal may have for a margin of 5, the tolerance and stability it may have for the target (or *no crystal fits: TCXO*), the drive rating, C1 and C2 (C0G), Rext when the drive is too high, and the layout (short traces, ground guard, no signals under the crystal). **Standard values** lists the series values around the exact one with their CL, error and margin.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Gain margin gm / gm_crit	margin	5 or more	3 or more	Less: low

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Negative resistance vs ESR	|Rn| · ESR + Rext	5 × or more	3 × or more	Less
Best |Rn| any gm can give	the peak · ESR	5 × or more	3 × or more	Less
Drive level	DL · crystal max	1.25 × margin	Within it	Over
Load capacitors vs stray	smaller of C1, C2	6 pF or more	Less: the stray rules	
Load error (all tolerances)	ppm	Under a quarter of the target	Under half	More
Frequency budget vs target	± ppm · target	Within it	Up to 1.25 × it	Over

MESSAGE	WHEN IT SHOWS
"Gain margin 1.4 is below 5, so start-up over temperature and aging is uncertain. Use a crystal with ESR ≤ 40.9 Ω or a lower CL (4 pF gives margin 5), or a stronger drive setting."	Margin under 5.
"Drive level 437 µW is over the crystal's 50 µW. It ages fast and can crack. Add Rext ≈ 995 Ω (the reactance of C2, AN2867), which gives a margin of 0.2, or lower the drive setting."	Over the drive limit.
"Worst-case budget ±138 ppm against the ±20 ppm target (the 32.768 kHz tuning fork loses up to 100 ppm at the temperature ends). 8.6 s/day. Calibrate in firmware or use a TCXO or a compensated RTC."	Over the target (an AT-cut crystal: use ±10 ppm / ±10 ppm or a TCXO).
"The E12 capacitors give CL 19.5 pF against 18 pF, –11.1 ppm. 30 pF is the exact value. Two capacitors in parallel or the next series get closer."	Load error over 5 ppm.
"gm_crit passes but the negative resistance with C0 and the pin capacitance is below 3 × ESR. Use a smaller CL."	The fuller model disagrees.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Load error (loop resonance)	AC around the loaded frequency: the loop phase of the crystal with C1 and C2 (each with 2 Cs) and the AC source in the loop	±6° at the calculated frequency
Negative resistance, Start-up, Frequency spread	Calculator only	

BUTTON	WHAT IT DOES
Place load circuit and run AC	V1 at the loaded frequency, X1 (freq, cl, esr, c0, cm), C1 and C2 with the stray, a 1 Ω sense resistor and 1 GΩ DC paths, IN and OUT, an AC sweep of ±300 ppm. *Loop phase at the loaded frequency* within ±6°. The amplifier, start-up and drive are not simulated.
Apply to crystal and caps	C1 into the selected capacitors, CL into a selected crystal.

SIMPLE	ADVANCED
CL, Stray capacitance, Frequency, ESR, C0, motional C1, Amplifier gm, Tolerance	The same fields of the Crystal, Board and Oscillator groups

TRY IT

A 16 MHz crystal for Ethernet

1. Open the crystal calculator and press **Advanced** (16 MHz preset, E12, Ethernet ±100 ppm).
2. Look at **Frequency budget**, then set **Crystal** to **32.768 kHz**.

YOU SHOULD SEE 33 pF gives CL 19.5 pF: −11.1 ppm (−23 to +3 ppm with the tolerances), margin 6.1 ×, |Rn| 243 Ω, drive 76.9 µW of 100 µW, start-up 1.93 ms. The budget is ±68.8 ppm (tolerance 20, stability 20, aging 6.0, load 22.8) against ±100: all checks pass. The tuning fork gets 22 pF, but its temperature parabola makes the budget ±138 ppm against the 20 ppm RTC target, 8.6 s/day: the budget check fails.

Sources. ST AN2867, NXP and Abracon application notes, Epson for the tuning fork, and Vittoz, Degrauwe and Bitz, IEEE JSSC 23(3) 1988. The tests check gm_{crit} 713.1 µA/V for 16 MHz, 40 Ω, 3 pF and 18 pF, the exact load error (33 pF: −11.1 ppm), the Vittoz curve, the fork's parabola and 0.0864 s/day per ppm, Rext, and the placed load circuit's zero loop phase.

60 Heatsink and junction

60.1 Simple: the thermal ladder 533
60.2 Advanced: heatsink, board and pulses 535

How hot a power part's junction gets, and the heatsink, interface or copper it needs. The Simple view is the series ladder of thermal resistances. The Advanced view adds the part's transient thermal impedance (four Foster stages), pulses, interface materials, PCB copper with vias, natural or forced air, an enclosure, derating and other parts on the same heatsink. Group Parts. Search words include thermal, heatsink, junction, theta, rth, derating and tj.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

60.1 Simple: the thermal ladder

FIELD	UNIT	DEFAULT	WHAT IT DOES
Power dissipated	W	5	Reads the selected part, or its mean power while the live view runs.
Junction to case θJC	°C/W	1.5	From the part's datasheet.
Case to heatsink θCS	°C/W	0.5	Paste or pad. Typical 0.2 to 1.
Heatsink to ambient θSA	°C/W	8 (solved)	SOLVE. The heatsink needed for the junction limit.
Ambient temperature	°C	25	
Junction limit	°C	125	The datasheet maximum, or a lower design limit.

Tj = Ta + P (θJC + θCS + θSA), Tc = Ta + P (θCS + θSA), Ts = Ta + P θSA, and the heatsink needed is θSA = (Tj_{max} − Ta) / P − θJC − θCS. θSA is the only field with SOLVE and it opens solved, so this view shows the heatsink needed for the limit.

RESULT	WHAT IT IS
Heatsink needed	The θSA for the junction limit (orange).
Junction Tj, Case Tc, Heatsink Ts	
Total θ	θJC + θCS + θSA.
Power limit	(Tj_{max} − Ta) / total θ.

MESSAGE	WHEN IT SHOWS
"θJC and θCS alone give Tj 175 °C at 50 W. No heatsink holds 125 °C. Lower the power, the ambient or the resistances."	The solved θSA is zero or negative.
"Tj is within 15 °C of the limit. Keep margin for hot days and for θ rising with age."	Little margin.
"Heatsink above 90 °C, hot enough to burn skin and to heat nearby parts."	Ts over 90 °C.
"θCS above 2 °C/W points to a poor interface. Check the pad or paste and the mounting torque."	θCS over 2.

The drawing **Thermal ladder** shows Tj, Tc, Ts and Ta with each resistance and its drop (*Heat flows left to right: each resistance drops P × θ degrees*). **Add the result as a note** puts a text on the sheet: *Thermal: 5 W at 25 °C ambient / Tj 125 °C, Tc 117.5 °C, Ts 115 °C / θJC 1.5 + θCS 0.5 + θSA 18 °C/W.*

TRY IT

The heatsink a 5 W part needs

1. Open Heatsink and junction (type **heatsink**): 5 W, θJC 1.5, θCS 0.5 °C/W, 25 °C, limit 125 °C.

YOU SHOULD SEE Heatsink needed 18 °C/W. Tj 125 °C, Tc 117.5 °C, Ts 115 °C, total θ 20 °C/W, power limit 5 W, and the warning that the heatsink is above 90 °C.

60.2 Advanced: heatsink, board and pulses

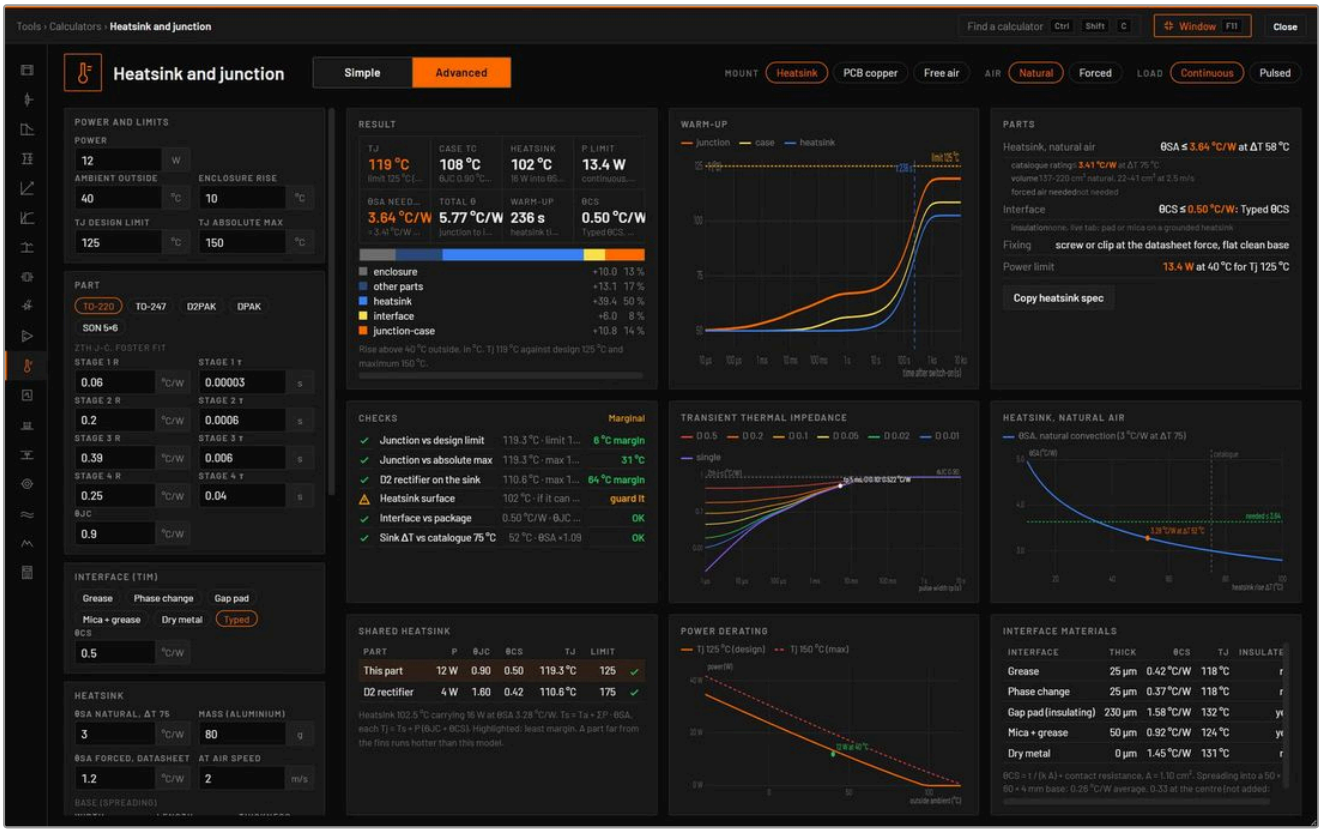


Figure 60.1 Heatsink and junction, Advanced, in full screen: 12 W in a TO-220 on a natural-air heatsink shared with a 4 W rectifier, with the warm-up, the parts, the checks, the transient thermal impedance, the heatsink against its rise, the shared heatsink, the derating and the interface materials.

CHOICE	OPTIONS	WHAT IT DOES
Mount	**Heatsink**, PCB copper, Free air	PCB copper changes a TO-220 or TO-247 to D2PAK and lowers a power over 5 W to 2.5 W. Heatsink from a small package picks TO-220.
Air	**Natural**, Forced	
Load	**Continuous**, Pulsed	

TAB	ITS DOT	CARDS
Design	The worst check.	Result, Parts, Checks.
Pulses	Pulsed: red when the peak Tj is over Tj max, amber over the design limit or with a swing over 40 °C.	Transient thermal impedance, Warm-up or Tj pulse train, Pulse train.
Heatsink and board	Red over Tj max, amber over the design limit.	The mount plot, Interface materials or Board changes and Thermal vias, Parts.
Derating	Green within the power limit, else red.	Power derating, Checks.
Shared heatsink	Heatsink with other parts on: red when one is over its limit, amber within 25 °C of it.	Shared heatsink.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Power (or Pulse power, Pulse width, Period)	W (W, ms, ms)	12 (60, 5, 50)	Group *Power and limits*. Pulsed shows the average and the duty.
Ambient outside, Enclosure rise	°C	40, 10	The air at the part is outside plus the rise.
Tj design limit, Tj absolute max	°C	125, 150	
Package		**TO-220**, TO-247, D2PAK, DPAK, SON 5×6	Group *Part*. Sets the contact area, θJC and θJA: TO-220 1.1 cm^2, 0.9, 62 °C/W, TO-247 2.4 cm^2, 0.45, 40, D2PAK 0.9 cm^2, 0.9, 62, DPAK 0.36 cm^2, 1.5, 100, SON 5×6 0.2 cm^2, 1.2, 125.
Stage 1 to 4 R and τ	°C/W, s	0.06/30 µs, 0.2/0.6 ms, 0.39/6 ms, 0.25/40 ms	Zth j-c as four Foster stages (the die-attach stack).
θJC	°C/W	0.9	Editing it scales the four stages to sum to it.
Interface		Grease, Phase change, Gap pad, Mica + grease, Dry metal, **Typed**	Group *Interface (TIM)*, heatsink only. A material gives θCS = t/(kA) + Rc/A from its thickness, k and contact resistance (grease 25 µm, 0.8 W/mK).
θCS	°C/W	0.5	Typed interface.
θSA natural, ΔT 75	°C/W	3.0	Group *Heatsink*: the catalogue rating at a 75 °C rise.
Mass (aluminium)	g	80	For the warm-up time.
θSA forced, datasheet, at air speed, Your air speed	°C/W, m/s, m/s	1.2, 2, 2	Forced air.
Base width, length, thickness, spreading	mm	50, 60, 4, **In θSA**	Add spreading adds the base spreading resistance.
Copper area top, Lower layers, Thermal vias, Via drill, Plating, Board thickness, Board area	cm^2, cm^2, , mm, µm, mm, cm^2	6.45, 6.45, 9, 0.3, 25, 1.6, 50	PCB copper. Also 1 oz or **2 oz**, 1, 2 or 4 layers, vertical or horizontal, bare board ignored or included.
θJA (datasheet)	°C/W	62	Free air.
Other parts, same heatsink		D2 rectifier 4 W on	Up to three rows: name, power, Tj max, θJC, θCS, each with a tick.

How it works it out. A natural-convection θSA scales as $(75/\Delta T)^{0.25}$, solved together with the rise the total power gives. Forced air scales as $1/\sqrt{v}$. The heatsink carries this part and the other ticked parts, and each junction sits P (θJC + θCS) above it. The PCB mount is an annular copper fin (Incropera) with convection and radiation from both faces, lower layers through plated vias and the FR-4, solved together with its temperature. Pulses use the Foster stages plus the interface and mount stages (the heatsink's τ from its θ and mass): the periodic steady state by superposition, the single pulse as $Zth(tp) = \Sigma\, R\,(1 - e^{-tp/\tau})$, and the datasheet form $D \cdot Rth + (1 - D) \cdot Zth(tp)$.

RESULT	WHAT IT IS

RESULT	WHAT IT IS
Tj (Tj peak when pulsed)	Against the design limit and the maximum. Amber over the design limit, red over the maximum.
Case Tc	
Heatsink, Board under part, or Inside ambient	Its temperature, with what flows into it.
P limit	The continuous power for the design limit.
θSA needed, Copper needed, or θJA used	With the catalogue equivalent at ΔT 75 °C, or the air speed, or the 2 oz and 1 oz copper per layer.
Total θ	Rise over average power.
Warm-up or Swing	The mount's time constant, or the Tj swing per pulse.
θCS or Vias	The interface, or the vias and their θ.

A stacked bar shows the rise above the outside air: enclosure, other parts, heatsink, interface and junction to case. **Parts** gives the heatsink to buy (θSA at the working rise and at ΔT 75, a volume range, the air speed needed), the interface, its insulation and the fixing, or the copper, vias and layers for a PCB.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Junction vs design limit	Tj · limit	Within it	Up to Tj max	Over
Junction vs absolute max	Tj · max	20 °C margin	Within it	Over
Temperature swing per pulse	°C	40 °C or less	80 °C or less	More
Tj, single pulse	Tj · Zth(tp)	Within Tj max		Over
D2 rectifier on the sink	Tj · its max	25 °C under it	Within it	Over
Heatsink surface	Ts	60 °C or less	Hotter: guard it	
Interface vs package	θCS · θJC	θCS ≤ θJC	Up to 2 × θJC	More
Sink ΔT vs catalogue 75 °C	ΔT	40 °C or more	Less: θSA is worse than the catalogue	
Board next to the part	Ts · FR-4 105 °C	105 °C or less	130 °C or less	More

MESSAGE	WHEN IT SHOWS
"Tj 188 °C is above the 150 °C maximum. Use θSA ≤ 0.97 °C/W, a better interface or forced air."	Over the maximum on a heatsink. On a PCB: *Board limit … Add copper and vias or use a heatsink.* In free air: *Add a heatsink.*
"Tj 24 °C above the 125 °C design limit."	Over the design limit.
"θCS … °C/W is above θJC … °C/W. Use grease or phase change on a flat heatsink, or a thinner pad."	The interface dominates.
"Heatsink rise 52 °C. Catalogue natural-convection θSA is for ΔT 75 °C, so θSA is 9 % higher here (included)."	A rise under 40 °C… or any rise below 75 °C that changes θSA.
"ΔTj … °C per pulse. Repeated swings fatigue the die attach and bond wires. Lower the pulse power or add thermal mass near the die."	A swing over 40 °C.
"D2 rectifier: Tj … °C, above its 175 °C limit."	A shared part over its limit.

Verify in simulation places the thermal network as a circuit (1 A = 1 W, 1 V = 1 °C, 1 Ω = 1 °C/W, 1 F = 1 J/K): a current source of the average power into TJ, each stage as R in parallel with C = τ/R, a source for the ambient. It checks *Steady Tj* and *Heatsink Ts* (operating point), *Warm-up, Tj at τ* (transient) and *Zth single pulse at tp*. The heatsink θ from the air flow or copper and the peak Tj of a pulse train are calculator only.

BUTTON	WHAT IT DOES
Place thermal network	The network (P_TJ, RTHn, CTHn, P_OTHERS, V_AMB), TJ and TS labelled, an operating point. Measurements *Junction temperature* V(TJ) and *Heatsink temperature* (or *Board temperature*) V(TS), ±0.1 °C.
Apply θ	With a diode, LED, transistor, regulator or op-amp selected: rth_jc, rth_ca, tamb and cth on it, so its self-heating gives the same Tj.

SIMPLE	ADVANCED
Power dissipated, Ambient temperature, Junction limit	Power, Ambient outside, Tj design limit
θJC, θCS, θSA	θJC, typed θCS, θSA natural ΔT 75

TRY IT

A TO-220 sharing a heatsink

1. Open Heatsink and junction, press **Advanced**: 12 W, TO-220, natural air, 3 °C/W at ΔT 75, 40 °C plus 10 °C in the box, a 4 W rectifier on the same heatsink.
2. Press **Place thermal network**.

YOU SHOULD SEE Tj 119.3 °C, Tc 108.5 °C, the heatsink at 102.5 °C with 16 W in 3.28 °C/W (its θ at a 52 °C rise), power limit 13.4 W, θSA needed 3.64 °C/W (3.41 in the catalogue), warm-up 236 s. The rectifier runs at 110.6 °C. *Heatsink surface* is amber (guard it). V(TJ) reads 119.3 °C and passes.

TRY IT

A D2PAK on copper

1. Set **Mount** to **PCB copper**: 2.5 W, 6.45 cm² of 2 oz on two layers, nine vias.

YOU SHOULD SEE Tj 148.8 °C with θ board 38.6 °C/W and a power limit of 1.76 W. It needs 13.5 cm² of 2 oz per layer (15.8 cm² of 1 oz). *Board next to the part* fails at 147 °C against the 105 °C FR-4 limit.

Sources. JEDEC JESD51-1 and TI SPRA953 for the thermal ladder, Incropera for the annular fin, Lee, Song, Au and Moran (1995) for spreading, Abramowitz and Stegun 9.8 for the Bessel functions. Interface and thick-film figures are typical and marked to be replaced by yours. The tests check the ladder, the $(\Delta T/75)^{-0.25}$ scaling, θCS for grease (0.42 °C/W on 1.1 cm²), the Foster stack, and the placed network against bspice.

61 Trace current and width

61.1 Simple: width for a current 540
61.2 Advanced: the worst corner 543

How wide a copper trace must be for a current and a temperature rise, and what it then drops and dissipates. The Simple view uses IPC-2221 or IPC-2152. The Advanced view sizes the trace on its worst manufacturing corner (IPC-6012 minimum copper, etched narrow) with the IPC-2152 modifiers for the board, a plane and the laminate, adds the AC ripple's skin loss, a fault pulse and the fusing time, and can insert the trace into a wire of your circuit. Group PCB. Search words include trace, track, width, current, ipc-2221, ipc-2152, copper and ampacity.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

61.1 Simple: width for a current

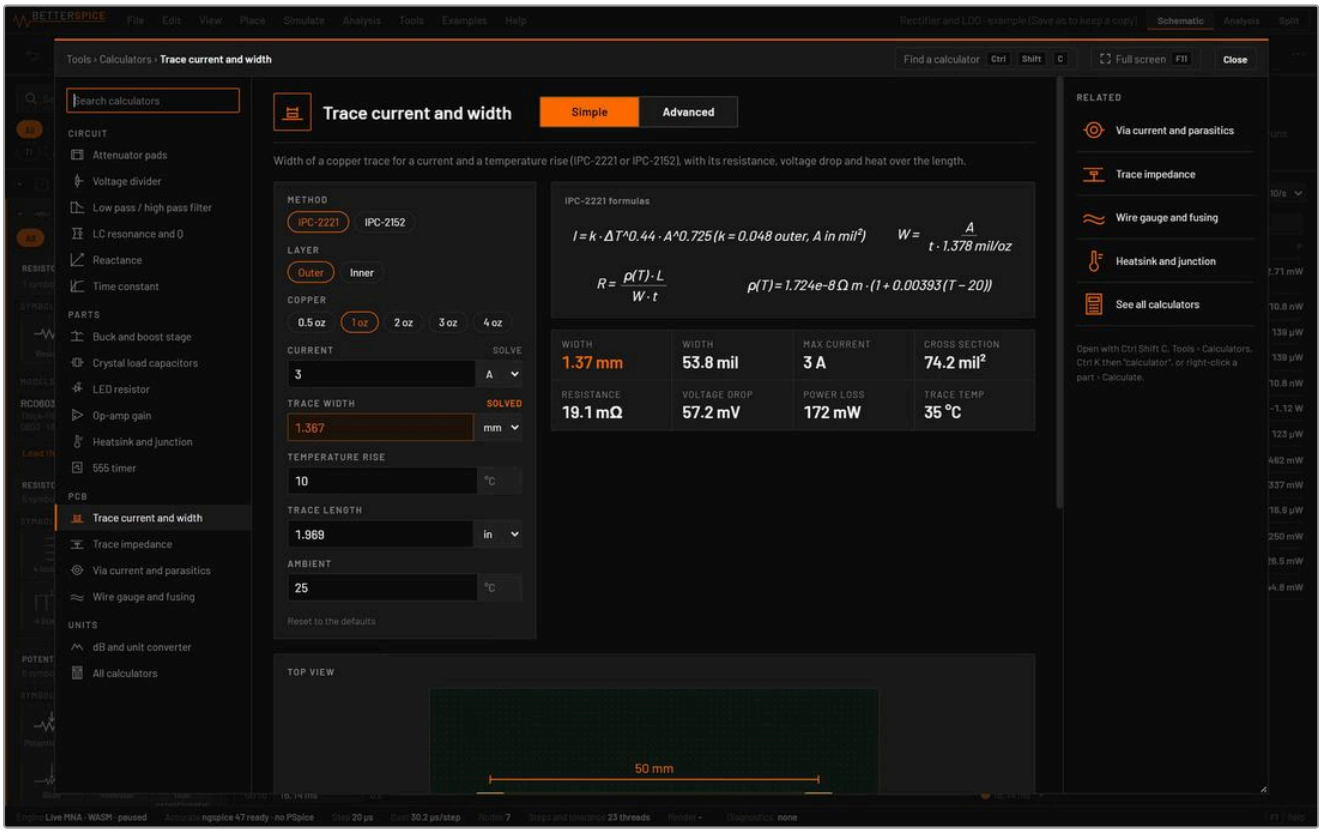


Figure 61.1 Trace current and width: 3 A on 1 oz outer copper with a 10 °C rise needs a trace 1.37 mm wide.

CHOICE	OPTIONS	WHAT IT DOES
Method	**IPC-2221**, IPC-2152	
Layer	**Outer**, Inner	
Copper	0.5 oz, **1 oz**, 2 oz, 3 oz, 4 oz	1 oz = 1.378 mil = 35 µm.
Copper plane next to the trace	**No plane**, Plane under it	IPC-2152.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Current	A, mA	3 A	SOLVE. Reads the measured RMS current of a selected wire or two-pin part while the live view runs.
Trace width	mm, mil, µm	1.5 mm (solved)	SOLVE, solved when the calculator opens.
Temperature rise	°C	10	1 to 150.
Trace length	mm, in, mil, cm	50 mm	
Ambient	°C	25	
Board thickness	mm, mil	1.6 mm	IPC-2152. Thin boards run hotter. Chart range 0.72 to 2.36 mm.
Distance to the plane	mm, mil	0.2 mm	IPC-2152 with a plane. Chart range 0.14 to 2.4 mm.

IPC-2221: $I = k\,\Delta T^{0.44}\,A^{0.725}$ with A in mil^2 and k = 0.048 outer, 0.024 inner, and the width A / t. IPC-2152 uses the Brooks and Adam fit of its charts ($\Delta T = K\,I^a\,W^b\,Th^c$, per layer and copper weight) and the modifiers for the board thickness and a plane. $R = \rho(T)\,L / (W\,t)$ with $\rho = 1.724 \times 10^{-8}\ \Omega\,m$ and +0.393 %/K at the trace temperature.

RESULT	WHAT IT IS
Width (mm), Width (mil)	Orange when solved.
Max current	Orange when solved.
Cross section	mil^2.
Resistance, Voltage drop, Power loss, Trace temp	At ambient + rise.

Drawings: the trace from above with its length and width (it glows hotter with the rise), the cross section, and a table **Width for 3 A and +10 °C, by copper** for outer and inner layers.

MESSAGE	WHEN IT SHOWS
"IPC-2221 charts stop at 35 A. Above that the formula is an extrapolation, check with a thermal model."	Over 35 A. Also over 400 mil wide, a rise outside 10 to 100 °C, or a section outside 1 to 250 mil^2.
"The IPC-2152 data covers 1 to about 100 °C of rise."	Also: the fit is documented for 5 to 400 mil, the data goes up to about 25 A.
"Estimate: the board thickness and the plane distance change the rise by factors fitted to the IPC-2152 modifier charts by a third party. They agree with the Brooks and Adam plane simulation within about 10 %. Check a tight design with a thermal model."	IPC-2152 with a plane or another board thickness.
"The trace runs at 145 °C. FR-4 glass transition is about 130 to 170 °C, keep margin and mind nearby parts."	Over 105 °C.
"A trace under 3 mil is limited by the fabricator, not by the current."	

BUTTON	WHAT IT DOES
Add the trace to the circuit and run	With a straight wire selected: R_TRACE (the Simple resistance, no tempco) in series with it, in the live view. No measurements.
Note on the trace's wire	A text above the selected wire: *PCB trace 1.37 mm (53.8 mil) x 50 mm, 1 oz outer, 19.1 mΩ, 3 A for +10 °C.*

TRY IT

3 A on 1 oz

1. Open Trace current and width (type **trace**): IPC-2221, outer, 1 oz, 3 A, +10 °C, 50 mm.
2. Set Method to **IPC-2152** and Plane under it.

YOU SHOULD SEE IPC-2221: 1.37 mm (53.8 mil), 74.2 mil^2, 19.1 mΩ, 57.2 mV, 172 mW at 35 °C. With IPC-2152 and a plane 0.2 mm under it the same current needs a much narrower trace: a plane lets a trace carry about twice the current for the same rise.

61.2 Advanced: the worst corner

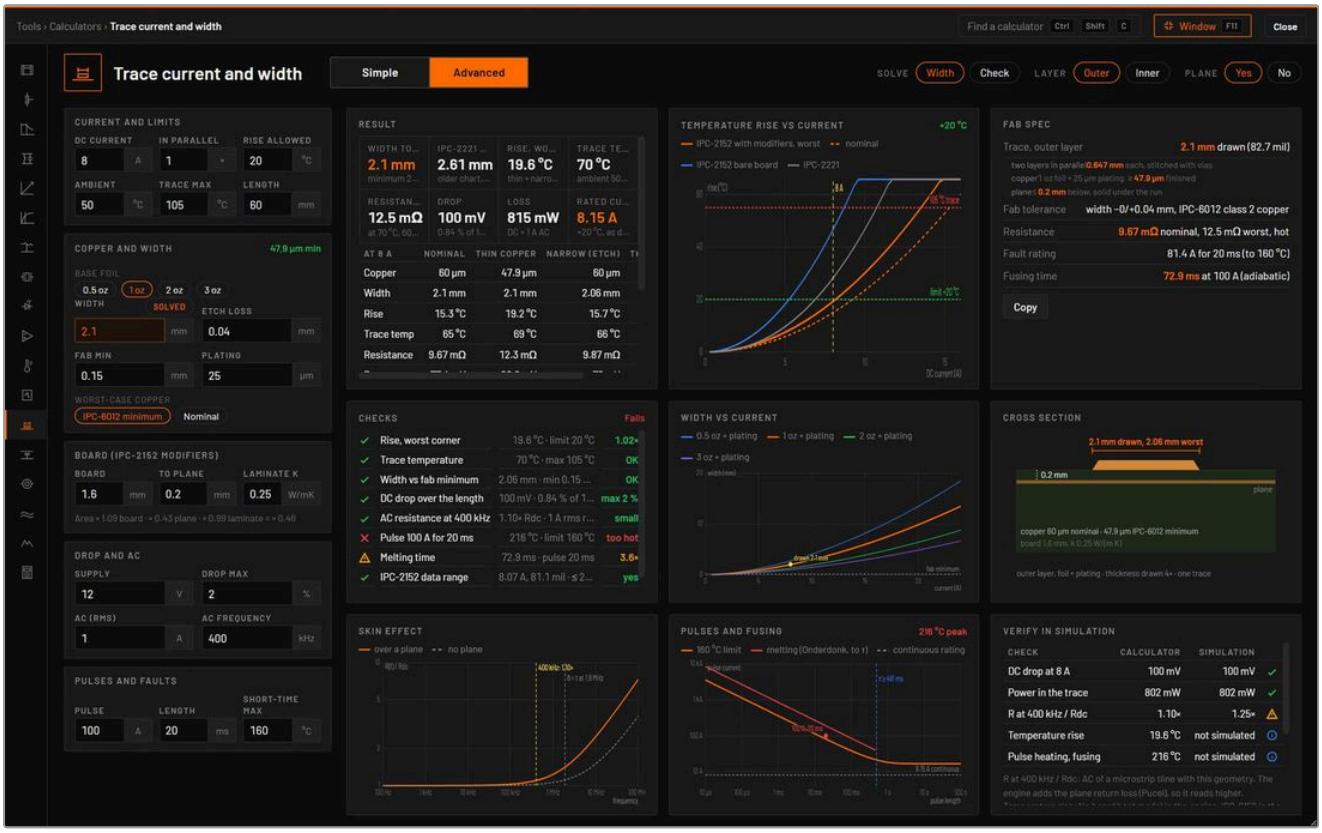


Figure 61.2 Trace current and width, Advanced, in full screen: 8 A on 1 oz outer with a plane, the width to draw on the worst corner, the corners, the fab spec, the rise against current, the checks, the skin effect and the pulse limits.

CHOICE	OPTIONS	WHAT IT DOES
Solve	**Width**, Check	Width works out the width to draw (SOLVED). Check takes a typed width.
Layer	**Outer**, Inner	
Plane	**Yes**, No	

TAB	ITS DOT	CARDS
Design	Rise, trace temperature, width against the fab minimum.	Result, Fab spec, Cross section, Corners.
Heat	Rise and trace temperature.	Temperature rise vs current, Checks, Width vs current, Methods, worst corner.
Drop and AC	DC drop and AC resistance.	Skin effect, Drop and loss, Drop vs current.
Pulses	Pulse and melting time.	Pulse current vs length, Pulse checks.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
DC current, In parallel	A, ×	8, 1	Group *Current and limits*.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Rise allowed, Ambient, Trace max, Length	°C, °C, °C, mm	20, 50, 105, 60	
Base foil		0.5, **1**, 2, 3 oz	Group *Copper and width*, badge the minimum copper.
Width	mm	SOLVED (2.5 typed)	
Etch loss, Fab min, Plating	mm, mm, µm	0.04, 0.15, 25	Plating on an outer layer.
Worst-case copper		**IPC-6012 minimum**, Nominal	IPC-6012 minimum after processing: outer 33.4, 47.9, 78.7, 108.0 µm, inner 11.4, 24.9, 55.9, 86.9 µm for 0.5 to 3 oz.
Board, To plane, Laminate k	mm, mm, W/mK	1.6, 0.2, 0.25	Group *Board (IPC-2152 modifiers)*, badge *clamped* outside the chart ranges, and the area multiplier line.
Supply, Drop max, AC (rms), AC frequency	V, %, A, kHz	12, 2, 1, 400	Group *Drop and AC*.
Pulse, Length, Short-time max	A, ms, °C	100, 20, 160	Group *Pulses and faults*.

How it works it out. IPC-2152 with the modifiers for board, plane and laminate (each held at its chart end). Four corners: Nominal, Thin copper, Narrow (etch), Thin + narrow. The width is sized on the worst one, and the width to draw is that plus the etch loss, rounded up to 0.05 mm and at least the fab minimum. The current per trace is the DC current over the traces in parallel, and the AC ripple heats as $\sqrt{(I_{dc}^2 + I_{ac}^2\, R(f)/R_{dc})}$, with R(f) from the skin form of the engine's transmission line. A pulse uses a one-pole thermal model (copper's 3.45 MJ/m³K, the time constant a lower bound), and the melting time the adiabatic IEC 60949 formula with Onderdonk's 1083 °C.

RESULT	WHAT IT IS
Width to draw (Width needed in Check mode)	Orange. Red in Check mode when the need is wider than drawn.
IPC-2221 width	The older chart, for comparison.
Rise, worst, Trace temp	Red over the allowed rise.
Resistance, Drop, Loss	At the worst temperature, the drop as % of the supply, DC plus AC loss.
Rated current	What the drawn trace carries on its worst corner for the allowed rise (orange).

The **Corners** table gives copper, width, rise, temperature, resistance, drop and loss for each corner, the worst in orange. The **Fab spec** gives the width in mm and mil (and on two stitched layers), the copper to require, the plane, the tolerance, the resistance, the fault rating and the fusing time, with **Copy**. **Methods, worst corner** compares IPC-2152 with modifiers, IPC-2152 bare board and IPC-2221.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Rise, worst corner	rise · allowed	Within it	Up to 1.11 × it	More
Trace temperature	T · trace max	10 % room	Within it	Over: hot
Width vs fab minimum	width · minimum	At or over		Under

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
DC drop over the length	% of supply · max	Within it	Up to 1.25 × it	More
AC resistance at 400 kHz	× Rdc	1.5 × or less: small	More: skin loss	
Pulse 100 A for 20 ms	peak T · short-time max	Within it	Up to 1.11 × its rise	More: too hot
Melting time	time · pulse length	10 × or more	2 × or more	Less
IPC-2152 data range	I, width, rise	Inside	Outside: extrapolated	
Modifier range	board, plane, laminate	All inside	Clamped	

MESSAGE	WHEN IT SHOWS
"Worst corner (thin + narrow): rise 769 °C, limit 10 °C. Draw at least 41.9 mm, or 12.6 mm on each of two layers."	Too narrow (Check mode).
"Trace at 854 °C, limit 105 °C. Lower the allowed rise or the ambient."	Over the trace maximum.
"100 A for 20 ms heats the trace to 216 °C, limit 160 °C. Draw at least 2.65 mm or clear the fault sooner."	The pulse is too hot.
"The trace melts after 229 µs at 300 A. Clear the fault well before that."	Melting under 2 × the pulse.
"No plane under the trace. A plane 0.2 mm below lowers the IPC-2152 rise by 2.6×."	Plane No.
"2 traces in parallel are treated as thermally separate. Side by side on one layer they heat each other (IPC-2152 section 5)."	More than one.
"Board thickness outside the chart range of 0.72 to 2.36 mm. Modifier held at the chart end value."	Also for the plane distance and the laminate.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
DC drop at 8 A, Power in the trace	Operating point of R_TRACE at the trace temperature	Equal
R at 400 kHz / Rdc	AC of a microstrip transmission line of this geometry. The engine adds the plane's return loss (Pucel), so it reads higher	Within 10 %
Temperature rise, Pulse heating, fusing	Not simulated: the engine has no board heat model. A fuse part in series shows when the protection opens	

BUTTON	WHAT IT DOES
Insert in wire and run	See below.
Place line and run AC	A source at the ripple frequency, RS = Z0, a microstrip **tline** with the worst-corner width, copper, height and length, a matched load, and an AC sweep. *Trace loss at 400 kHz* between the calculator's and the engine's copper loss.

Insert in wire and run puts the trace into your circuit: select a straight wire first (horizontal or vertical, at least 4 grid units long, 8 for the via's two parts). The part goes in series at the middle of the wire, 4 grid units long, and the wire is split at its pins. It is a resistor **R_TRACE** with copper's tempco (tc1 0.00393, tnom 20 °C) at the worst-corner temperature, so it has the calculator's hot resistance. Then the live view runs, an operating point is taken, and two measurements are added: *current against the calculator*

(PASS up to the design current) and *drop, % of the calculator's* (PASS up to 100.1 %). A wire that carries more than the design current fails both. It is one undo step, and a name in use becomes R_TRACE2. The button's tooltip asks for a wire at least 8 grid units long in all three, while the trace and wire need only 4.

SIMPLE	ADVANCED
Current, Trace width, Temperature rise, Trace length, Ambient, Board thickness	DC current, Width, Rise allowed, Length, Ambient, Board
Layer, Copper (4 oz ⟶ 3 oz), Plane	Layer, Base foil, Plane

TRY IT

8 A on an outer layer, then a fault

1. Open Trace current and width, press **Advanced**: 8 A, +20 °C over 50 °C, 1 oz outer with 25 µm plating, a plane 0.2 mm under it, 60 mm.
2. Open **Pulses**.

YOU SHOULD SEE Draw 2.1 mm (2.065 mm needed on the thin + narrow corner, 47.9 µm copper, area × 0.46 from the board, plane and laminate). IPC-2221 would ask 2.607 mm, IPC-2152 bare board 4.40 mm. Worst corner: 19.6 °C rise, 69.6 °C, 12.53 mΩ, 100 mV (0.84 %), 0.815 W, rated 8.15 A. The 100 A, 20 ms fault heats it to 216 °C against 160 °C: *Pulse* fails, and the warning asks for 2.65 mm. It would melt after 72.9 ms (3.6 ×, amber).

Sources. IPC-2221 (section 6.2, chart 6-4), IPC-2152 (2009) with the Brooks and Adam fit ("Trace Currents and Temperatures Revisited", 2015) and the section 5 modifiers as fitted by NinjaCalc, IPC-6012 for the minimum copper, IEC 60949 and Onderdonk for fusing. The tests check IPC-2221 at 1 A and 3 A (11.8 and 53.8 mil), the plane and board factors, 1 oz 10 mil 1 inch at 49 mΩ, the pulse model against the adiabatic form, Onderdonk's 14.7 A for 30 AWG in 1 s, and the placed R_TRACE and line against bspice.

62 Via current and parasitics

62.1 Simple: one via or n 547
62.2 Advanced: through, blind and micro 549

A plated via: its resistance, inductance and capacitance, the current it carries, its thermal resistance, and how many a current needs. The Advanced view adds through, blind and microvias with their fill, the IPC fabrication rules (land, plating, aspect ratio), a thermal-via array under a power pad, the stub resonance against a data rate with back-drilling, and inserts the via into a wire of your circuit. Group PCB. Search words include via, plated, hole, barrel, parasitic, inductance, capacitance and thermal.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

62.1 Simple: one via or n

CHOICE	OPTIONS	WHAT IT DOES
IPC-6012 class	**Class 2**, Class 3	The plating the class asks for: 20 µm or 25 µm average.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Hole diameter (finished)	mm, mil	0.3 mm	
Plating thickness	µm, mil	25 µm	
Via length (board thickness)	mm, mil	1.6 mm	
Pad diameter, Antipad diameter	mm, mil	0.6, 1.0 mm	
Board εr		4.5	
Current	A, mA	2 A	Reads the measured RMS current of a selected wire or part.
Temperature rise, Ambient	°C	10, 25	
Vias in parallel		1 (solved)	SOLVE, solved when the calculator opens: the number the current needs.

Barrel area A = πt(d + t), R = ρ(T) h / A, L = 5.08 h [ln(4h/d) + 1] nH and C = 1.41 εr T D1 / (D2 – D1) pF (Johnson and Graham, lengths in inches), Rθ = h / (kA) with k = 385 W/mK, and the current per via from IPC-2221 on the barrel section. n vias divide R, L and Rθ and add their C. Z = √(L/C).

RESULT	WHAT IT IS
Resistance	Of n in parallel (orange).
Inductance, Capacitance	Of n vias.
Current per via, Vias needed	
Voltage drop, Thermal resistance	
Via Z	√(L/C) of one via.

MESSAGE	WHEN IT SHOWS
"The antipad must be larger than the pad, or the capacitance has no meaning."	Antipad at or under the pad: the capacitance then reads negative and Via Z reads –.
"The pad is smaller than the plated hole."	
"Aspect ratio over 10 to 1. Plating in a hole this deep is hard to make, so ask the fabricator or use a larger hole."	
"The inductance formula assumes a via longer than it is wide."	
"... A per via is more than one via carries for +10 °C. Use ... or more."	Too few vias typed.
"Plating 10 µm is under the IPC-6012 class 3 average of 25 µm. Specify at least 25 µm in the hole."	

Drawings: the via from above (antipad, pad, plating, hole) and the barrel in cross section. **Add the via R and L in series and run** (with a straight wire of 8 grid units selected) puts R_VIA and L_VIA into it, in the live view, with no measurements.

