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# Calculator Tools

The KiCad Team

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*Reference manual*

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### Contributors

Heitor de Bittencourt. Mathias Neumann

### Feedback

The KiCad project welcomes feedback, bug reports, and suggestions related to the software or its documentation. For more information on how to submit feedback or report an issue, please see the instructions at <https://www.kicad.org/help/report-an-issue/>

## 1. Introduction

The KiCad PCB Calculator is a set of utilities to help you find the values of components or other parameters of a layout. The Calculator has the following tools:

- Regulators
- Track Width
- Electrical Spacing
- Trans Line

- RF Attenuators
- Color Code
- Board Classes

## 2. Calculators

### 2.1. Regulators

This calculator helps with the task of finding the values of the resistors needed for linear and low-dropout voltage regulators.

The screenshot shows the 'Regulators' tab in the 'PCB Calculator' software. The 'Type' is set to 'Standard Type'. The circuit diagram shows a voltage regulator with input  $V_{in}$ , output  $V_{out}$ , reference voltage  $V_{ref}$ , and resistors  $R_1$  and  $R_2$ . The formula  $V_{out} = V_{ref} \cdot (R_1 + R_2) / R_2$  is displayed. The input fields are:  $R_1$  (10 kΩ),  $R_2$  (10 kΩ),  $V_{out}$  (12 V),  $V_{ref}$  (3 V), and  $I_{adj}$  (μA). Buttons for 'Calculate' and 'Reset to Defaults' are present. A 'Regulator' dropdown menu is also visible.

For the *Standard Type*, the output voltage  $V_{out}$  as a function of the reference voltage  $V_{ref}$  and resistors  $R_1$  and  $R_2$  is given by:

$$V_{out} = V_{ref} \cdot \left( \frac{R_1 + R_2}{R_2} \right)$$

For the *3 terminal type*, there is a correction factor due to the quiescent current  $I_{adj}$  flowing from the adjust pin:

$$V_{out} = V_{ref} \cdot \left( \frac{R_1 + R_2}{R_1} \right) + I_{adj} \cdot R_2$$

This current is typically below 100 uA and can be neglected with caution.

To use this calculator, enter the parameters of the regulator *Type*, *Vref* and, if needed, *Iadj*, select the field you want to calculate (one of the resistors or the output voltage) and enter the other two values.

## 2.2. RF-Attenuators

With the RF Attenuator utility you can calculate the values of the resistors needed for different types of attenuators:

- PI
- Tee
- Bridged Tee
- Resistive Splitter

To use this tool, first select the type of attenuator you need, then enter the desired attenuation (in dB) and input/output impedances (in Ohms).

The screenshot shows the 'PCB Calculator' window with the 'RF Attenuators' tab selected. Under 'Attenuators', the 'Pi' option is chosen. The circuit diagram shows a Pi network with input impedance  $Z_{in}$ , output impedance  $Z_{out}$ , and resistors  $R1$ ,  $R2$ , and  $R3$ . The 'Parameters' section has 'Attenuation (a): 6 dB',  $Z_{in}: 50 \Omega$ , and  $Z_{out}: 50 \Omega$ . The 'Values' section has empty fields for  $R1$ ,  $R2$ , and  $R3$ . The 'Formula' section displays the following equations:

$$L = 10^{a/20}$$

$$A = (L+1) / (L-1)$$

$$R2 = (L-1) / 2 \cdot \sqrt{(Z_{in} \cdot Z_{out} / L)}$$

$$R1 = 1 / (A/Z_{in} - 1/R2)$$

$$R3 = 1 / (A/Z_{out} - 1/R2)$$

## 2.3. E-Series

This calculator helps to identify combinations of standard E-series resistors that meet a required resistance, optionally excluding several resistor values that are not available.

**PCB Calculator**

Regulators RF Attenuators **E-Series** Color Code TransLine Via Size Track Width Electrical Spacing Board Classes

**Inputs**

Required resistance:  kΩ

Exclude value 1:  kΩ

Exclude value 2:  kΩ

☐ E1 ☐ E3 ☒ E6 ☐ E12 ☐ E24

**Solutions**

Simple solution:  Error:  %

3R solution:  Error:  %

4R solution:  Error:  %

**Calculate**

**Help**

E-series are defined in IEC 60063.