TRY IT

2 A through 0.3 mm vias

1. Open Via current and parasitics (type **via**): 0.3 mm hole, 25 µm, 1.6 mm, 2 A, +10 °C.

YOU SHOULD SEE One via carries 1.9 A, so 2 are needed: 572 µΩ, 1.14 mV, 650 pH (1.3 nH for one), 1.2 pF, 81.4 K/W, Via Z 46.6 Ω.

62.2 Advanced: through, blind and micro

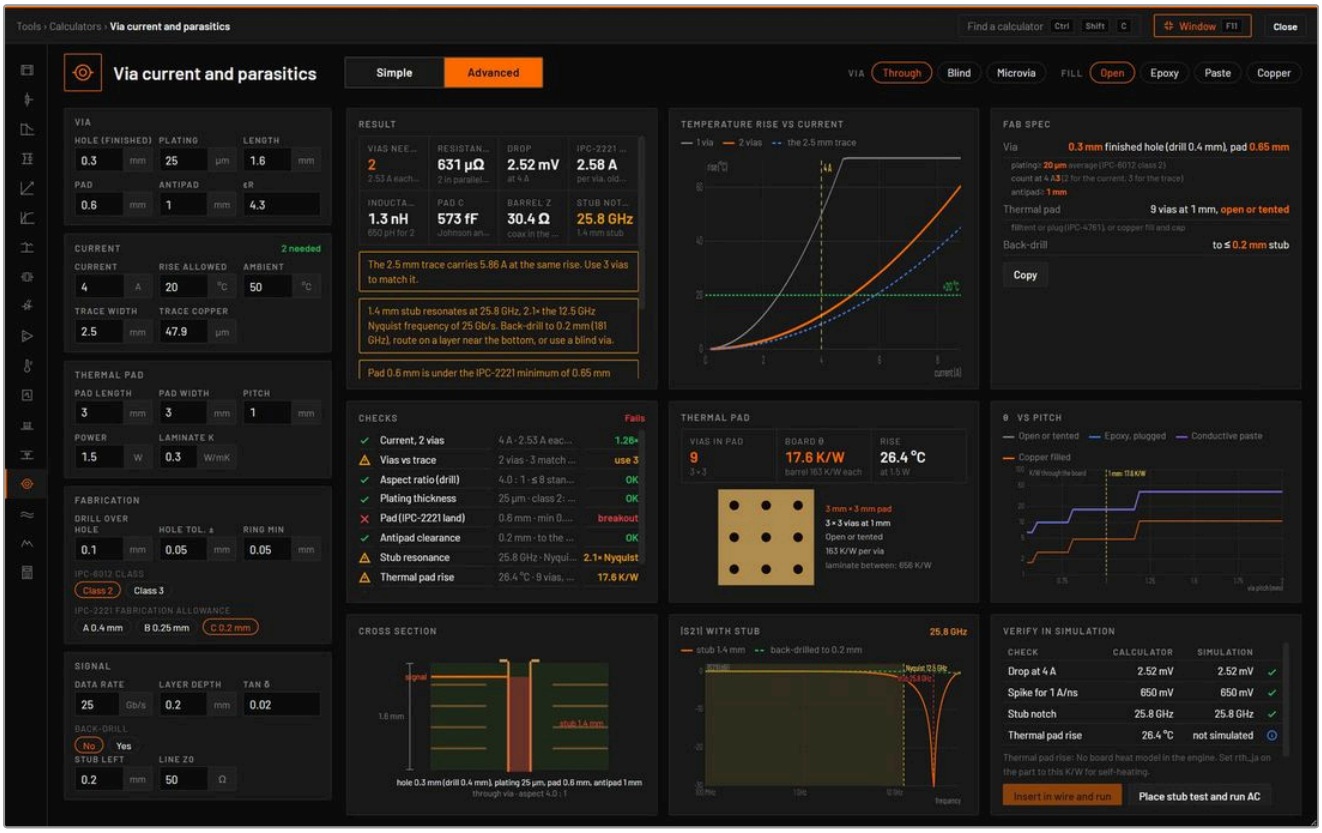


Figure 62.1 Via current and parasitics, Advanced, in full screen: two through vias for 4 A, with the fab spec, the thermal pad, the cross section, the land size, the stub response and the checks.

CHOICE	OPTIONS	WHAT IT DOES
Via	**Through**, Blind, Microvia	Loads typical geometry: through 0.3 mm, 25 µm, 1.6 mm, pad 0.6, antipad 1.0, drill allowance 0.1 mm. Blind 0.2 mm, 20 µm, 0.4 mm. Microvia 0.1 mm, 15 µm, 0.08 mm.
Fill	**Open** (or tented), Epoxy (plugged), Paste (conductive), Copper (filled)	Thermal k 0, 0.5, 3.5, 385 W/mK.

TAB	ITS DOT	CARDS
Current	Current, and vias against the trace.	Result, Temperature rise vs current, Fab spec.
Thermal pad	Pad rise, fill, hole spacing.	Thermal pad, θ vs pitch, Checks.
Fabrication	Aspect ratio, plating, land, antipad.	Cross section, Fabrication checks, Land size (IPC-2221).
Stub	Stub resonance.	|S21| with stub, Signal.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Hole (finished), Plating, Length, Pad, Antipad, εr	mm, µm, mm, mm, mm	0.3, 25, 1.6, 0.6, 1.0, 4.3	Group *Via*.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Current, Rise allowed, Ambient	A, °C, °C	4, 20, 50	Group *Current*, badge the vias needed.
Trace width, Trace copper	mm, µm	2.5, 47.9	The trace the vias feed: they should carry what it carries.
Pad length, Pad width, Pitch, Power, Laminate k	mm, mm, mm, W, W/mK	3, 3, 1, 1.5, 0.3	Group *Thermal pad*.
Drill over hole, Hole tol. ±, Ring min	mm	0.1, 0.05, 0.05	Group *Fabrication*.
IPC-6012 class, IPC-2221 fabrication allowance		**Class 2** or 3, A 0.4, B 0.25, **C 0.2 mm**	
Data rate, Layer depth, tan δ	Gb/s, mm	25, 0.2, 0.02	Group *Signal*.
Back-drill, Stub left, Line Z0	, mm, Ω	No, 0.2, 50	

How it works it out. The current per via uses the IPC-2152 fit on the barrel unrolled as an outer trace of width π(d + t), on the safe side (vias run cooler), and the vias needed is the current over that, rounded up. The trace match is the number of vias that carry what the entered trace carries at the same rise. The barrel impedance is 60/√εr ln(antipad / (d + 2t)), a coax in the antipad. The stub is the barrel below the signal layer (or what back-drilling leaves), with its notch at c / (4 l √εr) against the Nyquist frequency, half the data rate. The thermal array fits as many vias as the pitch allows in the pad, each a barrel and its fill, in parallel with the laminate between them. The minimum land is a + 2b + c: hole and tolerance, twice the ring, and the fab allowance.

RESULT	WHAT IT IS
Vias needed	With the current each (orange).
Resistance, Drop	Of n vias at their temperature.
IPC-2221 current	Per via, the older chart.
Inductance, Pad C, Barrel Z	
Stub notch	Amber under 3 × the Nyquist frequency.
Vias in pad, Board θ, Rise	On the Thermal pad card.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Current, 2 vias	I · per via × n	Within it	Up to 1.11 × it	More
Vias vs trace	n · the trace's match	n ≥ match	Fewer: use the match	
Aspect ratio (drill)	x : 1	8 or less (microvia 0.75)	10 or less: advanced (microvia 1)	More: too deep
Plating thickness	plating · class average	At or over	90 % or more	Thin
Pad (IPC-2221 land)	pad · minimum land	At or over	95 % or more	Breakout
Antipad clearance	(antipad – pad)/2 · 0.15 mm	At or over	80 % or more	Tight

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Stub resonance	notch · Nyquist	3 × or more	2 × or more	Less
Thermal pad rise	rise · n vias, power	20 °C or less	Up to 28.6 °C	More
Via fill in pad	fill	Filled or tented	Open: solder wicking	
Hole spacing	wall to wall · 0.2 mm	At or over	90 % or more	Too close

MESSAGE	WHEN IT SHOWS
"... needs ... vias of this size for +20 °C."	Too few.
"The 2.5 mm trace carries 5.86 A at the same rise. Use 3 vias to match it."	Fewer than the trace match.
"1.4 mm stub resonates at 25.8 GHz, 2.1× the 12.5 GHz Nyquist frequency of 25 Gb/s. Back-drill to 0.2 mm (181 GHz), route on a layer near the bottom, or use a blind via."	Notch under 3 × Nyquist.
"Aspect ratio 8.0 : 1 exceeds 8 : 1. Plating thins in the middle of the hole. Use a hole of 0.3 mm or larger."	
"Pad 0.6 mm is under the IPC-2221 minimum of 0.65 mm (hole + tolerance + 2 × ring + level C allowance). Drill wander can break out. Use a 0.65 mm pad."	
"IPC-6012 class 2 requires 20 µm average plating in the hole."	
"Open vias in a thermal pad wick solder from the joint. Tent, plug, or fill and cap them (IPC-4761 type VII), or place them at the pad edge."	Fill Open.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Drop at 4 A	Operating point of R_VIA and L_VIA in the selected wire	Equal
Spike for 1 A/ns	L/n × 1 A/ns, a transient with a fast current step	
Stub notch	AC of a 50 Ω line with an open ideal line as the stub (barrel Z, delay from the stub length)	At the quarter wave
Thermal pad rise	Not simulated: set rth_ja on the part to the K/W for self-heating	

BUTTON	WHAT IT DOES
Insert in wire and run	R_VIA (n in parallel, at temperature) and L_VIA (L/n) in the selected wire. See below.
Place stub test and run AC	A 50 Ω source and load with the stub as an open ideal line, swept past the notch. *Via stub loss* at half the notch within ±0.1 dB, and *Via stub notch* under –15 dB. Greyed when there is no stub.
Apply θ to part	The thermal pad's K/W as rth_ja on the selected parts.

Insert in wire and run puts the via into your circuit: select a straight wire first (horizontal or vertical, at least 4 grid units long, 8 for the via's two parts). The part goes in series at the middle of the wire, 4 grid units long, and the wire is split at its pins. It is a resistor **R_VIA** with copper's tempco (tc1 0.00393, tnom 20 °C) at the worst-corner temperature, so it has the calculator's hot resistance. Then the live view runs, an operating point is taken, and two measurements are added: *current against the calculator* (PASS up to the design current) and *drop, % of the calculator's* (PASS up to 100.1 %). A wire that carries more than the design current fails both. It is one

undo step, and a name in use becomes R_VIA2. The button's tooltip asks for a wire at least 8 grid units long in all three, while the trace and wire need only 4.

SIMPLE	ADVANCED
Hole, Plating, Via length, Pad, Antipad, Board εr	Hole, Plating, Length, Pad, Antipad, εr
Current, Temperature rise, Ambient, IPC-6012 class	Current, Rise allowed, Ambient, IPC-6012 class

TRY IT

4 A, a thermal pad and a 25 Gb/s stub

1. Open Via current and parasitics, press **Advanced**: through, open, 4 A, +20 °C, a 3 × 3 mm pad with 1 mm pitch and 1.5 W, 25 Gb/s on a layer 0.2 mm deep.

YOU SHOULD SEE 2 vias (2.53 A each): 0.631 mΩ, 2.52 mV, 1.30 nH each, 573 fF, barrel Z 30.4 Ω. Four rows are amber and one red: the 2.5 mm trace would need 3 vias, the 1.4 mm stub notches at 25.8 GHz (2.1 × the 12.5 GHz Nyquist, back-drill to 0.2 mm), the 9-via pad rises 26.4 °C, the open vias wick solder, and the 0.6 mm pad is under the 0.65 mm minimum land.

Sources. Johnson and Graham, *High-Speed Digital Design* (vias), IPC-2221 (current and land), IPC-2152 (the barrel as a trace), IPC-6012 (plating), IPC-4761 (via fill), IPC-2226 (microvia capture pad), the quarter-wave stub. The tests check the barrel R and θ, Johnson's 1.18 nH for a 0.062 × 0.016 inch via, IPC-2221 and the unrolled IPC-2152 within 3 %, the land, plating, aspect ratio and pad array, the notch, and the placed R_VIA and stub test against bspice.

63 Trace impedance

63.1 Simple: Z0 and the width 553
63.2 Advanced: the line as built 555

The characteristic impedance of a PCB trace over a plane: microstrip, buried microstrip, stripline and edge-coupled differential pairs, with the width for a target and the delay. The Advanced view adds a coplanar waveguide with ground, solder mask and etch, the laminate's εr and loss against frequency, copper roughness, the line's loss, a Monte Carlo of the fab tolerances, a fab note to send, and a TDR check in the simulator. Group PCB. Search words include impedance, microstrip, stripline, differential, z0, delay, transmission line and controlled impedance.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

63.1 Simple: Z0 and the width

CHOICE	OPTIONS	WHAT IT DOES
Structure	**Microstrip**, Buried microstrip, Stripline, Diff microstrip, Diff stripline	Sets the target: 100 Ω for the pairs, 50 Ω otherwise.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Trace width	mm, mil	0.35 mm (solved)	SOLVE, solved when the calculator opens: the width for the target.
Dielectric height (to the plane)	mm, mil	0.2 mm	Stripline: from the trace to each plane.
Copper thickness	µm, mil, oz	35 µm	
Dielectric εr		4.3	
Spacing between the pair (edge to edge)	mm, mil	0.2 mm	Pairs.
Cover above the trace	mm, mil	0.2 mm	Buried microstrip.
Target impedance	Ω	50	The differential impedance for pairs, 90 or 100 Ω usually.
Line length	mm, in, cm	100 mm	

Microstrip: Hammerstad and Jensen (1980) with the thickness correction (Wadell 3.2). Buried microstrip: the IPC-2141 cover blend exp(−1.55 h2/h). Stripline: Cohn's thick-strip formula, Wheeler's round-wire form for narrow strips. Pairs: the Kirschning-Jansen coupled microstrip and Cohn coupled stripline of the engine's **tline_diff** part, so a placed pair agrees with the calculator.

RESULT	WHAT IT IS
Z0, or Single-ended Z0, Differential Zdiff, Odd mode Zodd	Zdiff in orange for a pair.
Effective εr, Delay per mm, Delay per inch, Delay of 100 mm	
L per length, C per length	
Width for target	Orange when solved, *not reachable* when no width gives it.

The cross section is drawn with its dimensions, and a table gives Z0 at 0.5 to 2 × the width.

MESSAGE	WHEN IT SHOWS
"Width over height is outside 0.01 to 100, where the Hammerstad-Jensen formula is documented."	Microstrip types.
"The copper is thick against the dielectric (t / h over 0.2), the thickness correction loses accuracy."	
"t / b over 0.25 is outside the stripline formula."	Also: a very narrow stripline (w / (b – t) under 0.1).
"The pair is so far apart that it is nearly two single lines, the coupling formula is least reliable there."	s/h over 4.
"Estimate within a few percent: the pair uses the Kirschning-Jansen (microstrip) and Cohn (stripline) coupled-line model of the engine tline_diff part. Check a tight design with a field solver."	Always for a pair.
"Estimate: the buried microstrip cover correction blends the surface value into the fully covered one with an exponential in the cover thickness (IPC-2141 form), it is not a closed-form solution."	Always for buried. A cover under 0.2 h adds: *solder mask is not a full dielectric cover.*
"No width gives that impedance with these dimensions. Change the height or the spacing."	

BUTTON	WHAT IT DOES
Place line test and run	A pulse through an ideal line of this Z0 and delay, source and load matched, in the live view: V out follows V in after the delay.
Put the line in series with the selected wire	With a horizontal wire of 6 grid units selected: an ideal line TL1 with its return to ground.
Apply Z0 and delay to the selected line	With a line part selected: variant ideal, z0 and td.

TRY IT

50 Ω on 0.2 mm FR-4

1. Open Trace impedance (type **impedance**): microstrip, 0.2 mm, 35 µm, εr 4.3, 50 Ω.
2. Switch to **Diff microstrip** with 0.1 mm height and 0.2 mm spacing.

YOU SHOULD SEE 0.359 mm wide, εeff 3.17, 5.94 ps/mm (594 ps over 100 mm), 0.297 nH/mm and 0.119 pF/mm. The 100 Ω pair needs 0.146 mm: 53.9 Ω single-ended, 50 Ω odd mode, 5.8 ps/mm.

63.2 Advanced: the line as built

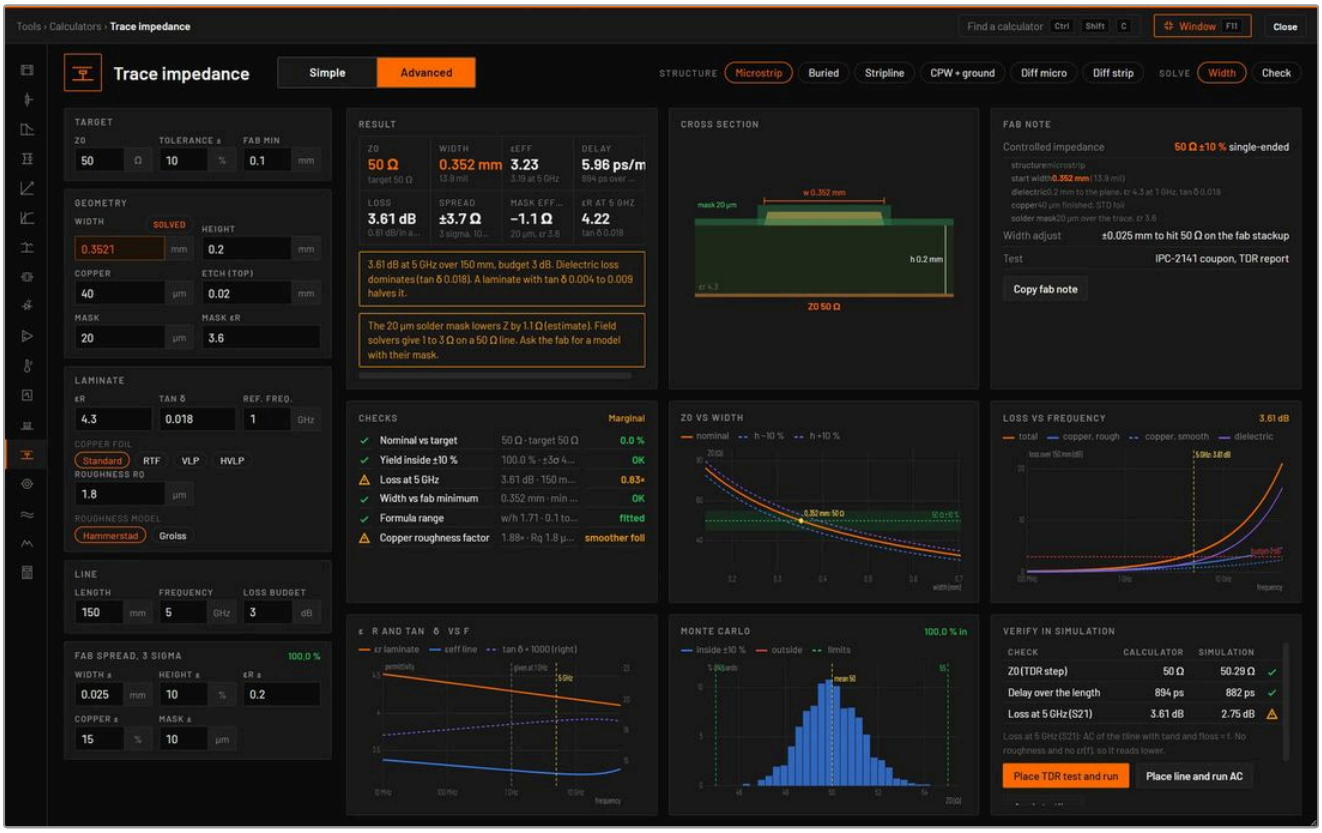


Figure 63.1 Trace impedance, Advanced, in full screen: a 50 Ω microstrip with mask and etch, the width against impedance, the fab note, the loss against frequency, εr against frequency, the Monte Carlo, the sensitivity and the checks.

CHOICE	OPTIONS	WHAT IT DOES
Structure	**Microstrip**, Buried, Stripline, CPW + ground, Diff micro, Diff strip	Loads typical geometry and target.
Solve	**Width**, Check	

TAB	ITS DOT	CARDS
Design	Nominal vs target, width, formula range.	Result, Cross section, Z0 vs width, Fab note, Checks.
Loss	Loss and roughness.	Loss vs frequency, Loss at 5 GHz.
Material	None.	εr and tan δ vs f, Dispersion.
Tolerance	Yield.	Monte Carlo, Sensitivity, Checks.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Z0 (Zdiff), Tolerance ±, Fab min	Ω, %, mm	50, 10, 0.1	Group *Target*.
Width, Gap, Height, Copper	mm, mm, mm, µm	SOLVED, 0.2, 0.2, 40	Group *Geometry*. Gap for pairs and CPW.
Etch (top), Cover, Mask, Mask εr	mm, mm, µm	0.02, 0.15, 20, 3.6	The etch makes a trapezoid. Cover for buried. Mask on the surface types.

FIELD	UNIT	DEFAULT	WHAT IT DOES
εr, tan δ, Ref. freq.	, , GHz	4.3, 0.018, 1	Group *Laminate*.
Copper foil, Roughness Rq, Roughness model	, µm	**Standard** (1.8 µm), RTF (0.8), VLP (0.5), HVLP (0.25), **Hammerstad** or Groiss	
Length, Frequency, Loss budget, Skew budget	mm, GHz, dB, ps	150, 5, 3, 5	Group *Line*. Skew for pairs.
Width ±, Height ±, εr ±, Copper ±, Mask ±	mm, %, , %, µm	0.025, 10, 0.2, 15, 10	Group *Fab spread, 3 sigma*, badge the yield.

How it works it out. The engine's own line formulas, the same code as the line parts: Hammerstad-Jensen microstrip, Wheeler stripline, a conductor-backed CPW by conformal mapping, Kirschning-Jansen and Cohn coupled lines. The calculator adds the mask or cover as a blend of the field's air share (an estimate), the etch as the mean width, Djordjevic-Sarkar εr(f) and tan δ(f) from the pair at the reference frequency, Kirschning-Jansen dispersion of εeff, Hammerstad or Groiss roughness (saturating at 2 ×), and the loss 8.686 (α_c rough + α_d). The Monte Carlo draws 1500 boards with each ± entry as a 3σ limit, and the two lines of a pair etch together.

RESULT	WHAT IT IS
Z0 or Zdiff	Against the target, with Zodd and Zcm for a pair (orange).
Width	mm and mil (orange in Width mode).
εeff, Delay, Loss	Static and at the frequency, ps/mm and over the length, dB and dB/inch.
Spread	±3σ in Ω, and the yield.
Mask effect or Cover effect, εr at 5 GHz	The impedance drop, and the laminate at the frequency.

The **Fab note** card writes what to send the fabricator: controlled impedance with its tolerance, the structure, the start width and gap, the dielectric, copper and mask, the width adjustment allowed, and an IPC-2141 coupon with a TDR report, with **Copy fab note**. **Sensitivity** moves each spread to its 3σ limit alone.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Nominal vs target	%	Within 2 %	Within 5 %	More
Yield inside ±10 %	% of boards	99.7 % or more	95 % or more	Less: tighten
Loss at 5 GHz	dB · budget	Within it	Up to 1.25 × it	More
Width vs fab minimum	width	At or over		Too thin
Formula range	w/h (and s/h)	0.1 to 20 (pairs 0.1 to 10)	Outside: fitted	

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Copper roughness factor	K	1.6 or less	More: smoother foil	
Coupling, Skew budget (pairs)	k and Zcm, the length mismatch allowed	(information)		
Copper vs gap (CPW)	copper · 0.3 × gap	Under	Over: Z0 high	

MESSAGE	WHEN IT SHOWS
"No width reaches … Ω with this height and εr. Use a thinner dielectric."	No width between 2 % and 40 × the height gives the target.
"86.1 % of boards inside ±5 %. Largest share: width (±0.025 mm, −7.8 Ω). Tighten the width tolerance or widen the impedance tolerance."	Yield under 99.7 %.
"3.61 dB at 5 GHz over 150 mm, budget 3 dB. Dielectric loss dominates (tan δ 0.018). A laminate with tan δ 0.004 to 0.009 halves it."	Over the loss budget (or: *Copper loss dominates. Use a wider line or a smoother foil.*).
"The 20 µm solder mask lowers Z by 1.1 Ω (estimate). Field solvers give 1 to 3 Ω on a 50 Ω line. Ask the fab for a model with their mask."	Mask on a surface line.
"The … cover lowers Z0 by … Ω against the bare microstrip. Estimate from the IPC-2141 cover blend. Confirm with the fab field solver."	Buried.
"Pair model: Kirschning-Jansen and Cohn coupled lines, as in the engine tline_diff. Within a few % of a field solver for 0.1 ≤ w/h and s/h ≤ 10."	Pairs.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Z0 (TDR step), Zdiff for a pair	Transient: a step from 50 Ω into the line, open at the end. The input plateau reads Z/(50 + Z)	±1.5 % of Z. The engine has no mask or etch
Delay over the length	The far end rises after the delay	Within 3 %
Loss at 5 GHz (S21)	AC of the matched line. The engine has no roughness or εr(f), so it reads lower	Between the calculator's and the engine's loss

BUTTON	WHAT IT DOES
Place TDR test and run	A pulse behind 50 Ω into the line (the engine's microstrip, stripline or CPW variant, or an ideal line for a buried line or a pair's odd mode), open at the far end, a transient of 6 delays. *Z0 plateau at the input*, *Far end before the delay* and *Far end after the delay*.
Place line and run AC	The line matched at its own Z0 and an AC sweep. *Line loss at 5 GHz*.
Apply to tline	The structure and geometry into the selected line parts.

SIMPLE	ADVANCED
Trace width, Dielectric height, Copper thickness, Dielectric εr, Spacing, Cover, Target impedance, Line length	Width, Height, Copper, εr, Gap, Cover, Z0, Length
Structure	Structure (Advanced adds CPW + ground)

TRY IT

A 50 Ω microstrip as built

1. Open Trace impedance, press **Advanced**: 50 Ω ±10 %, 0.2 mm, 40 µm copper with 0.02 mm etch, 20 µm mask, εr 4.3 and tan δ 0.018 at 1 GHz, standard foil, 150 mm at 5 GHz with a 3 dB budget.
2. Press **Place TDR test and run**.

YOU SHOULD SEE Width 0.3521 mm for 49.998 Ω (51.08 Ω without the mask), εeff 3.233, 5.958 ps/mm. The loss is 3.61 dB against 3 dB: amber, dielectric loss dominates. Roughness 1.88 ×: amber. The Monte Carlo gives ±3σ 46.3 to 53.8 Ω, 100 % inside ±10 %. The TDR plateau reads 0.500 V for 50 Ω and the far end rises after 894 ps: both pass.

Sources. Hammerstad and Jensen (IEEE MTT-S 1980), Wadell, *Transmission Line Design Handbook* (1991), Cohn (1955), Wheeler (1978), Kirschning and Jansen (1982, 1984), IPC-2141, Djordjevic-Sarkar, Hammerstad and Groiss roughness. The tests check microstrip, stripline, CPW and pairs against **bspice tline-calc** to four digits, the roughness factor, the mask effect, the Monte Carlo, and the TDR and AC runs against bspice.

64 Wire gauge and fusing

64.1 Simple: size, drop and fusing 559
64.2 Advanced: cables, faults and fuses 561

A copper wire or cable: its resistance and drop, the current it carries in air before its insulation is too hot, and the current and time that melt it. The Advanced view adds stranded wire, bundles, a round trip, the skin effect, a fault with its clearing time and the fuse that protects the wire, the smallest size that works, and inserts the wire into your circuit. Group PCB. Search words include wire, awg, gauge, mm2, ampacity, fusing, onderdonk, preece and cable.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

64.1 Simple: size, drop and fusing

CHOICE	OPTIONS	WHAT IT DOES
Size in	**AWG**, mm²	Solid wire.
Insulation	PVC 70 °C, **PVC 105 °C**, XLPE 125 °C, Silicone 180 °C, PTFE 200 °C	The temperature the ampacity is taken at.
Conductor	**Solid**, Stranded	

FIELD	UNIT	DEFAULT	WHAT IT DOES
AWG (0000 = –3, 000 = –2, 00 = –1)		22	Solid, AWG.
Cross section	mm²	0.5	Solid, mm².
Strands, AWG of one strand		7, 30	Stranded.
Length	m, ft, cm, mm	1 m	
Wire temperature	°C	20	For the resistance.
Operating current	A, mA	0.5 A	Reads the measured RMS current of a selected wire or part.
Fault current	A	100	SOLVE.
Time to fuse	s, ms	0.1 s (solved)	SOLVE, solved when the calculator opens.
Ambient, Insulation wall	°C, mm	25, 0.4	

The AWG diameter is 0.127 mm × $92^{(36 - n)/39}$ (ASTM B258). Stranded wire is the strands' area, with 2 % more resistance for the lay. $\rho = 1.7241 \times 10^{-8}$ Ω m at 20 °C, +0.393 %/K. The ampacity is a heat balance of the insulated wire in still air (Churchill and Chu convection, radiation, the wall as a thermal

resistance) at the insulation's rating, within 8 % of NEC Table 310.17 for a single conductor in free air. Fusing: Onderdonk, $I = A\sqrt{(\log_{10}(1 + (1083 - Ta)/(234 + Ta))/33t)}$ with A in circular mils, and Preece's steady melting current $I = 10244\ d^{1.5}$ (d in inches).

RESULT	WHAT IT IS
R per length	Ω/km (orange).
Total resistance, Voltage drop, Power loss, Cross section	
Ampacity, Conductor temp	The current at the insulation rating, and the conductor's temperature at the operating current.
Fusing current, Fusing time	Orange for the solved one.
Melting current (Preece)	

MESSAGE	WHEN IT SHOWS
"10 A is above the ampacity of 3.19 A for PVC 105 °C at 60 °C. Use a larger size or a higher insulation class."	
"Under 5 ms the heating is not adiabatic for thick wire and Onderdonk is optimistic at the short end. Check the fuse maker curves."	
"Onderdonk assumes no heat leaves the wire, which fails for long times. Beyond about 10 s use Preece, the steady melting current."	
"The size is outside the AWG 0000 to 40 range."	
"Above 105 °C most insulation is past its rating."	Wire temperature over 105 °C.
"The fault current is below the operating current."	

The plot **Fusing current against time (Onderdonk)** runs from 1 ms to 10 s, and the table **Neighbouring sizes** gives three sizes each way. **Add the wire as a resistor in series and run** (with a straight wire of 4 grid units selected) puts R_WIRE into it, with no measurements.

TRY IT

22 AWG

1. Open Wire gauge and fusing (type **awg**): 22 AWG solid, PVC 105 °C, 1 m, 0.5 A, 100 A fault.
2. Press **SOLVE** on Fault current with Time to fuse 0.1 s.

YOU SHOULD SEE 52.96 Ω/km, 53 mΩ, 26.5 mV, 0.3255 mm², ampacity 12.1 A, 25.2 °C. 100 A melts it in 883 ms, 297 A in 0.1 s, and Preece's steady melting current is 41.3 A.

64.2 Advanced: cables, faults and fuses

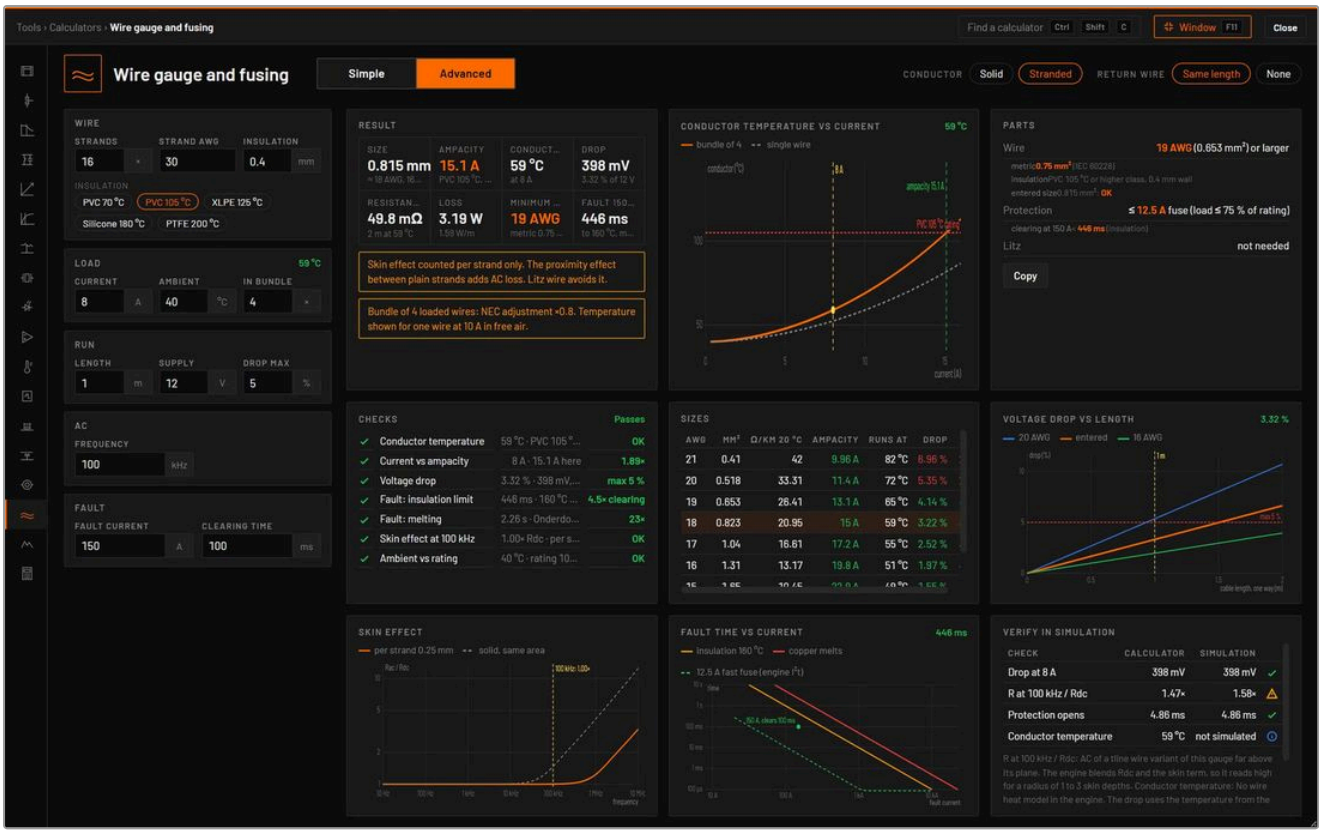


Figure 64.1 Wire gauge and fusing, Advanced, in full screen: a 16 × 30 AWG stranded wire at 8 A in a bundle of four, with the parts, the checks, the conductor temperature against current, the sizes, the drop against length, the skin effect and the fault times.

CHOICE	OPTIONS	WHAT IT DOES
Conductor	Solid, **Stranded**	
Size in	**AWG**, mm²	Solid.
Return wire	**Same length**, None	Same length counts the run there and back.

TAB	ITS DOT	CARDS
Design	Temperature, ampacity, drop.	Result, Parts, Checks.
Ampacity	Temperature, ampacity, ambient.	Conductor temperature vs current, Sizes.
Voltage drop	Drop.	Voltage drop vs length, Sizes.
Skin effect	Skin effect.	Skin effect, Skin depth.
Faults	Insulation limit and melting.	Fault time vs current, Fault checks.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Strands, Strand AWG (or AWG, Section)		16, 30 (18, 1.0 mm²)	Group *Wire*.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Insulation (wall), Emissivity	mm	0.4, 0.9	
Insulation		PVC 70 °C, **PVC 105 °C**, XLPE 125 °C, Silicone 180 °C, PTFE 200 °C	
Current, Ambient, In bundle	A, °C, ×	8, 40, 4	Group *Load*, badge the conductor temperature.
Length, Supply, Drop max	m, V, %	1, 12, 5	Group *Run*.
Frequency	kHz	100	Group *AC*.
Fault current, Clearing time	A, ms	150, 100	Group *Fault*.

How it works it out. The heat balance $I^2R'(Tc) = (Tc - Ts)/R'_{ins} = h\pi D(Ts - Ta)$, with h from Churchill-Chu convection and radiation. A bundle derates the ampacity by the NEC 310.15(C)(1) factors (0.8 for 4 to 6 wires, 0.7 for 7 to 9, 0.5 for 10 to 20 and so on). The skin effect is the exact Bessel solution for a round wire, per strand for stranded wire. A fault uses IEC 60949, $I^2t = k^2S^2$, to the insulation's short-circuit limit (160 °C for PVC, 250 °C for XLPE, 350 °C for silicone, 300 °C for PTFE), and to 1083 °C for melting. The fuse suggested is the first standard rating at or above the load / 0.75, and a fast fuse opens in 0.7 × rated² / fault² (the engine's fuse). The minimum size is the smallest AWG and IEC 60228 size that meet the ampacity and the drop.

RESULT	WHAT IT IS
Size	mm^2 and its AWG.
Ampacity	With the bundle factor (orange).
Conductor	Its temperature. Red over the rating.
Drop, Resistance, Loss	Red over the drop limit.
Minimum size	AWG and metric (orange).
Fault 150 A	The time to the insulation limit, and when it melts.

CHECK	VALUE AND LIMIT	PASSES	MARGINAL	FAILS
Conductor temperature	Tc · rating, bundle	10 % room	Within it	Too hot
Current vs ampacity	ampacity / I	1.25 × or more	1 × or more	Less
Voltage drop	% · max	Within it	Up to 1.18 × it	More
Fault: insulation limit	time · clearing	2 × or more	1 × or more	Less
Fault: melting	time · clearing	5 × or more	1 × or more	Less
Skin effect at 100 kHz	Rac/Rdc	1.2 or less	More: use litz	
Ambient vs rating	rating – Ta · 20 °C	20 °C room or more	10 °C or more	Less

MESSAGE	WHEN IT SHOWS
"Conductor at 161 °C at 6 A, rating 105 °C (PVC 105 °C, bundle ×0.8). Use 13 AWG or a higher insulation class."	Too hot.
"Drop 103.98 % over 10 m of wire, limit 5 %. 13 AWG (2.62 mm²) or 2.5 mm² meets it."	Over the drop.
"At 300 A the insulation reaches its 160 °C limit after 0 s, before the 500 ms clearing time. A 8 A fast fuse opens in about 498 µs."	The fault damages the insulation.
"Skin depth 29.6 µm at 5 MHz: Rac is 3.69× Rdc. Use litz with strands under 59.1 µm."	Rac over 1.2 × Rdc.
"Skin effect counted per strand only. The proximity effect between plain strands adds AC loss. Litz wire avoids it."	Stranded.
"Bundle of 4 loaded wires: NEC adjustment ×0.8. Temperature shown for one wire at 10 A in free air."	More than 3 in the bundle.

The **Parts** card gives the wire (AWG and IEC 60228), the insulation and wall, whether the entered size is enough, the fuse and its clearing time, and litz when needed, with **Copy**.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Drop at 8 A	Operating point of R_WIRE at the conductor temperature	Equal
R at 100 kHz / Rdc	AC of a wire transmission line of this gauge far above its plane. The engine blends Rdc and the skin term, so it reads high at 1 to 3 skin depths	Within 5 %
Protection opens	The fuse's opening time	Before the insulation limit
Conductor temperature	Not simulated	

BUTTON	WHAT IT DOES
Insert in wire and run	R_WIRE, the whole run (both ways with a return wire). See below.
Place fault test	A 12 V source, the suggested fast fuse F1 and a resistor that sets the fault current, a transient past the fuse's opening. *Fault current*, *Fuse still closed*, *Fuse open* and *Open before the insulation limit*.

Insert in wire and run puts the wire into your circuit: select a straight wire first (horizontal or vertical, at least 4 grid units long, 8 for the via's two parts). The part goes in series at the middle of the wire, 4 grid units long, and the wire is split at its pins. It is a resistor **R_WIRE** with copper's tempco (tc1 0.00393, tnom 20 °C) at the worst-corner temperature, so it has the calculator's hot resistance. Then the live view runs, an operating point is taken, and two measurements are added: *current against the calculator* (PASS up to the design current) and *drop, % of the calculator's* (PASS up to 100.1 %). A wire that carries more than the design current fails both. It is one undo step, and a name in use becomes R_WIRE2. The button's tooltip asks for a wire at least 8 grid units long in all three, while the trace and wire need only 4.

SIMPLE	ADVANCED
Length, Operating current, Ambient, Fault current, Insulation wall	Length, Current, Ambient, Fault current, Insulation
AWG, Cross section, Strands, AWG of one strand	AWG, Section, Strands, Strand AWG
Conductor, Size in, Insulation	Conductor, Size in, Insulation

TRY IT

A 16 × 30 AWG lead at 8 A in a bundle

1. Open Wire gauge and fusing and press **Advanced**: 16 × 30 AWG, PVC 105 °C, 8 A at 40 °C in a bundle of four, 1 m there and back on 12 V, a 150 A fault cleared in 100 ms.
2. Press **Place fault test**.

YOU SHOULD SEE 0.815 mm² (about 18 AWG), ampacity 15.1 A (18.9 A alone × 0.8), 58.9 °C, 49.8 mΩ over 2 m, 398 mV (3.32 %). 19 AWG or 0.75 mm² would do. A 12.5 A fast fuse opens the 150 A fault in 4.86 ms, long before the insulation reaches 160 °C (446 ms). All checks pass, and the fault test passes its four measurements.

Sources. ASTM B258 (AWG, copper), NEC Table 310.17 and 310.15(C)(1), IEC 60228 sizes, IEC 60949 (adiabatic short circuit), Onderdonk and Preece (fusing), Churchill and Chu (convection), the exact skin effect of a round wire. The tests check NEC 310.17 within 8 % for 12, 14 and 10 AWG, the bundle factors, k, Preece, the skin effect, the round-trip drop, the smallest size, R_WIRE, and the fuse opening time against bspice.

65 dB and unit converter

65.1 Simple: levels, ratios and prefixes 565
65.2 Advanced: noise, chains, links, ADCs and mismatch 567

Levels, ratios and prefixes. The Simple view converts between dBm, dBW, dBV, dBu, dBµV, volts and watts into an impedance, ratios and decibels both ways, and SI prefixes. The Advanced view is an RF and signal-chain toolkit: levels in twelve units with a crest factor, level sums, the noise floor and sensitivity, a gain chain with its noise figure and intercept, a free-space link budget, an ADC's SNR, and the mismatch of a load. Group Units. Search words include db, decibel, dbm, dbv, dbu, rms, peak, watts, ratio, gain, prefix and convert.

The window, the Simple and Advanced views, full screen and the place buttons are in **The calculator window**, p. 441.

65.1 Simple: levels, ratios and prefixes

CHOICE	OPTIONS	WHAT IT DOES
Convert	**Levels**, Ratio and dB, SI prefixes	
Unit	**dBm**, dBW, dBV, dBu, dBµV, V rms, V peak, V peak to peak, W	Levels: the unit of the value typed.
Ratio of	**Voltage (20 log)**, Power (10 log)	Ratio and dB.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Value	(the unit chosen)	0	Levels. From a selected part it is its rms voltage: pick V rms.
Impedance	Ω, kΩ	50 Ω	Levels.
Ratio	×	2	Ratio and dB. SOLVE.
Decibels	dB	6.0206 (solved)	Ratio and dB. SOLVE, solved when the tab opens.
Value	T … f	4700 (k)	SI prefixes, with a prefix menu.

dBm is 10 $\log_{10}$ of the power over 1 mW and dBW over 1 W. dBV is 20 $\log_{10}$ of the voltage over 1 V rms, dBu over 0.7746 V rms (the voltage across 600 Ω at 1 mW), dBµV over 1 µV. $P = V^2/Z$. Peak and peak-to-peak values are for a sine ($\sqrt{2}$ and $2\sqrt{2}$ × rms).

RESULT	WHAT IT IS
Levels	Every unit except the one typed, with V rms in orange (or dBm when V rms is typed), and a table **All levels into 50 Ω**.
Ratio and dB	The dB (or the ratio), the same ratio taken with the other law, and the power or voltage ratio, with a table of common values from –60 to +60 dB.
SI prefixes	The engineering form (4.7 k) and the value in every prefix.

MESSAGE	WHEN IT SHOWS
"Voltage levels do not depend on the impedance. Watts and dBm do, so check the impedance."	dBu, dBV or dBµV typed.
"A power of zero or less has no level in dB. Enter a power above 0 W."	W at 0 or less (volts likewise).
"Impedance must be above zero. Enter a value above 0 Ω."	
"A ratio has to be above zero."	

There are no place buttons in this view.

TRY IT

0 dBm into 50 Ω, and 1 V into 600 Ω

1. Open the dB converter (type **dbm**): 0 dBm into 50 Ω.
2. Choose V rms, type **1** and Impedance **600**.

YOU SHOULD SEE 0 dBm is 223.6 mV rms, 316.2 mV peak, 632.5 mV p-p, –13.01 dBV, –10.79 dBu, 107 dBµV, 1 mW. 1 V rms into 600 Ω is 2.218 dBm and 2.218 dBu, 0 dBV, 120 dBµV, 1.667 mW. A voltage ratio of 2 is 6.021 dB (3.01 dB as power).

65.2 Advanced: noise, chains, links, ADCs and mismatch

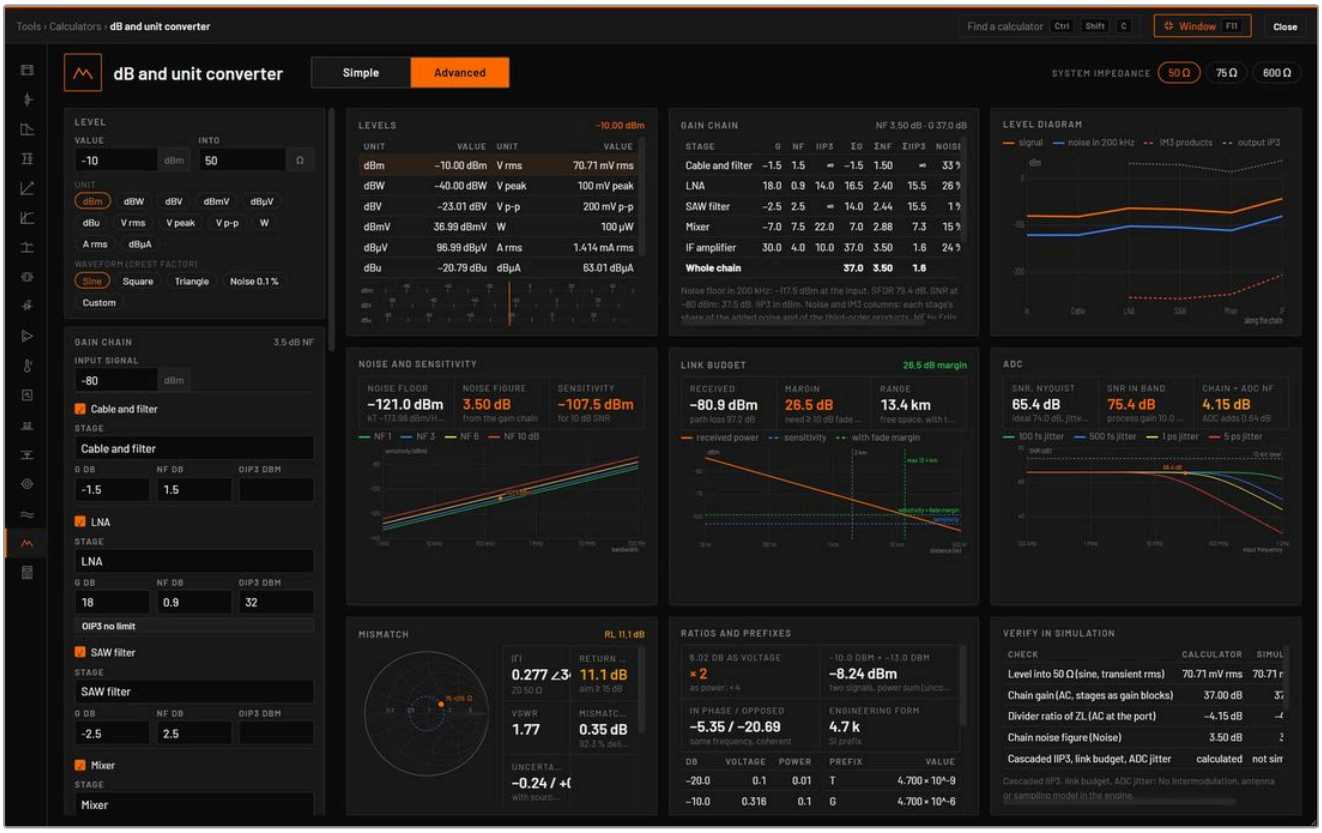


Figure 65.1 The dB converter's Advanced view in full screen: the levels with the ruler, the gain chain and its level diagram, noise and sensitivity, the link budget, the ADC, the mismatch on a Smith chart, the ratios and the verify table.

CHOICE	OPTIONS	WHAT IT DOES
System impedance	**50 Ω**, 75 Ω, 600 Ω	The Z0 of the chain, the mismatch and the placed circuits. It also sets the level's Into impedance.

TAB	ITS DOT	CARDS
Levels	None.	Levels (twelve units and the ruler).
Ratios and prefixes	None.	Ratios and prefixes.
Noise and sensitivity	Green when the SNR at the input signal reaches the SNR needed, else amber.	Noise and sensitivity.
Gain chain	Green when the SNR out reaches the SNR needed, else red.	Gain chain, Level diagram.
Link budget	Green with the fade margin and the EIRP within its limit, amber with a margin over 0, red under 0.	Link budget.
ADC	Green when the ADC adds 0.5 dB or less to the NF, amber up to 2 dB, else red.	ADC.
Mismatch	Green with a return loss of 15 dB or more, amber 10 dB or more, else red.	Mismatch.
Verify in simulation	None.	Calculator vs simulation.

FIELD	UNIT	DEFAULT	WHAT IT DOES
Value, Into	(unit), Ω	–10, 50	Group *Level*.
Unit		**dBm**, dBW, dBV, dBmV, dBµV, dBu, V rms, V peak, V p-p, W, A rms, dBµA	
Waveform (crest factor)		**Sine** (1.4142), Square (1), Triangle (1.7321), Noise 0.1 % (3.29), Custom	Peak = crest factor × rms.
Decibels, Ratio, Voltage or Power	dB, ×	6.0206, SOLVED	Group *Ratios and prefixes*. Also Level A and Level B (–10, –13 dBm) and an SI prefix value.
Bandwidth, SNR needed, Temperature, Resistor	kHz, dB, K, Ω	200, 10, 290, 1000	Group *Noise and sensitivity*. Noise figure from the **Gain chain** or **Manual** (NF 3 dB).
Input signal	dBm	–80	Group *Gain chain*, badge the chain NF.
Stages 1 to 6	G dB, NF dB, OIP3 dBm	Cable and filter –1.5 / 1.5, LNA 18 / 0.9 / 32, SAW filter –2.5 / 2.5, Mixer –7 / 7.5 / 15, IF amplifier 30 / 4 / 40	Each with a tick and a name. Passive parts: NF = loss, OIP3 no limit.
Transmit power, EIRP limit, TX antenna, TX cable loss, RX antenna, RX cable loss	dBm, dBm, dBi, dB, dBi, dB	14, 16.15, 2.15, 1, 2.15, 1	Group *Link budget*, badge the margin.
Frequency, Distance, Fade margin	MHz, km, dB	868, 2, 10	
Resolution, Sample rate, Signal bandwidth, Input frequency	bits, MHz, MHz, MHz	12, 100, 5, 30	Group *ADC*.
Clock jitter, Datasheet SNR, Full scale, Input impedance	ps, dBFS, Vpp, Ω	1, 66, 1, 100	
Load R, Load X, Source |Γ|	Ω, Ω	75, 25, 0.1	Group *Mismatch*.

How it works it out. The noise floor is kT + 10 log B (–173.98 dBm/Hz at 290 K) and the sensitivity adds the NF and the SNR needed. The chain's NF is Friis ($F = F1 + (F2 - 1)/G1 + \ldots$), its input IP3 from $1/IIP3 = \Sigma\, G_{before}/IIP3_k$ (coherent, worst case), the SFDR ⅔ (IIP3 – floor). The link uses the free-space path loss $20 \log(4\pi df/c)$ and the Fresnel radius $8.66 \sqrt{(d_{km}/f_{GHz})}$ m. The ADC's SNR

combines quantisation (6.02 N + 1.76), jitter ($-20 \log(2\pi f_{in} t_j)$) and the datasheet figure, adds the process gain 10 log(fs / 2 BW), and turns the floor into a noise figure in its input impedance. Mismatch: $\Gamma = (Z - Z0)/(Z + Z0)$.

RESULT	WHAT IT IS
Levels	All twelve units, a ruler with the dBm, dBV, dBu and dBµV scales lined up, and the note *In 50 Ω: dBµV = dBm + 107.0.* (75 Ω: dBmV = dBm + 48.75).
Ratios	The dB as power and voltage, the power sum of two levels, their coherent sum and difference, and the engineering form.
Noise	Noise floor, Noise figure, Sensitivity, Noise temperature, Resistor noise ($\sqrt{4kTR}$) and Noise in B, with a plot of sensitivity against bandwidth for NF 1, 3, 6 and 10 dB.
Gain chain	A table per stage: G, NF, IIP3, the running gain, NF and IIP3, and each stage's share of the noise and of the IM3, with the whole chain. The level diagram draws the signal, the noise, the IM3 products and the output IP3 along the chain.
Link	Received, Margin, Range (with the fade margin kept), EIRP, Fresnel zone and the path loss slope, with received power against distance.
ADC	SNR at Nyquist, ENOB, SNR in band, noise density, the ADC's noise figure and the chain + ADC NF, with SNR against input frequency for jitter of 0.1 to 5 ps.
Mismatch	A Smith chart, |Γ|, Return loss, VSWR, Mismatch loss and the uncertainty with the source's |Γ|, and a VSWR table.

MESSAGE	WHEN IT SHOWS
"Link … dB short at …. Range with fade margin: …. Use higher-gain antennas, a lower NF or less bandwidth."	A negative margin.
"EIRP 21.1 dBm is above the 16.1 dBm limit."	Over the EIRP limit.
"ADC adds 0.6 dB to the NF. Chain noise at the ADC is 8 dB above its floor (–141.4 dBm/Hz). Add 2 dB of gain before the ADC for a 10 dB gap, or use an ADC with a lower floor."	The ADC adds over 0.5 dB.
"6.0 dB loss before the LNA adds 6.0 dB to the NF. Move the LNA closer to the antenna where the filtering allows."	Loss before the first active stage.
"Level referenced to 75 Ω. System impedance is 50 Ω."	The level's impedance differs from the system's.
"Generator levels assume a 50 Ω load. A 1 MΩ scope input reads twice the voltage (+6.02 dB)."	A level into 75 Ω or less.

CHECK	ANALYSIS AND MEASUREMENT	LIMIT
Level into 50 Ω (sine, transient rms)	A generator behind Z into Z: rms and peak of V(LOAD)	±1 %. Sine only: the crest factor of other waves is not placed.
Chain gain (AC, stages as gain blocks)	AC at 1 MHz: one Z0 gain block per stage	±0.02 dB
Divider ratio of ZL (AC at the port)	AC at 100 MHz of the load against the source	±0.02 dB
Chain noise figure (Noise)	Noise analysis: a matched pad of loss F before a noiseless block per stage	Read in the Noise view
Cascaded IIP3, link budget, ADC jitter	Not simulated: the engine has no intermodulation, antenna or sampling model	

BUTTON	WHAT IT DOES
Place chain, run Noise	Per stage a matched T-pad of loss F (a pad alone has NF = F) and a noiseless gain block, and a noise analysis at OUT from 100 kHz to 10 MHz. The chain NF comes out of the noise contributions in the Noise view.
Place chain, run AC	V1, RS = Z0, per stage RIN, a controlled source of twice the voltage gain and ROUT, then RL, and an AC sweep. *Chain gain, V(OUT) against half the source* = chain gain − 6.02 dB, ±0.02 dB.
Place source and load	A 1 kHz generator behind Z into Z, a transient of 10 periods. *Load level, rms* and *Load level, peak*, ±1 %.
Place mismatch, run AC	V1 at 100 MHz, RS = Z0, the load R with a series L or C for X. *Divider ratio of the load* = 20 log(|1 + Γ|/2), ±0.02 dB.

The simulator runs at 27 °C, 0.15 dB above the 290 K of the NF definition in absolute floor, which cancels in the ratio.

SIMPLE	ADVANCED
Value, Impedance, Unit	Value, Into, Unit
Ratio, Decibels, Ratio of	Ratio, Decibels, Voltage or Power

TRY IT

A receiver from antenna to ADC

1. Open the dB converter and press **Advanced**: the five default stages, −80 dBm in, 200 kHz, the 868 MHz link over 2 km, a 12-bit 100 MS/s ADC.
2. Read the Gain chain, Link budget and ADC tabs.

YOU SHOULD SEE The chain has 37.0 dB gain, NF 3.50 dB (1.50, 2.40, 2.44, 2.88, 3.50 along it) and IIP3 1.6 dBm: SFDR 79.4 dB, SNR out 37.5 dB. The link receives −80.9 dBm after 97.2 dB path loss: 26.5 dB margin, 13.4 km range, Fresnel radius 13.1 m. The ADC gives 65.4 dB at Nyquist (10.6 bits ENOB) and 75.4 dB in band, but adds 0.64 dB to the NF: amber, with the advice to add 2 dB of gain before it. The 75 + j25 Ω load has |Γ| 0.277, return loss 11.1 dB (amber), VSWR 1.77. **Place chain, run AC** passes at 30.98 dB.

Sources. The standard definitions of the units, Friis for the noise figure and the path loss, the cascade formula for the intercept, 6.02 N + 1.76 and the aperture-jitter limit for ADCs. The tests check levels into 50 Ω (0 dBm is 223.6 mV, dBµV = dBm + 107), a two-stage NF of 3.953 dB, pad NF = loss, the SFDR, the path loss 32.44 + 20 log d_{km} + 20 log f_{MHz}, the 75 + j25 mismatch, and the placed chain's noise figure in bspice within 0.01 dB.

PART

VIII

Files and integration

The circuit, part and symbol file formats, importing KiCad and EasyEDA Pro, exporting pictures, netlists and reports, AI agents, and the bspice command line.

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66 Files and formats

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BetterSPICE keeps everything in plain JSON text files that you can read, diff and keep in version control. All three formats are UTF-8. A file saved by Notepad with a byte-order mark opens normally. UTF-16, binary files and files over 64 MB are refused with a message that says so. Keys BetterSPICE doesn't know are kept when a file is saved, so other tools can store their own data.

EXTENSION	WHAT IT'S	OPENED BY
.bsc	A circuit	Double-click, **File** › **Open**, the command line, AI agents
.bspart	A part: identity, datasheet values, pins, optional symbol and SPICE model	Double-click (adds to My parts), the Part Wizard, **bspice parts**
.bssym	A schematic symbol	Double-click (adds to My parts), the symbol editor
.cir	An ngspice netlist, written by Export SPICE netlist	**bspice ngspice**, ngspice
.verify.json	The settings of a verification circuit	**bspice verify**

66.1 Saving

- Save writes to a temporary file first and then replaces the old one, so a crash cannot leave a half-written circuit.
- The desktop app watches the open file: if another program changes it, such as an AI agent, a text editor or git, the circuit reloads in place as one undo step, and the changed parts flash. Its own saves aren't reloaded.
- Hierarchical sheets are stored inside the circuit file, or as separate files next to it.
- Custom symbols and part files a circuit uses are copied into it, so it opens on another computer.

66.2 Circuit files (.bsc)

KEY	TYPE	MEANING
bsc	1	Format version. Required.

KEY	TYPE	MEANING
name, **description**, **category**	text	Title, a line saying what to watch, and the examples category.
sim	object	Simulation settings, see below.
parts	list	The components.
wires	list of [x1, y1, x2, y2]	Wire segments in grid units. Only their ends connect.
labels	list of {name, at}	Net labels. The same name is the same net on a sheet.
power	list of {net, at, style}	Power flags, global by name. style: bar, arrow, gnd, chassis.
globals, **ports**	list of {name, at}	Global labels, and sheet ports inside a child sheet.
probes	list	Scope probes: {label, kind (v, vd or i), at, ref, part, pin, scope, color, value, tag}. **value: true** shows the live value in the probe's tag. **tag: [dx, dy]** is where the tag sits, in grid units from the probed point (absent: beside the probe). **color** is the trace colour.
graphics	list	Text, lines, rectangles, circles, arcs, polylines. No electrical meaning.
sheets	list	Hierarchical sheets: {id, name, file or doc, at, size, pins}.
buses, **busEntries**	list	Drawing aids. They never connect.
symbols, **partDefs**	object	Custom symbols and part files embedded in the circuit.

SIM KEY	MEANING
dt	The live engine's maximum timestep in seconds.
speed	The starting timebase: simulated seconds per real second.
start	**"rest"**: the live simulation starts at 0 V with capacitors empty (power-on). Absent or **"op"**: it starts from the DC operating point. New circuits write **"rest"**. Simulate › Start at rest (power-on) toggles it. The live simulation only: Simulate doesn't use it.
vRange	The voltage at which wire colours are full.
simulate	{stop, maxStep, method, uic, options}: the Transient setup, also used by **bspice tran**. **method** is trap, gear or be. **uic: true** always starts from 0 V. **options** is a string of ngspice *name=value* options (**Settings saved in the circuit**, p. 223).
ac	{source, fStart, fStop, ppd, out}: the AC setup.

A part is **{id, type, variant, pins, p}**: the designator, the device type, the symbol variant, its pin points in the order the device lists them, and its parameters in SI units. A part can also have **sliders** (the inspector slider ranges), **symbol** and **symPins** for a custom symbol. Model references live in **p**: **model**, **lib**, **libSource**, **modelId**, **modelLine**, **pinmap**.

A microcontroller (**mcu**) keeps its program in **p.code**, as text in the MCU language (**Programming the MCU**, p. 373); its pins come from the **pin** and **bus** lines of that text, and the part's **pins** are laid out again when the code changes. The memory, flash and RTC chips and the USB-UART bridge are **chip** parts with the variants **eeprom**, **spi_flash**, **rtc** and **usb_uart**. The bridge keeps its settings in **p.baud**, **p.send**, **p.send_at**, **p.eol**, **p.dtr**, **p.rts** and **p.flow**. A battery keeps its chemistry in **variant** and its start in **soc**.

PART (TYPE)	PINS	KEYS IN P
PWL source (**vpwl**)	+, -	**points** [[t, v], …] in s and V. **td**, the time offset in s (default 0). **r**, the repeat time in s, a time before the last point (absent: the points play once, 0: the whole list repeats). SPICE **PWL(…) r=… td=…**.
Voltage-controlled sources (**vcvs**, **vccs**)	+, -, c+, c-	**gain** (V/V), **gm** (S).
Current-controlled voltage source (**ccvs**)	+, -, s+, s-	**rt** in Ω (default 1000). The current into s+ and out of s- is sensed. SPICE **H** with a 0 V source.
Current-controlled current source (**cccs**)	+, -, s+, s-	**gain** in A/A (default 1). SPICE **F** with a 0 V source.
Pulse source (**vpulse**)	+, -	**v1**, **v2**, **delay**, **rise**, **fall**, **width**, **period**. Times are 0 or more. Edges and width longer than the period warn **W_PARAM**.
Digital filter, lookup table, state machine (**filter**, **lut**, **fsm**)	in, out, gnd; in0 …, out0 …, gnd	**coeffs**, **table** [[in, out], …], **states** [{name, out}], **transitions** [{from, to, after, when}], **initial**. The inspector edits them as tables.
MCU (**mcu**)	from the code	**code**. A complementary output is declared in it: **pin LO complement HI dead 200ns**.

A sine source can carry **delay**. A sheet made with **Edit subcircuit** is an ordinary entry in **sheets**, with the inside in **doc**.

```
{
  "bsc": 1,
  "name": "RC step",
  "sim": { "simulate": { "stop": 0.005, "maxStep": 1e-5 } },
  "parts": [
    { "id": "V1", "type": "vdc", "pins": [[0, 0], [0, 6]], "p": { "v": 1 } },
    { "id": "R1", "type": "res", "pins": [[0, 0], [6, 0]], "p": { "r": 1000 } },
    { "id": "C1", "type": "cap", "pins": [[6, 0], [6, 6]], "p": { "c": 1e-6 } },
    { "id": "GND", "type": "gnd", "pins": [[3, 6]] }
  ],
  "wires": [[0, 6, 3, 6], [3, 6, 6, 6]],
  "labels": [{ "name": "OUT", "at": [6, 0] }]
}
```

How nets are formed

- Pins, wire ends, labels, flags and ports on the same grid point are one net. A point in the middle of a wire doesn't connect, the editor splits the wire at a T.
- Labels, flags and ports with the same name join. Global labels and power flags join across sheets, labels and ports only within their sheet.
- Ground is every gnd part, a flag with style gnd or net GND, and a label named GND or 0.
- Net names come from labels and flags. Unnamed nets are named after their first point, like **N@12,4**. Inside sheets names get the sheet prefix, **S1/**.
- Pin currents are measured into the part.

66.3 Part files (.bspart)

A part file describes a real part from its datasheet. Every value has its minimum, typical and maximum where the datasheet gives them, its unit, its test conditions and the page it came from.

SECTION	CONTENTS
bspart	"1.0". Must be the first key.
kind	The template, for example **regulator.ldo**. It decides the device type and the fields (**Part templates reference**, p. 606).
identity	mpn (required), manufacturer, family, description, aliases, lifecycle, tags.
package	name, mounting (smd, tht, chassis, module), pins (number, name, function), fields.
electrical, **noise**, **thermal**	The values. Each one: min, typ, max, unit, conditions, source {page, table, row, figure}, unverified, note.
curves	Points read from datasheet graphs, sorted by x.
model	live (device, variant, parameters that override the derived ones, pin map) and spice (file, sha256, name, type, dialect, pins, encrypted).
provenance	datasheet (file, sha256, url, revision, date), author, created, tool, verified_by, notes.
symbol	An optional custom symbol, as in a .bssym.

```
"vdo": { "typ": 0.25, "max": 0.4, "unit": "V",
         "conditions": { "iout": 0.6, "ta": 25 },
         "source": { "page": 4, "table": "Electrical Characteristics", "row": "Dropout Voltage" } }
```

Rules: units are SI base units (store 0.25 V, never 250 mV), min ≤ typ ≤ max, every value inside its field's sanity range, pin numbers unique, every simulation pin on a package pin. A bare number is shorthand for a typical value. The live model uses the typical value, or the middle of min and max. **bspice parts validate** checks a file and names every problem, for example *"electrical.vout: min 3.4 V is greater than typ 3.3 V, expected min ≤ typ ≤ max"*. A template's TODO placeholders give **E_PART_TODO** until they are filled.

66.4 Symbol files (.bssym)

Symbols are outlines on the 20 px grid, with the origin near the body centre and y pointing down. Pin connection points are whole grid units, drawings can use tenths.

KEY	MEANING
bssym	1, in standalone files.
id	Lower-case letters, digits, dots, dashes and underscores. Parts refer to it by id.
name, **description**, **title**, **titleAt**	Library text, and the bold title in the body.
body	[x0, y0, x1, y1]: the body box.
pinNames, **pinNumbers**	inside or hidden, outside or hidden.
pins	{name, number, at, side (l, r, t, b), role, length, shape, hideName}.
graphics	line, polyline, rect, circle, arc, text, with width and dash. No fills.
variants	Alternative drawings a part picks with symVariant.

```
{ "bssym": 1, "id": "ap2112", "name": "AP2112 LDO", "body": [-3, -2, 3, 2], "title": "AP2112",
  "pins": [
    { "name": "VIN",  "number": "1", "at": [-5, -1], "side": "l", "role": "power_in" },
    { "name": "EN",   "number": "3", "at": [-5,  1], "side": "l", "role": "in" },
    { "name": "GND",  "number": "2", "at": [ 0,  4], "side": "b", "role": "power_in" },
    { "name": "NC",   "number": "4", "at": [ 5,  1], "side": "r", "role": "nc" },
    { "name": "VOUT", "number": "5", "at": [ 5, -1], "side": "r", "role": "power_out" } ] }
```

67 Importing KiCad and EasyEDA Pro

67.1 What the importer does 578
67.2 The Import report 579

File › **Import KiCad / EasyEDA / LTspice...** (Ctrl + I), or Import in the toolbar, reads a schematic from another tool and opens it as a new circuit in its own tab.

TOOL	FILES
KiCad 6 to 10	**.kicad_sch**, **.kicad_pro**, or a **.zip** of the project
EasyEDA Pro	**.epro**, **.epro2**, or a local **.eprj**
LTspice	**.asc**

An LTspice schematic comes in with its parts, wiring, symbols and SPICE models. Each part gets the model LTspice itself would use: the **.model** lines on the schematic, the files it includes and LTspice's standard libraries. Symbols come from the **.asy** files next to the schematic, or from an installed LTspice. A value such as **200** is 200 ohm, as in LTspice. LTspice hierarchical blocks and digital gates come in as boxes.

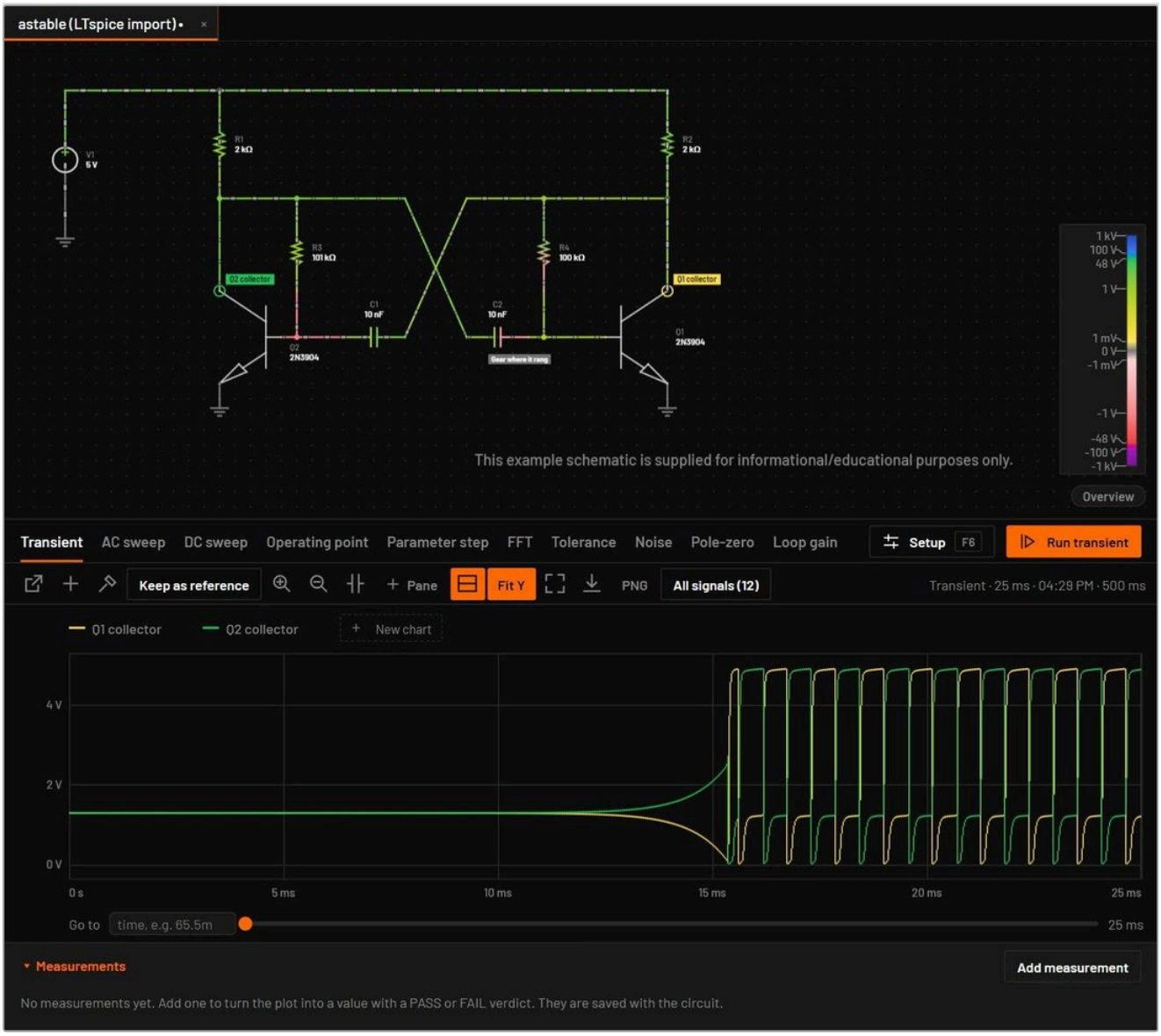


Figure 67.1 LTspice's astable multivibrator example after the import, with probes on the two collectors, in Split view after a Simulate run.

> **CAUTION** **Hierarchical KiCad designs.** Choose the project **.zip**. A **.kicad_sch** or **.kicad_pro** chosen on its own cannot bring its sub-sheet files with it. LTspice models are also in the library.

67.1 What the importer does

1. Reads every symbol, wire, label, power flag, junction and sheet.
2. Matches each symbol to a BetterSPICE device by its library name, value and reference, with a rule for each kind of part: resistors, capacitors, inductors, diodes, transistors, op-amps, regulators, connectors and more.
3. Maps the symbol's pins to the device's pins and checks that every net still has the same pins as in the source.

4 Keeps parts it can't match as boxes with their pins, so the drawing is complete.

5 Adds a DC source for each supply rail named like a voltage (for example **+3V3**) that nothing drives, so the board can run.

6 Where a part names a vendor model in the project, keeps it for Simulate and fits the live model from the catalogue model of the same name.

A bare resistor value from KiCad or EasyEDA, such as **500**, is 500 Ω. The three-digit marking code (**104** = 100 nF) is read on capacitors only. An **.epro** that holds an entry over 256 MB is refused at once with a short message, before anything is unpacked.

67.2 The Import report

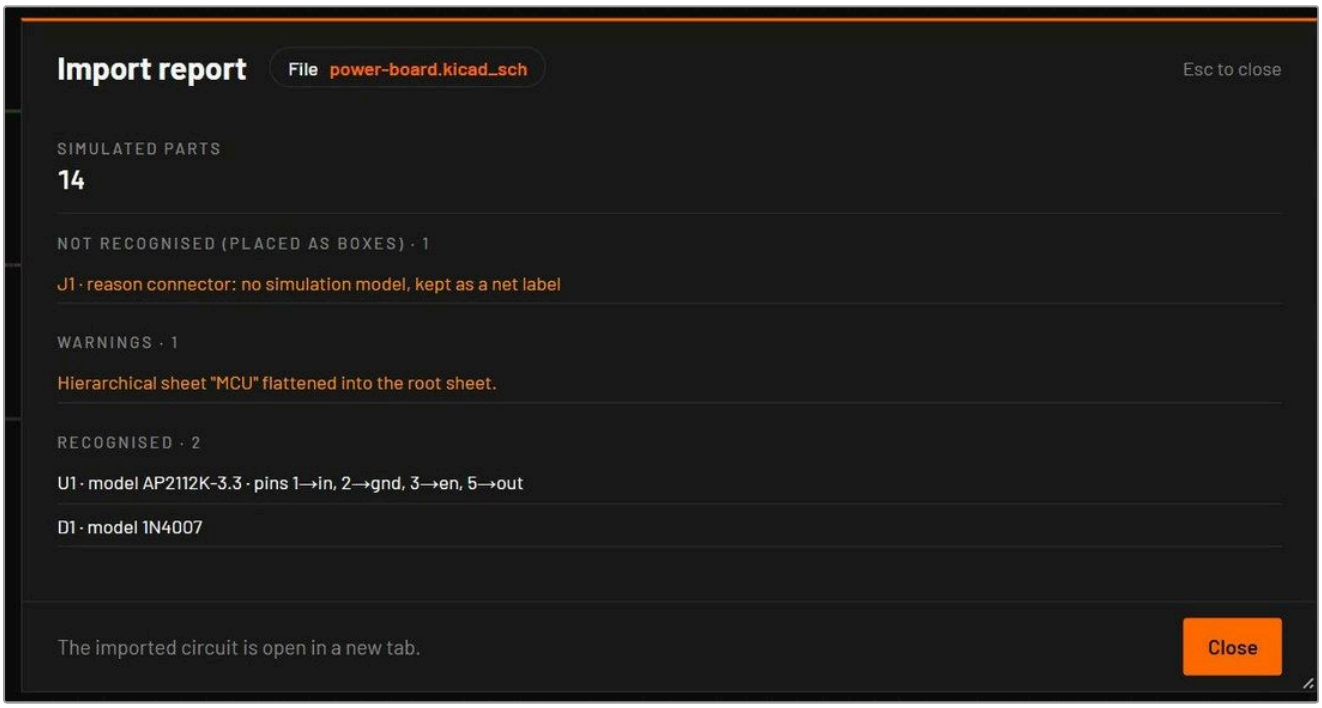


Figure 67.2 The Import report after a KiCad import.

While the importer runs, a message says *"Importing <file>..."*, and a second import waits for it. The report opens after the import. It has a summary sentence, number tiles and sections. Rows that name a part are links: a click selects the part, zooms to it (no further than a fit, 1.3×) and closes the report. Parts that were not recognised have an **Assign model...** button.
File › **Import report...** reopens the report of an imported tab.

ITEM	MEANING
Format, Grid in mm	The source tool and its grid.
Components, Recognised, Not recognised, Skipped	How many symbols, how many became simulated devices, how many stayed boxes, and how many have no electrical meaning (logos, mounting holes).
Recognised share	Recognised as a percentage of the parts that could be.

ITEM	MEANING
Nets in the source / in the circuit, Pins checked	The net check: every net must keep the same pins.
Joined with ~ labels, Nets merged	Nets joined by name, as the source tool did.
Not recognised (placed as boxes)	Shown first. Each part with its symbol and the reason.
Errors	Shown first, red: problems that stopped part of the import, counted in the summary line, such as *"0 warnings, 1 error"*.
Warnings	Amber: importer diagnostics with their codes and fixes, and **I_MODEL_FIT** where live values came from a catalogue model.
Recognised	Each part: reference, symbol → device type and variant, value, model, confidence, pin map and the rule that matched it.
Skipped, Added supplies, Sheets	What was left out, which sources were added, and the sheet structure.

NOTE **Boards without supplies or models.** An imported board draws completely, but ICs without a model leave their nets undetermined, and a board with no source runs at 0 V. A circuit with no source raises **W_NO_SOURCE** and the message *"No supply in the imported circuit: add a DC source."* Assign models to the ICs that matter and add a source.

TRY IT

Import a KiCad project

1. Zip the KiCad project folder.
2. Press Ctrl + I and choose the zip.
3. Read the Not recognised section. Assign a model to each IC that matters (Ctrl + M).
4. Add a DC source if the report didn't add one, and press Ctrl+R.

YOU SHOULD SEE The board runs. Hover any net to read its voltage, and probe the rails to check them.

Command line: **bspice import board.kicad_sch —out board.bsc —report report.json**, with **—flat** for one flat sheet and **—no-supplies** to add no sources (**The command line (bspice)**, p. 596).

68 Export and reports

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68.5 Export data 588

68.1 Export image

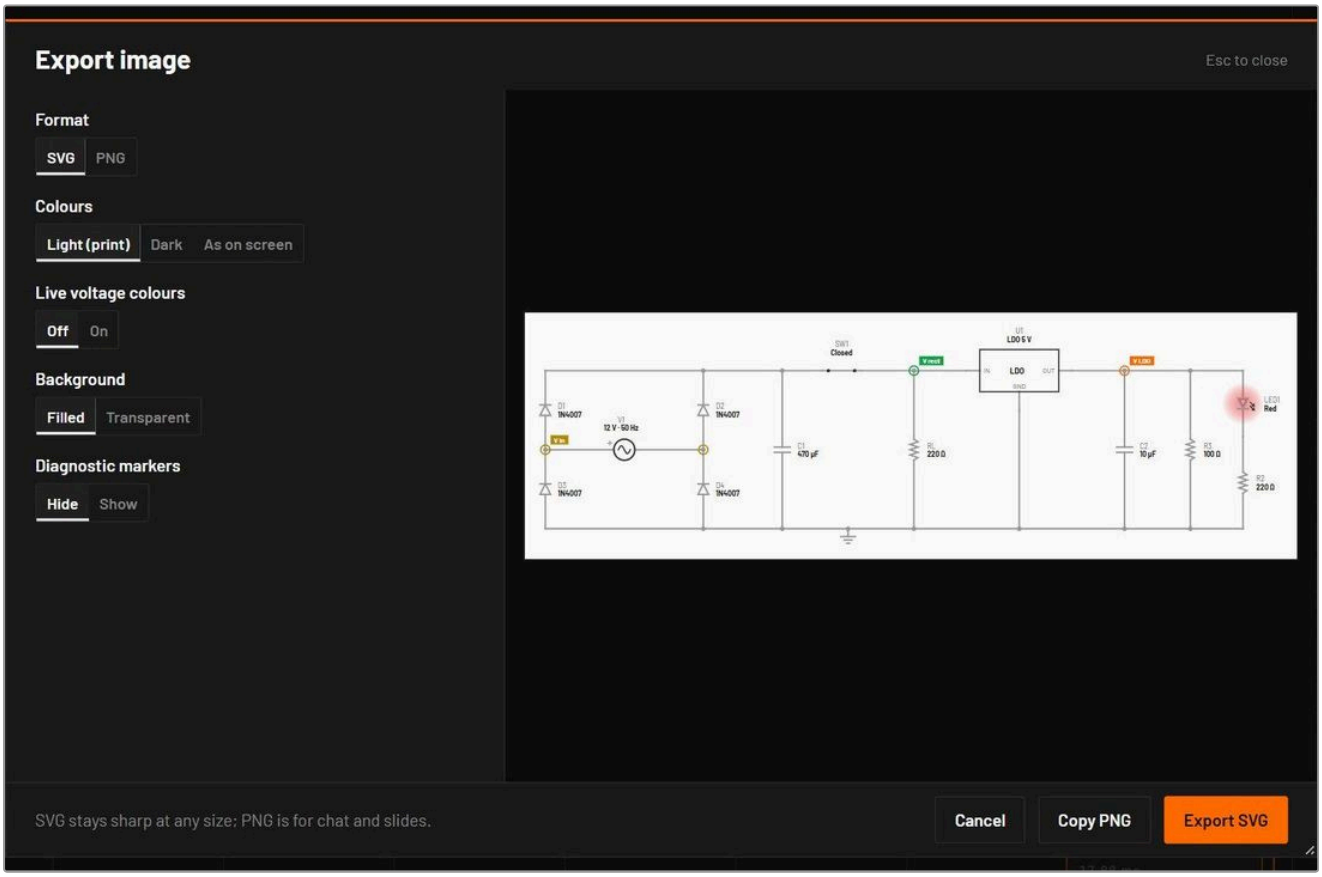


Figure 68.1 Export image: format, colours, background and what to include.

File › **Export image (SVG / PNG)...** (Ctrl + Shift + P) saves a picture of the whole open sheet with a small margin, without the grid or the selection. The preview updates as you change the options.

FIELD	VALUES	DEFAULT	WHAT IT DOES
Format	SVG, PNG	SVG	SVG stays sharp at any size, for documents. PNG is for chat and slides.
Colours	Light (print), Dark, As on screen	Light (print)	The colour theme of the picture.
Live voltage colours	Off, On	Off	Wires coloured by their present voltage, or neutral.
Background	Filled, Transparent	Filled	
Diagnostic markers	Hide, Show	Hide	Include the red and amber markers.
Resolution	1x, 2x, 4x	2x	PNG only. Pixels per screen pixel at 100 % zoom.

The file is named after the circuit, for example **rc-filter.svg** or **rc-filter@2x.png**. A PNG is at most 16 384 px on a side, and a sheet too large for 4x is exported at the largest scale that fits, with a message. An empty sheet gives *"Nothing to export: the sheet is empty."*

68.2 Export SPICE netlist



Figure 68.2 Export SPICE netlist confirms where the file went.