Available values are approximately equally spaced in a logarithmic scale.

E24 (5%): 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0 3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1

E12 (10%): 1.0 1.2 1.5 1.8 2.2 2.7 3.3 3.9 4.7 5.6 6.8 8.2

E6 (20%): 1.0 - 1.5 - 2.2 - 3.3 - 4.7 - 6.8 -

E3 (50%): 1.0 - - - 2.2 - - - 4.7 - - -

E1 : 1.0 - - - - - - - - - -

- This calculator finds combinations of standard E-series (between 10Ω and 1MΩ) to create arbitrary values.
- You can enter the required resistance from 0.0025 to 4000 kΩ.
- Solutions using up to 4 components are given.

The requested value is always excluded from the solution set.

## 2.4. Color-Code

This calculator helps translating the color bars from the resistor to its value. To use it, first select the *tolerance* of the resistor: 10%, 5% or equal or smaller than 2%. For example:

- Yellow Violet Red Gold:  $4\ 7\ \times 100 \pm 5\% = 4700\ \text{Ohm}$ , 5% tolerance
- 1kOhm, 1% tolerance: Brown Black Black Brown Brown

**PCB Calculator**

Regulators RF Attenuators E-Series **Color Code** TransLine Via Size Track Width Electrical Spacing Board Classes

**Tolerance**

☒ 10% / 5% ☐ <= 2%

	1st Band	2nd Band	3rd Band	Multiplier	Tolerance
Black	0	0	0	x 1	
Brown	1	1	1	x 10	± 1%
Red	2	2	2	x 100	± 2%
Orange	3	3	3	x 1k	
Yellow	4	4	4	x 10k	
Green	5	5	5	x 100k	± 0.5%
Blue	6	6	6	x 1M	± 0.25%
Violet	7	7	7	x 10M	± 0.10%
Gray	8	8	8	x 100M	± 0.05%
White	9	9	9	x 1G	
Gold				x 0.1	± 5%
Silver				x 0.01	± 10%

## 2.5. TransLine

Transmission line theory is a cornerstone in the teaching of RF and microwave engineering.

In the calculator you can choose different sorts of Line Types and their special parameters. The models implemented are frequency-dependent, so they disagree with simpler models at high *enough* frequencies.

This calculator is heavily based on Transcalc [<http://transcalc.sourceforge.net/>].

The transmission line types and the reference of their mathematical models are listed below:

- Microstrip line:
  - H. A. Atwater, "Simplified Design Equations for Microstrip Line Parameters", Microwave Journal, pp. 109-115, November 1989.
- Coplanar wave guide.
- Coplanar wave guide with ground plane.
- Rectangular waveguide:
  - S. Ramo, J. R. Whinnery and T. van Duzer, "Fields and Waves in Communication Electronics", Wiley-India, 2008, ISBN: 9788126515257.
- Coaxial line.
- Coupled microstrip line:
  - H. A. Atwater, "Simplified Design Equations for Microstrip Line Parameters", Microwave Journal, pp. 109-115, November 1989.
  - M. Kirschning and R. H. Jansen, "Accurate Wide-Range Design Equations for the Frequency-Dependent Characteristic of Parallel Coupled Microstrip Lines," in IEEE Transactions on Microwave Theory and Techniques, vol. 32, no. 1, pp. 83-90, Jan. 1984. doi: 10.1109/TMTT.1984.1132616.
  - Rolf Jansen, "High-Speed Computation of Single and Coupled Microstrip Parameters Including Dispersion, High-Order Modes, Loss and Finite Strip Thickness", IEEE Trans. MTT, vol. 26, no. 2, pp. 75-82, Feb. 1978.
  - S. March, "Microstrip Packaging: Watch the Last Step", Microwaves, vol. 20, no. 13, pp. 83-94, Dec. 1981.
- Stripline.
- Twisted pair.