File › **Export SPICE netlist...** (Ctrl + Alt + N) writes the circuit as an ngspice netlist (**.cir**), with hierarchical sheets flattened. Parts that are only a symbol are left out and the message counts them. It also names sheets left out because their contents aren't loaded. From 0.7.0 it also writes comparators, the 555 and 556 timers, regulators of every kind, LDOs, supercapacitors, three-terminal capacitors, ferrite beads, crystals, resonators and varistors with the datasheet fields they carry, each checked against ngspice. From 0.8.0 the voltage-controlled switch exports with the engine's own smooth law and is compared point by point. Relays, manual switches, motors, self-heating thermal parts, memories and microcontrollers have no netlist equivalent. For a circuit with a vendor model, **bspice export-spice** writes the netlist Simulate runs, with the vendor libraries in their namespaces. If the export fails, the message gives the first problems with their fixes and the rest go to Diagnostics as **E_EXPORT**.

The example **basics/rc-charge.bsc** exports as:

```
* RC charge and discharge
* exported by bs-engine for ngspice
V1 IN 0 DC 0 PULSE(0 5e0 0 1e-6 1e-6 5e-3 1e-2)
R1 IN C1 1e3
C1 C1 0 1e-6
```

Every model parameter is written out, so ngspice's own defaults never change the result. Transmission lines export as T or LTRA elements. Behavioural parts (power blocks, controllers, most of the extended library)

are written as comments, because ngspice has no equivalent.

68.3 Generate report

File › **Generate report...** (Ctrl + Shift + G) opens a short dialog. Tick the sections you want and press **Generate**. The file is one HTML page with the fonts inside it, so it opens the same offline. On screen it follows the app's theme. Printed to PDF it is always on white paper, with a page break before each section and no plot cut by a page edge. The plots are vector graphics, so they stay sharp at any zoom and in print.

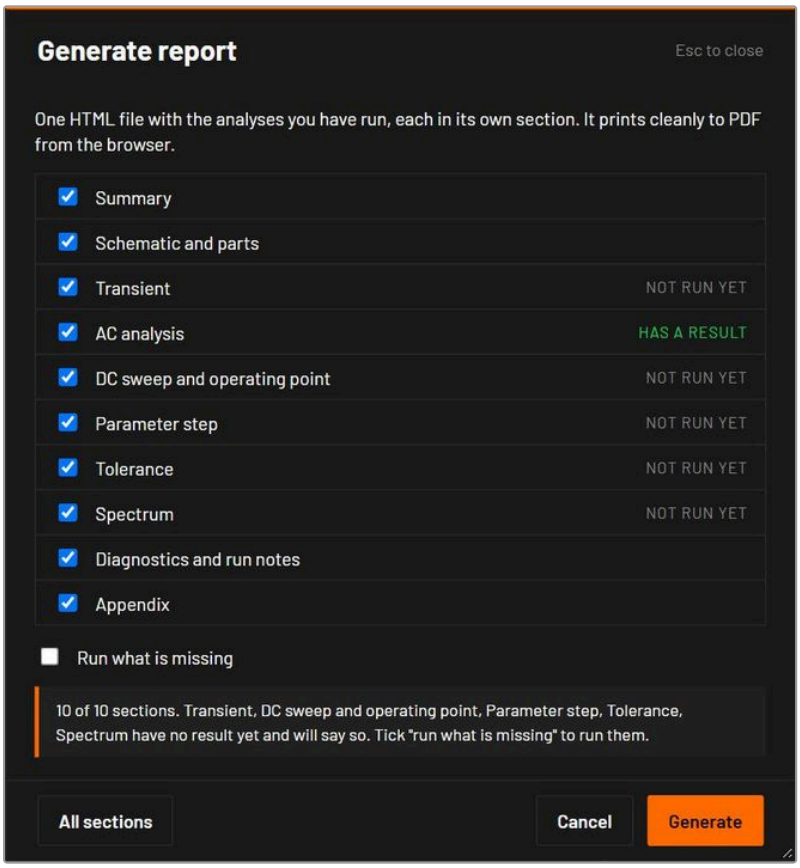


Figure 68.3 The Generate report dialog: one tick box per section, which sections have a result, and Run what is missing.

The report covers every analysis that has been run for the circuit in this session. Each one gets its own section.

SECTION	WHAT IT HOLDS
Summary	The circuit name, the date, the BetterSPICE version and the engine. A table of every named measurement with its value, its limits and PASS or FAIL. Four verdicts in plain words with their numbers: all measurements pass, the tolerance yield, no overstress, and no convergence aids needed.
Schematic and parts	The schematic picture. The part list with values, tolerances, the model (vendor or generic, with its source) and the ratings that are set. The operating point of each part against its ratings, with the margin in percent. A margin under 20 percent reads LOW MARGIN, below zero reads OVER.
Transient	One plot per probe, the statistics of each signal, the named measurements, and the kept reference run drawn dashed behind the plot of the same signal.

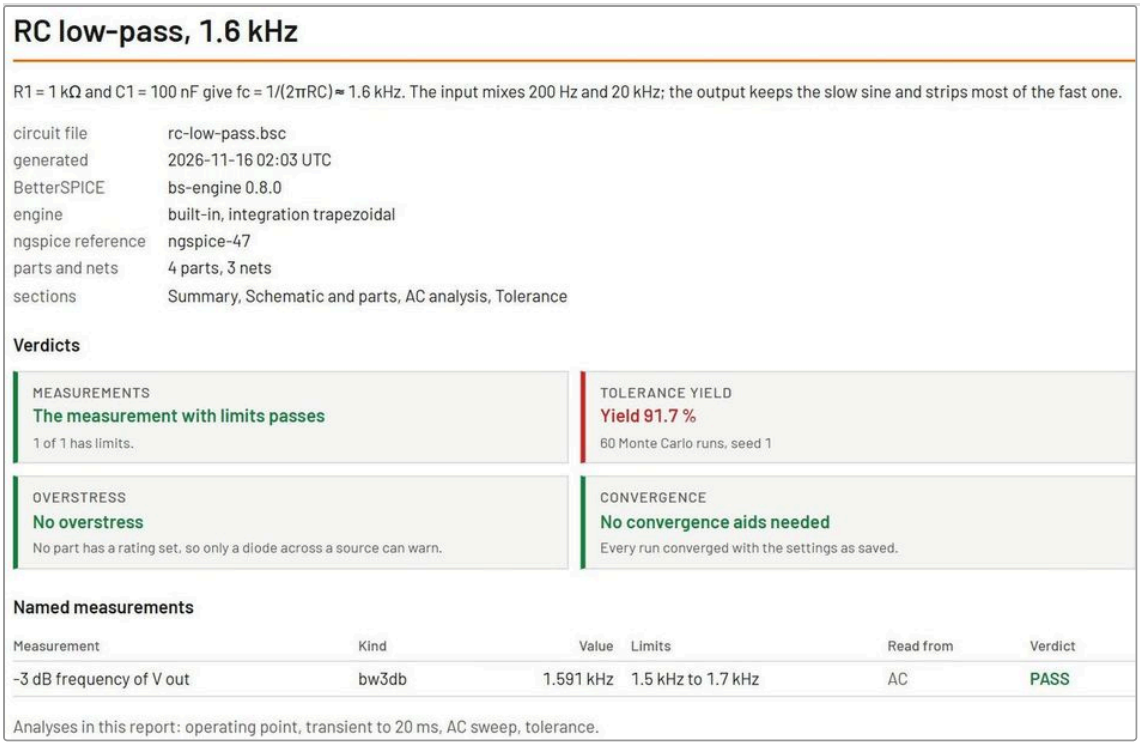
SECTION	WHAT IT HOLDS
AC	The Bode plots with the -3 dB points marked. For a loop gain, the 0 dB crossing, the phase margin and the gain margin. Gain and phase at each decade and at the frequencies your measurements name.
DC sweep and operating point	The operating point tables, and the DC sweep as a plot and a table.
Parameter step	The curves of every step overlaid on one plot per signal, and the measurements of each step in a table.
Tolerance	The cloud of runs behind the nominal curve, a histogram of each measurement with its limits, the yield, the sensitivity bars, the statistics table, the toleranced parts, the seed and the number of runs. The same seed gives the same runs as in the app and in the command line.
Spectrum	The FFT of a probe with the window used, the harmonics table, and THD, THD+N, SNR, SINAD, SFDR and ENOB. The numbers come from the same code as the live FFT tab.
Diagnostics and run notes	Every warning and error with its fix, the notes of the convergence doctor, and the settings used (integration method, tolerances, step sizes, seed) so the result can be reproduced.
Appendix	The SPICE netlist, the simulation settings saved in the file, and the verification status of the device models used.

In the app, a section is made from the analyses you have run in the session. A selected section with no result says so in a short note. Tick **Run what is missing** to run those analyses for the report, with the setup saved in the circuit or with defaults when it has none. The desktop asks where to save **name-report.html**, and the browser downloads it. The tolerance section needs parts with a tolerance. Measurements without limits cannot fail, so a circuit with none gets no yield. The overstress verdict can only warn about parts that have a rating.

While the report is made, a panel at the bottom of the window shows the step it is on, the run within a tolerance or step analysis, a bar, the percentage and the time so far. Running the missing analyses can take a minute or more on a large circuit. **Cancel** stops the report after the current step or run, and nothing is saved. When the report is ready the panel reads *Report ready* while the Save dialog is open, and a message names the file once it is saved. A second Generate while one runs is refused with a message.



Figure 68.4 The report being made: step 3 of 4, the tolerance analysis at run 38 of 200, and Cancel.



RC low-pass, 1.6 kHz

R1 = 1 kΩ and C1 = 100 nF give fc = 1/(2πRC) ≈ 1.6 kHz. The input mixes 200 Hz and 20 kHz; the output keeps the slow sine and strips most of the fast one.

circuit file	rc-low-pass.bsc
generated	2026-11-16 02:03 UTC
BetterSPICE	bs-engine 0.8.0
engine	built-in, integration trapezoidal
ngspice reference	ngspice-47
parts and nets	4 parts, 3 nets
sections	Summary, Schematic and parts, AC analysis, Tolerance

Verdicts

MEASUREMENTS
The measurement with limits passes
1 of 1 has limits.

TOLERANCE YIELD
Yield 91.7 %
60 Monte Carlo runs, seed 1

OVERSTRESS
No overstress
No part has a rating set, so only a diode across a source can warn.

CONVERGENCE
No convergence aids needed
Every run converged with the settings as saved.

Named measurements

Measurement	Kind	Value	Limits	Read from	Verdict
-3 dB frequency of V out	bw3db	1.591 kHz	1.5 kHz to 1.7 kHz	AC	PASS

Analyses in this report: operating point, transient to 20 ms, AC sweep, tolerance.

Figure 68.5 The top of a report: the verdicts and the named measurements with PASS or FAIL.

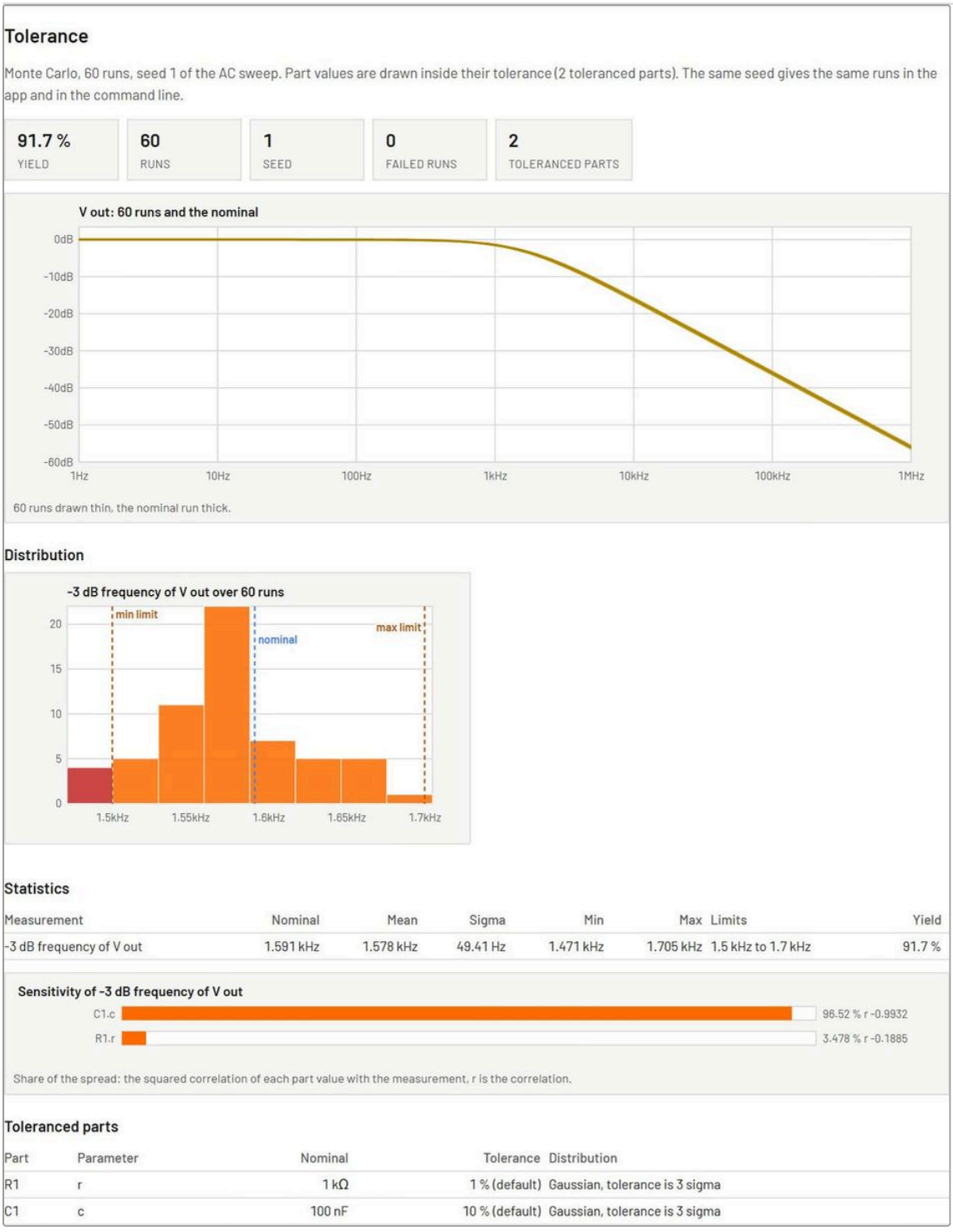


Figure 68.6 The tolerance section of the same report: the cloud of runs, the histogram with its limits, the statistics and the sensitivity bars.

```
bspice report circuit.bsc --html out.html
bspice report circuit.bsc --sections summary,tol,spectrum --window blackmanharris --run-missing --theme light
bspice app get-report --sections tol --sections spectrum --out out.html
```

On the command line and in the agent tool there is no session, so the report includes the analyses the circuit file has a setup for and runs the others only with **—run-missing**. **—sections** takes any of **summary, parts, tran, ac, dc, step,**

tol, spectrum, diagnostics, appendix. **—theme** is **auto**, **dark** or **light**. **—fft** names the probe for the spectrum and **—window** is **hann**, **hamming**, **blackman**, **blackmanharris**, **flattop** or **rect**.

68.4 Share link and interactive HTML

File › **Share link...** puts the open circuit into a web address and copies it. The circuit travels inside the address, after the **#**, compressed. Nothing is uploaded and no server is involved. Whoever opens the link in a browser sees the circuit running in the **The browser viewer**, p. 589. The dialog shows the link, its length and the viewer address it starts with. A link over 2000 characters is marked *long*, because some chat apps and forums cut those. A circuit that needs more than 60000 characters is *too big for a link*, and the dialog offers the two other ways. While the viewer address is the placeholder, the dialog makes no link and offers Export interactive HTML instead.

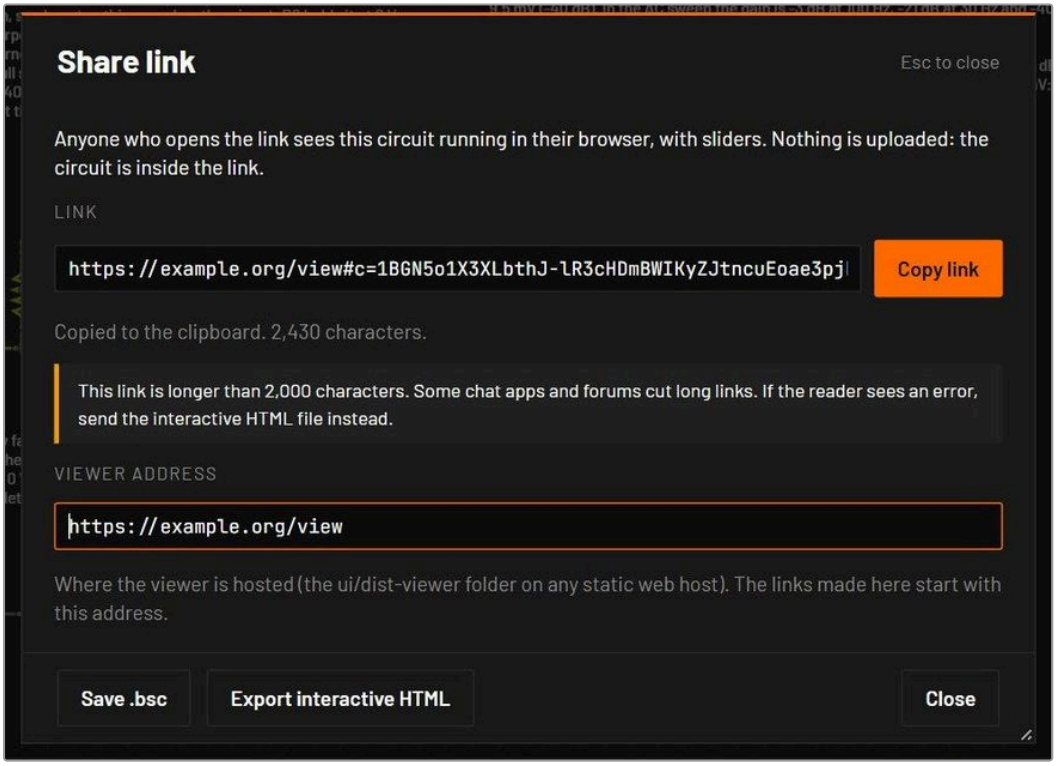


Figure 68.7 The Share link dialog: the link, its length and the viewer address.

File › **Export interactive HTML...** saves one **.html** file with the viewer, the engine and the circuit inside. It is about 3.7 MB, opens by double-click from disk and needs no network, so it works as an email attachment or on a forum that allows file attachments.

68.5 Export data

FROM	HOW	FILE
A scope	Right-click, **Export CSV**	**scopeN.csv**: time and one column per trace
The Analysis view	**Export CSV** in the plot toolbar	**transient.csv**, **bode.csv**, **operating-point.csv**
The Analysis view	**PNG**	The plot with its legend
The command line	**bspice tran … —out f.csv**	Any analysis to CSV

69 The browser viewer

69.1 What a viewer user can do 589
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69.3 Where the viewer lives 590
69.4 Privacy 590

The viewer is a second build of the same interface for people who only need to look at a circuit and play with it. It runs in any current browser as plain static files and installs nothing.

69.1 What a viewer user can do

- Open a share link (**...#c=<circuit>**), or an **.bsc** file with **Open file**, or drop a file on the page. A file on another site opens with **...#u=<address of the .bsc file>** when that site allows it (it must send **Access-Control-Allow-Origin**, or sit on the same host as the viewer).
- See the schematic, the live scope (the Scope, FFT, Logic, Console, Diagnostics and Modules tabs), **Run / Pause**, step, restart, the **Timebase** and the inspector.
- Change values with the inspector fields and their sliders, move parts and change the timebase. All of it stays in the window. **Revert edits** opens the circuit again as it arrived, and reloading the page does the same. Nothing is saved or sent anywhere.
- Press Ctrl + R to run or pause.

The viewer leaves out what needs the desktop app: the file system, the part library, the AI agent connection, updates, the accurate (ngspice) Simulate and the AC sweep.

69.2 Vendor models

The viewer does not carry the vendor model library. A part with a vendor model runs in the viewer only when its live-view equivalent is stored in the circuit. BetterSPICE adds it when it opens a circuit that uses the model, and it goes into the saved file and into share links. Other vendor parts run as generic devices or not at all, and the viewer says which parts at the top of the canvas. Share does the same check and warns the sender.

69.3 Where the viewer lives

Links start with the viewer address, which is one setting. The default is a placeholder until a host is chosen. To use another address, type it in the Share dialog (it is kept in the browser as **bs.viewerUrl**), or build the app with **VITE_VIEWER_URL=https://example.org/view**.

To build it, run **npm run build:viewer** in **ui/**. That writes **ui/dist-viewer/**, which is the whole viewer: **index.html**, an **assets** folder and **viewer-single.html**, the template Export interactive HTML fills. It uses relative paths, so it works from any folder of any static host, such as GitHub Pages, Netlify, Cloudflare Pages, an S3 bucket or an ordinary web server. No server code runs. Serve **.wasm** files as **application/wasm**.

69.4 Privacy

The link holds the circuit after the **#**. Browsers do not send that part to the host. The viewer loads no outside fonts, scripts or analytics.

70 Working with an AI agent

70.1	Setting up Claude Code	591	70.4	Edits (ops)	594
70.2	What you see while an agent works	592	70.5	Errors an agent can get	595
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An AI agent such as Claude Code works in the same circuit you see, with the same operations as your own clicks, and you watch it happen. It connects through MCP, the Model Context Protocol, with the server **bspice mcp**. When the desktop app isn't running, the same tools edit circuit files on disk instead.

70.1 Setting up Claude Code

```
claude mcp add bspice -- "C:\Program Files\BetterSPICE\bspice.exe" mcp
```

Or in an MCP configuration file:

```
{ "mcpServers": { "bspice": { "command": "C:\\Program Files\\BetterSPICE\\bspice.exe", "args": ["mcp"],
                    "env": { "BSPICE_AGENT_NAME": "claude" } } } }
```

- The app listens on **ws://127.0.0.1:47800**, on this computer only. **BSPICE_PORT** changes the port for both the app and the agent.
- The agent needs the key in **%APPDATA%\BetterSPICE\agent-token**, which the MCP server reads by itself. Treat it as a secret.
- The agent's name, shown as **AI · *name***, is **BSPICE_AGENT_NAME**, else the name the agent reports, else *agent*.
- If the app isn't running, the tools work on files ("headless"). If the app is running but the connection fails, every result says so: *"Note: this ran headless on files, NOT in the BetterSPICE window: …"*

70.2 What you see while an agent works

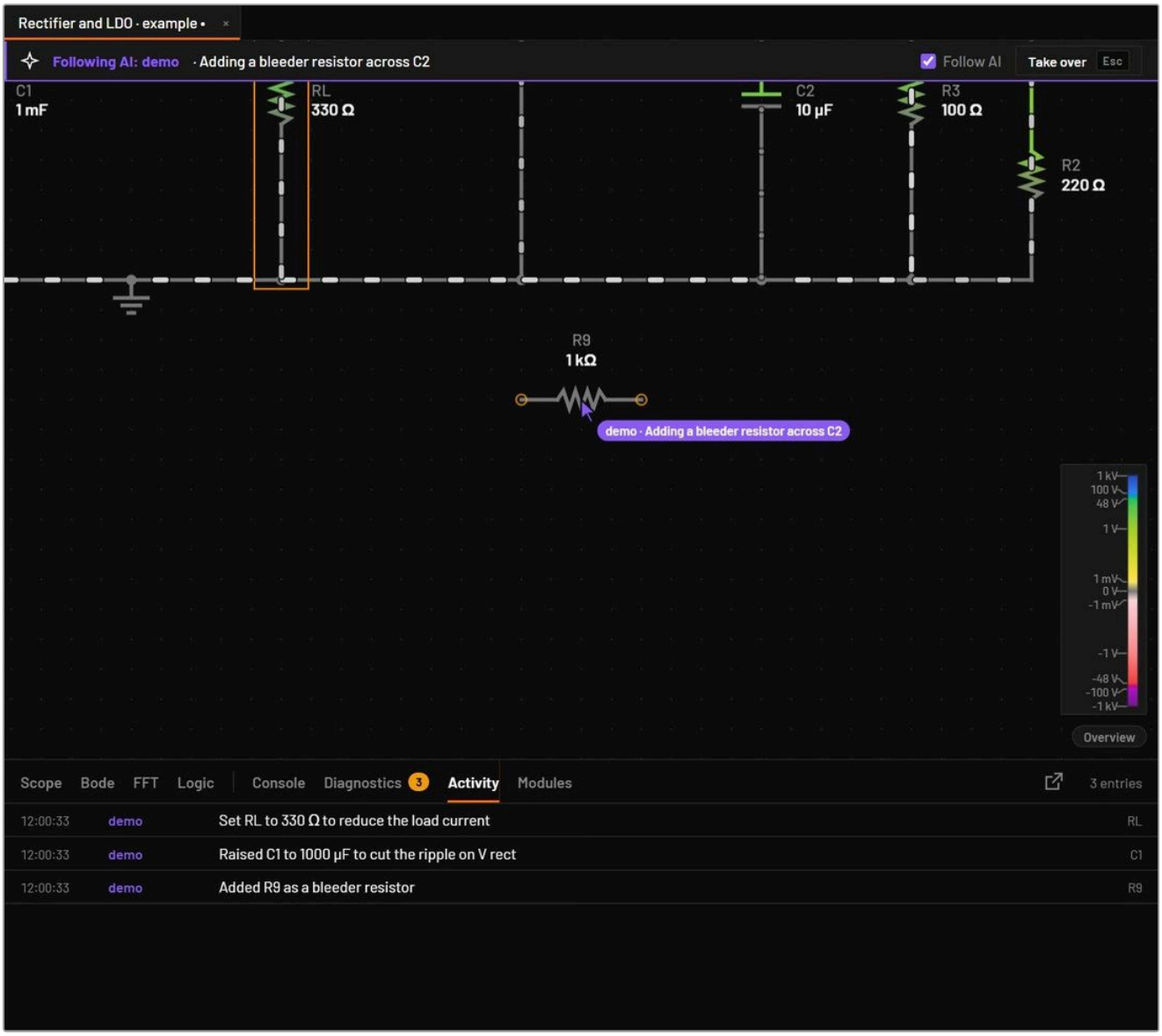


Figure 70.1 An agent at work: the top bar says what it is doing, its cursor marks the part, and Activity logs each edit.

WHAT YOU SEE	MEANING
Following AI: ***name · action***	The bar at the top of the canvas names the agent and what it's doing. Its cursor moves to each part it touches. The bar fades four seconds after its last action.
Follow AI	The pill appears once an agent has talked to the window in this session; the View menu entry is always there. On by default: your view pans and zooms to what the agent touches. Turn it off (Ctrl + Shift + F) to keep your view where it's while its edits still appear.
Take over or Esc	Stops the agent: its edits are refused for 10 seconds, and Follow AI turns off. Reading tools still work.
AI badge	In the inspector, on parts an agent changed last.
Activity	Every edit and run, with the agent's name in violet.
Pinned notes	Violet notes the agent pinned to the schematic. Click to dismiss.

Edits by an agent are normal undo steps: Ctrl + Z takes them back. Parts and symbols an agent creates go to My parts.

70.3 Every tool

TOOL	ARGUMENTS	WHAT IT DOES
open_circuit	path or json	Opens a circuit, like File, Open.
get_circuit		The circuit, the file, the selection and the view.
save_circuit	path	Saves it.
apply	ops	Applies a list of edits as one undo step.
add_part	type, id, at, rot, mirror, variant, pins, p	Places a part. With p.modelId it takes the catalogue model's live values.
add_wire	a, b, via	Draws a wire. A diagonal becomes two segments.
set_param	id, key, value	Sets a parameter, the variant or the designator.
delete	ids	Deletes elements.
move	ids, dx, dy	Moves elements, wires follow.
select	ids	Selects in your view (app only).
view_focus	ids or points	Pans your view there, unless you turned Follow AI off (app only).
view_set	zoom, center	Sets your view (app only).
open_panel	name	inspector, diagnostics, activity, scope, bode, fft, examples, palette, wizard, simsetup, about, shortcuts (app only).
set_mode	mode	schematic, analysis or split (app only).
show_trace	probe	Shows a probe's trace (app only).
annotate	at, text	Pins a note on the schematic (app only).
run_live	speed	Runs the live simulation (app only).
pause		Pauses it (app only).
simulate	analysis, stop, maxStep, source, out, at, fStart, fStop, ptsPerDec, start, step	Runs op, tran, ac, dc, noise, pz or loopgain, with ngspice or PSpice for vendor models, and returns the signals and measurements. noise and pz need out, the output net. loopgain needs at, the break point. An engineering text value such as 10m is taken.
run_analysis	as simulate, plus out, all, start	Runs the analysis in the Analysis view you see.
get_measurements	names	Live probe values and min, max, mean, RMS, peak to peak and final of the last run.
get_waveform	name, maxPoints, from, to	A signal's data, thinned to maxPoints (500).
get_diags		The diagnostics.
screenshot		A picture of your canvas, or a render when there's no window.
list_parts	query	Part files in the parts library.

TOOL	ARGUMENTS	WHAT IT DOES
parts_list	query, kind, source	My parts and the part library.
parts_get	id	One part or symbol with its data.
create_part	bspart, replace	Validates a part file and saves it to My parts and the circuit.
create_symbol	symbol, replace	Saves a symbol.
place_part	partRef, at, rot, mirror, id, p	Places a part from My parts or the library (app only).
symbols_list	builtin	The symbols, and optionally the built-in ones.
list_examples	query, category, offset, limit	The example circuits.
open_example	path or name, newTab	Opens an example as an unsaved copy, in a new tab unless the current one is empty.
import_file	path or name and base64, flat, addSupplies, open	Imports a KiCad or EasyEDA Pro file.
get_report	out, fftProbe, maxChars	Writes the HTML report and returns its text.
verify_circuit		Compares the engine with ngspice on this circuit.
get_events		Events since the last call: edits, selection, view, simulation state, diagnostics, activity.

70.4 Edits (ops)

Every change is an op. A list of ops sent with **apply** is one undo step, and if one op fails, none is applied.

OP	FIELDS	EFFECT
add	part {type, id, variant, p, pins or at, rot, mirror, symbol, symPins}	Adds a part. A missing or taken id gets the next free one.
wire	a, b, via (hv or vh)	Adds a wire.
move	ids, dx, dy	Moves elements.
rotate	ids, dir	Rotates 90°.
mirror	ids	Mirrors.
set	id, key, value	Sets a parameter (null removes it), the variant, the id, the pins, the slider ranges, or a source type.
del	ids	Deletes elements.
label	name, at	A net label.
probe	probe {label, kind, at or part, scope}	A probe.
doc	key, value	name, description, category, or a sim key.
power, **global**, **port**, **graphic**, **sheet**, **bus**, **busEntry**, **subcircuit**		Flags, labels, ports, drawings, sheets, buses (app only).

Coordinates are whole grid units. Element ids: parts by designator, wires **w:x1,y1,x2,y2**, labels **l:name@x,y**, probes **p:label**. Working on files without the app, **add** with **at** places two-pin parts and ground by itself. Other parts need explicit pins.

TRY IT

Ask an agent to design a filter

1. Open the app and start Claude Code with the bspice server configured.
2. Ask: *"Build a 1 kHz second-order Sallen-Key low-pass with a TL072 and show me its Bode plot."*

YOU SHOULD SEE The presence bar shows each step as the agent places parts, wires them, probes the output and runs the AC sweep in the Analysis view in front of you. Press Esc at any time to take over.

70.5 Errors an agent can get

CODE	MEANING
-32700, -32600	The message isn't JSON, or not a valid request.
-32601	Unknown tool or method.
-32602	A missing or wrong argument. The message names it.
-32001	Not authenticated, or you took over (retry in N seconds).
-32002	No BetterSPICE window is connected.
-32003	The window didn't answer within 30 s (600 s for simulations).
-32010	The tool ran and failed. The diagnostics are attached.
-32603	An unexpected failure in the window.

70.6 The control API for your own scripts

Any program can drive the app over WebSocket JSON-RPC 2.0: connect to **ws://127.0.0.1:47800/?token=<token>&agent=<name>**, call **hello**, then **subscribe** to events (**circuit.changed**, **selection.changed**, **view.changed**, **sim.state**, **sim.diags**, **sim.frame** at most ten a second, **file.changed**, **activity**), and call the same methods as the tools above. **bspice serve** runs the same server without a window, for the browser version.

71 The command line (bspice)

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bspice.exe runs the BetterSPICE engine without a window, with the same circuit files. It's installed next to the app.

71.1 Conventions

TOPIC	RULE
Invocation	**bspice <command> [file] [options]**. No command prints the usage.
Exit codes	0 success, 1 diagnostics with errors or a failed check, 2 a usage error.
Output	Results (JSON, CSV, netlists, tables) on standard output. Diagnostics as one JSON object per line. Progress and summaries on standard error.
Options	**—name value**, **—name=value** or **-o value**. Negative numbers work: **—start -5**. An option a command doesn't know is an error that lists the ones it does know, never ignored.
Numbers	SI suffixes f, p, n, u (or µ), m, k, meg, g, t and mil, case-insensitive (so **1M** is milli, **1meg** mega). Trailing units are ignored: **5ms**.
Threads	**—threads auto** (the default) or **—threads N** on any command. validate and verify run their files side by side on that many threads, and ngspice runs that overlap go to hidden ngspice worker processes. Auto is every core but one. **BSPICE_THREADS=N** sets the same thing, and **—threads 1** makes runs sequential. Results are the same on any thread count (**Threads**, p. 216).
Engine	op, tran, ac, dc, noise, pz and loopgain use the built-in engine. Vendor-model runs in ngspice need export-spice and ngspice, or the app.

71.2 Every command

COMMAND	OPTIONS	WHAT IT DOES
validate <file|folder>...		Checks circuits without simulating: ground, floating nets, source loops, pins, parameters. A folder is searched for .bsc files. Exit 1 on any error.
op <file>	—out	DC operating point: net names, node voltages, pin currents and power per part.
tran <file>	—stop, —max-step, --out	Transient. Defaults from the file's sim.simulate, max step stop/1000.
ac <file>	—source, —fstart (1), —fstop (1 MHz), —ppd (20), —out	AC sweep: magnitude in dB and phase per signal, relative to a 1 V stimulus on the source.

COMMAND	OPTIONS	WHAT IT DOES
dc <file>	—source, —start, —stop, —step, —out	DC sweep of a source.
render <file>	—png (required), —scale (20)	A PNG picture of the schematic.
export-spice <file>	-o	An ngspice netlist, every model parameter written out.
ngspice <netlist>	—analysis, —out	Runs a netlist in the bundled ngspice.
verify <folder|file>	—html, —json, —failures, —all, —grid union|ngspice	Runs circuits in BetterSPICE and ngspice and compares every signal. Exit 1 on any failure.
verify-vendor	—models, —html	Checks vendor model conversion and pin mapping against direct ngspice runs.
verify-approx	—models, —json	Measures the behavioural models against reference circuits.
verify-status		The verification status of every device type, as JSON.
report <file>	—html, —fft, —svg	The self-contained HTML report.
import <file>	—out, —report, —no-supplies, —flat, —schematic, —quiet	KiCad or EasyEDA Pro to .bsc.
parts list [folder]	—query	Lists part files.
parts show <file|MPN>		Prints a part file and its problems.
parts validate <file|folder>...		Checks part files.
parts new —template <kind>	-o	A new part file with TODO markers and datasheet hints.
parts quick <kind> key=value...		Fits model parameters to datasheet numbers.
parts quick defaults <type> [variant]		The typical values of a device type.
tline-calc <variant> key=value...	—diff, or <file> —part	The transmission line calculator.
models ...		The model catalogue tools (**Commands for the catalogue**, p. 407).
mcp		The MCP server for AI agents.
serve	—port (47800)	The control API without a window, for the browser version.
help, **version**		Usage and version.

71.3 Examples

```
bspice validate examples
bspice op examples\basics\voltage-divider.bsc
bspice tran examples\basics\rc-charge.bsc --stop 10m --max-step 10u --out run.csv
bspice ac filter.bsc --source V1 --fstart 10 --fstop 100k --ppd 50 --out bode.csv
bspice dc divider.bsc --source V1 --start 0 --stop 5 --step 0.1
bspice render board.bsc --png board.png --scale 30
bspice export-spice rc.bsc -o rc.cir
bspice ngspice rc.cir --analysis ".tran 1u 5m" --out ng.csv
bspice report psu.bsc --html psu-report.html
bspice import board.kicad_sch --out board.bsc --report import.json
bspice parts new --template ldo -o ap2112.bspart
bspice parts validate parts\library
bspice parts quick diode vf=0.7 if=10m
bspice tline-calc microstrip w=3m h=1.6m er=4.5 len=0.1
bspice verify verification\circuits --html verification\report.html
```

71.4 Output formats

—out omitted or **json** prints JSON, **csv** prints CSV, and anything else is a file name (CSV when it ends in .csv). A transient's CSV has a time column and one column per signal, **V(net)** and **I(part)**. An AC CSV has frequency and a dB and degrees column per signal. An operating point cannot be CSV.

```
> bspice parts quick diode vf=0.7 if=10m
{"type":"diode","variant":"rectifier","p":{"is":2.93e-9,"n":1.8,"rs":0.0},
 "notes":["n = 1.8 assumed; give vf2 at if2 to fit it."]}

> bspice tline-calc microstrip w=3m h=1.6m er=4.5
{"ok":true,"z0":49.66,"epsEff":3.368,"vf":0.545,"td":6.12e-10, ...}
```

TRY IT

Check every example before a release

1. Run **bspice validate examples**.
2. Run **bspice verify verification\circuits —failures**.

YOU SHOULD SEE The first prints a summary such as "validated 523 file(s): 0 with errors". The second lists only failing comparisons, and exits 0 when everything passes.

PART

IX

Lists and data

Example circuits worth opening first, every Part Wizard template field, environment variables, install details and how the engine is verified.

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72 Example circuits

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BetterSPICE ships 715 example circuits in 40 categories. Each opens running, with probes on the signals worth watching and a description that says what to try. This chapter is a path through 47 of them. The in-app browser (E) has every one and searches them all.

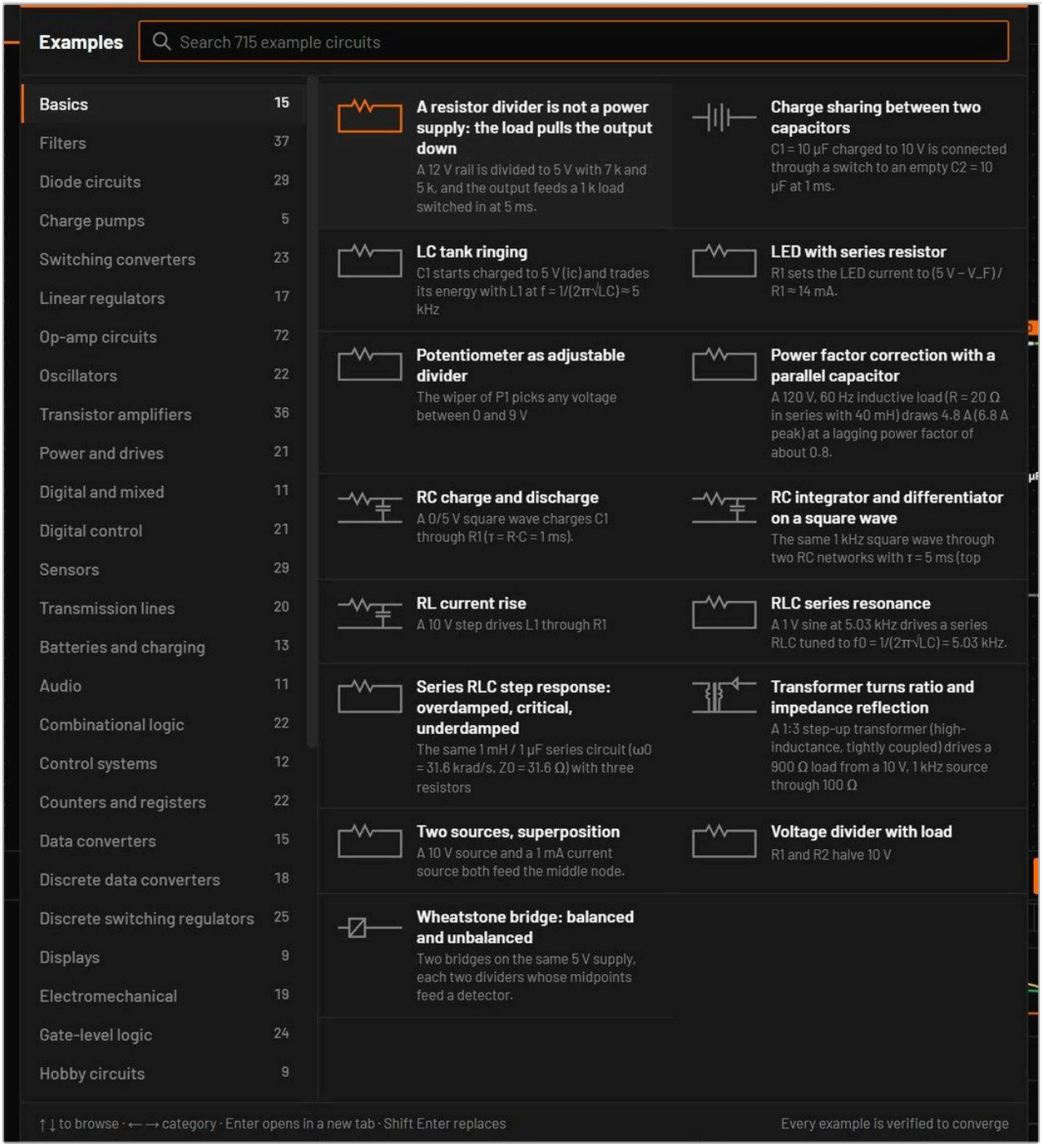


Figure 72.1 The example browser.

72.1 The example browser

KEY OR GESTURE	WHAT IT DOES
Type	Searches names, descriptions and categories.
Up / Down	Moves through the list.
Left / Right	Changes category, when not searching.
Enter or **click**	Opens the example in a new tab.
Shift + Enter or **Shift-click**	Opens it in a new tab too. The browser says so. Nothing is replaced, so no unsaved work is lost.
Esc	Closes the browser.

While you search, the browser shows the number of results and each category's match count. The Examples menu has one entry per category, and the library search lists matching examples too. The desktop reads the **examples** folder next to the app, or the folder in **BSPICE_EXAMPLES**.

72.2 Start here

EXAMPLE	WHAT IT TEACHES
Voltage divider with load basics/voltage-divider.bsc	Read a net voltage, and see a load pull a divider down.
RC charge and discharge basics/rc-charge.bsc	One time constant on the scope: 63 % after τ.
RC low-pass, 1.6 kHz filters/rc-low-pass.bsc	The Quick start circuit: a corner frequency you can check by hand.
LED with series resistor basics/led-current-limit.bsc	Sliders: change R and watch the LED current follow.
RLC series resonance basics/rlc-series-resonance.bsc	Resonance: the capacitor voltage is Q times the input.
LC tank ringing basics/lc-tank.bsc	Initial conditions (ic) and a ringing that decays.

72.3 Measure with the analyses

EXAMPLE	WHAT IT TEACHES
Sallen-Key low-pass, 1 kHz Butterworth filters/sallen-key-low-pass.bsc	AC sweep: a second-order slope of −40 dB per decade.
Sallen-Key high-pass, 100 Hz filters/active-high-pass.bsc	AC sweep and the margins strip on an active filter.
Common-emitter amplifier (2N3904) transistor-amplifiers/common-emitter.bsc	Operating point of a biased stage, then its gain.
CMOS inverter and its transfer curve logic-families/cmos-inverter-transfer.bsc	DC sweep: a transfer curve.

EXAMPLE	WHAT IT TEACHES
Wien-bridge oscillator with diode amplitude control oscillators/wien-bridge.bsc	FFT of an oscillator and its harmonics.
Series RLC step response: overdamped, critical, underdamped basics/rlc-damping-comparison.bsc	Three damping cases side by side, the idea behind a parameter step.
Noise of a common-emitter amplifier transistor-amplifiers/common-emitter-noise.bsc	The Noise tab: which part adds the noise of an amplifier stage.
Poles and zeros of a Sallen-Key low-pass filters/sallen-key-poles-zeros.bsc	The Pole-zero tab: the poles of a second-order filter with their Q.
Loop gain of an op-amp driving a capacitive load op-amp-circuits/opamp-capacitive-load-loop-gain.bsc	The Loop gain tab: the phase margin of an op-amp that drives a capacitor.

72.4 Power

EXAMPLE	WHAT IT TEACHES
Mains transformer, bridge and reservoir cap diode-circuits/bridge-rectifier-transformer.bsc	Ripple on a reservoir capacitor, measured with Show stats.
Op-amp series regulator (LM317 principle) linear-regulators/opamp-series-regulator.bsc	Tutorial 3: a regulation loop, then a vendor op-amp model.
LDO load-transient response linear-regulators/ldo-load-transient.bsc	A load step: the dip and recovery of an LDO.
Buck converter, 12 V to 5 V, 1 A switching-converters/buck-12v-to-5v.bsc	A buck converter: inductor ripple and start-up.
Synchronous buck with dead time switching-converters/sync-buck.bsc	Dead time in a synchronous buck.
Boost converter, 5 V to 12 V switching-converters/boost-5v-to-12v.bsc	A boost converter and its output ripple.
Buck converter IC 12 V → 3.3 V with a load step power-management/buck-ic-12v-to-3v3-load-step.bsc	A buck IC block with a load step.
TVS diode clamping a surge on a 24 V line protection/tvs-surge-clamp.bsc	A TVS clamping a surge: peak voltage and current.

72.5 Analog signal

EXAMPLE	WHAT IT TEACHES
Inverting amplifier, gain –10 op-amp-circuits/inverting-amplifier.bsc	Gain set by two resistors.
Integrator: square in, triangle out op-amp-circuits/integrator.bsc	Square in, triangle out.
Difference amplifier rejects common-mode hum op-amp-circuits/difference-amplifier.bsc	Common-mode rejection.
Photodiode transimpedance amplifier sensors/photodiode-tia.bsc	A transimpedance amplifier.
Low-side current sense amplifier sensors/low-side-current-sense.bsc	Current sensing with a shunt and an amplifier.
LM386 audio amplifier into an 8 Ω speaker audio/lm386-audio-amp.bsc	An audio amplifier into a speaker.

72.6 Digital and mixed signal

EXAMPLE	WHAT IT TEACHES
4-bit binary counter with LEDs digital-and-mixed/binary-counter-leds.bsc	The logic analyzer on a counter.
555 astable, 690 Hz LED blinker oscillators/555-astable.bsc	A 555 blinker: duty cycle with Show stats.
PWM from a comparator and a triangle wave digital-and-mixed/comparator-pwm.bsc	PWM from a comparator and a triangle wave.
State machine traffic light with pedestrian button mixed-signal/fsm-traffic-light.bsc	A programmable state machine block.
Digital PI voltage loop for a buck converter digital-control/digital-pi-buck.bsc	A control block closing a buck converter loop.
MCU blink (MCU language) digital-control/mcu-blink.bsc	The smallest MCU program: an LED toggled every 500 ms.
MCU pot to PWM fan speed digital-control/mcu-pot-pwm-fan.bsc	ADC to PWM: a pot sets a fan speed.
MCU writes text to an I2C OLED digital-control/mcu-i2c-oled.bsc	An MCU writes text to an I2C OLED. Delete a pull-up to see the warning.
Two MCUs on a CAN bus digital-control/mcu-can-two-nodes.bsc	Two MCUs on a CAN bus with transceivers. The Logic tab opens with the CAN frames decoded.

EXAMPLE	WHAT IT TEACHES
4-digit 7-segment display with multiplexing displays/seven-segment-4-digit-multiplex.bsc	A four-digit display scanned digit by digit.
JK flip-flop from a D flip-flop and gates latches-and-flip-flops/jk-flip-flop.bsc	A JK flip-flop: hold, set, reset and toggle.
PLL locking a VCO to 10× the reference mixed-signal/pll-lock.bsc	A PLL locking: watch the control voltage settle.

72.7 Lines, motors and interfaces

EXAMPLE	WHAT IT TEACHES
Open-ended line: the step doubles transmission-lines/tline-open-end.bsc	A reflection: the step doubles at an open end.
Series termination of a fast driver transmission-lines/tline-series-termination.bsc	Series termination of a fast driver.
H-bridge driver with PWM speed and direction motors/h-bridge-speed-direction-ramp.bsc	An H-bridge with PWM speed and direction.
Relay driver with flyback diode electromechanical/relay-driver-flyback.bsc	A relay coil and its flyback diode.
I2C bus: open-drain lines, pull-ups and rise time interface/i2c-bus-pull-ups-rise-time.bsc	I2C pull-ups and rise time.
RS-485 half-duplex link interface/rs485-link.bsc	An RS-485 link.

72.8 Every category

Basics (15), Filters (37), Diode circuits (29), Charge pumps (5), Switching converters (23), Linear regulators (17), Op-amp circuits (72), Oscillators (22), Transistor amplifiers (36), Power and drives (21), Digital and mixed (11), Digital control (21), Sensors (29), Transmission lines (20), Batteries and charging (13), Electromechanical (19), Mixed-signal (6), Power management (13), Protection (19), Interface (20), Timing (6), Displays (9), Audio (11), RF (12), Combinational logic (22), Latches and flip-flops (15), Counters and registers (22), State machines (11), Logic families (16), Data converters (15), PLL and clocking (8), Control systems (12), Motors (7), LED drivers (7), Hobby circuits (9), Discrete switching regulators (25), Gate-level logic (24), Discrete data converters (18), Transformers (10), Vendor-chip regulators (8).

73 Part templates reference

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Every Part Wizard template, with every field it asks for, where in the datasheet to find it, and the live-model parameter it sets. **Columns** says which of min, typ and max the field takes. Required fields are marked *. **Sets** names the simulation parameter the value feeds, where it feeds one directly. The others are kept in the part file and used by checks, reports and the datasheet limits.

The template files are in **parts/templates**. A template's **kind** becomes the device type shown after the arrow when the part is placed.

73.1 Analog ICs

Analog · 555 timer (analog.timer555 → device timer555)

Simulation pins: **gnd**, **trig**, **out**, **reset**, **ctrl**, **thr**, **dis**, **vcc**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply voltage range *	V_CC	V	min, max		Recommended Operating Conditions, row "Supply Voltage" (V_CC).
Supply current	I_CC	A	typ, max		Electrical Characteristics, row "Supply Current" with output low, no load, at V_CC = 5 V and 15 V.
Threshold voltage (fraction of V_CC)	V_TH/V_CC		typ		Electrical Characteristics, row "Threshold Voltage Level" divided by V_CC (nominally 2/3).
Trigger voltage (fraction of V_CC)	V_TRIG/V_CC		typ		Electrical Characteristics, row "Trigger Voltage Level" divided by V_CC (nominally 1/3).
Output high drop below V_CC	V_CC – V_OH	V	typ, max		Electrical Characteristics, row "High-Level Output Voltage" at I_OH = –100 mA: V_CC minus that value (≈1.7 V for bipolar, ≈0 for CMOS).
Output low voltage	V_OL	V	typ, max		Electrical Characteristics, row "Low-Level Output Voltage" at I_OL = 10 mA..100 mA.
Output current	I_O	A	max		Absolute Maximum Ratings, row "Output Current" (±200 mA for NE555).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Output rise time	t_r	s	typ		Switching Characteristics, row "Output Pulse Rise Time".
Maximum astable frequency	f_max	Hz	typ		Electrical Characteristics, row "Maximum Frequency" in astable mode (typ).
Initial timing error	Δt/t	%	typ, max		Electrical Characteristics, row "Timing Error, Initial Accuracy" (monostable and astable rows).
Threshold current	I_THR	A	typ, max		Electrical Characteristics, row "Threshold Current".
Trigger current	I_TRIG	A	typ, max		Electrical Characteristics, row "Trigger Current".
Reset current	I_RST	A	typ, max		Electrical Characteristics, row "Reset Current".
Discharge on-resistance	R_DIS	Ohm	typ		Electrical Characteristics, row "Discharge Switch On-State Voltage" divided by the stated current, or "Discharge Saturation Voltage".
Timing drift with temperature	Δt/ΔT	ppm/C	typ		Electrical Characteristics, row "Temperature Drift of Timing".
Timing drift with supply	Δt/ΔV	%/V	typ		Electrical Characteristics, row "Drift With Supply Voltage".
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Analog · Comparator (analog.comparator → **device** comparator)

Simulation pins: **in+**, **in−**, **out**, **v+**, **v−**. Curves: Propagation delay vs input overdrive, Output low voltage vs sink current, Supply current vs supply voltage.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply voltage range (total)	V_S	V	min, max		Recommended Operating Conditions, row "Supply Voltage".
Propagation delay *	t_PD	s	typ, max		Switching Characteristics, row "Response Time" or "Propagation Delay" with the stated overdrive (for example 5 mV or 100 mV) and pull-up.
Input hysteresis	V_HYST	V	typ		Electrical Characteristics, row "Input Hysteresis". 0 when the part has none (most LM393-class parts).
Open-drain / open-collector output (1 = yes) *	OD		typ		Block diagram or pin description: an output transistor with no internal pull-up means open collector / drain (1). Push-pull is 0.
Input offset voltage	V_OS	V	typ, max		Electrical Characteristics, row "Input Offset Voltage" at 25 °C.
Input bias current	I_B	A	typ, max		Electrical Characteristics, row "Input Bias Current".
Supply current	I_Q	A	typ, max		Electrical Characteristics, row "Supply Current" (per comparator).
Output sink current	I_SINK	A	min		Electrical Characteristics, row "Output Sink Current" at V_O = 1.5 V.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Output low voltage	V_OL	V	typ, max		Electrical Characteristics, row "Low-Level Output Voltage" at the stated sink current.
Input offset current	I_OS	A	typ, max		Electrical Characteristics, row "Input Offset Current".
Common-mode range beyond the rail	V_ICM	V	typ		Electrical Characteristics, row "Input Common-Mode Voltage Range": how far past each supply the inputs may go (negative = inside the rail).
Output leakage (open-drain high)	I_OH	A	max		Electrical Characteristics, row "Output Leakage Current" (open-drain or open-collector outputs).
Common-mode rejection ratio	CMRR	dB	min, typ		Electrical Characteristics, row "Common-Mode Rejection Ratio".
Power-supply rejection ratio	PSRR	dB	min, typ		Electrical Characteristics, row "Power-Supply Rejection Ratio".
Power-on delay	t_on	s	typ		Electrical Characteristics, row "Power-On Time" or "Turn-On Delay".
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Analog · Current-sense amplifier (analog.csa → device csa)

Simulation pins: **IN+**, **IN–**, **OUT**, **VS**, **GND**. Symbol variants: uni, bidir, hs. Curves: Gain vs frequency.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Gain *	G	V/V	typ	**gain**	Gain option of the part number (INA180A1 = 20, A2 = 50, A3 = 100, A4 = 200).
Bandwidth	BW	Hz	typ	**bw**	"Bandwidth" (–3 dB) at your gain.
Offset voltage	V_OS	V	typ, max	**vos**	"Offset voltage, RTI".
Common-mode range	V_CM	V	min, max	**vcm_max**	"Common-mode input range".
Gain error	ε_G	%	typ, max		Electrical Characteristics, row "Gain Error".
Offset voltage drift	ΔV_OS/ΔT	V/C	typ, max		Electrical Characteristics, row "Offset Voltage Drift".
Common-mode rejection ratio	CMRR	dB	min, typ		Electrical Characteristics, row "CMRR".
Power-supply rejection ratio	PSRR	dB	min, typ		Electrical Characteristics, row "PSRR".
Quiescent current	I_Q	A	typ, max		Electrical Characteristics, row "Quiescent Current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Analog · Instrumentation amplifier (analog.inamp → device inamp)

Simulation pins: **in+**, **in–**, **rg1**, **rg2**, **ref**, **out**, **v+**, **v–**. Symbol variants: rg, fixed, diff. Curves: CMRR vs frequency, Gain vs frequency.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Gain-equation resistor	R_F	Ohm	typ	**rf**	Gain equation: G = 1 + 49.4 kΩ / R_G → R_F = 24.7 kΩ (AD620). INA128: 50 kΩ / R_G → 25 kΩ.
Fixed gain	G	V/V	typ	**gain**	Fixed-gain parts / difference amps: "Gain".
Gain-bandwidth	GBW	Hz	typ	**gbw**	"Bandwidth" at G = 1 or GBW.
Slew rate	SR	V/s	typ	**slew**	"Slew rate" (V/µs × 1e6).
Input offset voltage	V_OS	V	typ, max	**vos**	"Input offset voltage" (RTI).
CMRR	CMRR	dB	min, typ	**cmrr_db**	"Common-mode rejection" at your gain.
Quiescent current	I_Q	A	typ, max	**iq**	"Quiescent current".
Offset voltage drift	ΔV_OS/ΔT	V/C	typ, max		Electrical Characteristics, row "Offset Voltage Drift" (µV/°C).
Input bias current	I_B	A	typ, max		Electrical Characteristics, row "Input Bias Current".
Gain error	ε_G	%	typ, max		Electrical Characteristics, row "Gain Error" at the stated gain.
Gain nonlinearity	NL	ppm	typ, max		Electrical Characteristics, row "Nonlinearity".
Power-supply rejection ratio	PSRR	dB	min, typ		Electrical Characteristics, row "PSRR".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Input voltage noise density	e_n	V/rtHz	typ		Electrical Characteristics, row "Voltage Noise Density" at 1 kHz.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Analog · Multiplier (analog.mult → device mult)

Simulation pins: **x1**, **x2**, **y1**, **y2**, **z**, **w**, **v+**, **v–**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Scale factor	SF	V	typ	**scale**	Transfer function W = (X1 – X2)(Y1 – Y2) / SF + Z (AD633: 10 V).
Bandwidth	BW	Hz	typ	**bw**	"Small-signal bandwidth".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Analog · Op-amp (analog.opamp → device opamp)

Simulation pins: **in+**, **in-**, **out**, **v+**, **v-**. Symbol variants: 5pin, 3pin, 8pin, sd. Curves: Open-loop gain vs frequency, CMRR vs frequency, PSRR vs frequency, Voltage noise vs frequency, Open-loop phase vs frequency, Output impedance vs frequency, Output swing from the rail vs load current, Input bias current vs temperature, Offset voltage vs temperature, Supply current vs supply voltage.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply voltage range (total)	V_S	V	min, max		Recommended Operating Conditions, row "Supply Voltage" (V_S = V+ – V–. ±15 V means 30 V).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Open-loop voltage gain *	A_OL	dB	min, typ		Electrical Characteristics, row "Large-Signal Voltage Gain" (A_VD or A_OL). Convert V/mV to dB: 20·log10(V/mV × 1000).
Gain-bandwidth product *	GBW	Hz	min, typ		Electrical Characteristics, row "Gain Bandwidth Product" (GBW, or unity-gain bandwidth B_1).
Slew rate *	SR	V/s	min, typ		Electrical Characteristics, row "Slew Rate" (V/µs. Store in V/s, 13 V/µs = 1.3e7) at unity gain.
Input offset voltage	V_OS	V	typ, max		Electrical Characteristics, row "Input Offset Voltage" at 25 °C (the full-range value is larger).
Input bias current	I_B	A	typ, max		Electrical Characteristics, row "Input Bias Current" at 25 °C.
Input offset current	I_OS	A	typ, max		Electrical Characteristics, row "Input Offset Current".
Supply current per amplifier	I_Q	A	typ, max		Electrical Characteristics, row "Supply Current" (no load). Divide by the number of amplifiers if the row says "all amplifiers".
Output headroom to the rails	V_DROP	V	typ		Electrical Characteristics, rows "Output Voltage Swing" V_OH / V_OL: headroom = V+ − V_OH at your load. 0 for rail-to-rail output.
Input common-mode headroom	V_ICR	V	typ		Electrical Characteristics, row "Common-Mode Input Voltage Range": distance from the positive rail to the top of the range.
Open-loop output resistance	R_O	Ohm	typ		Row "Open-Loop Output Impedance" or the Z_O vs frequency graph at low frequency. Often absent (use 50 to 100 Ω).
Short-circuit output current	I_SC	A	typ		Electrical Characteristics, row "Short-Circuit Output Current".
Offset voltage drift	ΔV_OS/ΔT	V/C	typ, max		Electrical Characteristics, row "Input Offset Voltage Drift" (µV/°C). Type 2u for 2 µV/°C.
Differential input resistance	R_IN(dm)	Ohm	typ		Electrical Characteristics, row "Input Resistance, Differential".
Common-mode input resistance	R_IN(cm)	Ohm	typ		Electrical Characteristics, row "Input Resistance, Common-Mode".
Input capacitance	C_IN	F	typ		Electrical Characteristics, row "Input Capacitance" (differential or common-mode, say which in the note).
Rail-to-rail input (1 = yes)	RRI		typ		Front page feature list: "Rail-to-rail input" gives 1, otherwise 0. Check the common-mode range row for the real limits.
Rail-to-rail output (1 = yes)	RRO		typ		Front page feature list: "Rail-to-rail output" gives 1, otherwise 0. The swing row has the real headroom.
Settling time	t_s	s	typ		Electrical Characteristics, row "Settling Time" to 0.1 % or 0.01 % (say which in the note).
Turn-on time	t_on	s	typ		Electrical Characteristics, row "Turn-On Time" or "Start-Up Time".
Phase margin	φ_m	deg	typ		Row "Phase Margin" or the Open-Loop Gain and Phase graph at the unity-gain frequency.
Capacitive load for stability	C_L(max)	F	typ		Typical Characteristics, "Small-Signal Overshoot vs Capacitive Load", or the applications note: the largest load with no oscillation.
Input voltage noise density	e_n	V/rtHz	typ		Electrical Characteristics, row "Input Voltage Noise Density" (nV/√Hz) at 1 kHz.
Input current noise density	i_n	A/rtHz	typ		Electrical Characteristics, row "Input Current Noise Density" (fA/√Hz or pA/√Hz) at 1 kHz.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Common-mode rejection ratio	CMRR	dB	min, typ		Electrical Characteristics, row "Common-Mode Rejection Ratio" (DC).
Power-supply rejection ratio	PSRR	dB	min, typ		Electrical Characteristics, row "Supply-Voltage Rejection Ratio" (k_SVR or PSRR, DC).
Noise 0.1 to 10 Hz, peak to peak	e_n(pp)	V	typ		Electrical Characteristics, row "Input Voltage Noise, 0.1 Hz to 10 Hz" (µV p-p).
1/f noise corner frequency	f_c	Hz	typ		Typical Characteristics, "Input Voltage Noise Density vs Frequency": the frequency where the density has fallen to 1.41 times its flat value.
Total harmonic distortion plus noise	THD+N	%	typ		Electrical Characteristics, row "THD+N" with f, gain and output level in the conditions.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Analog · OTA (analog.ota → device ota)

Simulation pins: **in+**, **in–**, **iabc**, **out**, **v+**, **v–**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Transconductance per I_ABC	g_m/I_ABC	1/V	typ		"Forward transconductance" vs I_ABC graph (≈ 19.2 /V at 25 °C).
Max amplifier bias current	I_ABC	A	max		Absolute maximum, "Amplifier bias current" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Analog · Voltage reference (analog.reference → device vref)

Simulation pins: **out**, **gnd**. Symbol variants: shunt. Curves: Reference voltage vs temperature, Output impedance vs frequency, Noise density vs frequency, Cathode current vs cathode voltage (shunt).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Reference voltage *	V_REF	V	min, typ, max		Electrical Characteristics, row "Reference Voltage" (V_REF, or V_KA = V_REF for shunt references) at 25 °C and the stated cathode current.
Output / dynamic impedance	Z_KA	Ohm	typ, max		Electrical Characteristics, row "Dynamic Impedance" (|Z_KA|) for shunt types, or "Load Regulation" (ΔV / ΔI) for series types.
Minimum cathode current	I_K(min)	A	max		Electrical Characteristics, row "Minimum Cathode Current for Regulation" (shunt types).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Maximum cathode / output current	I_K(max)	A	max		Recommended Operating Conditions, row "Cathode Current" (shunt) or "Output Current" (series).
Maximum cathode voltage	V_KA	V	max		Recommended Operating Conditions, row "Cathode Voltage" (adjustable shunt types).
Temperature drift	TC	ppm/C	typ, max		Electrical Characteristics, row "Temperature Coefficient" (ppm/°C), or derive from "V_REF deviation over temperature" ÷ (V_REF · ΔT).
Reference input current	I_REF	A	typ, max		Electrical Characteristics, row "Reference Input Current" (adjustable shunt types).
Initial accuracy	ΔV_REF	%	typ, max		Electrical Characteristics, row "Initial Accuracy" or "Output Voltage Tolerance" at 25 °C.
Line regulation	ΔV/ΔV_IN	%/V	typ, max		Electrical Characteristics, row "Line Regulation".
Load regulation	ΔV/ΔI	V/A	typ, max		Electrical Characteristics, row "Load Regulation" (mV/mA is the same as V/A: type 0.2 for 0.2 mV/mA).
Supply current	I_Q	A	typ, max		Electrical Characteristics, row "Supply Current" or "Quiescent Current" (series references).
Maximum load current	I_L	A	max		Electrical Characteristics, row "Output Current" (sourcing, and sinking if listed).
Long-term drift	ΔV/Δt	ppm	typ		Electrical Characteristics, row "Long-Term Stability" (ppm per 1000 h).
Thermal hysteresis	ΔV_hys	ppm	typ		Electrical Characteristics, row "Thermal Hysteresis".
Output noise	e_n	V	typ		Electrical Characteristics, row "Output Noise Voltage" (µVrms or µVpp), note the bandwidth (0.1 to 10 Hz or 10 Hz to 10 kHz).
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.2 Any device

Any device · Device type of your choice (generic.device → **device** of your choice)

A part of any of the 165 device types the engine simulates. It has no datasheet fields: the Part Wizard asks for the device's own parameters (the inspector's fields), saved in **model.live.p**, and maps its pins like any other part.

Simulation pins: none.

73.3 Audio

Audio · Audio amplifier (audio.audioamp → device audioamp)

Simulation pins: **IN+**, **IN–**, **OUT+**, **OUT–**, **VDD**, **GND**, **SD**. Symbol variants: btl, se, lm386.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Voltage gain *	A_V	V/V	typ	**gain**	Electrical characteristics, "Gain" (dB → 10^(dB/20)). LM386: 20 / 200.
Output power	P_O	W	typ	**pout**	"Output power at THD+N = 10 %" and the load.
Quiescent current	I_Q	A	typ, max	**iq**	"Quiescent current".
Efficiency	η		typ	**eff**	"Efficiency" at rated power.
Supply range	V_DD	V	min, max		Recommended operating conditions.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Audio · Buzzer (audio.buzzer → device buzzer)

Simulation pins: **+**, **–**. Symbol variants: magnetic, piezo, active, active_piezo.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resonant / rated frequency *	f_O	Hz	typ	**f0**	Specification, "Resonant frequency" / "Oscillation frequency".
Rated voltage	V_N	V	min, typ, max	**v_rated**	Specification, "Rated voltage" / "Operating voltage".
Rated current	I_N	A	max	**i_rated**	Specification, "Current consumption" at rated voltage.
Coil resistance (magnetic)	R	Ohm	typ	**r**	Magnetic transducers: "Coil resistance".
Capacitance (piezo)	C	F	typ	**c**	Piezo elements: "Capacitance at 1 kHz".
Sound pressure level	SPL	dB	min		"Sound output at 10 cm" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Audio · Microphone (audio.mic → device mic)

Simulation pins: **out**, **gnd**. Symbol variants: electret, mems_analog, mems_pdm.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Sensitivity *	S	dBV/Pa	typ	**sens**	Specification, "Sensitivity" at 1 kHz, 94 dB SPL (dBV/Pa. DBFS for PDM).
Current consumption	I_D	A	max	**i_d**	"Current consumption" (electret: at the standard load).
Supply / operating voltage	V_S	V	min, typ, max		"Standard operating voltage".
Signal-to-noise ratio	SNR	dB	typ		"S/N ratio" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Audio · Speaker (audio.speaker → **device** speaker)

Simulation pins: **+**, **–**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Nominal impedance *	Z	Ohm	typ	**z**	Specification, "Impedance".
DC resistance	R_e	Ohm	typ	**re**	Thiele–Small table, "Re".
Resonance frequency	f_s	Hz	typ	**fs**	Specification, "Resonance frequency F0 / Fs".
Voice-coil inductance	L_e	H	typ	**le**	Thiele–Small table, "Le".
Mechanical Q	Q_ms		typ	**qms**	Thiele–Small table, "Qms".
Electrical Q	Q_es		typ	**qes**	Thiele–Small table, "Qes".
Rated power	P	W	max	**p_rated**	"Rated input power".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.4 Connectors and mechanical

Connectors · Connector (connectors.conn → **device** conn)

Simulation pins: **1**, **2**, **3**, **4**. Symbol variants: 1xN, 2xN, usb_c, usb_micro, usb_a, barrel, trs, trs_sw, rj45, sma, microsd, bat_holder, banana.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Number of positions *	N		typ	**n**	Part number / drawing, "Number of positions / contacts".
Pitch	p	m	typ		Drawing, "Pitch" (informational).
Current rating per contact	I	A	max		Electrical, "Current rating" (informational).
Contact resistance	R_C	Ohm	max	**r_contact**	Electrical, "Contact resistance" (used only when mated with r_contact >. 0).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).

Connectors · Fiducial (connectors.fiducial → **device** fiducial)

Simulation pins: **anchor**. Symbol variants: global, local.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Copper diameter	d	m	typ		Board drawing (informational).

Connectors · Jumper / solder jumper (connectors.jumper → device jumper)

Simulation pins: **a**, **b**. Symbol variants: open, closed, 3way, link0.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resistance when closed	R	Ohm	max	**r**	0 Ω link datasheet, "Resistance" (≤ 50 mΩ typical).
Rated current	I_R	A	max		0 Ω link: "Rated current" (informational).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Connectors · Mounting hole (connectors.mhole → device mhole)

Simulation pins: **mh**. Symbol variants: pad, np.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Hole diameter	d	m	typ		Mechanical drawing (informational).

Connectors · Net tie (connectors.net_tie → device net_tie)

Simulation pins: **a**, **b**. Symbol variants: 2, 3.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Connectors · Test point (connectors.tp → device tp)

Simulation pins: **tp**. Symbol variants: pad, loop.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.5 Data converters

Converter · ADC (converter.adc → device adc)

Simulation pins: **ain**, **clk**, **d**, **gnd**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resolution *	N	bit	typ		Electrical Characteristics, row "Resolution" (bits, no missing codes).
Sample rate *	f_S	Hz	max		Electrical Characteristics, row "Throughput Rate" / "Sample Rate" (max).
Reference / full-scale voltage *	V_REF	V	min, typ, max		Electrical Characteristics, row "Reference Input Voltage" or "Full-Scale Input Range".
Sigma-delta architecture (1 = yes)	ΣΔ		typ		Title / functional description: SAR, pipeline (0) or sigma-delta (1).
Integral non-linearity	INL	LSB	typ, max		Electrical Characteristics, row "Integral Nonlinearity".
Differential non-linearity	DNL	LSB	typ, max		Electrical Characteristics, row "Differential Nonlinearity".
Signal-to-noise ratio	SNR	dB	min, typ		AC Characteristics, row "SNR" at the stated input frequency.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Effective number of bits	ENOB	bit	min, typ		AC Characteristics, row "ENOB" (or (SINAD – 1.76) / 6.02).
Conversion latency	t_LAT	s	typ		Timing: conversion time (SAR) or digital filter latency (sigma-delta).
Supply current	I_DD	A	typ, max		Electrical Characteristics, row "Supply Current" at full rate.
Signal-to-noise-and-distortion	SINAD	dB	typ		Dynamic Performance table, row "SINAD" at the stated input frequency.
Spurious-free dynamic range	SFDR	dB	typ		Dynamic Performance table, row "SFDR".
Total harmonic distortion	THD	dB	typ		Dynamic Performance table, row "THD" (negative dB).
Gain error	E_G	%	typ, max		DC Accuracy table, row "Gain Error".
Offset error	E_OS	V	typ, max		DC Accuracy table, row "Offset Error".
Aperture jitter	t_j	s	typ		Dynamic Performance or Timing table, row "Aperture Jitter".
Power consumption	P	W	typ		Electrical Characteristics, row "Power Dissipation" at the stated rate.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Converter · DAC (converter.dac → device dac)

Simulation pins: **d**, **out**, **gnd**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resolution *	N	bit	typ		Electrical Characteristics, row "Resolution".
Reference / full-scale voltage *	V_REF	V	min, typ, max		Electrical Characteristics, row "Reference Voltage" or "Full-Scale Output".
Settling time *	t_S	s	typ, max		AC Characteristics, row "Settling Time" (to ±0.5 LSB, full-scale step).
Integral non-linearity	INL	LSB	typ, max		Electrical Characteristics, row "Relative Accuracy" / "INL".
Differential non-linearity	DNL	LSB	typ, max		Electrical Characteristics, row "DNL" (guaranteed monotonic if <. 1 LSB).
Glitch impulse	Q_G	Vs	typ		AC Characteristics, row "Digital-to-Analog Glitch Impulse" (nV·s).
Output noise density	e_n	V/rtHz	typ		Electrical Characteristics, row "Output Noise Density" at 1 kHz.
Output resistance	R_OUT	Ohm	typ		Electrical Characteristics, row "Output Impedance" (buffered DACs: DC output resistance).
Output slew rate	SR	V/s	typ		AC Characteristics, row "Slew Rate" (V/µs → V/s).
Gain error	E_G	%	typ, max		DC Accuracy table, row "Gain Error".

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Offset error	E_OS	V	typ, max		DC Accuracy table, row "Offset Error".
Power-supply rejection	PSRR	dB	typ		Electrical Characteristics, row "PSRR".
Supply current	I_Q	A	typ, max		Electrical Characteristics, row "Supply Current".
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.6 Diodes and thyristors

Diode · LED (diode.led → device led)

Simulation pins: **anode**, **cathode**. Curves: Forward voltage vs current, Luminous intensity vs forward current, Relative intensity vs junction temperature, Forward voltage vs junction temperature, Current derating vs ambient temperature.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage *	V_F	V	min, typ, max		Electro-Optical Characteristics table, row "Forward Voltage" (V_F) at I_F = 20 mA (or the stated test current).
Continuous forward current	I_F	A	max		Absolute Maximum Ratings, row "Forward Current" (DC, I_F).
Peak forward current	I_FP	A	max		Absolute Maximum Ratings, row "Peak Forward Current" with its duty cycle and pulse width.
Reverse voltage	V_R	V	max		Absolute Maximum Ratings, row "Reverse Voltage" (often 5 V. LEDs are not meant to block).
Dominant wavelength	λ_d	m	min, typ, max		Electro-Optical Characteristics, row "Dominant Wavelength" (nm, store in metres).
Luminous intensity	I_V	cd	min, typ, max		Electro-Optical Characteristics, row "Luminous Intensity" (mcd) at the test current.
Viewing angle (2θ½)	2θ½	deg	typ		Electro-Optical Characteristics, row "Viewing Angle" or the radiation pattern diagram.
Emission coefficient (model)	n		typ		Not in the datasheet: fit two points of the "Forward Current vs Forward Voltage" graph. Leave empty for 1.9.
Series resistance (model)	R_S	Ohm	typ		Not in the datasheet: slope of the I_F vs V_F graph near the rated current.
Peak wavelength	λ_P	m	typ		Electrical / Optical Characteristics, row "Peak Wavelength" (λ_P). The row above it is usually the dominant wavelength.
Spectral half-width	Δλ	m	typ		Optical Characteristics, row "Spectral Line Half-Width" (Δλ).
Reverse current	I_R	A	max		Electrical Characteristics, row "Reverse Current" at the stated V_R.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Junction capacitance	C_J	F	typ		Electrical Characteristics, row "Capacitance" at V_R = 0 and 1 MHz.
Forward voltage temperature coefficient	ΔV_F/ΔT	V/C	typ		Typical Characteristics, "Forward Voltage vs Temperature" (about -2 to -4 mV/°C).
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diode · Rectifier / signal (diode.rectifier → device diode)

Simulation pins: **anode**, **cathode**. Symbol variants: rectifier, signal. Curves: Forward voltage vs current, Reverse current vs reverse voltage, Junction capacitance vs reverse voltage, Forward voltage vs junction temperature, Current derating vs temperature.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage *	V_F	V	typ, max		Electrical Characteristics table, row "Forward Voltage" (V_F) at the stated I_F. Put that I_F in the conditions.
Repetitive peak reverse voltage	V_RRM	V	max		Absolute Maximum Ratings, row "Peak Repetitive Reverse Voltage" (V_RRM) or "DC Blocking Voltage" (V_R).
Average forward current	I_F(AV)	A	max		Absolute Maximum Ratings, row "Average Rectified Forward Current" (I_F(AV) or I_O).
Surge forward current	I_FSM	A	max		Absolute Maximum Ratings, row "Non-repetitive Peak Forward Surge Current" (I_FSM, 8.3 ms half sine).
Reverse leakage current	I_R	A	max		Electrical Characteristics, row "Reverse Current" (I_R) at the rated V_R, 25 °C (the 100 °C value is much larger).
Junction capacitance	C_J	F	typ		Electrical Characteristics, row "Junction Capacitance" (C_J or C_T) at V_R = 4 V, 1 MHz, or the C vs V_R graph.
Emission coefficient (model)	n		typ		Not in the datasheet: fit from two points of the "Forward Current vs Forward Voltage" graph (n = ΔV_F / (V_T·ln(I2/I1))). Leave empty for the rectifier default.
Series resistance (model)	R_S	Ohm	typ		Not in the datasheet: slope of the V_F vs I_F graph at high current (ΔV_F / ΔI_F).
Reverse recovery time	t_rr	s	max		Electrical Characteristics, row "Reverse Recovery Time" (t_rr) with its I_F / I_R / I_rr test conditions.
Forward voltage at low current	V_F	V	typ		Forward-voltage graph or table at a second, lower current (for example 1 mA). With V_F above it, it sets the emission coefficient.
Reverse leakage at high temperature	I_R	A	max		Electrical Characteristics, row "Reverse Current" at T_A or T_J = 100 to 150 °C.
Reverse recovery charge	Q_rr	C	typ		Electrical Characteristics, row "Reverse Recovery Charge".
Repetitive peak forward current	I_FRM	A	max		Absolute Maximum Ratings, row "Repetitive Peak Forward Current".