**PCB Calculator**

Regulators RF Attenuators E-Series Color Code **TransLine** Via Size Track Width Electrical Spacing Board Classes

**Transmission Line Type**

- ☒ Microstrip Line
- ☐ Coplanar wave guide
- ☐ Coplanar wave guide w/ ground plane
- ☐ Rectangular Waveguide
- ☐ Coaxial Line
- ☐ Coupled Microstrip Line
- ☐ Stripline
- ☐ Twisted Pair

**Substrate Parameters**

$\epsilon_r$ : 4.6

$\tan \delta$ : 0.02

$\rho$ : 1.72e-08

H: 0.2 mm

H(top): 1e+20 mm

T: 0.035 mm

Roughness: 0 mm

$\mu(\text{substrate})$ : 1

$\mu(\text{conductor})$ : 1

**Physical Parameters**

W: 0.2 mm

L: 50 mm

Analyze Synthesize

**Electrical Parameters**

Z0: 50  $\Omega$

Ang. l: 0 rad

**Results**

Effective  $\epsilon_r$ :  
 Conductor losses:  
 Dielectric losses:  
 Skin depth:

Frequency: 1 GHz

Reset to Defaults

## 2.6. Via Size

The Via Size tool calculates the electrical and thermal properties of a given plated through-hole pad or via.

**PCB Calculator**

Regulators RF Attenuators E-Series Color Code TransLine **Via Size** Track Width Electrical Spacing Board Classes

**Parameters**

Finished hole diameter (D): 0.4 mm

Plating thickness (T): 0.035 mm

Via length: 1.6 mm

Via pad diameter: 0.6 mm

Clearance hole diameter: 1.0 mm

Z0: 50  $\Omega$

Applied current: 1 A

Plating resistivity: 1.72e-8  $\Omega \cdot m$

Substrate relative permittivity: 4.5

Temperature rise: 10  $^{\circ}C$

Pulse rise time: 1 ns

**Results**

Resistance: 0.000575362  $\Omega$   
 Voltage drop: 0.000575362 V  
 Power loss: 0.000575362 W  
 Thermal resistance: 83.2937  $^{\circ}C/W$   
 Estimated ampacity: 2.9993 A  
 Capacitance: 0.599508 pF  
 Rise time degradation: 32.9729 ps  
 Inductance: 1.20723 nH  
 Reactance: 3.79262  $\Omega$

Reset to Defaults

## 2.7. Track Width

The Track Width tool calculates the trace width for printed circuit board conductors for a given current and temperature rise. It uses formulas from IPC-2221 (formerly IPC-D-275).

**PCB Calculator**

Regulators RF Attenuators E-Series Color Code TransLine Via Size **Track Width** Electrical Spacing Board Classes

Parameters

Current (I): 1.0 A

Temperature rise (ΔT): 10.0 °C

Conductor length: 20 mm

Copper resistivity: 1.72e-08 Ω·m

External Layer Traces

Trace width (W): 0.300387 mm

Trace thickness (H): 0.035 mm

Cross-section area: 0.0105135 mm²

Resistance: 0.0327197 Ω

Voltage drop: 0.0327197 V

Power loss: 0.0327197 W

Internal Layer Traces

Trace width (W): 0.781437 mm

Trace thickness (H): 0.035 mm

Cross-section area: 0.0273503 mm²

Resistance: 0.0125776 Ω

Voltage drop: 0.0125776 V

Power loss: 0.0125776 W

Reset to Defaults

If you specify the maximum current, then the trace widths will be calculated to suit.

If you specify one of the trace widths, the maximum current it can handle will be calculated. The width for the other trace to also handle this current will then be calculated.

The controlling value is shown in bold.

The calculations are valid for currents up to 35 A (external) or 17.5 A (internal), temperature rises up to 100 °C, and widths of up to 400 mils (10 mm).