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage temperature coefficient	ΔV_F/ΔT	V/C	typ		Typical Characteristics, "Forward Voltage vs Temperature": about -2 mV/°C for silicon junctions (type -2m).
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diode · Schottky (diode.schottky → **device** diode)

Simulation pins: **anode**, **cathode**. Symbol variants: schottky. Curves: Forward voltage vs current, Reverse current vs voltage, Junction capacitance vs reverse voltage, Forward voltage vs junction temperature, Reverse current vs junction temperature, Current derating vs temperature.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage *	V_F	V	typ, max		Electrical Characteristics table, row "Forward Voltage" (V_F) at the stated I_F. Put that I_F in the conditions.
Repetitive peak reverse voltage	V_RRM	V	max		Absolute Maximum Ratings, row "Peak Repetitive Reverse Voltage" (V_RRM) or "DC Blocking Voltage" (V_R).
Average forward current	I_F(AV)	A	max		Absolute Maximum Ratings, row "Average Rectified Forward Current" (I_F(AV) or I_O).
Surge forward current	I_FSM	A	max		Absolute Maximum Ratings, row "Non-repetitive Peak Forward Surge Current" (I_FSM, 8.3 ms half sine).
Reverse leakage current	I_R	A	max		Electrical Characteristics, row "Reverse Current" (I_R) at the rated V_R, 25 °C (the 100 °C value is much larger).
Junction capacitance	C_J	F	typ		Electrical Characteristics, row "Junction Capacitance" (C_J or C_T) at V_R = 4 V, 1 MHz, or the C vs V_R graph.
Emission coefficient (model)	n		typ		Not in the datasheet: fit from two points of the "Forward Current vs Forward Voltage" graph (n = ΔV_F / (V_T·ln(I2/I1))). Leave empty for the Schottky default.
Series resistance (model)	R_S	Ohm	typ		Not in the datasheet: slope of the V_F vs I_F graph at high current (ΔV_F / ΔI_F).
Forward voltage at low current	V_F	V	typ		Forward-voltage graph or table at a second, lower current (for example 1 mA).
Reverse leakage at high temperature	I_R	A	max		Electrical Characteristics, row "Reverse Current" at T_J = 100 to 125 °C. Schottky leakage grows by orders of magnitude with temperature.
Total capacitive charge	Q_c	C	typ		Electrical Characteristics, row "Total Capacitive Charge" (Q_c), the Schottky counterpart of reverse recovery charge.
Repetitive peak forward current	I_FRM	A	max		Absolute Maximum Ratings, row "Repetitive Peak Forward Current".
Forward voltage temperature coefficient	ΔV_F/ΔT	V/C	typ		Typical Characteristics, "Forward Voltage vs Temperature" (about -1 to -2 mV/°C).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diode · TVS (diode.tvs → **device diode**)

Simulation pins: **anode**, **cathode**. Symbol variants: tvs. Curves: Clamping voltage vs peak pulse current, Peak pulse power vs pulse width, Capacitance vs reverse voltage.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Reverse stand-off voltage	V_RWM	V	max		Electrical Characteristics table, column "Reverse Stand-off Voltage" (V_RWM or V_R): the highest normal working voltage.
Breakdown voltage *	V_BR	V	min, typ, max		Electrical Characteristics table, column "Breakdown Voltage" V_BR min / max at the test current I_T (1 mA or 10 mA).
Clamping voltage *	V_C	V	max		Electrical Characteristics table, column "Maximum Clamping Voltage" V_C at I_PP (8/20 µs or 10/1000 µs pulse, say which).
Peak pulse current *	I_PP	A	max		Electrical Characteristics table, column "Peak Pulse Current" I_PP for the same pulse shape as V_C.
Peak pulse power	P_PP	W	max		Absolute Maximum Ratings, row "Peak Pulse Power Dissipation" (P_PPM) for the 10/1000 µs waveform.
Reverse leakage current	I_R	A	max		Electrical Characteristics table, column "I_R" at V_RWM.
Junction capacitance	C_J	F	typ		Electrical Characteristics, row "Capacitance" at 0 V or V_RWM, 1 MHz (matters for data lines).
Breakdown test current	I_T	A	typ		Electrical Characteristics: the current V_BR is measured at (I_T), typically 1 or 10 mA.
Breakdown voltage temperature coefficient	α_VBR	%/C	typ		Electrical Characteristics, row "Temperature Coefficient of V_BR" (about 0.1 %/°C).
Response time	t_resp	s	typ		Features or Electrical Characteristics, row "Response Time" (a few ps to ns for the junction itself).
Bidirectional (1 = yes)	bi		typ		Part number suffix: "CA" or "C" means bidirectional, "A" unidirectional.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diode · Zener (diode.zener → device diode)

Simulation pins: **anode**, **cathode**. Symbol variants: zener. Curves: Zener current vs voltage, Dynamic impedance vs zener current, Zener voltage vs junction temperature, Capacitance vs reverse voltage.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Zener voltage *	V_Z	V	min, typ, max		Electrical Characteristics table, row for your part number, columns V_Z min / nom / max at the test current I_ZT.
Dynamic impedance at I_ZT	Z_ZT	Ohm	max		Electrical Characteristics table, column "Z_ZT" (or r_dif) at I_ZT.
Dynamic impedance at the knee	Z_ZK	Ohm	max		Electrical Characteristics table, column "Z_ZK" at I_ZK (a small current, for example 0.25 mA).
Reverse leakage current	I_R	A	max		Electrical Characteristics table, column "I_R" at the stated V_R below V_Z.
Forward voltage	V_F	V	max		Electrical Characteristics header or footnote: "V_F = 0.9 V max at I_F = 10 mA".
Temperature coefficient of V_Z	S_Z	V/C	typ		Electrical Characteristics table, column "Temperature Coefficient" (mV/K). Store in V/°C.
Maximum zener current	I_ZM	A	max		Usually not listed: I_ZM = P_D / V_Z(max) from the Power Dissipation rating.
Test current	I_ZT	A	typ		Electrical Characteristics: the test current V_Z is quoted at (I_ZT). Put the same value in the V_Z condition.
Knee current	I_ZK	A	typ		Electrical Characteristics, row "Knee Impedance" (Z_ZK) names the knee current I_ZK.
Non-repetitive surge current	I_ZSM	A	max		Absolute Maximum Ratings or the surge table, row "Non-Repetitive Peak Reverse Current".
Junction capacitance	C_J	F	typ		Electrical Characteristics, row "Total Capacitance" (C_T) at the stated V_R and 1 MHz.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diodes · Bridge rectifier (diodes.bridge → device bridge)

Simulation pins: **ac1**, **ac2**, **+**, **–**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage per element *	V_F	V	max	**vf**	Electrical characteristics, "Forward voltage drop per element" at I_F.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
VF test current	I_F	A	typ	**if_test**	Condition of the V_F row.
Average rectified current	I_O	A	max	**irated**	Maximum ratings, "Average rectified output current".
Repetitive reverse voltage	V_RRM	V	max	**bv**	Maximum ratings, "V_RRM".
Surge current	I_FSM	A	max		Maximum ratings, "Peak forward surge current" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diodes · Current-regulating diode (diodes.crd → device crd)

Simulation pins: **anode**, **cathode**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Regulated current *	I_P	A	min, typ, max	**ip**	Electrical characteristics, "Pinch-off current I_P" at V_T.
Knee (limiting) voltage	V_K	V	max	**vk**	Row "Limiting voltage V_L" / "knee voltage".
Peak operating voltage	POV	V	max	**vmax**	Absolute maximum, "Peak operating voltage".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diodes · DIAC / SIDAC / TSS (diodes.diac → device diac)

Simulation pins: **a**, **b**. Symbol variants: diac, sidac, tss.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Breakover voltage *	V_BO	V	min, typ, max	**vbo**	Electrical characteristics, row "Breakover voltage V_BO".
Breakover voltage symmetry / fold-back	ΔV	V	typ	**dv**	Row "Dynamic breakover voltage ΔV" (DIAC).
Holding current	I_H	A	typ	**ih**	Row "Holding current" (SIDAC / TSS).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diodes · Dual diode (diodes.diode2 → device diode2)

Simulation pins: **a1**, **a2**, **k**. Symbol variants: cc, ca, series, dual.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage *	V_F	V	max		Electrical characteristics, "Forward voltage" at I_F (per diode).
VF test current	I_F	A	typ		Condition of the V_F row.
Reverse voltage	V_R	V	max	**bv**	Maximum ratings, "V_RRM" / "V_R".
Reverse recovery time	t_rr	s	max	**tt**	Row "t_rr".
Junction capacitance	C_J	F	max	**cj0**	Row "C_T / C_D" at V_R.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diodes · SCR (diodes.scr → **device** scr)

Simulation pins: **anode**, **cathode**, **gate**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Gate trigger current *	I_GT	A	max	**igt**	Electrical characteristics, row "Gate trigger current I_GT" (max).
Gate trigger voltage	V_GT	V	max	**vgt**	Row "Gate trigger voltage V_GT".
Holding current	I_H	A	max	**ih**	Row "Holding current I_H".
On-state voltage	V_TM	V	max	**vtm**	Row "On-state voltage V_TM" at I_TM.
Repetitive off-state voltage	V_DRM	V	max	**vdrm**	Absolute maximum, "V_DRM / V_RRM".
RMS on-state current	I_T(RMS)	A	max		Absolute maximum, "I_T(RMS)" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Diodes · TRIAC (diodes.triac → **device** triac)

Simulation pins: **mt1**, **mt2**, **gate**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Gate trigger current *	I_GT	A	max	**igt**	Electrical characteristics, "I_GT" per quadrant. Use the largest of Q1–Q3.
Holding current	I_H	A	max	**ih**	Row "Holding current I_H".
On-state voltage	V_TM	V	max	**vtm**	Row "V_TM" at I_TM.
Repetitive off-state voltage	V_DRM	V	max	**vdrm**	Absolute maximum, "V_DRM".
RMS on-state current	I_T(RMS)	A	max		Absolute maximum, "I_T(RMS)" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.7 Displays

Displays · 4-digit 7-segment display (displays.seg7x4 → **device** seg7x4)

Simulation pins: **a**, **b**, **c**, **d**, **e**, **f**, **g**, **dp**, **d1**, **d2**, **d3**, **d4**. Symbol variants: cc, ca.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage *	V_F	V	typ, max	**vf**	Electro-optical characteristics, "Forward voltage" at I_F (per colour / segment).
Test current	I_F	A	typ	**if_test**	Condition of the V_F row (10 mA / 20 mA).
Max forward current	I_F(max)	A	max		Absolute maximum, "Forward current" (W_RATING).
Common anode / cathode *	CA/CC		typ		Internal circuit drawing → variant.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Displays · 7-segment display (displays.seg7 → **device** seg7)

Simulation pins: **a**, **b**, **c**, **d**, **e**, **f**, **g**, **dp**, **com**. Symbol variants: cc, ca.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage *	V_F	V	typ, max	**vf**	Electro-optical characteristics, "Forward voltage" at I_F (per colour / segment).
Test current	I_F	A	typ	**if_test**	Condition of the V_F row (10 mA / 20 mA).
Max forward current	I_F(max)	A	max		Absolute maximum, "Forward current" (W_RATING).
Common anode / cathode *	CA/CC		typ		Part number / internal circuit drawing (…AS = cathode, … BS = anode for 5161) → variant.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Displays · Display module (displays.display → **device** display)

Simulation pins: **VSS**, **VDD**, **V0**, **RS**, **RW**, **E**, **D0**, **D1**, **D2**, **D3**, **D4**, **D5**, **D6**, **D7**, **A**, **K**. Symbol variants: hd44780, oled_i2c, oled_spi, tft_spi, epaper.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply current *	I_DD	A	typ, max	**idd**	Electrical characteristics, "Supply current" (logic, backlight off).
Backlight forward voltage	V_F(BL)	V	typ	**vf_bl**	Backlight characteristics, "Forward voltage" (LED A–K).
Backlight current	I_F(BL)	A	typ		Backlight characteristics, "Forward current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Displays · LED matrix (displays.ledmatrix → **device** ledmatrix)

Simulation pins: **r1**, **r2**, **r3**, **r4**, **r5**, **r6**, **r7**, **r8**, **c1**, **c2**, **c3**, **c4**, **c5**, **c6**, **c7**, **c8**. Symbol variants: row_anode, row_cathode.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage *	V_F	V	typ, max	**vf**	Electro-optical characteristics, "Forward voltage" at I_F (per colour / segment).
Test current	I_F	A	typ	**if_test**	Condition of the V_F row (10 mA / 20 mA).
Max forward current	I_F(max)	A	max		Absolute maximum, "Forward current" (W_RATING).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.8 Electromechanical

Electromechanical · Latching relay (electromech.relay_latch → **device** relay_latch)

Simulation pins: **coil+**, **coil–**, **com**, **no**, **nc**. Symbol variants: single_coil, single_coil_2p, dual_coil, dual_coil_2p.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Nominal coil voltage *	V_coil	V	typ	**vcoil**	Coil Data table, column "Nominal Voltage" (or "Rated Voltage") for your coil code.
Coil resistance *	R_coil	Ohm	typ	**rcoil**	Coil Data table, column "Coil Resistance" (±10 %). Or nominal power P → R = V^2/P.
Set / reset voltage	V_set	V	max	**vpick**	Coil Data table, column "Set Voltage" / "Must Set" (max).
Set time	t_set	s	typ, max	**t_op**	Characteristics table, row "Set Time" (or Operate Time).
Minimum pulse width	t_pulse	s	min	**pulse_min**	Coil Data notes: "Minimum pulse width" / "recommended set pulse" (often 10 ms or 3 × set time).
Contact resistance	R_contact	Ohm	max	**ron**	Contact Data, row "Contact Resistance".
Rated contact current	I_contact	A	max	**imax**	Contact Data, row "Rated Load".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Electromechanical · Relay (electromech.relay → **device** relay)

Simulation pins: **coil+**, **coil–**, **com**, **no**, **nc**. Symbol variants: spdt, spst_no, spst_nc, dpst_no, dpdt, 4pdt, reed.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Nominal coil voltage *	V_coil	V	typ	**vcoil**	Coil Data table, column "Nominal Voltage" (or "Rated Voltage") for your coil code.
Coil resistance *	R_coil	Ohm	typ	**rcoil**	Coil Data table, column "Coil Resistance" (±10 %). Or nominal power P → R = V^2/P.
Must-operate voltage	V_op	V	max	**vpick**	Coil Data table, column "Must Operate" / "Pick-up Voltage" (max, typically 75 % of nominal).
Must-release voltage	V_rel	V	min	**vdrop**	Coil Data table, column "Must Release" / "Drop-out Voltage" (min, typically 10 % of nominal).
Operate time	t_op	s	typ, max	**t_op**	Characteristics table, row "Operate Time" at nominal voltage, without bounce.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Release time	t_rel	s	typ, max	**t_rel**	Characteristics table, row "Release Time" (without coil diode).
Contact resistance	R_contact	Ohm	max	**ron**	Contact Data, row "Initial Contact Resistance" (max, for example 100 mΩ at 6 V 1 A).
Rated contact current	I_contact	A	max	**imax**	Contact Data, row "Rated Load" / "Max Switching Current".
Max switching voltage	V_contact	V	max	**vmax**	Contact Data, row "Max Switching Voltage".
Contact bounce time	t_bounce	s	max	**bounce**	Characteristics table, row "Bounce Time" (often in the operate-time footnote).
Built-in coil diode	D_coil	0/1	typ	**diode**	Ordering code / schematic on page 1: "with diode" (often suffix D) → 1.
Coil power	P_c	W	typ		Specifications, row "Coil Power" (nominal).
Maximum switching current	I_sw	A	max		Contact data, row "Switching Current (max)".
Mechanical life	N_mech		min		Specifications, row "Mechanical Life" (operations).
Electrical life	N_elec		min		Specifications, row "Electrical Life" at the stated load (operations).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Electromechanical · Rotary encoder (electromech.encoder → device encoder)

Simulation pins: **A**, **C**, **B**. Symbol variants: 3pin, 5pin.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Pulses per revolution *	PPR		typ	**ppr**	Specifications: "Resolution" / "Pulses / 360°" (per channel).
Detents	N_det		typ	**detents**	Specifications: "Detent" / "Click" count per revolution.
Contact resistance	R_contact	Ohm	max	**ron**	Electrical: "Contact Resistance" (max).
Chattering / bounce	t_bounce	s	max	**bounce**	Electrical: "Chattering" or "Bounce" (ms at a given speed).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Electromechanical · Solid-state relay (electromech.ssr → device ssr)

Simulation pins: **in+**, **in–**, **out1**, **out2**. Symbol variants: dc, ac, photomos.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
LED operate current *	I_F(on)	A	max	**if_on**	Input characteristics, row "LED Operate Current" / "Trigger current" (max).
Input forward voltage	V_F	V	typ	**vf**	Input characteristics, row "LED Forward Voltage" at I_F = 10 mA.
On resistance	R_on	Ohm	typ, max	**ron**	Output characteristics, row "On-state Resistance" (DC / PhotoMOS).
On-state voltage (AC)	V_TM	V	typ, max	**vtm**	Output characteristics, row "On-state Voltage Drop" (triac SSR).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Load current	I_L	A	max	**imax**	Output ratings, row "Load Current".
Turn-on time	t_on	s	max	**t_on**	Switching characteristics, row "Turn-on Time".
Turn-off time	t_off	s	max	**t_off**	Switching characteristics, row "Turn-off Time".
Holding current (AC)	I_H	A	max	**ih**	Output characteristics, row "Holding Current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Electromechanical · Switch (electromech.sw → **device** sw)

Simulation pins: **com**, **a**. Symbol variants: spst, spdt, dpst, dpdt, push_no, push_nc, tact4, toggle, slide, micro, reed, dip1, dip2, dip3, dip4, dip5, dip6, dip8, dip10, rotary.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Contact resistance	R_contact	Ohm	max	**ron**	Electrical specifications, row "Contact Resistance" (max, initial).
Contact rating, current	I_rating	A	max	**imax**	Electrical specifications, row "Rating" (for example 50 mA 12 VDC).
Contact rating, voltage	V_rating	V	max		Electrical specifications, row "Rating" (voltage part).
Bounce time	t_bounce	s	max	**bounce**	Electrical specifications, row "Bounce Time" (tactile switches: ≤ 5 ms typical).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Positions	N_pos		typ	**positions**	Mechanical specifications: number of positions (rotary / selector switches).
Electrical life	N_ops	cycles	min		Life / Durability row (informational).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.9 Interface

Interface · Analog switch / multiplexer (interface.amux → **device** amux)

Simulation pins: **Y0**, **Y1**, **Y2**, **Y3**, **Y4**, **Y5**, **Y6**, **Y7**, **Z**, **S0**, **S1**, **S2**, **EN**, **VDD**, **VSS**, **VEE**. Symbol variants: 1x8, 1x4, 1x16, 2x4, 3x2, spst_quad, spst, spdt, dual_spdt.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
On resistance *	R_ON	Ohm	typ, max	**ron**	Electrical Characteristics, row "ON Resistance" (R_ON) at the supply you use. Read the typ / max at V_IS = mid supply.
Supply for R_ON	V_DD(R_ON)	V	typ	**ron_vdd**	Condition column of the R_ON row (V_CC / V_DD).
R_ON flatness	R_FLAT	Ohm	typ, max	**ron_flat**	Row "ON-resistance flatness" (ΔR_ON over the signal range). Converted to the relative ron_flat.
Turn-on / switching time	t_ON	s	typ, max	**tsw**	Switching Characteristics, row "t_ON" / "Propagation delay, select to output".
Charge injection	Q_INJ	C	typ	**qinj**	Row "Charge Injection" (pC).
Off capacitance (channel)	C_S(OFF)	F	typ	**cs**	Row "Source OFF capacitance" / "C_IS".

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply range	V_DD	V	min, max		Recommended Operating Conditions, row "Supply Voltage".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Interface · CAN transceiver (interface.can → device can)

Simulation pins: **TXD**, **GND**, **VCC**, **RXD**, **VREF**, **CANL**, **CANH**, **S**. Symbol variants: 5v, 3v3.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Dominant differential voltage	V_OD(D)	V	min, typ, max	**v_dom**	Driver characteristics, "Differential output voltage, dominant".
Receiver threshold	V_TH	V	min, typ, max	**vth**	Receiver, "Differential input threshold".
Loop delay	t_LOOP	s	max	**tpd**	"Loop delay TXD to RXD".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Interface · Digital isolator (interface.isolator → device isolator)

Simulation pins: **VCC1**, **INA**, **INB**, **GND1**, **GND2**, **OUTB**, **OUTA**, **VCC2**. Symbol variants: 2ch, 4ch, i2c.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Propagation delay	t_PD	s	typ, max	**tpd**	Switching characteristics, "Propagation delay".
Supply current per side	I_CC	A	typ, max	**icc**	"Supply current" (side 1 / side 2, DC).
Isolation rating	V_ISO	V	min		"Isolation voltage" (informational).
Common-mode transient immunity	CMTI	V/s	min		Electrical Characteristics, row "CMTI" (kV/µs: 50 kV/µs is 5e10 V/s).
Maximum data rate	DR	Hz	min		Switching Characteristics, row "Data Rate" (Mbps counts as MHz here).
Pulse width distortion	PWD	s	max		Switching Characteristics, row "Pulse Width Distortion".
Channel-to-channel skew	t_sk	s	max		Switching Characteristics, row "Channel-to-Channel Output Skew".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Interface · Integrated circuit (interface.chip → device chip)

Simulation pins: **1**, **2**, **3**, **4**. Symbol variants: generic, eeprom, spi_flash, i2c_dev, spi_dev, usb_uart, rtc.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply current	I_DD	A	typ, max	**idd**	Electrical characteristics, "Supply / operating current" in your mode.
Supply range	V_DD	V	min, max		Recommended operating conditions.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Interface · RS-232 transceiver (interface.rs232 → device rs232)

Simulation pins: **C1+**, **V+**, **C1–**, **C2+**, **C2–**, **V–**, **T2OUT**, **R2IN**, **R2OUT**, **T2IN**, **T1IN**, **R1OUT**, **R1IN**, **T1OUT**, **GND**, **VCC**. Symbol variants: max232, max3232.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Driver output swing	V_O	V	min	**v_pump**	Driver characteristics, "Output voltage swing" (±).
Receiver threshold	V_TH	V	typ	**vth**	Receiver, "Input threshold low / high".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Interface · RS-485 transceiver (interface.rs485 → device rs485)

Simulation pins: **RO**, **nRE**, **DE**, **DI**, **GND**, **A**, **B**, **VCC**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Differential output voltage	V_OD	V	min, typ	**vod**	Driver characteristics, "Differential output voltage" with R_L = 54 Ω.
Receiver threshold	V_TH	V	min, max	**vth**	Receiver characteristics, "Differential input threshold".
Receiver input resistance	R_IN	Ohm	min	**rin**	"Receiver input resistance" (12 kΩ = 1 unit load).
Propagation delay	t_PD	s	typ, max	**tpd**	"Driver / receiver propagation delay".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.10 Logic and digital

Digital · Microcontroller (ctrl block) (digital.mcu → device ctrl)

Simulation pins: **ain**, **out**, **gnd**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply / output high voltage *	V_DD	V	min, typ, max		Recommended Operating Conditions, row "Supply Voltage" (V_DD). Outputs swing to this level (vhi in the ctrl block).
ADC resolution *	N	bit	typ		ADC Characteristics table, row "Resolution" (bits). Use the effective value if you will oversample.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Sample / control-loop rate *	f_S	Hz	max		ADC Characteristics, row "Sampling Rate" or "Conversion Time" (f_S = 1 / t_CONV). The ctrl block runs step() at this rate.
ADC reference voltage *	V_REF	V	min, typ, max		ADC Characteristics, row "Reference Voltage" (V_REF+, internal reference or V_DDA): full-scale input.
ADC input channels	n_ch		typ		Pinout / ADC overview: number of analog input channels.
ADC integral non-linearity	INL	LSB	typ, max		ADC Characteristics, row "Integral Linearity Error" (±LSB).
ADC input impedance (sampling)	R_AIN	Ohm	min		ADC Characteristics, rows "R_AIN" / "C_ADC" (or the max source impedance table). The ctrl block models 1 MΩ.
Output drive current	I_OH / I_OL	A	max		I/O Port Characteristics, rows I_OH / I_OL at the V_OH / V_OL limits.
Output resistance	R_OUT	Ohm	typ		Not listed directly: R_OUT ≈ (V_DD − V_OH) / I_OH from the I/O Port Characteristics table.
PWM resolution	N_PWM	bit	typ		Timer / PWM chapter: counter width (16-bit timer) or the high-resolution PWM step.
Timer clock	f_TIM	Hz	max		Clock tree / Timer characteristics: timer input clock. PWM resolution = log2(f_TIM / f_PWM).
Output edge time	t_r	s	typ, max		I/O AC Characteristics, rows t_r / t_f at the selected speed setting and load.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Logic · 74xx / 4000 IC (logic.logic → device logic)

Simulation pins: **1A**, **1Y**, **2A**, **2Y**, **3A**, **3Y**, **GND**, **4Y**, **4A**, **5Y**, **5A**, **6Y**, **6A**, **VCC**. Symbol variants: 14, 32, 74, 86, 123, 125, 138, 151, 157, 161, 164, 165, 244, 245, 573, 574, 595, 4017, 4040, 4060, 4511, 00, 08, 02, 04, 1g00, 1g08, 1g32, 1g86, 1g04, 1g14, 1g125.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Logic family *	family		typ	**family**	Part-number letters: HC, HCT, AHC, LVC, LS, CD4000 → family (sets thresholds, drive, tpd).
Supply voltage	V_CC	V	min, typ, max	**vcc**	Recommended operating conditions, "Supply voltage".
Propagation delay	t_PD	s	typ, max	**tpd**	Switching characteristics, "t_PLH / t_PHL" at your V_CC and C_L.
Output drive current	I_OH / I_OL	A	typ		"High / low-level output current" (fits rout_h / rout_l).
Quiescent current	I_CC	A	max		"Quiescent supply current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Logic · Gate (logic.gate → device nand)

Simulation pins: **in1**, **in2**, **out**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply voltage *	V_CC	V	min, typ, max		Recommended Operating Conditions, row "Supply Voltage" (V_CC). The live model uses typ as the logic high level.
Propagation delay *	t_PD	s	typ, max		Switching Characteristics, rows t_PLH / t_PHL at your V_CC and C_L = 15 or 50 pF. Use the larger.
High-level input voltage	V_IH	V	min		Recommended Operating Conditions / DC Characteristics, row "High-Level Input Voltage" at your V_CC.
Low-level input voltage	V_IL	V	max		Same table, row "Low-Level Input Voltage".
High-level output current	I_OH	A	max		Recommended Operating Conditions, row "High-Level Output Current" (magnitude).
Low-level output current	I_OL	A	max		Recommended Operating Conditions, row "Low-Level Output Current".
Quiescent supply current	I_CC	A	max		DC Characteristics, row "Supply Current" (static, inputs at a rail).
Input capacitance	C_I	F	typ		DC / Switching Characteristics, row "Input Capacitance" (C_I).
High-level output voltage	V_OH	V	min		Electrical Characteristics, row "High-Level Output Voltage" at the stated I_OH.
Low-level output voltage	V_OL	V	max		Electrical Characteristics, row "Low-Level Output Voltage" at the stated I_OL.
Output transition time	t_t	s	typ, max		Switching Characteristics, row "Transition Time" (t_t, t_r or t_f).
Input leakage current	I_I	A	max		Electrical Characteristics, row "Input Current" (I_I).
Off-state output current	I_OZ	A	max		Electrical Characteristics, row "Off-State Output Current" (three-state outputs).
Gates per package	n		typ		Title and pinout: "quad 2-input" = 4.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Logic · Level translator (logic.lvlshift → device lvlshift)

Simulation pins: **VCCA**, **VCCB**, **OE**, **GND**, **A1**, **A2**, **B1**, **B2**. Symbol variants: txs2, txs8, 1t45, 2t45.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Propagation delay	t_PD	s	typ, max	**tpd**	Switching characteristics at your VCCA / VCCB pair.
Internal pull-up (TXS)	R_PU	Ohm	typ	**r_pu**	Auto-direction parts: "Integrated pull-up resistors" (TXS0108: 10 kΩ / 4 kΩ).
VCCA range	V_CCA	V	min, max		Recommended operating conditions.
VCCB range	V_CCB	V	min, max		Recommended operating conditions.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.11 Microcontrollers and programmable

MCU · Microcontroller (pin level) (mcu.mcu → device mcu)

Simulation pins: **VDD**, **GND**, **PA0**, **PA1**, **PB0**, **PB1**. Symbol variants: generic, atmega328p_tqfp32, attiny85_dip8, stm32f103c8_lqfp48.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply voltage	V_DD	V	min, typ, max	**vdd**	Recommended operating conditions, "V_DD".
Run current	I_DD	A	typ	**idd**	Electrical characteristics, "Supply current, run mode" at your clock.
GPIO output resistance	R_OUT	Ohm	typ		I/O characteristics: V_OH / V_OL at I_OH / I_OL → (V_DD − V_OH) / I_OH.
ADC resolution	N	bits	typ		ADC characteristics, "Resolution" (for pins mapped as ain).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.12 Mixed-signal

Mixed-signal · Digital potentiometer (mixed.digipot → device digipot)

Simulation pins: **nINC**, **U_nD**, **VH**, **VSS**, **VW**, **VL**, **nCS**, **VCC**. Symbol variants: updown, spi, i2c.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
End-to-end resistance *	R_AB	Ohm	typ	**r**	Ordering option, "Resistance" (X9C103 = 10 kΩ).
Number of taps *	N		typ	**steps**	"Resolution" / "Taps" (X9C: 100, MCP4131: 129).
Wiper resistance	R_W	Ohm	typ, max	**r_w**	"Wiper resistance".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.13 Motors and actuators

Motors · BLDC motor (motors.bldc → device bldc)

Simulation pins: **u**, **v**, **w**. Symbol variants: sensorless, hall.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Velocity constant *	Kv	rpm/V	typ	**kv**	Specification, "KV".
Phase resistance *	R_ph	Ohm	typ	**r_phase**	"Internal resistance" (line-to-line / 2).
Pole count	p		typ	**poles**	"Configuration" (for example 12N14P → 14 poles).
Phase inductance	L_ph	H	typ	**l_phase**	"Inductance" (line-to-line / 2).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Motors · DC motor (motors.dcmotor → device dcmotor)

Simulation pins: **+**, **–**. Symbol variants: brushed, fan, vibration, gear.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Rated voltage *	V_N	V	typ	**v_rated**	Specification table, "Rated voltage".
No-load speed *	n_0	rpm	typ	**rpm_noload**	Specification table, "No-load speed".
No-load current	I_0	A	typ	**i_noload**	Specification table, "No-load current".
Stall current *	I_S	A	typ	**i_stall**	Specification table, "Stall current" (or rated voltage / terminal resistance).
Stall torque	T_S	N·m	typ		Specification table, "Stall torque" (mN·m, g·cm × 9.81e-5).
Terminal resistance	R	Ohm	typ		"Terminal resistance" (overrides V/I_stall).
Terminal inductance	L	H	typ	**l**	"Terminal inductance".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Rotor inertia	J	kg·m^2	typ		"Rotor inertia" (g·cm^2 × 1e-7).
Gear ratio	i		typ	**gear**	Gear motors: "Reduction ratio".
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Motors · Dual H-bridge driver (motors.hbridge2 → device hbridge2)

Simulation pins: **AIN1**, **AIN2**, **BIN1**, **BIN2**, **AOUT1**, **AOUT2**, **BOUT1**, **BOUT2**, **VM**, **GND**, **nSLEEP**.
Symbol variants: in_in, pwm_dir.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Output on resistance (HS + LS) *	R_DS(on)	Ohm	typ, max	**ron**	Electrical characteristics, "HS + LS on resistance".
Output current / limit	I_OUT	A	max	**ilim**	"Continuous output current" or "Overcurrent protection".
Motor supply range	V_M	V	min, max		Recommended operating conditions, "VM".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Motors · Peltier module (motors.peltier → device peltier)

Simulation pins: **+**, **–**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Max current *	I_max	A	max		Specification, "I_max".
Max voltage *	V_max	V	max	**r**	Specification, "V_max" (r ≈ V_max / I_max at ΔT = 0).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Max temperature difference	ΔT_max	K	typ	**seebeck**	Specification, "ΔT_max" (fits the Seebeck coefficient).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Motors · RC servo (motors.servo → device servo)

Simulation pins: **sig**, **vcc**, **gnd**. Symbol variants: analog, digital, continuous.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Travel *	θ	deg	typ	**range**	Specification, "Operating angle" / "Travel".
Operating speed	ω	deg/s	typ	**speed**	Specification, "Speed" (s / 60° → 60 / value).
Pulse width at 0°	PW_min	s	typ	**pw_min**	"Pulse width range" (for example 500–2500 µs or 1000–2000 µs).
Pulse width at full travel	PW_max	s	typ	**pw_max**	Same row, upper end.
Stall current	I_stall	A	max	**i_stall**	"Stall current".
Idle current	I_idle	A	typ	**i_idle**	"Idle / standby current".
Operating voltage (min)	V_min	V	min	**v_min**	"Operating voltage".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Motors · Solenoid (motors.solenoid → device solenoid)

Simulation pins: **+**, **–**. Symbol variants: pull, push, valve, lock.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Rated voltage *	V_N	V	typ	**v_rated**	Specification, "Rated voltage".

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Coil resistance *	R	Ohm	typ	**r**	Specification, "Coil resistance".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Stroke	s	m	typ	**stroke**	Specification, "Stroke" (mm).
Holding force	F	N	typ		Force vs stroke graph at rated voltage (informational. Fits I_in).
Duty cycle	ED	%	max		"Duty cycle" (informational, W_RATING for long energisation).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Motors · Stepper driver (motors.stepdrv → device stepdrv)

Simulation pins: **EN**, **MS1**, **MS2**, **MS3**, **RST**, **SLP**, **STEP**, **DIR**, **VMOT**, **GND**, **1A**, **1B**, **2A**, **2B**, **VDD**, **VREF**. Symbol variants: a4988, drv8825.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Sense resistor *	R_S	Ohm	typ	**rsense**	Module / board: the sense resistors (R100 = 0.1 Ω, R068 = 0.068 Ω).
Current limit	I_TRIP	A	typ	**ilim**	From VREF: A4988 I = VREF / (8 · R_S), DRV8825 I = VREF / (5 · R_S).
Output on resistance	R_DS(on)	Ohm	typ, max	**ron**	"Output on resistance" (source + sink).
Fixed off time	t_OFF	s	typ	**toff**	"Fixed off-time" (A4988 ~20 µs).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Motors · Stepper motor (motors.stepper → device stepper)

Simulation pins: **a+**, **a–**, **b+**, **b–**. Symbol variants: bipolar, unipolar6, unipolar5.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Step angle *	θ_step	deg	typ	**steps**	Specification table, "Step angle" (1.8° → 200 steps).
Rated current per phase *	I_N	A	typ	**i_rated**	Specification table, "Rated current" / "Current per phase".
Phase resistance *	R_ph	Ohm	typ	**r_phase**	Specification table, "Phase resistance".
Phase inductance	L_ph	H	typ	**l_phase**	Specification table, "Phase inductance".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Holding torque	T_H	N·m	typ	**t_hold**	Specification table, "Holding torque" (kg·cm × 0.098).
Detent torque	T_D	N·m	typ	**t_detent**	"Detent torque".
Rotor inertia	J	kg·m²	typ	**j**	"Rotor inertia" (g·cm² × 1e-7).
Gear ratio	i		typ	**gear**	Geared steppers (28BYJ-48: 63.68).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.14 Optoelectronics

Optoelectronics · Addressable LED (opto.ws2812 → device ws2812)

Simulation pins: **VDD**, **DOUT**, **GND**, **DIN**. Symbol variants: ws2812b, sk6812_rgbw.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
LED current per colour	I_LED	A	typ	**i_led**	Electrical characteristics, "LED output current" per channel at full brightness.
T0H (0 bit high time)	T0H	s	min, typ, max		Data transfer time table, "T0H".
T1H (1 bit high time)	T1H	s	min, typ, max	**t_th**	Table, "T1H" (threshold t_th = (T0H + T1H) / 2).
Reset time	RES	s	min	**t_reset**	Table, "RES / Treset".
Quiescent supply current	I_DD	A	typ	**idd**	"Supply current" with LEDs off.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Optoelectronics · IR receiver module (opto.irrx → device irrx)

Simulation pins: **OUT**, **GND**, **VS**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Carrier frequency *	f_0	Hz	typ	**f0**	Ordering table, "Carrier frequency" (36 / 38 / 40 / 56 kHz).
Supply voltage	V_S	V	min, max		Recommended operating conditions.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Minimum burst length	t_pi	cycles	min	**n_min**	"Minimum burst length" (cycles).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Optoelectronics · Lamp (opto.lamp → device lamp)

Simulation pins: **a**, **b**. Symbol variants: lamp, neon.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Rated voltage *	V_N	V	typ	**v_rated**	Lamp data, "Voltage".
Rated power	P_N	W	typ	**p_rated**	Lamp data, "Wattage" (or I × V).
Striking voltage (neon)	V_S	V	max	**v_strike**	Neon lamps: "Striking voltage".
Maintaining voltage (neon)	V_M	V	typ	**v_maint**	Neon lamps: "Maintaining voltage".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Optoelectronics · LED bar graph (opto.led_bar → device led_bar)

Simulation pins: **a1**, **k1**, **a2**, **k2**, **a3**, **k3**, **a4**, **k4**. Symbol variants: 4, 8, 10.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Forward voltage *	V_F	V	typ, max	**vf**	Electro-optical characteristics, "Forward voltage" at I_F (per colour / segment).
Test current	I_F	A	typ	**if_test**	Condition of the V_F row (10 mA / 20 mA).
Max forward current	I_F(max)	A	max		Absolute maximum, "Forward current" (W_RATING).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Optoelectronics · Optocoupler (opto.opto → device opto)

Simulation pins: **anode**, **cathode**, **collector**, **emitter**. Symbol variants: transistor, transistor_b, darlington, triac, triac_zc, logic, slot, reflective.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Current transfer ratio *	CTR	%	min, typ, max	**ctr**	Transfer characteristics, row "Current Transfer Ratio" at I_F and V_CE given in the conditions (rank letter: A 80-160 %, B 130-260 %…).
CTR test current	I_F	A	typ	**if_test**	Condition column of the CTR row (typically 5 mA or 10 mA).
LED forward voltage	V_F	V	typ, max	**vf**	Input characteristics, row "Forward Voltage" at I_F = 10 mA / 20 mA.
Collector-emitter saturation	V_CE(sat)	V	max		Transfer characteristics, row "Collector-emitter saturation voltage" (informational. Fit through bf).
Rise / fall time	t_r	s	typ	**tr**	Switching characteristics, rows "Rise time" / "Fall time" at the given R_L.
Collector-emitter voltage	BV_CEO	V	min	**bvceo**	Absolute Maximum Ratings, row "Collector-emitter voltage".
Triac trigger current	I_FT	A	max	**ift**	Triac optos (MOC30xx): row "LED Trigger Current" (max).
Triac holding current	I_H	A	typ	**ih**	Triac optos: row "Holding Current".
Isolation voltage	V_ISO	V	min		Isolation characteristics, row "Isolation voltage" (Vrms, 1 min. Informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Optoelectronics · Photodiode (opto.photodiode → device photodiode)

Simulation pins: **anode**, **cathode**. Symbol variants: pin, ir, uv.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Light current *	I_L	A	typ	**s_lux**	Electro-optical characteristics, "Reverse light current" at E_v (lx) or E_e (mW/cm²). Divide by the illuminance → s_lux.
Test illuminance	E_v	lx	typ		Condition of the light-current row (convert mW/cm² at 870 nm: × ~600 lx).
Dark current	I_D	A	typ, max	**i_dark**	"Reverse dark current" at V_R.
Junction capacitance	C_D	F	typ	**cj0**	"Diode capacitance" at V_R = 0 / 3 V.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Optoelectronics · Phototransistor (opto.phototr → **device** phototr)

Simulation pins: **collector**, **emitter**. Symbol variants: 2pin, 3pin.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Collector light current *	I_C(on)	A	min, typ	**s_lux**	Electro-optical characteristics, "Collector light current" at E_e / E_v, V_CE = 5 V. Divide by the illuminance → s_lux.
Test illuminance	E_v	lx	typ		Condition of that row (1 mW/cm² at 940 nm ≈ 700 lx equivalent).
Dark current	I_CEO	A	max	**i_dark**	"Collector dark current".
Rise / fall time	t_r	s	typ	**tr**	"Rise time / fall time" at R_L.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Optoelectronics · RGB LED (opto.led_rgb → **device** led_rgb)

Simulation pins: **r**, **g**, **b**, **com**. Symbol variants: cc, ca.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Red forward voltage *	V_F(R)	V	typ, max	**vf_r**	Electro-optical table, red column, "V_F" at 20 mA.
Green forward voltage *	V_F(G)	V	typ, max	**vf_g**	Green column.
Blue forward voltage *	V_F(B)	V	typ, max	**vf_b**	Blue column.
Test current	I_F	A	typ	**if_test**	Condition of the V_F rows.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.15 Passives

Passive · Capacitor (passive.capacitor → **device** cap)

Simulation pins: **a**, **b**. Curves: ESR vs frequency, Impedance vs frequency, Capacitance change vs DC bias, Capacitance change vs temperature.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Capacitance *	C	F	min, typ, max		Part-number decoder or Ratings table, "Capacitance" (code 106 = 10 µF). For MLCCs check the DC-bias curve at your working voltage.
Tolerance	±tol	%	typ		Ordering code tolerance letter (K = 10 %, M = 20 %) or the Specifications table.
Rated voltage	V_R	V	max		Ratings table, column "Rated Voltage" (WV or V_R). Do not use the surge voltage.
Equivalent series resistance	ESR	Ohm	typ, max		Electrolytics: Standard Ratings table, column "ESR" or "Impedance" at 100 kHz, 20 °C. MLCC: the ESR vs frequency graph at the switching frequency.
Rated ripple current	I_ripple	A	max		Standard Ratings table, column "Rated Ripple Current" (mA rms) at 105 °C, 100 kHz. Apply the frequency multiplier table for other frequencies.
Leakage current	I_leak	A	max		Specifications table, row "Leakage Current" (often a formula like 0.01CV or 3 µA, after 2 minutes at rated voltage).
Equivalent series inductance	ESL	H	typ		Impedance vs frequency graph: ESL = 1 / ((2π f_res)² C) from the self-resonant dip, or a stated ESL row.
Dissipation factor	tan δ		max		Specifications table, row "Dissipation Factor (tan δ)" at 120 Hz.
Endurance (load life)	L_life	h	min		Specifications, row "Endurance" or "Load Life": hours at the maximum category temperature.
Capacitance change over temperature	ΔC/C	%	typ, max		Dielectric code: X7R is ±15 %, X5R ±15 %, C0G ±0.3 % (30 ppm/°C), Y5V +22/−82 %. Or the "Capacitance vs Temperature" graph.
Self-resonant frequency	f_SRF	Hz	typ		Impedance vs frequency graph: the frequency of the lowest impedance, or the SRF row.
Insulation resistance	IR	Ohm	min		Electrical Specifications, row "Insulation Resistance" (or a time constant R·C in Ω·F).
Operating temperature range	T_op	C	min, max		Features, row "Operating Temperature Range" (minimum and maximum).
Aging rate	aging	%	typ		Electrical Specifications, row "Aging Rate" (percent per decade-hour, class II ceramics).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Common-mode choke (passives.cmc → **device** cmc)

Simulation pins: **a1**, **b1**, **a2**, **b2**. Curves: Common-mode impedance vs frequency, Differential impedance vs frequency.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Inductance per winding *	L	H	min, typ	**l**	Ordering table, "Inductance" (per line, at 10 kHz / 100 kHz).
DC resistance per line	R_DC	Ohm	max	**dcr**	Ordering table, "DC Resistance".
Rated current	I_R	A	max	**irated**	Ordering table, "Rated Current".
Leakage inductance	L_leak	H	typ	**k**	"Leakage inductance" (→ k = 1 − L_leak / L).
Common-mode impedance at 100 MHz	Z_CM	Ohm	typ		Impedance graph or table (informational for USB / CAN chokes).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Dual potentiometer (passives.pot_dual → device pot_dual)

Simulation pins: **a1**, **b1**, **w1**, **a2**, **b2**, **w2**. Symbol variants: lin, log.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Total resistance *	R	Ohm	typ	**r**	Ordering code, "Resistance" (B103 = 10 kΩ linear, A = log).
Taper	taper		typ		Ordering code taper letter: B linear, A audio (log), C reverse log → variant.
Tolerance	±tol	%	typ		"Total resistance tolerance".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Power rating	P	W	max		"Rated power".
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Feed-through capacitor / EMI filter (passives.cap3 → device cap3)

Simulation pins: **in**, **out**, **gnd**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Capacitance *	C	F	typ	**c**	Ordering table, "Capacitance".
Rated current	I_R	A	max		Ordering table, "Rated current" (through conductor).
DC resistance	R_DC	Ohm	max	**rdc**	Ordering table, "DC resistance".
Rated voltage	V_R	V	max		Ordering table, "Rated voltage".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Ferrite bead (passives.ferrite → device ferrite)

Simulation pins: **a**, **b**. Curves: Impedance vs frequency, Impedance vs DC bias current.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Impedance at 100 MHz *	Z100	Ohm	typ	**z100**	Ordering table, column "Impedance at 100 MHz" (±25 %).
DC resistance	R_DC	Ohm	max	**dcr**	Ordering table, column "DC Resistance" (max).
Rated current	I_R	A	max	**irated**	Ordering table, column "Rated Current".
Impedance peak frequency	f_peak	Hz	typ	**f_srf**	Impedance vs frequency graph: frequency of the |Z| peak.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Inductor (passive.inductor → device ind)

Simulation pins: **a**, **b**. Curves: Inductance vs DC current, Inductance vs frequency, Quality factor vs frequency, Impedance vs frequency, DC resistance vs temperature, Inductance change vs temperature.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Inductance *	L	H	min, typ, max		Electrical Specifications table, column "Inductance" (L0 at 0 A, test frequency 100 kHz or 1 MHz).
Tolerance	±tol	%	typ		Table header or footnote, "Inductance tolerance" (typically ±20 %).
DC resistance	DCR	Ohm	typ, max		Electrical Specifications table, column "DCR" (typ and max, mΩ, at 20 °C).
Saturation current	I_sat	A	typ, max		Electrical Specifications table, column "I_sat": the current where L drops by 10 %, 20 % or 30 % (read the footnote for which).
Rated (heating) current	I_rms	A	max		Electrical Specifications table, column "I_rms" or "I_rated": current for a 40 K temperature rise.
Self-resonant frequency	SRF	Hz	min, typ		Electrical Specifications table, column "SRF" (MHz). Stay well below it.
Saturation current at 30 % drop	I_sat(30)	A	typ, max		Electrical Specifications: the current where L has fallen by 30 % (I_sat). The 10 % and 20 % rows are the next fields.
Current at 10 % inductance drop	I_sat(10)	A	typ, max		Electrical Specifications, row "I_sat" for a 10 % drop (some vendors call it I_DC1).
Temperature rise at rated current	ΔT	C	typ		Electrical Specifications, the rise the rated I_rms causes (usually 40 °C).
Quality factor	Q		typ		Electrical Specifications, row "Q" at the stated frequency (RF parts).
Parasitic winding capacitance	C_p	F	typ		Often implied by the self-resonant frequency ($C_p = 1 / ((2\pi \cdot SRF)^2 \cdot L)$). A few pF to nF.
Inductance temperature coefficient	TCL	%/C	typ		Electrical Specifications or the L vs temperature graph (%/°C).
Operating temperature range	T_op	C	min, max		Features, row "Operating Temperature Range".
Shielded (1 = yes)	shield		typ		Product title or construction drawing: "shielded", "semi-shielded" or "unshielded".
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Resistor (passive.resistor → device res)

Simulation pins: **a**, **b**. Curves: Power derating, Impedance vs frequency.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resistance *	R	Ohm	typ		Ordering information or part-number decoder: the resistance code (for example 4K7 or 472 = 4.7 kΩ).
Tolerance	±tol	%	typ		Ordering information, tolerance letter (F = 1 %, J = 5 %), or the Electrical Specifications table.
Power rating	P_R	W	max		Electrical Specifications table, row "Power Rating at 70 °C" (check the derating curve above that temperature).
Maximum working voltage	V_max	V	max		Electrical Specifications table, row "Maximum Working Voltage" or "Limiting Element Voltage".
Temperature coefficient	TCR	ppm/C	min, max		Electrical Specifications table, row "Temperature Coefficient" (ppm/°C), per resistance range.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Parasitic inductance	L_s	H	typ		Rarely in the table. Look for "High Frequency Performance" or an impedance graph, else leave empty.
Voltage coefficient	VCR	ppm/V	max		Electrical Specifications, row "Voltage Coefficient of Resistance" (precision and thick-film parts).
Short-time overload voltage	V_ov	V	max		Electrical Specifications, row "Overload Voltage" (usually 2.5 times the rated voltage for 5 s).
Rated ambient temperature	T_R	C	typ		Electrical Specifications, the temperature the power rating holds up to (usually 70 °C).
Current noise index	NI	dB	typ		Electrical Specifications, row "Current Noise" (dB, µV/V per decade).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Resistor network (passives.rnet → device rnet)

Simulation pins: **a1**, **b1**, **a2**, **b2**, **a3**, **b3**, **a4**, **b4**. Symbol variants: iso4, iso2, iso8, bus4, bus8.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resistance *	R	Ohm	typ	**r**	Part-number decoder (for example 4D02WGJ0103 → 10 kΩ).
Number of resistors *	N		typ		Circuit diagram on page 1 (isolated / bussed and count) → variant.
Tolerance	±tol	%	typ	**tol**	Tolerance letter (F 1 %, J 5 %).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Transformer (passive.transformer → device xfmr)

Simulation pins: **p1**, **p2**, **s1**, **s2**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Primary inductance *	L_P	H	min, typ, max		Electrical Specifications table, row "Primary Inductance" (open-circuit, at the stated frequency and level).
Turns ratio (secondary / primary) *	N_S/N_P		typ		Electrical Specifications, row "Turns Ratio". Write it as secondary over primary (1:0.1 for a 10:1 step-down).
Coupling coefficient	k		typ		Not usually listed: k = sqrt(1 – L_leak / L_P) from rows "Leakage Inductance" and "Primary Inductance".
Leakage inductance	L_lk	H	max		Electrical Specifications, row "Leakage Inductance" (measured with the secondary shorted).
Primary DC resistance	DCR_P	Ohm	typ, max		Electrical Specifications, row "DCR Primary" or "Winding Resistance".
Secondary DC resistance	DCR_S	Ohm	typ, max		Electrical Specifications, row "DCR Secondary".
Isolation voltage	V_iso	V	min		Electrical Specifications, row "Hipot" or "Isolation" (Vrms for 1 minute).
Primary saturation current	I_sat	A	max		Row "Saturation Current" or "Peak Current", if given (flyback transformers).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Passive · Transformer (multi-winding) (passives.xfmr_multi → device xfmr_multi)

Simulation pins: **p1**, **p2**, **s1**, **sct**, **s2**. Symbol variants: ct, ct_pri, dual, flyback, current.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Primary inductance *	L_P	H	min, typ	**lp**	Electrical specifications, "Primary inductance" (at f, level).
Turns ratio (Np:Ns) *	n		typ	**ratio**	Electrical specifications, "Turns ratio" (Ns / Np as the ratio param).
Second winding ratio	n2		typ	**ratio2**	Dual / flyback aux winding turns ratio.
Leakage inductance	L_leak	H	max	**k**	"Leakage inductance" (secondaries shorted) → k.
Primary DCR	R_P	Ohm	max	**rp**	"DC resistance, primary".
Secondary DCR	R_S	Ohm	max	**rs**	"DC resistance, secondary".
Current transformer turns	N		typ	**n**	Current-sense transformers: "Turns ratio 1:N".
Isolation voltage	V_ISO	V	min		"Hi-pot / isolation" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.16 Power management

Controller · Battery charger (controller.charger → device chgctl)

Simulation pins: **vin**, **bat**, **gnd**, **cs**, **gate**. Symbol variants: cccv, float.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Float / regulation voltage *	V_FLOAT	V	min, typ, max		Electrical Characteristics, row "Regulated Output (Float) Voltage" / "V_BAT(REG)" for your cell count option.
Fast-charge current (as programmed) *	I_CHG	A	min, typ, max		Programming section: I_CHG formula with your R_PROG / R_SENSE (for example I = V_CS / R_SENSE or 1000 V / R_PROG).
Termination current	I_TERM	A	min, typ, max		Electrical Characteristics, row "Termination Current Threshold" (often C/10 of I_CHG).
Pre-charge current	I_PRE	A	min, typ, max		Electrical Characteristics, row "Pre-charge / Trickle Current".
Pre-charge threshold	V_PRE	V	min, typ, max		Electrical Characteristics, row "Pre-charge Threshold Voltage".
Input voltage range	V_IN	V	min, max		Recommended Operating Conditions, row "Input Voltage".
Current-sense threshold	V_CS	V	min, typ, max		Electrical Characteristics, row "Current Sense Voltage" (switching chargers with an external shunt).
Switching frequency	f_SW	Hz	typ		Switching chargers: row "Oscillator Frequency". Empty for linear chargers.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Safety timer	t_TIMER	s	typ		Timer section, row "Charge Safety Timer".
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Controller · LED driver (controller.led → **device** ledctl)

Simulation pins: **vin**, **gnd**, **cs**, **gate**, **dim**. Symbol variants: buck_cc, boost_cc.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Current-sense regulation voltage *	V_CS	V	min, typ, max		Electrical Characteristics, row "Current Sense Threshold" / "V_CS": I_LED = V_CS / R_SENSE (average or peak, say which in the note).
Switching frequency *	f_SW	Hz	min, typ, max		Oscillator section, row "Switching Frequency" (or the hysteretic frequency formula).
Input voltage range	V_IN	V	min, max		Recommended Operating Conditions, row "Input Voltage".
Maximum PWM dimming frequency	f_DIM	Hz	max		Dimming section, row "PWM Dimming Frequency" or minimum DIM pulse width.
DIM pin threshold	V_DIM	V	typ		Dimming section, row "DIM High / Low Threshold".
Operating supply current	I_Q	A	typ, max		Electrical Characteristics, row "Quiescent Current".
Gate drive source current	I_SOURCE	A	typ		Gate Driver section, row "Source Current".
Gate drive sink current	I_SINK	A	typ		Gate Driver section, row "Sink Current".
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Controller · PWM (DC-DC / PFC) (controller.pwm → **device** pwmctl)

Simulation pins: **vin**, **gnd**, **fb**, **comp**, **cs**, **gate**, **ss**, **en**, **rt**. Symbol variants: vmode, cmode, hyst, cot, pfc_tm, llc, qr.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Feedback reference voltage *	V_FB	V	min, typ, max		Electrical Characteristics, row "Feedback Voltage" / "Reference Voltage" / "Error Amplifier Reference" (the FB pin regulation point).
Switching frequency *	f_SW	Hz	min, typ, max		Oscillator section: row "Frequency" at your RT / CT values, or the f_SW vs R_T graph.
Maximum duty cycle *	D_MAX		min, typ		Oscillator / PWM section, row "Maximum Duty Cycle" (store 0.95 for 95 %. 0.5 for single-output push-pull parts).
Minimum duty cycle	D_MIN		max		PWM section, row "Minimum Duty Cycle" or minimum on-time × f_SW.
Error amplifier open-loop gain	A_VOL	dB	min, typ		Error Amplifier section, row "Open-Loop Voltage Gain" (voltage-output error amps).
Error amplifier transconductance	g_m	S	min, typ, max		Error Amplifier section, row "Transconductance" (gm-type error amps, µmho = µS).
Error amplifier bandwidth	GBW	Hz	typ		Error Amplifier section, row "Unity Gain Bandwidth".
Current-sense limit threshold	V_CS(max)	V	min, typ, max		Current Sense section, row "Maximum Input Signal" / "Current Limit Threshold" (V at the CS pin).
Current-sense gain	A_CS	V/V	typ		Current Sense section, row "Gain" (for example 3 V/V on UC3843: COMP-to-CS ratio).
Slope compensation	S_e	V/s	typ		Current-mode parts: row "Slope Compensation" (mV/µs or µA through R_SLOPE). Store V/s.
Soft-start time	t_SS	s	typ		Soft-Start section: internal t_SS, or t_SS = C_SS · V / I_SS with the stated charge current.
UVLO start threshold	V_ON	V	min, typ, max		Under-Voltage Lockout section, row "Start Threshold" (rising V_CC / V_IN).
UVLO stop threshold	V_OFF	V	min, typ, max		Under-Voltage Lockout section, row "Minimum Operating Voltage" (falling).
Gate drive source current	I_SOURCE	A	typ		Output section, row "Peak Source Current" (or output resistance R_OH: I ≈ V_CC / R_OH).
Gate drive sink current	I_SINK	A	typ		Output section, row "Peak Sink Current".
Dead time	t_D	s	typ		Synchronous / push-pull parts: row "Dead Time" or "Shoot-Through Delay".
Leading-edge blanking	t_LEB	s	typ		Current Sense section, row "Leading Edge Blanking Time".
On-time (COT parts)	t_ON	s	typ		Constant-on-time parts: row "On-Time" at your R_ON / V_IN.
Supply / input voltage range	V_IN	V	min, max		Recommended Operating Conditions, row "V_CC" / "V_IN".
Operating supply current	I_CC	A	typ, max		Supply section, row "Operating Supply Current" (not switching, or with the stated load).
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Driver · Gate driver (driver.gate → device gatedrv)

Simulation pins: **hin**, **lin**, **vdd**, **gnd**, **ho**, **hs**, **lo**, **vb**. Symbol variants: low, high_boot, half_bridge, isolated.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Supply voltage range *	V_DD	V	min, max		Recommended Operating Conditions, row "V_DD" / "V_CC" (low-side supply).
Supply UVLO threshold (rising)	V_DD(on)	V	min, typ, max		Electrical Characteristics, row "V_DD Under-Voltage Lockout, rising".
Peak source current *	I_OH	A	min, typ		Electrical Characteristics, row "Peak Output Current, Source" (or 'Output High Short-Circuit Pulsed Current').
Peak sink current *	I_OL	A	min, typ		Electrical Characteristics, row "Peak Output Current, Sink".
Propagation delay *	t_PD	s	typ, max		Switching Characteristics, rows t_ON / t_OFF (input to output). Use the larger.
Output rise time	t_r	s	typ, max		Switching Characteristics, row "Rise Time" at C_L = 1 nF.
Output fall time	t_f	s	typ, max		Switching Characteristics, row "Fall Time" at C_L = 1 nF.
Built-in dead time	t_DT	s	min, typ, max		Half-bridge drivers: row "Dead Time". 0 for drivers that pass HIN / LIN straight through.
Delay matching	t_MT	s	max		Switching Characteristics, row "Delay Matching" (high vs low side).
Bootstrap / high-side offset voltage	V_HB / V_S	V	max		Absolute Maximum Ratings, row "High-Side Floating Offset Voltage" (V_S) or "V_HB".
Quiescent supply current	I_QDD	A	typ, max		Electrical Characteristics, row "Quiescent V_DD Supply Current".
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Power · Battery protection IC (power.batprot → device batprot)

Simulation pins: **OD**, **CS**, **OC**, **TD**, **VCC**, **GND**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Overcharge detection *	V_OCP	V	min, typ, max	**v_oc**	Electrical characteristics, "Overcharge detection voltage".
Overdischarge detection *	V_ODP	V	min, typ, max	**v_od**	"Overdischarge detection voltage".
Overcurrent detection	V_OI1	V	min, typ, max	**v_ocp**	"Overcurrent detection voltage" (V at CS).
Overcharge delay	t_OC	s	typ	**t_oc**	"Overcharge detection delay time".

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Overdischarge delay	t_OD	s	typ	**t_od**	"Overdischarge detection delay time".
Overcurrent delay	t_OI1	s	typ	**t_ocp**	"Overcurrent detection delay time".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Power · Boost converter IC (power.boostic → device boostic)

Simulation pins: **SW**, **GND**, **FB**, **EN**, **VIN**. Symbol variants: async, sync.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Feedback voltage *	V_FB	V	min, typ, max	**vref**	Electrical characteristics, "Feedback voltage" (MT3608: 0.6 V).
Switching frequency *	f_SW	Hz	min, typ, max	**fsw**	"Switching frequency".
Switch current limit	I_LIM	A	min, typ	**ilim**	"Switch current limit".
Switch on resistance	R_DS(on)	Ohm	typ	**ron**	"Switch on resistance".
Maximum duty cycle	D_max		min	**dmax**	"Maximum duty cycle".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Power · Buck converter IC (power.buckic → device buckic)

Simulation pins: **VIN**, **SW**, **GND**, **FB**, **EN**, **BST**. Symbol variants: async, sync, module.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Feedback voltage *	V_FB	V	min, typ, max	**vref**	Electrical characteristics, "Feedback voltage" (0.8 V / 0.6 V / 1.23 V).
Switching frequency *	f_SW	Hz	min, typ, max	**fsw**	"Switching frequency" (or the RT / FREQ formula).
Switch current limit	I_LIM	A	min, typ	**ilim**	"High-side switch current limit" / "Peak current limit".
High-side switch R_DS(on)	R_HS	Ohm	typ	**ron_hs**	"High-side switch on resistance".
Low-side switch R_DS(on)	R_LS	Ohm	typ	**ron_ls**	Synchronous parts: "Low-side switch on resistance".
Soft-start time	t_SS	s	typ	**ss_time**	"Soft-start time" (internal) or formula with C_SS.
Input voltage range	V_IN	V	min, max		Recommended operating conditions.
Quiescent current	I_Q	A	typ, max	**iq**	"Quiescent current, not switching".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Power · LDO regulator IC (power.ldo → device ldo)

Simulation pins: **IN**, **GND**, **OUT**. Symbol variants: fixed3, adj3, en5, en_pg, neg3, ams1117, adj5. Curves: Dropout vs load current, PSRR vs frequency.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Output voltage *	V_OUT	V	min, typ, max	**vset**	Electrical characteristics, "Output voltage" (fixed option in the part number).
Reference / ADJ voltage	V_REF	V	min, typ, max	**vref**	Adjustable parts: "Reference voltage" (V_OUT – V_ADJ, 1.25 V for LM317 / AMS1117-ADJ).
Dropout voltage	V_DO	V	typ, max	**vdo**	"Dropout voltage" at the stated load (use the row at your current).
Output current / limit	I_LIM	A	min, typ	**ilim**	"Output current limit" or "Maximum output current".
Quiescent current	I_Q	A	typ, max	**iq**	"Quiescent / ground current" at no load.
Enable threshold	V_EN	V	min, max	**ven_on**	"EN input high threshold".
Shutdown current	I_SD	A	typ, max		Electrical Characteristics, row "Shutdown Current" with EN low.
Line regulation	ΔV/ΔV_IN	%/V	typ, max		Electrical Characteristics, row "Line Regulation".
Load regulation	ΔV/ΔI	%	typ, max		Electrical Characteristics, row "Load Regulation".
Short-circuit current	I_SC	A	typ		Electrical Characteristics, row "Short-Circuit Current".
Start-up time	t_on	s	typ, max		Electrical Characteristics, row "Turn-On Time".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
PSRR	PSRR	dB	typ	**psrr_db**	"PSRR" at 1 kHz.
Output noise	e_n	V	typ		Electrical Characteristics, row "Output Noise Voltage" (10 Hz to 100 kHz).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Power · Li-ion charger IC (power.charger → device charger)

Simulation pins: **TEMP**, **PROG**, **GND**, **VCC**, **BAT**, **STDBY**, **CHRG**, **CE**. Symbol variants: tp4056, mcp73831.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Regulation (float) voltage *	V_FLOAT	V	min, typ, max	**vfloat**	Electrical characteristics, "Regulated output (float) voltage".
PROG current constant *	K_PROG	V	typ	**k_prog**	Charge-current formula: I_BAT = K / R_PROG (TP4056: 1200 V, MCP73831: 1000 V).
Termination current ratio	I_TERM / I_CHG		typ	**i_term**	"Termination current" (C/10 → 0.1).
Trickle-charge threshold	V_TRIKL	V	typ	**v_trickle**	"Trickle charge threshold voltage".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Power · Load switch / eFuse / ideal diode (power.loadsw → device loadsw)

Simulation pins: **VIN**, **VOUT**, **ON**, **GND**. Symbol variants: loadsw, efuse, ideal_diode, hiside.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
On resistance *	R_ON	Ohm	typ, max	**ron**	Electrical characteristics, "ON-state resistance" at your V_IN.
Output rise time	t_R	s	typ	**t_rise**	Switching characteristics, "V_OUT rise time" (often set by CT).
Current limit	I_LIM	A	min, typ, max	**ilim**	"Current limit" (eFuse: formula with R_ILIM → k_ilim).
ON threshold	V_IH	V	max	**von**	"ON pin high-level input voltage".
Quiescent current	I_Q	A	typ, max	**iq**	"Quiescent current".
Input voltage range	V_IN	V	min, max		Recommended operating conditions.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Power · Off-line switcher IC (power.offline → device offline)

Simulation pins: **D**, **S**, **FB**, **BP**. Symbol variants: buck, flyback.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Current limit *	I_LIMIT	A	min, typ, max	**ilim**	Electrical characteristics, "Current limit".
Switching frequency *	f_OSC	Hz	min, typ, max	**fsw**	"Output frequency".
Feedback threshold	V_FB	V	typ	**vfb**	"Feedback pin voltage" / "FB threshold".
MOSFET on resistance	R_DS(on)	Ohm	typ, max	**rds_on**	"ON-state resistance" at 25 °C.
Breakdown voltage	BV_DSS	V	min	**vdss**	Absolute maximum, "Drain voltage".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

Power · Power supply module (power.psu_module → device psu_module)

Simulation pins: **VIN**, **GND**, **VOUT**, **EN**. Symbol variants: dcdc, dcdc_iso, acdc.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Output voltage *	V_OUT	V	typ	**vout**	Selection table, "Output voltage".
Output power *	P_OUT	W	max	**pout**	Selection table, "Output power" (or V × I).
Efficiency	η		typ	**eff**	Selection table, "Efficiency" at full load.
Input voltage range	V_IN	V	min, max	**vin_min**	Input specifications, "Input voltage range".
Output ripple and noise	V_rip	V	max	**ripple**	Output specifications, "Ripple &. Noise" (mVp-p, 20 MHz BW).
Isolation voltage	V_ISO	V	min		"Isolation voltage" (informational).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Regulator · Boost module (regulator.boost → **device** reg boost)

Simulation pins: **in**, **out**, **gnd**, **en**. Curves: Efficiency vs output current, Efficiency vs input voltage, Output voltage vs load current, Quiescent current vs input voltage.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Input voltage range *	V_IN	V	min, max		Module: product table "Input Voltage". IC: Recommended Operating Conditions, row "Input Voltage".
Output voltage (as set) *	V_OUT	V	min, typ, max		Module: the set output (or the feedback divider formula, V_OUT = V_FB(1 + R1/R2)). IC: "Feedback Voltage" row and your divider.
Maximum output current *	I_OUT(max)	A	max		Product table "Output Current" (continuous. Module ratings often need airflow, read the derating curve).
Efficiency at typical load *	η		typ		Graph "Efficiency vs Output Current" at your V_IN / V_OUT, read at your load. Store 0.9 for 90 %.
Switching frequency *	f_SW	Hz	min, typ, max		Electrical Characteristics, row "Switching Frequency" (f_SW or f_OSC).
Output ripple (peak-to-peak)	V_RIPPLE	V	typ, max		Module: specification "Output Ripple" (mVpp, 20 MHz bandwidth). IC: the steady-state switching waveform in Typical Characteristics.
Switch current limit	I_LIM	A	min, typ		Electrical Characteristics, row "Switch Current Limit" or "Peak Current Limit".
Quiescent / no-load input current	I_Q	A	typ, max		Electrical Characteristics, row "Quiescent Current" (switching, no load) or module no-load input current.
Soft-start time	t_SS	s	typ		Electrical Characteristics, row "Soft-Start Time". Sets the live model response time constant.
High-side switch on-resistance	R_DS(on),HS	Ohm	typ		Electrical Characteristics, row "High-Side Switch On Resistance" (integrated-switch ICs).
Minimum V_OUT above V_IN	V_OUT – V_IN	V	min		Application Information: a boost cannot regulate when V_IN approaches V_OUT. Note the stated margin (output then follows V_IN – V_F).
Feedback reference voltage	V_FB	V	typ, max		Electrical Characteristics, row "Feedback Voltage" or "Reference Voltage" (V_FB).
Minimum on-time	t_on(min)	s	typ		Electrical Characteristics, row "Minimum On-Time".
Shutdown current	I_SD	A	typ, max		Electrical Characteristics, row "Shutdown Current" with EN low.
Input undervoltage lockout, rising	V_UVLO	V	typ		Electrical Characteristics, row "UVLO Threshold, Rising".
Input undervoltage lockout, falling	V_UVLO	V	typ		Electrical Characteristics, row "UVLO Threshold, Falling".
Line regulation	ΔV/ΔV_IN	%/V	typ		Electrical Characteristics, row "Line Regulation".
Load regulation	ΔV/ΔI	%	typ		Electrical Characteristics, row "Load Regulation".
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Thermal shutdown temperature	T_SD	C	typ		Electrical Characteristics, row "Thermal Shutdown".
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Regulator · Buck module (regulator.buck → **device** reg buck)

Simulation pins: **in**, **out**, **gnd**, **en**. Curves: Efficiency vs output current, Efficiency vs input voltage, Output voltage vs load current, Quiescent current vs input voltage, Switching frequency vs load current.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Input voltage range *	V_IN	V	min, max		Module: product table "Input Voltage". IC: Recommended Operating Conditions, row "Input Voltage".
Output voltage (as set) *	V_OUT	V	min, typ, max		Module: the set output (or the feedback divider formula, V_OUT = V_FB(1 + R1/R2)). IC: "Feedback Voltage" row and your divider.
Maximum output current *	I_OUT(max)	A	max		Product table "Output Current" (continuous. Module ratings often need airflow, read the derating curve).
Efficiency at typical load *	η		typ		Graph "Efficiency vs Output Current" at your V_IN / V_OUT, read at your load. Store 0.9 for 90 %.
Switching frequency *	f_SW	Hz	min, typ, max		Electrical Characteristics, row "Switching Frequency" (f_SW or f_OSC).
Output ripple (peak-to-peak)	V_RIPPLE	V	typ, max		Module: specification "Output Ripple" (mVpp, 20 MHz bandwidth). IC: the steady-state switching waveform in Typical Characteristics.
Switch current limit	I_LIM	A	min, typ		Electrical Characteristics, row "Switch Current Limit" or "Peak Current Limit".
Quiescent / no-load input current	I_Q	A	typ, max		Electrical Characteristics, row "Quiescent Current" (switching, no load) or module no-load input current.
Soft-start time	t_SS	s	typ		Electrical Characteristics, row "Soft-Start Time". Sets the live model response time constant.
High-side switch on-resistance	R_DS(on),HS	Ohm	typ		Electrical Characteristics, row "High-Side Switch On Resistance" (integrated-switch ICs).
Inductor value (module / recommended)	L	H	typ		Module: BOM or schematic. IC: Application Information "Inductor Selection" table.
Feedback reference voltage	V_FB	V	typ, max		Electrical Characteristics, row "Feedback Voltage" or "Reference Voltage" (V_FB).
Maximum duty cycle	D_max		typ		Electrical Characteristics, row "Maximum Duty Cycle".
Minimum on-time	t_on(min)	s	typ		Electrical Characteristics, row "Minimum On-Time".
Shutdown current	I_SD	A	typ, max		Electrical Characteristics, row "Shutdown Current" with EN low.
Input undervoltage lockout, rising	V_UVLO	V	typ		Electrical Characteristics, row "UVLO Threshold, Rising".

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Input undervoltage lockout, falling	V_UVLO	V	typ		Electrical Characteristics, row "UVLO Threshold, Falling".
Low-side switch on-resistance	R_DS(on)	Ohm	typ, max		Electrical Characteristics, row "Low-Side MOSFET On-Resistance" (synchronous parts).
Line regulation	ΔV/ΔV_IN	%/V	typ		Electrical Characteristics, row "Line Regulation".
Load regulation	ΔV/ΔI	%	typ		Electrical Characteristics, row "Load Regulation".
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Thermal shutdown temperature	T_SD	C	typ		Electrical Characteristics, row "Thermal Shutdown".
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Regulator · Charge pump (regulator.chargepump → **device** reg chargepump)

Simulation pins: **in**, **out**, **gnd**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Mode (–1 = inverter, 2 = doubler) *	mode		typ		Title and Typical Application drawing: "voltage inverter" (–1) or "voltage doubler" (2).
Input voltage range *	V_IN	V	min, max		Recommended Operating Conditions, row "Supply Voltage".
Output resistance *	R_OUT	Ohm	typ, max		Electrical Characteristics, row "Output Resistance" (R_O) with the recommended pump capacitors (for example 10 µF).
Oscillator frequency	f_OSC	Hz	typ		Electrical Characteristics, row "Oscillator Frequency" (the pump runs at half of it on some parts).
Supply current	I_Q	A	typ, max		Electrical Characteristics, row "Supply Current" with no load.
Maximum output current	I_OUT	A	max		Recommended Operating Conditions, or Electrical Characteristics, row "Output Current".
Power efficiency	η_P		typ		Electrical Characteristics, row "Power Efficiency" at the stated load.
Recommended pump capacitor	C_1, C_2	F	typ		Typical Application drawing, values of C1 (flying) and C2 (reservoir).
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Regulator · LDO (regulator.ldo → **device** reg ldo)

Simulation pins: **in**, **out**, **gnd**, **en**. Curves: PSRR vs frequency, Dropout vs load current, Ground current vs load current, Output voltage vs load current (load regulation), Output voltage vs temperature, Dropout voltage vs temperature, Output noise density vs frequency, Output impedance vs frequency.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Output voltage *	V_OUT	V	min, typ, max		Electrical Characteristics table, row "Output Voltage", at the nominal load current (pick the row for your fixed-voltage option).
Dropout voltage *	V_DO	V	typ, max		Electrical Characteristics, row "Dropout Voltage" at I_OUT max. If only a curve exists read "Dropout vs Load Current" at your maximum load.
Maximum output current *	I_OUT(max)	A	max		Recommended Operating Conditions, row "Output Current" (not Absolute Maximum Ratings).
Current limit	I_LIM	A	min, typ		Electrical Characteristics, row "Current Limit" or "Short Circuit Current".
Quiescent current *	I_Q	A	typ, max		Electrical Characteristics, row "Quiescent Current" or "Ground Pin Current" with no load, EN high.
Input voltage range *	V_IN	V	min, max		Recommended Operating Conditions, row "Input Voltage".
Line regulation	ΔV_OUT/ ΔV_IN	%/V	typ, max		Electrical Characteristics, row "Line Regulation". Convert mV/V to %/V by dividing by V_OUT.
Load regulation	ΔV_OUT	%	typ, max		Electrical Characteristics, row "Load Regulation", 1 mA to I_OUT max.
Shutdown current	I_SD	A	typ, max		Electrical Characteristics, row "Shutdown Current" or "Standby Current" with EN low.
Ground current at full load	I_GND	A	typ, max		Electrical Characteristics, row "Ground Pin Current" at the stated load.
Output voltage accuracy	ΔV_OUT	%	typ, max		Electrical Characteristics, row "Output Voltage Accuracy" or "Tolerance" over line, load and temperature.
Output voltage temperature coefficient	TC	ppm/C	typ		Electrical Characteristics, row "Output Voltage Temperature Coefficient".
Short-circuit current	I_SC	A	typ		Electrical Characteristics, row "Short-Circuit Current" (foldback parts list a lower value than the limit).
Enable threshold, high	V_EN(H)	V	min		Electrical Characteristics, row "EN Input High Voltage".
Enable threshold, low	V_EN(L)	V	max		Electrical Characteristics, row "EN Input Low Voltage".
Start-up time	t_on	s	typ, max		Electrical Characteristics, row "Turn-On Time" or "Start-Up Time" at the stated C_OUT.
Input undervoltage lockout	V_UVLO	V	typ		Electrical Characteristics, row "UVLO Threshold" (rising).
PSRR at 1 kHz	PSRR	dB	typ		Graph "PSRR vs Frequency" (or row "Ripple Rejection") at 1 kHz. Add more points as a curve for accuracy.
Output noise	V_N	V	typ		Electrical Characteristics, row "Output Noise Voltage" (e_n or V_N, µVrms). Note the bandwidth it is quoted over.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Minimum output capacitor *	C_OUT(min)	F	min		Application Information, "Output Capacitor". Ceramic is fine when no minimum ESR is given.
Output capacitor ESR, minimum	ESR_min	Ohm	min		Graph "Stability Region vs ESR", if present. Leave empty for ceramic-stable parts.
Output capacitor ESR, maximum	ESR_max	Ohm	max		Same graph, upper edge of the stable region.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings or Recommended Operating Conditions, row "Junction Temperature". Also note the thermal shutdown threshold.
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Thermal shutdown temperature	T_SD	C	typ		Electrical Characteristics, row "Thermal Shutdown Temperature".
Thermal shutdown hysteresis	ΔT_SD	C	typ		Electrical Characteristics, row "Thermal Shutdown Hysteresis".
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.17 Protection

Protection · ESD / TVS array (protection.esd → device esd)

Simulation pins: **io1**, **io2**, **gnd**. Symbol variants: 2ch, 1ch, 4ch, 2ch_vbus, 4ch_vbus, usblc6.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Reverse working voltage *	V_RWM	V	max	**vrwm**	Electrical characteristics, row "Reverse working voltage V_RWM".
Breakdown voltage	V_BR	V	min	**vbr**	Row "Breakdown voltage V_BR" at I_T.
Clamping voltage	V_C	V	max	**vc**	Row "Clamping voltage" at I_PP (8/20 µs).
Peak pulse current	I_PP	A	max	**ipp**	Same row, I_PP.
Line capacitance	C_J	F	typ, max	**cj**	Row "Line capacitance / Junction capacitance" (I/O to GND).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Protection · Fuse (fast / slow / breaker) (protection.fuse → device fuse)

Simulation pins: **a**, **b**. Symbol variants: fast, veryfast, slow, breaker, thermal, thermostat.
Curves: Time-current curve.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Rated current *	I_N	A	typ	**irated**	Ordering table, column "Current Rating" (I_N).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Voltage rating	V_N	V	max	**vrated**	Ordering table, column "Voltage Rating".
Cold resistance	R_cold	Ohm	typ	**r**	Ordering table, column "Cold Resistance" / "Typical DC resistance". Or voltage drop / I_N.
Nominal melting I^2t	I^2t	A2s	typ	**i2t**	Ordering table, column "Nominal Melting I^2t" (A^2s).
Breaking capacity	I_break	A	min		Ordering table, column "Interrupting Rating" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Protection · Gas discharge tube (protection.gdt → device gdt)

Simulation pins: **a**, **b**. Symbol variants: 2pin, 3pin.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
DC spark-over voltage *	V_s(DC)	V	min, typ, max	**v_spark**	Electrical characteristics, "DC spark-over voltage" (100 V/s).
Impulse spark-over voltage	V_s(imp)	V	max		Row "Impulse spark-over at 100 V/µs" / "1 kV/µs". Fits k_imp.
Arc voltage	V_arc	V	typ	**v_arc**	Row "Arc voltage".
Capacitance	C	F	max		Row "Capacitance" (pF).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Protection · Resettable fuse (PPTC) (protection.pptc → device pptc)

Simulation pins: **a**, **b**. Curves: Time to trip.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Hold current *	I_hold	A	typ	**ihold**	Electrical characteristics, column "I_hold" at 25 °C.
Trip current *	I_trip	A	typ	**itrip**	Electrical characteristics, column "I_trip" at 25 °C.
Initial resistance (min)	R_min	Ohm	min	**r_min**	Column "R_min".
Post-trip resistance (max)	R1_max	Ohm	max	**r1max**	Column "R1max" (1 h after trip).
Time to trip	t_trip	s	max	**t_trip**	Columns "Max time to trip": the time and its current (for example 0.1 s at 8 A). Enter the current in i_ttrip.
Current for time to trip	I_t	A	typ	**i_ttrip**	Same row, the current at which the time to trip is given.
Maximum voltage	V_max	V	max	**vmax**	Column "V_max".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Protection · Varistor (MOV) (protection.mov → device mov)

Simulation pins: **a**, **b**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Varistor voltage at 1 mA *	V_1mA	V	min, typ, max	**v1ma**	Ratings table, column "Varistor Voltage V_1mA" (±10 %).
Max AC voltage	V_rms	V	max		Column "Max. allowable voltage AC (rms)".
Clamping voltage	V_C	V	max		Column "Max. clamping voltage V_C at I_P". With I_P it fits alpha.
Clamping test current	I_P	A	typ		Same column, the test current I_P.
Energy rating	W_max	J	max	**e_max**	Column "Energy (10/1000 µs)".
Capacitance	C	F	typ	**c**	Column "Typical capacitance at 1 kHz".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.18 RF

RF · Antenna (rf.antenna → **device** antenna)

Simulation pins: **feed**. Symbol variants: mono, dipole, chip, pcb.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Centre frequency *	f_0	Hz	typ	**f0**	Electrical specifications, "Frequency range" (centre).
Impedance	Z	Ohm	typ	**r_rad**	"Impedance" (50 Ω).
VSWR	VSWR		max		"VSWR" (informational).
Peak gain	G	dBi	typ		"Peak gain" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).

RF · Attenuator (rf.attenuator → **device** attenuator)

Simulation pins: **IN**, **OUT**, **GND**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Attenuation *	A	dB	typ	**atten_db**	"Attenuation".
Impedance	Z_0	Ohm	typ	**z0**	"Impedance".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

RF · Balun (rf.balun → **device** balun)

Simulation pins: **UNBAL**, **GND**, **BAL+**, **BAL−**. Symbol variants: 1:1, 1:2, 1:4.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Impedance ratio *	Z ratio		typ	**ratio**	"Impedance ratio" (1:1, 1:2, 1:4) → variant.
Frequency range	f	Hz	min, max		"Frequency range" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

RF · RF amplifier (rf.rfamp → device rfamp)

Simulation pins: **IN**, **OUT**, **VCC**, **GND**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Gain *	G	dB	typ	**gain_db**	Electrical characteristics, "Small-signal gain" at your frequency.
Bandwidth	f_3dB	Hz	typ	**f3db**	"Frequency range" upper limit.
Output P1dB	P1dB	dBm	typ	**p1db**	"Output power at 1 dB compression".
Noise figure	NF	dB	typ	**nf_db**	"Noise figure".
Supply current	I_CC	A	typ	**icc**	"Device current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

RF · SAW / band-pass filter (rf.saw → device saw)

Simulation pins: **IN**, **OUT**, **GND**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Centre frequency *	f_C	Hz	typ	**f0**	Electrical characteristics, "Center frequency".
Bandwidth *	BW	Hz	typ	**bw**	"Pass bandwidth" (–3 dB).
Insertion loss	IL	dB	typ, max	**il_db**	"Insertion loss".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.19 Sensors

Sensors · Analog-output sensor (sensors.asensor → device asensor)

Simulation pins: **VCC**, **GND**, **OUT**. Symbol variants: temp, pressure, humidity, light, accel, generic.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Sensitivity *	S	V/unit	typ	**sens**	Electrical characteristics, "Sensitivity" / "Scale factor" (LM35: 10 mV/°C).
Output at x = 0	V_0	V	typ	**offset**	"Offset" / "Output at 0 °C" (TMP36: 0.5 V. MCP9700: 0.5 V).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Ratiometric output	ratiometric	0/1	typ	**ratiometric**	Notes: "ratiometric to V_S" → 1 (pressure sensors, Hall linear).
Supply current	I_Q	A	typ, max	**icc**	"Quiescent current".
Measurement range	range	unit	min, max		"Measurement range" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · Bridge sensor / load cell (sensors.bridge_sensor → device bridge_sensor)

Simulation pins: **exc+**, **exc–**, **out+**, **out–**. Symbol variants: loadcell, pressure.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Rated output *	RO	mV/V	typ	**sens**	Specifications, "Rated output" / "Sensitivity" at full scale.
Bridge resistance	R_in	Ohm	typ	**r_bridge**	"Input resistance" / "Output resistance".
Zero balance	ZB	mV/V	typ	**zero**	"Zero balance" / "Zero output".
Capacity	FS	unit	typ		"Rated capacity" (informational: x = load / capacity).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · Gas sensor (MQ series) (sensors.gas → device gas)

Simulation pins: **h1**, **h2**, **a**, **b**. Symbol variants: mq2, mq135, mq7.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Heater resistance *	R_H	Ohm	typ	**r_h**	Standard work condition table, "Heater resistance R_H".
Sensing resistance in reference gas	R_S	Ohm	min, max	**r0**	Characteristics, "Sensing resistance" in the stated gas / concentration.
Concentration slope	α		typ	**k**	Sensitivity graph log(Rs/R0) vs log(ppm): the slope.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · Hall current sensor (sensors.isense_hall → device isense_hall)

Simulation pins: **ip+**, **ip–**, **vcc**, **gnd**, **out**, **filt**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Sensitivity *	Sens	V/A	typ	**sens**	Electrical characteristics, "Sensitivity" (mV/A) for your current range option.
Primary conductor resistance	R_IP	Ohm	typ	**r_ip**	"Internal conductor resistance".
Bandwidth	BW	Hz	typ	**bw**	"Bandwidth" (–3 dB) or rise time.
Zero-current output	V_IOUT(Q)	V	typ	**vq**	"Zero current output voltage" (V_CC × 0.5 ratiometric).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · Hall sensor (sensors.hall → device hall)

Simulation pins: **VCC**, **GND**, **OUT**. Symbol variants: switch, latch, omni, linear.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Operate point *	B_OP	mT	min, typ, max	**bop**	Magnetic characteristics, "Operate point B_OP" (G → /10 for mT).
Release point	B_RP	mT	min, typ, max	**brp**	"Release point B_RP".
Sensitivity (linear)	Sens	mV/mT	min, typ, max	**sens**	Linear parts: "Sensitivity" (mV/G × 10 → mV/mT).
Supply current	I_CC	A	typ, max	**icc**	"Supply current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · NTC thermistor (sensors.ntc → device ntc)

Simulation pins: **a**, **b**. Symbol variants: sensor, icl. Curves: R/T table.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resistance at 25 °C *	R25	Ohm	typ	**r25**	Part-number table, column "R25" (for example 103 = 10 kΩ).
B-constant *	B25/50	K	typ	**beta**	Column "B25/50" or "B25/85" (state which pair in the notes).
Dissipation constant	δ	W/K	typ	**dissipation**	Characteristics, row "Dissipation factor" (mW/°C in still air).
Thermal time constant	τ	s	typ	**tau**	Characteristics, row "Thermal time constant" (s in still air).
Max power	P_max	W	max	**pmax**	Absolute maximum, "Rated power" / "Max power at 25 °C".
Max steady current (ICL)	I_max	A	max		Inrush limiters: "Max. steady state current" (informational).
Resistance tolerance at 25 °C	±tol	%	typ		Electrical Specifications, row "R25 Tolerance" (F = 1 %, J = 5 %).
B-value tolerance	±tol_B	%	typ		Electrical Specifications, row "B Constant Tolerance".
Dissipation constant	δ	W/C	typ		Electrical Specifications, row "Dissipation Constant" (mW/°C in still air).
Thermal time constant	τ	s	typ		Electrical Specifications, row "Thermal Time Constant".
Maximum operating temperature	T_max	C	max		Electrical Specifications, row "Operating Temperature Range" (upper limit).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · Photoresistor (LDR) (sensors.ldr → device ldr)

Simulation pins: **a**, **b**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Light resistance at 10 lx *	R10	Ohm	min, max	**r10**	Characteristics table, column "Light resistance (10 lux)" (often a min–max range).
Gamma	γ		typ	**gamma**	Column "γ (100/10)" or "γ".
Dark resistance	R_dark	Ohm	min	**r_dark**	Column "Dark resistance" (min, after 10 s).
Response time, rise	t_r	s	typ	**t_rise**	Column "Response time rise / decay" (ms).
Response time, decay	t_f	s	typ	**t_fall**	Same column, decay value.
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · PIR motion module (sensors.pir → device pir)

Simulation pins: **VCC**, **OUT**, **GND**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Output hold time	t_hold	s	typ	**t_hold**	Module spec, "Delay time" (trimmer range).
Quiescent current	I_Q	A	typ	**icc**	"Static current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).

Sensors · PTC thermistor (sensors.ptc → device ptc)

Simulation pins: **a**, **b**. Symbol variants: switching, linear.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resistance at 25 °C *	R25	Ohm	typ	**r25**	Ordering table, column "R25" / "R_N".
Reference (switching) temperature	T_ref	C	typ	**t_c**	Ceramic PTC: "Reference temperature T_ref" / "Curie temperature".
Temperature coefficient	α	1/K	typ	**alpha**	Silicon KTY: "Temperature coefficient α" (%/K → /100).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Dissipation constant	δ	W/K	typ	**dissipation**	Characteristics, "Dissipation factor".
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · RTD (Pt100 / Pt1000) (sensors.rtd → device rtd)

Simulation pins: **a**, **b**. Symbol variants: pt100, pt1000, ni1000.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Resistance at 0 °C *	R0	Ohm	typ	**r0**	Ordering table: Pt100 / Pt1000 (R0).
Temperature coefficient	α	1/K	typ	**cvd_a**	Specification: α = 0.00385 (IEC 60751) or 0.00392. Converted to the CVD coefficients.
Tolerance class	class		typ		Class B / A / AA (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Self-heating coefficient	δ	W/K	typ	**dissipation**	Row "Self-heating" (mK/mW → 1/value).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · Strain gauge (sensors.strain → **device** strain)

Simulation pins: **a**, **b**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Nominal resistance *	R_0	Ohm	typ	**r0**	Specification, "Resistance" (120 / 350 / 1000 Ω).
Gauge factor *	k		typ	**gf**	Specification, "Gauge factor".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · Thermocouple (sensors.tcouple → **device** tcouple)

Simulation pins: **+**, **–**. Symbol variants: K, J, T, E, N.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Thermocouple type *	type		typ		Type letter (K, J, T, E, N) → variant.
Loop resistance	R_loop	Ohm	typ	**r**	Wire table: Ω/m × length (both legs).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Max temperature	T_max	C	max		Specifications: "Temperature range" (informational).