The formula, from IPC 2221, is

$$I = K \sqrt{\Delta T^{0.44} \sqrt{W \sqrt{H}}^{0.725}}$$

where:

I is maximum current in A

ΔT is temperature rise above ambient in °C

W is width in mils

H is thickness (height) in mils

K is 0.024 for internal traces or 0.048 for external traces

## 2.8. Electrical Spacing

This table helps finding the minimum clearance between conductors.

Each line of the table has a minimum recommended distance between conductors for a given voltage (DC or AC peaks) range. If you need the values for voltages higher than 500V, enter the value in the box in the left corner and press *Update Values*.

**PCB Calculator**

Regulators RF Attenuators E-Series Color Code TransLine Via Size Track Width **Electrical Spacing** Board Classes

Note: Values are minimal values (from IPC 2221)

mm

Voltage > 500 V: 500

Update Values

	B1	B2	B3	B4	A5	A6	A7
0 .. 15 V	0.05	0.1	0.1	0.05	0.13	0.13	0.13
16 .. 30 V	0.05	0.1	0.1	0.05	0.13	0.25	0.13
31 .. 50 V	0.1	0.6	0.6	0.13	0.13	0.4	0.13
51 .. 100 V	0.1	0.6	1.5	0.13	0.13	0.5	0.13
101 .. 150 V	0.2	0.6	3.2	0.4	0.4	0.8	0.4
151 .. 170 V	0.2	1.25	3.2	0.4	0.4	0.8	0.4
171 .. 250 V	0.2	1.25	6.4	0.4	0.4	0.8	0.4
251 .. 300 V	0.2	1.25	12.5	0.4	0.4	0.8	0.8
301 .. 500 V	0.25	2.5	12.5	0.8	0.8	1.5	0.8
> 500 V	0.25	2.5	12.5	0.8	0.8	1.5	0.8

\* B1 - Internal Conductors

\* B2 - External Conductors, uncoated, sea level to 3050 m

\* B3 - External Conductors, uncoated, over 3050 m

\* B4 - External Conductors, with permanent polymer coating (any elevation)

\* A5 - External Conductors, with conformal coating over assembly (any elevation)

\* A6 - External Component lead/termination, uncoated

\* A7 - External Component lead termination, with conformal coating (any elevation)

## 2.9. Board-Classes

### Performance Classes

In IPC-6011 have been three performance classes established

- **Class 1 General Electronic Products:** Includes consumer products, some computer and computer peripherals suitable for applications where cosmetic imperfections are not important and the major requirement is function of the completed printed board.
- **Class 2 Dedicated Service Electronic Products:** Includes communications equipment, sophisticated business machines, instruments where high performance and extended life is required and for which uninterrupted service is desired but not critical. Certain cosmetic imperfections are allowed.
- **Class 3 High Reliability Electronic Products:** Includes the equipment and products where continued performance or performance on demand is critical. Equipment downtime cannot be tolerated and must function when required such as in life support items or flight control systems. Printed boards in this class are suitable for applications where high levels of assurance are required and service is essential.

### PCB Types

In IPC-6012B there are also 6 Types of PCB defined:

- Printed Boards without plated through holes (1)
  - 1 Single-Sided Board
- And Boards with plated through holes (2-6)
  - 2 Double-Sided Board
  - 3 Multilayer board without blind or buried vias
  - 4 Multilayer board with blind and/or buried vias
  - 5 Multilayer metal core board without blind or buried vias
  - 6 Multilayer metal core board with blind and/or buried vias



## Calculator Tools

PCB Calculator

RegulatorsRF AttenuatorsE-SeriesColor CodeTransLineVia SizeTrack WidthElectrical SpacingBoard Classes

Note: Values are minimal values

mm

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Lines width	0.8	0.5	0.31	0.21	0.15	0.12
Min clearance	0.68	0.5	0.31	0.21	0.15	0.12
Via: (diam - drill)	--	--	0.45	0.34	0.24	0.2
Plated Pad: (diam - drill)	1.19	0.78	0.6	0.49	0.39	0.35
NP Pad: (diam - drill)	1.57	1.13	0.9	--	--	--