Sensors · Touch sensor IC (sensors.touch → **device** touch)

Simulation pins: **Q**, **VSS**, **I**, **AHLB**, **VDD**, **TOG**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Response time	t_R	s	typ	**t_resp**	"Response time" (fast / low-power mode).
Operating current	I_DD	A	typ		"Operating current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Sensors · Ultrasonic ranger (sensors.ultrasonic → **device** ultrasonic)

Simulation pins: **VCC**, **TRIG**, **ECHO**, **GND**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Range	d	m	min, max		Module spec, "Ranging distance" (informational).
Operating current	I	A	typ	**icc**	"Working current".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).

73.20 Sources

Sources · Solar cell (sources.solar → **device** solar)

Simulation pins: **+**, **–**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Short-circuit current *	I_SC	A	typ	**isc**	Electrical data at STC (1000 W/m^2), "I_sc".
Open-circuit voltage *	V_OC	V	typ	**voc**	Electrical data at STC, "V_oc" (enter the panel value and the cell count).
Cells in series	N_s		typ	**cells**	Mechanical data, "Cells".
Max power	P_mpp	W	typ		"P_max", with V_mpp / I_mpp (fit n and rs).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.21 Timing

Timing · 556 dual timer (timing.timer556 → **device** timer556)

Simulation pins: **DIS1**, **THR1**, **CTRL1**, **RST1**, **OUT1**, **TRIG1**, **GND**, **TRIG2**, **OUT2**, **RST2**, **CTRL2**, **THR2**, **DIS2**, **VCC**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Technology	family		typ	**family**	NE556 (bipolar) or TLC556 / ICM7556 (CMOS) → family.
Supply current	I_CC	A	typ, max		"Supply current" (both timers).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Timing · Ceramic resonator (timing.resonator → **device** resonator)

Simulation pins: **in**, **gnd**, **out**. Symbol variants: 3pin, 2pin.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Oscillation frequency *	f_osc	Hz	typ	**freq**	Ordering table, "Oscillating frequency".
Built-in load capacitance	C_L1, C_L2	F	typ	**cl_int**	Ordering table, "Built-in load capacitance" (each side).
Resonant resistance	R_1	Ohm	max	**rm**	Equivalent circuit constants table, "R1".
Frequency tolerance	Δf/f	%	max	**tol**	"Initial tolerance".
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Timing · Crystal (timing.xtal → **device** xtal)

Simulation pins: **x1**, **x2**. Symbol variants: 2pin, 4pin.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Nominal frequency *	f_0	Hz	typ	**freq**	Ordering code / Electrical specifications, "Nominal frequency".
Load capacitance *	C_L	F	typ	**cl**	Electrical specifications, "Load capacitance C_L" (ordering option, for example 12 / 18 / 20 pF).
Equivalent series resistance	ESR	Ohm	max	**esr**	Electrical specifications, "ESR / Series resistance R1" (max).
Shunt capacitance	C_0	F	max	**c0**	Electrical specifications, "Shunt capacitance C0" (max).
Motional capacitance	C_1	F	typ	**cm**	"Motional capacitance C1" (fF), often only in the extended table.
Frequency tolerance	Δf/f	ppm	max	**ppm**	"Frequency tolerance at 25 °C".
Drive level	DL	W	max	**drive_max**	"Drive level" (µW).
Aging	Δf/f	ppm	max		Electrical Specifications, row "Aging (first year)".
Frequency stability over temperature	Δf/f	ppm	max		Electrical Specifications, row "Frequency Stability over Temperature".
Pullability	S	ppm/F	typ		Electrical Specifications, row "Pullability" (ppm per pF: 20 ppm/pF is 2e13 per F).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Timing · Oscillator module (timing.xo → **device** xo)

Simulation pins: **EN**, **GND**, **OUT**, **VDD**. Symbol variants: xo, tcxo, vcxo, mems.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Output frequency *	f_out	Hz	typ	**freq**	Ordering code, "Frequency".
Supply voltage	V_DD	V	min, typ, max	**vdd_min**	Electrical specifications, "Supply voltage".
Supply current	I_DD	A	max	**idd**	Electrical specifications, "Supply current" at your frequency, no load.
Rise / fall time	t_r	s	max	**tr**	"Rise / fall time" (10–90 %).
Start-up time	t_start	s	max	**startup**	"Start-up time".
Frequency stability	Δf/f	ppm	max		"Frequency stability" over temperature (informational).
Pull range (VCXO)	APR	ppm	typ	**pull**	VCXO: "Absolute pull range".

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Timing · PLL / VCO (timing.pll → device vco)

Simulation pins: **ref**, **fb**, **out**, **gnd**.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
VCO centre frequency *	f_0	Hz	min, typ, max		VCO section, row "Center Frequency" or the f vs V_TUNE graph at mid-scale.
VCO gain *	K_VCO	Hz/V	min, typ, max		VCO section, row "Tuning Sensitivity" / "K_VCO" (MHz/V → Hz/V), or the slope of f vs V_TUNE.
VCO minimum frequency	f_MIN	Hz	min		VCO section, row "Frequency Range" (low end).
VCO maximum frequency	f_MAX	Hz	max		VCO section, row "Frequency Range" (high end).
Maximum reference frequency	f_REF	Hz	max		Phase Detector section, row "PFD Frequency" (max).
Charge-pump current	I_CP	A	min, typ, max		Charge Pump section, row "Charge Pump Current" (sink / source, per setting).
Feedback divider range (max N)	N		max		Divider section, row "N Counter Range".
Lock time	t_LOCK	s	typ		Typical Characteristics or loop-filter application section, "Lock Time" with the stated loop bandwidth.
Phase noise at 10 kHz offset	L(10k)	dBc/Hz	typ		Phase Noise graph or table: value at 10 kHz offset for the stated carrier.
Output high level	V_OH	V	typ		Output section, row "Output High Voltage" (CMOS outputs: V_DD).
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

73.22 Transistors

Transistor · IGBT (transistor.igbt → device igbt)

Simulation pins: **c**, **g**, **e**. Curves: Output characteristic, Transfer characteristic, Saturation voltage vs collector current, Saturation voltage vs junction temperature, Input capacitance vs collector-emitter voltage, Switching energy vs collector current.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Collector-emitter voltage	V_CES	V	max		Absolute Maximum Ratings, row "Collector-Emitter Voltage" (V_CES).
Continuous collector current	I_C	A	max		Absolute Maximum Ratings, row "Continuous Collector Current" at T_C = 100 °C (more realistic than 25 °C).
Gate threshold voltage *	V_GE(th)	V	min, typ, max		Electrical Characteristics, row "Gate-Emitter Threshold Voltage" (V_GE(th)) at I_C = 250 µA..1 mA, V_CE = V_GE.
Collector-emitter saturation voltage *	V_CE(sat)	V	typ, max		Electrical Characteristics, row "Collector-Emitter Saturation Voltage" at the nominal I_C and V_GE = 15 V. Put both in the conditions.
Forward transconductance	g_fs	S	typ		Electrical Characteristics, row "Transconductance" (g_fs), if given.
Input capacitance	C_ies	F	typ		Dynamic Characteristics, row "Input Capacitance" (C_ies).
Total gate charge	Q_G	C	typ		Dynamic Characteristics, row "Gate Charge Total" (Q_G) at V_GE = 15 V.
Turn-on switching energy	E_on	J	typ		Switching Characteristics, row "Turn-On Switching Loss" (E_on) at the stated I_C, V_CE, R_G.
Turn-off switching energy	E_off	J	typ		Switching Characteristics, row "Turn-Off Switching Loss" (E_off).
Maximum gate-emitter voltage	V_GES	V	max		Absolute Maximum Ratings, row "Gate-Emitter Voltage" (V_GES).
Continuous collector current at 100 °C	I_C(100)	A	max		Absolute Maximum Ratings, row "Collector Current" at T_C = 100 °C.
Pulsed collector current	I_CM	A	max		Absolute Maximum Ratings, row "Pulsed Collector Current" (I_CM).
Collector cut-off current	I_CES	A	max		Electrical Characteristics, row "Zero Gate Voltage Collector Current" (I_CES).
Turn-on delay time	t_d(on)	s	typ		Switching Characteristics, row "Turn-On Delay Time". Test conditions in the footnote.
Rise time	t_r	s	typ		Switching Characteristics, row "Rise Time".
Turn-off delay time	t_d(off)	s	typ		Switching Characteristics, row "Turn-Off Delay Time".
Fall time	t_f	s	typ		Switching Characteristics, row "Fall Time" (the current tail may follow, see the note).
Total switching energy	E_ts	J	typ		Switching Characteristics, row "Total Switching Loss" (E_ts = E_on + E_off).
Gate-emitter charge	Q_ge	C	typ		Electrical Characteristics, row "Gate-Emitter Charge".
Gate-collector charge	Q_gc	C	typ		Electrical Characteristics, row "Gate-Collector Charge".
Output capacitance	C_oes	F	typ		Electrical Characteristics, row "Output Capacitance" (C_oes) at V_CE = 25 V.
Reverse transfer capacitance	C_res	F	typ		Electrical Characteristics, row "Reverse Transfer Capacitance" (C_res).
Anti-parallel diode forward voltage	V_F	V	typ, max		Diode Characteristics, row "Diode Forward Voltage". I_F in the conditions.
Anti-parallel diode reverse recovery time	t_rr	s	typ		Diode Characteristics, row "Diode Reverse Recovery Time".
Short-circuit withstand time	t_SC	s	min		Absolute Maximum Ratings or Electrical Characteristics, row "Short-Circuit Withstand Time" at the stated V_GE and V_CC.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Transistor · JFET (transistor.jfet → device njf)

Simulation pins: **d**, **g**, **s**. Curves: Transfer characteristic, Output characteristic.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Gate-source cut-off voltage *	V_GS(off)	V	min, typ, max		Electrical Characteristics, "OFF Characteristics", row "Gate-Source Cutoff Voltage" (V_GS(off)) at V_DS = 15 V, I_D = 10 nA. Keep its sign (negative for N-channel).
Zero-gate-voltage drain current *	I_DSS	A	min, typ, max		Electrical Characteristics, "ON Characteristics", row "Zero-Gate-Voltage Drain Current" (I_DSS) at V_DS = 15 V, V_GS = 0. Positive number.
Forward transfer admittance	|y_fs|	S	min, typ		Small-Signal Characteristics, row "Forward Transfer Admittance" (|y_fs| or g_fs) at 1 kHz.
Drain-source voltage	V_DS	V	max		Absolute Maximum Ratings, row "Drain-Source Voltage".
Gate reverse current	I_GSS	A	max		OFF Characteristics, row "Gate Reverse Current" (I_GSS) at the stated V_GS.
Input capacitance	C_iss	F	typ		Small-Signal Characteristics, row "Input Capacitance" (C_iss).
Reverse transfer capacitance	C_rss	F	typ		Small-Signal Characteristics, row "Reverse Transfer Capacitance" (C_rss).
Drain-source on-resistance	r_ds(on)	Ohm	typ		Electrical Characteristics, row "Static Drain-Source On-Resistance" at V_GS = 0 (small-signal parts).
Gate-source capacitance	C_gs	F	typ		Electrical Characteristics, row "Gate-Source Capacitance".
Gate-drain capacitance	C_gd	F	typ		Electrical Characteristics, row "Gate-Drain Capacitance" (C_rss).
Input voltage noise density	e_n	V/rtHz	typ		Small-Signal Characteristics, row "Equivalent Short-Circuit Input Noise Voltage" (nV/√Hz) at 1 kHz.
Noise figure	NF	dB	typ		Electrical Characteristics, row "Noise Figure" with R_G and f.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Transistor · N-channel MOSFET (transistor.nmos → device nmos)

Simulation pins: **d**, **g**, **s**. Symbol variants: enh, power, 4pin, dep. Curves: On-resistance vs gate voltage, Transfer characteristic, Output characteristic, Input capacitance vs drain voltage, Output capacitance vs drain voltage, Reverse transfer capacitance vs drain voltage, On-resistance vs junction temperature, Gate threshold vs junction temperature, Gate voltage vs gate charge, Body diode forward characteristic.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Drain-source voltage	V_DS	V	max		Absolute Maximum Ratings, row "Drain-Source Voltage" (V_DSS). Store as a positive number.
Continuous drain current	I_D	A	max		Absolute Maximum Ratings, row "Continuous Drain Current" at T_A = 25 °C (the T_C = 25 °C value assumes an ideal heatsink). Positive number.
Gate threshold voltage *	V_GS(th)	V	min, typ, max		Electrical Characteristics, "Static", row "Gate Threshold Voltage" at V_DS = V_GS, I_D = 250 µA. Store as a positive number.
Drain-source on-resistance *	R_DS(on)	Ohm	typ, max		Electrical Characteristics, row "Static Drain-Source On-Resistance" at the V_GS you will drive (for example V_GS = 4.5 V). Put that V_GS in the conditions.
Gate-source voltage	V_GS(max)	V	max		Absolute Maximum Ratings, row "Gate-to-Source Voltage" (±V_GS).
Input capacitance	C_iss	F	typ		Dynamic Characteristics, row "Input Capacitance" (C_iss) at the stated V_DS, 1 MHz.
Output capacitance	C_oss	F	typ		Dynamic Characteristics, row "Output Capacitance" (C_oss).
Reverse transfer capacitance	C_rss	F	typ		Dynamic Characteristics, row "Reverse Transfer Capacitance" (C_rss, the Miller capacitance).
Total gate charge	Q_g	C	typ, max		Dynamic Characteristics, row "Total Gate Charge" (Q_g) at the stated V_GS. Also in the gate-charge graph.
Forward transconductance	g_fs	S	min, typ		Static Characteristics, row "Forward Transconductance" at the stated V_DS and I_D.
Body diode forward voltage	V_SD	V	max		Source-Drain Diode Characteristics, row "Diode Forward Voltage" (V_SD) at I_S. Positive number.
Body diode reverse recovery time	t_rr	s	typ		Source-Drain Diode Characteristics, row "Reverse Recovery Time" (t_rr).
Continuous drain current at 100 °C	I_D(100)	A	max		Absolute Maximum Ratings, row "Continuous Drain Current" at T_C = 100 °C (the first row is usually 25 °C).
Pulsed drain current	I_DM	A	max		Absolute Maximum Ratings, row "Pulsed Drain Current" (I_DM). The pulse width is in the footnote.
On-resistance at low gate drive	R_DS(on)	Ohm	typ, max		Electrical Characteristics, the second R_DS(on) row (for example at V_GS = 4.5 V when the first is at 10 V). Put V_GS and I_D in the conditions.
On-resistance at high temperature	R_DS(on)	Ohm	typ, max		Electrical Characteristics at T_J = 125 or 150 °C, or the normalised R_DS(on) vs temperature graph times the 25 °C value.
Zero-gate-voltage drain current	I_DSS	A	max		Electrical Characteristics, row "Zero Gate Voltage Drain Current" (I_DSS), at V_DS = the rated voltage.
Gate-body leakage current	I_GSS	A	max		Electrical Characteristics, row "Gate-Body Leakage Current" (I_GSS) at V_GS = ±the rated gate voltage.
Gate resistance	R_G	Ohm	typ		Electrical Characteristics, row "Gate Resistance" (R_G) at f = 1 MHz.
Gate-source charge	Q_gs	C	typ		Electrical Characteristics, row "Gate-Source Charge" (Q_gs).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Gate-drain (Miller) charge	Q_gd	C	typ		Electrical Characteristics, row "Gate-Drain Charge" (Q_gd).
Turn-on delay time	t_d(on)	s	typ		Switching Characteristics, row "Turn-On Delay Time". The test circuit and R_G are in the conditions.
Rise time	t_r	s	typ		Switching Characteristics, row "Rise Time".
Turn-off delay time	t_d(off)	s	typ		Switching Characteristics, row "Turn-Off Delay Time".
Fall time	t_f	s	typ		Switching Characteristics, row "Fall Time".
Body diode continuous current	I_S	A	max		Absolute Maximum Ratings or Source-Drain Diode Characteristics, row "Continuous Source Current (Body Diode)".
Body diode reverse recovery charge	Q_rr	C	typ		Source-Drain Diode table, row "Reverse Recovery Charge" (Q_rr), with I_F and di/dt in the footnote.
Single-pulse avalanche energy	E_AS	J	max		Absolute Maximum Ratings, row "Single Pulse Avalanche Energy" (E_AS). The starting T_J, L and I_AS are in the footnote.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Transistor · NPN BJT (transistor.npn → **device** npn)

Simulation pins: **c**, **b**, **e**. Curves: DC current gain vs collector current, Base-emitter voltage vs collector current, Collector-emitter saturation vs current, Transition frequency vs collector current, Output capacitance vs collector-base voltage.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
DC current gain *	h_FE		min, typ, max		Electrical Characteristics, "ON Characteristics", row "DC Current Gain" (h_FE) at the I_C / V_CE closest to your circuit (for example I_C = 10 mA, V_CE = 1 V).
Collector-emitter voltage	V_CEO	V	max		Absolute Maximum Ratings, row "Collector-Emitter Voltage" (V_CEO, base open). Store as a positive number.
Continuous collector current	I_C	A	max		Absolute Maximum Ratings, row "Collector Current - Continuous" (I_C). Store as a positive number.
Collector-emitter saturation voltage	V_CE(sat)	V	typ, max		ON Characteristics, row "Collector-Emitter Saturation Voltage" at I_C / I_B = 10. Store as a positive number.
Base-emitter voltage	V_BE(on)	V	min, typ, max		ON Characteristics, row "Base-Emitter On Voltage" V_BE(on) (or V_BE(sat)) at the stated I_C. Store as a positive number.
Transition frequency	f_T	Hz	min, typ		Small-Signal Characteristics, row "Current-Gain-Bandwidth Product" (f_T).
Output capacitance	C_obo	F	max		Small-Signal Characteristics, row "Output Capacitance" (C_obo, C_CB at V_CB = 5 V, 1 MHz).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Input capacitance	C_ibo	F	max		Small-Signal Characteristics, row "Input Capacitance" (C_ibo, C_EB at V_EB = 0.5 V, 1 MHz).
Early voltage (model)	V_AF	V	typ		Rarely listed: extrapolate the I_C vs V_CE output curves back to I_C = 0. Typical 50 to 150 V for small-signal parts.
Turn-on time (delay + rise)	t_d + t_r	s	max		Switching Characteristics, rows "Delay Time" and "Rise Time". Add them.
Turn-off time (storage + fall)	t_s + t_f	s	max		Switching Characteristics, rows "Storage Time" and "Fall Time". Add them.
Collector-base voltage	V_CBO	V	max		Absolute Maximum Ratings, row "Collector-Base Voltage" (V_CBO).
Emitter-base voltage	V_EBO	V	max		Absolute Maximum Ratings, row "Emitter-Base Voltage" (V_EBO).
Peak collector current	I_CM	A	max		Absolute Maximum Ratings, row "Peak Collector Current" (I_CM), with the pulse width in the footnote.
Collector cut-off current	I_CBO	A	max		Electrical Characteristics, row "Collector Cut-Off Current" (I_CBO).
Emitter cut-off current	I_EBO	A	max		Electrical Characteristics, row "Emitter Cut-Off Current" (I_EBO).
Base-emitter saturation voltage	V_BE(sat)	V	typ, max		Electrical Characteristics, row "Base-Emitter Saturation Voltage". I_C and I_B (usually a ratio of 10) in the conditions.
Storage time	t_s	s	max		Switching Characteristics, row "Storage Time".
Noise figure	NF	dB	typ		Electrical Characteristics, row "Noise Figure" with source resistance and f.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Transistor · P-channel MOSFET (transistor.pmos → device pmos)

Simulation pins: **d**, **g**, **s**. Symbol variants: enh, power, 4pin, dep. Curves: On-resistance vs gate voltage, Output characteristic, Input capacitance vs drain voltage, Output capacitance vs drain voltage, Reverse transfer capacitance vs drain voltage, On-resistance vs junction temperature, Gate threshold vs junction temperature, Gate voltage vs gate charge, Body diode forward characteristic, Transfer characteristic.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Drain-source voltage	V_DS	V	max		Absolute Maximum Ratings, row "Drain-Source Voltage" (V_DSS). Store as a positive number.
Continuous drain current	I_D	A	max		Absolute Maximum Ratings, row "Continuous Drain Current" at T_A = 25 °C (the T_C = 25 °C value assumes an ideal heatsink). Positive number.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Gate threshold voltage *	V_GS(th)	V	min, typ, max		Electrical Characteristics, "Static", row "Gate Threshold Voltage" at V_DS = V_GS, I_D = –250 µA. Store as a positive number.
Drain-source on-resistance *	R_DS(on)	Ohm	typ, max		Electrical Characteristics, row "Static Drain-Source On-Resistance" at the V_GS you will drive (for example V_GS = –4.5 V). Put that V_GS in the conditions.
Gate-source voltage	V_GS(max)	V	max		Absolute Maximum Ratings, row "Gate-to-Source Voltage" (±V_GS).
Input capacitance	C_iss	F	typ		Dynamic Characteristics, row "Input Capacitance" (C_iss) at the stated V_DS, 1 MHz.
Output capacitance	C_oss	F	typ		Dynamic Characteristics, row "Output Capacitance" (C_oss).
Reverse transfer capacitance	C_rss	F	typ		Dynamic Characteristics, row "Reverse Transfer Capacitance" (C_rss, the Miller capacitance).
Total gate charge	Q_g	C	typ, max		Dynamic Characteristics, row "Total Gate Charge" (Q_g) at the stated V_GS. Also in the gate-charge graph.
Forward transconductance	g_fs	S	min, typ		Static Characteristics, row "Forward Transconductance" at the stated V_DS and I_D.
Body diode forward voltage	V_SD	V	max		Source-Drain Diode Characteristics, row "Diode Forward Voltage" (V_SD) at I_S. Positive number.
Body diode reverse recovery time	t_rr	s	typ		Source-Drain Diode Characteristics, row "Reverse Recovery Time" (t_rr).
Continuous drain current at 100 °C	I_D(100)	A	max		Absolute Maximum Ratings, row "Continuous Drain Current" at T_C = 100 °C (the first row is usually 25 °C).
Pulsed drain current	I_DM	A	max		Absolute Maximum Ratings, row "Pulsed Drain Current" (I_DM). The pulse width is in the footnote.
On-resistance at low gate drive	R_DS(on)	Ohm	typ, max		Electrical Characteristics, the second R_DS(on) row (for example at V_GS = 4.5 V when the first is at 10 V). Put V_GS and I_D in the conditions.
On-resistance at high temperature	R_DS(on)	Ohm	typ, max		Electrical Characteristics at T_J = 125 or 150 °C, or the normalised R_DS(on) vs temperature graph times the 25 °C value.
Zero-gate-voltage drain current	I_DSS	A	max		Electrical Characteristics, row "Zero Gate Voltage Drain Current" (I_DSS), at V_DS = the rated voltage.
Gate-body leakage current	I_GSS	A	max		Electrical Characteristics, row "Gate-Body Leakage Current" (I_GSS) at V_GS = ±the rated gate voltage.
Gate resistance	R_G	Ohm	typ		Electrical Characteristics, row "Gate Resistance" (R_G) at f = 1 MHz.
Gate-source charge	Q_gs	C	typ		Electrical Characteristics, row "Gate-Source Charge" (Q_gs).
Gate-drain (Miller) charge	Q_gd	C	typ		Electrical Characteristics, row "Gate-Drain Charge" (Q_gd).
Turn-on delay time	t_d(on)	s	typ		Switching Characteristics, row "Turn-On Delay Time". The test circuit and R_G are in the conditions.
Rise time	t_r	s	typ		Switching Characteristics, row "Rise Time".
Turn-off delay time	t_d(off)	s	typ		Switching Characteristics, row "Turn-Off Delay Time".
Fall time	t_f	s	typ		Switching Characteristics, row "Fall Time".
Body diode continuous current	I_S	A	max		Absolute Maximum Ratings or Source-Drain Diode Characteristics, row "Continuous Source Current (Body Diode)".

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Body diode reverse recovery charge	Q_rr	C	typ		Source-Drain Diode table, row "Reverse Recovery Charge" (Q_rr), with I_F and di/dt in the footnote.
Single-pulse avalanche energy	E_AS	J	max		Absolute Maximum Ratings, row "Single Pulse Avalanche Energy" (E_AS). The starting T_J, L and I_AS are in the footnote.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Transistor · PNP BJT (transistor.pnp → device pnp)

Simulation pins: **c**, **b**, **e**. Curves: DC current gain vs collector current, Base-emitter voltage vs collector current, Collector-emitter saturation vs current, Transition frequency vs collector current, Output capacitance vs collector-base voltage.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
DC current gain *	h_FE		min, typ, max		Electrical Characteristics, "ON Characteristics", row "DC Current Gain" (h_FE) at the I_C / V_CE closest to your circuit (for example I_C = –10 mA, V_CE = –1 V).
Collector-emitter voltage	V_CEO	V	max		Absolute Maximum Ratings, row "Collector-Emitter Voltage" (V_CEO, base open). Store as a positive number.
Continuous collector current	I_C	A	max		Absolute Maximum Ratings, row "Collector Current - Continuous" (I_C). Store as a positive number.
Collector-emitter saturation voltage	V_CE(sat)	V	typ, max		ON Characteristics, row "Collector-Emitter Saturation Voltage" at I_C / I_B = 10. Store as a positive number.
Base-emitter voltage	V_BE(on)	V	min, typ, max		ON Characteristics, row "Base-Emitter On Voltage" V_BE(on) (or V_BE(sat)) at the stated I_C. Store as a positive number.
Transition frequency	f_T	Hz	min, typ		Small-Signal Characteristics, row "Current-Gain-Bandwidth Product" (f_T).
Output capacitance	C_obo	F	max		Small-Signal Characteristics, row "Output Capacitance" (C_obo, C_CB at V_CB = 5 V, 1 MHz).
Input capacitance	C_ibo	F	max		Small-Signal Characteristics, row "Input Capacitance" (C_ibo, C_EB at V_EB = 0.5 V, 1 MHz).
Early voltage (model)	V_AF	V	typ		Rarely listed: extrapolate the I_C vs V_CE output curves back to I_C = 0. Typical 50 to 150 V for small-signal parts.
Turn-on time (delay + rise)	t_d + t_r	s	max		Switching Characteristics, rows "Delay Time" and "Rise Time". Add them.
Turn-off time (storage + fall)	t_s + t_f	s	max		Switching Characteristics, rows "Storage Time" and "Fall Time". Add them.
Collector-base voltage	V_CBO	V	max		Absolute Maximum Ratings, row "Collector-Base Voltage" (V_CBO).
Emitter-base voltage	V_EBO	V	max		Absolute Maximum Ratings, row "Emitter-Base Voltage" (V_EBO).

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Peak collector current	I_CM	A	max		Absolute Maximum Ratings, row "Peak Collector Current" (I_CM), with the pulse width in the footnote.
Collector cut-off current	I_CBO	A	max		Electrical Characteristics, row "Collector Cut-Off Current" (I_CBO).
Emitter cut-off current	I_EBO	A	max		Electrical Characteristics, row "Emitter Cut-Off Current" (I_EBO).
Base-emitter saturation voltage	V_BE(sat)	V	typ, max		Electrical Characteristics, row "Base-Emitter Saturation Voltage". I_C and I_B (usually a ratio of 10) in the conditions.
Storage time	t_s	s	max		Switching Characteristics, row "Storage Time".
Noise figure	NF	dB	typ		Electrical Characteristics, row "Noise Figure" with source resistance and f.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal Characteristics / Thermal Information table, row "Junction-to-Ambient" (R_θJA). Note the PCB it is quoted on (JEDEC 1s or 2s2p).
Thermal resistance, junction to case	θ_JC	C/W	typ, max		Thermal Characteristics table, row "Junction-to-Case" (R_θJC). For power packages use the tab / bottom value.
Maximum junction temperature	T_J(max)	C	max		Absolute Maximum Ratings table, row "Junction Temperature" or "Operating Junction Temperature" (T_J).
Power dissipation	P_D	W	max		Absolute Maximum Ratings, row "Power Dissipation" (P_D or P_tot) at T_A = 25 °C. If only a derating curve exists read its 25 °C value.
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.

Transistors · Darlington array (transistors.darr → **device** darr)

Simulation pins: **in1**, **in2**, **in3**, **in4**, **in5**, **in6**, **in7**, **gnd**, **com**, **out7**, **out6**, **out5**, **out4**, **out3**, **out2**, **out1**. Symbol variants: uln2003, uln2803.

FIELD	SYMBOL	UNIT	COLUMNS	SETS	WHERE TO FIND IT IN THE DATASHEET
Collector-emitter saturation *	V_CE(sat)	V	max	**vce_sat**	Electrical characteristics, "V_CE(sat)" at I_C = 200 mA (or 350 mA).
Output current per channel	I_C	A	max	**imax**	Absolute maximum, "Output current".
Input resistance	R_IN	Ohm	typ	**rin**	Equivalent schematic: series input resistor (2.7 kΩ for ULN2003).
Output voltage	V_CE	V	max		Absolute maximum, "Output voltage" (informational).
Operating temperature range	T_op	C	min, max		Features or Recommended Operating Conditions, row "Operating Temperature Range" (minimum and maximum).
Pin count	N_pins		typ		Package / Pin Configuration drawing on page 1 or 2. Count every terminal including the exposed pad.
Thermal resistance, junction to ambient	θ_JA	C/W	typ, max		Thermal characteristics table, "Thermal resistance junction to ambient".

74 Environment variables and files

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Environment variables change where BetterSPICE looks for things. The desktop app reads them from your user environment when it starts.

74.1 For users and integrators

VARIABLE	MEANING	DEFAULT
BSPICE_NGSPICE	ngspice.dll, or the folder containing it.	Next to the app, or vendor\ngspice\bin.
BSPICE_PSPICE	pspice.exe or its folder. **0** or **off** turns PSpice off.	Found from the registry, C:\Cadence\PSpiceTI, and C:\Cadence, C:\Program Files\Cadence, C:\OrCAD.
BSPICE_PSPICE_TRACES	The most traces saved per PSpice run.	4 for PSpice for TI, unlimited otherwise.
BSPICE_PORT	The AI agent control port, for the app and the agent.	47800
BSPICE_AGENT_NAME	The agent's name shown in the app.	The name the agent reports.
BSPICE_EXAMPLES	The folder of example circuits.	examples next to the app.
BSPICE_PARTS	The folder of part files for the command line.	parts, searched upward.
BSPICE_MODELS	Folders, separated by semicolons, searched first for the vendor model library.	The repository, %APPDATA%\BetterSPICE\models, the working folder.
BETTERSPICE_CATALOG	The model catalogue folder.	ui\public\catalog, searched upward.
BSPICE_THREADS	Threads for bspice and the app's native engines: **auto** or a number. 1 is sequential. **–threads** and the app's Threads menu override it.	auto: every core but one.
BSPICE_LOAD_THREADS	Threads for the device load of one run: a number. Without it a run uses up to 4 when its device load takes more than about 9 µs a step, else one. The result is the same on any number.	automatic
BSPICE_NO_FMA	**1** makes the math library take its plain path on processors with AVX2 and FMA too. The result is the same bits, only slower. For checks.	off
SPICE_LIB_DIR	Where ngspice finds its code models.	Set from the ngspice folder.

74.2 For debugging

VARIABLE	MEANING
BSPICE_NGSPICE_ECHO	Print every ngspice output line to standard error.
BSPICE_PSPICE_KEEP	Keep the PSpice run folders.
BSPICE_PSPICE_DEBUG	Print PSpice's dialogs when it hangs.
BSPICE_PSPICE_TIMEOUT	Seconds per circuit when the catalogue is checked in PSpice (60).
BSPICE_MODELS_DEBUG, **BSPICE_MODELS_DUMP**	Folders to keep failing, or all, test decks of the catalogue check.
BSPICE_SEARCH_DEBUG	A file for the log of the pin search.
BSPICE_RESOLVE_TRACE	Trace how model dependencies are found.
BSPICE_VENDOR_DUMP	A folder for verify-vendor decks.

74.3 Files the desktop app keeps

IN %APPDATA%\BETTERSPICE	PURPOSE
agent-token	The AI agent key, made at the first start.
betterspice.log	The log, restarted at 1 MB with the previous kept as .old.
recent.json	Recent files. A damaged one is kept as recent.json.bad.
window.json	Window size and position.
autosave-discarded	Written by Don't save, so the autosave copy isn't recovered.
parts	My parts.
models	An optional place for the vendor model library.

74.4 Browser storage

KEY	PURPOSE
bs.layout	Pane sizes.
bs.currentSpeed	The current dot speed.
bspice.autosave.v1	Autosave copies of unsaved circuits.
bs.partWizard.v1	Part Wizard progress.
bspice.agentRelay, **bspice.agentPort**	The browser version's agent relay: off, and its port.

75 Install details: files, engines, browser

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The steps to install are in **Install and start**, p. 9. This chapter is the detail: what goes where, where BetterSPICE looks for ngspice and PSpice, and how the desktop app and the browser version differ.

75.1 What the installer puts where

LOCATION	WHAT IT HOLDS
Install folder	**betterspice.exe**, **bspice.exe** (the command line), **ngspice.dll** and its code models (**vendor\ngspice\bin**), the **examples** folder and the model catalogue (the list of models). The vendor model files themselves aren't installed: Simulate finds them in a folder with the model library (**Where the models come from**, p. 401).
%APPDATA%\BetterSPICE\window.json	Window size, position and maximised state. Restored at the next start if the monitor is still there.
%APPDATA%\BetterSPICE\recent.json	The last 10 circuits you opened or saved. File shows 8 of them.
%APPDATA%\BetterSPICE\parts	My parts: the **.bspart** and **.bssym** files you made or added.
%APPDATA%\BetterSPICE\agent-token	The key an AI agent needs to reach the running app (**Working with an AI agent**, p. 591).
%APPDATA%\BetterSPICE\betterspice.log	Problems the app can't show anywhere else, and start-up timings. It restarts at 1 MB and keeps the previous one as **.old**. **Help** › **About BetterSPICE** shows the folder.

75.2 ngspice for vendor models

Simulate runs circuits with vendor subcircuit models (op-amps, regulators, current-sense amplifiers, references) in ngspice-47 through **ngspice.dll**. The installer ships it. BetterSPICE looks for it in this order:

1. The folder named by the environment variable **BSPICE_NGSPICE**.
2. Next to **betterspice.exe**.
3. In **vendor\ngspice\bin** of a source checkout. **scripts\fetch-ngspice.ps1** downloads it there.

The status bar says **ngspice 47 ready** when it's found and **ngspice not found** when it's not. Without ngspice, Simulate still runs circuits made only of built-in parts and discrete vendor models (diodes, transistors) in the BetterSPICE engine. A circuit that needs ngspice stops with a banner, **E_NGSPICE_MISSING**, and never fails silently.

75.3 PSpice for TI

Some Texas Instruments models are encrypted by Cadence and only PSpice can read them. If PSpice for TI is installed (free from ti.com, default folder **C:\Cadence\PSpiceTI**), Simulate runs those models in PSpice, hidden, and shows the result like any other run. The progress line says **Simulating in PSpice (encrypted vendor models)**. The environment variable **BSPICE_PSPICE** points to another installation, or turns PSpice off when set to **0**. **PSpice for encrypted models**, p. 224 explains the limits.

75.4 The browser version

The same interface runs in a current Chrome or Edge. Files open through the browser's file picker and save as downloads. Your own parts are kept in the browser's storage (IndexedDB). Simulate and the analyses run the BetterSPICE engine compiled to WebAssembly, in a pool of background workers. The browser version can't run ngspice or PSpice.

75.5 The command line

bspice.exe runs the same engine without a window: check circuits, run analyses into CSV, render pictures, build reports, import boards and verify against ngspice. It's installed next to the app.
The command line (bspice), p. 596 lists every command and option.

75.6 Desktop or browser

FEATURE	DESKTOP	BROWSER
Editor, live simulation, scopes, logic analyzer, inspector, library, model dialog, Part Wizard, symbol editor, examples, import, export image and netlist	Yes	Yes
Native Open and Save dialogs, Save as remembering the folder	Yes	File picker and downloads
Recent files, file associations, one window for every file opened from Explorer	Yes	No
Reload when the open file changes on disk	Yes	No
Window size and position remembered, Save / Don't save / Cancel on close	Yes	The browser's "Leave site?" prompt

FEATURE	DESKTOP	BROWSER
ngspice for vendor models, PSpice for encrypted models	Yes	No, built-in engine only
Report	Native, with every analysis	Built in the page: schematic, parts, operating point, waveforms, diagnostics
AI agents	Built in, port 47800	Through **bspice serve** on the same computer
Pop-out windows for scopes, the dock and the Analysis view	Yes	Yes, if pop-ups are allowed
My parts storage	**%APPDATA%\BetterSPICE\parts**	Browser storage
Autosave and recovery of unsaved circuits	Yes	Yes

75.7 System requirements

REQUIREMENT	VALUE
Operating system	Windows 10 or 11, 64-bit
Memory	8 GB. Large vendor-model transients in ngspice use more.
Display	The window needs at least 1024 x 640. The layout is designed for 1440 x 900 and up, and opens at 1600 x 1000.
Fonts	Barlow and JetBrains Mono are loaded from Google Fonts. Offline, the app falls back to the system sans-serif.
Browser version	A current Chrome or Edge

76 Verification

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76.5 The numbers 680

BetterSPICE sorts its devices into two classes, exact and approximate, and says which class every part is in, in reports and in the library's level badges (a group shows a badge only when it's not exact). **Exact and approximate**, p. 34 explains what the classes mean. This chapter is how they are checked.

76.1 The verification set

438 circuits in **verification/circuits** each come with an expected result. Run the check yourself:

```
bspice verify verification/circuits --html verification/report.html
```

It runs every circuit in both engines, compares every signal and writes an HTML report with overlay plots: BetterSPICE solid, ngspice dashed. The logic parts are part of those ngspice runs, and an inductor's current is compared with its parallel Rp and Cp included. It exits with 1 if any circuit fails. **—failures** lists only failures, **—json** writes machine-readable results.

SET (0.8.0)	CIRCUITS	ANALYSES	SIGNALS	RESULT
verification/circuits	438	791	4,892	all pass: 3,797 against ngspice, 1,095 against a closed form or a datasheet window
verification/params (datasheet parameters)	74	117	417	all pass
bspice verify examples —all	193 of the 715 examples compared point by point		3,415	all pass. The rest hold approximate-class parts or vendor models and are skipped or measured as approximate, with the parts named.

Not comparable is not a failure. A comparison with ngspice fails only when ngspice has the function, a model or element for the part, and the results disagree. Parts ngspice cannot simulate, such as the microcontroller, ctrl scripts and behavioural blocks with no ngspice element, are checked on BetterSPICE's own result against a closed form or a datasheet window instead. 162 of the 438 circuits are checked that way, and the run notes *closed-form checks on bs-engine's result (no ngspice reference for these parts)*. A run that compares nothing says SKIP with the reason and exits with

1, never *0 / 0 pass*. A circuit with vendor models is compared with the deck Simulate runs, and a switching one is measured by its steady state (the means of the last quarter, the switching frequency and the duty).

76.2 The beta test suite

One runner checks a build before a release: **python tools/test/run_tier.py quick**, **prerelease** or **weekly**. Its entries cover verify and the parameter circuits, the live view against Simulate (about 6,350 checks) and the native engine against WebAssembly bit for bit, about 1,100 checks in the real app with 84 screenshot baselines and 25 import fixtures, edge cases and fuzzers for the command line, MCP and the file readers, the update path on a mock server, Linux in WSL, and the Rust and UI test suites. A skip is never counted as a pass, and a failing check of a known bug names the bug. **tools/test/README.md** describes the tiers and how to run one entry.

76.3 The model catalogue

Every model in the library was run before it was listed. **The model catalogue**, p. 401 explains how: each model is placed in a test circuit for its kind, run in ngspice (or PSpice for encrypted models), and checked for sensible behaviour. Models that can't run in any engine aren't in the app.

76.4 Robustness against ngspice and LTspice

docs/ROBUSTNESS.md counts how often each simulator reads a netlist and runs it to the end. The same netlists, 1,061 analyses from 271 verification circuits and 193 example circuits, went through BetterSPICE and ngspice 47 on 16 November 2026. BetterSPICE ran 1,060 of them to the end with its convergence rescue switched off (**bspice –rescue off**), which is the same footing as ngspice and LTspice, and all 1,061 with it on: the rescue fired once. ngspice did not finish 8. LTspice 26.1.1 was not run again for this release. Its column holds the runs of 8 November 2026 for the 678 analyses whose netlist is byte for byte the same as then, and it could not read 3 of them, because they use ngspice-only parameters.

	BETTERSPICE (RESCUE OFF)	BETTERSPICE (DEFAULT)	NGSPICE	LTSPICE (8 NOVEMBER 2026)
Netlist read (1,061 analyses)	1,061	1,061	1,061	675 of 678
Ran to the end	1,060	1,061	1,053	675 of 678
Within the strict verify tolerances of ngspice	929 of 1,052	930 of 1,053	reference	420 of 672
Median time per run	0.06 s	0.06 s	0.08 s	0.51 s

The agreement row uses a strict point-by-point rule, stricter than **bspice verify**, which passes every one of its signals, so 929 of 1,052 is not a contradiction. LTspice differs more because its device models differ from ngspice's. Method, failure messages and limits are in the page.

76.5 The numbers

WHAT	NUMBER
Models in the library search	**169 551**
Example circuits	**715** in 40 categories
Part Wizard templates	**137**
Engine verification circuits	**438**

A–Z Index

Terms, tasks, on-screen words, diagnostic codes, parameter keys, file types and environment variables. *see* sends you to the word this manual uses. Sub-entries name the chapter or the part.

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The source of truth

This manual is a rendering, not an original. Where it and the files disagree, the files win and this manual is out of date.

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