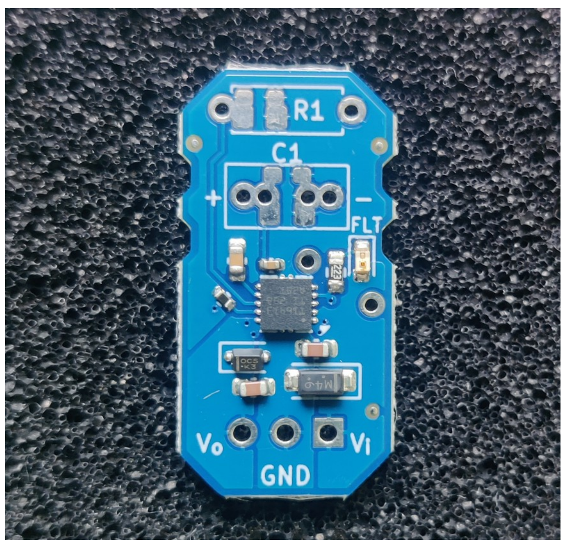
eFuse Module TPS16413

by

Last updated on 2024/12/30



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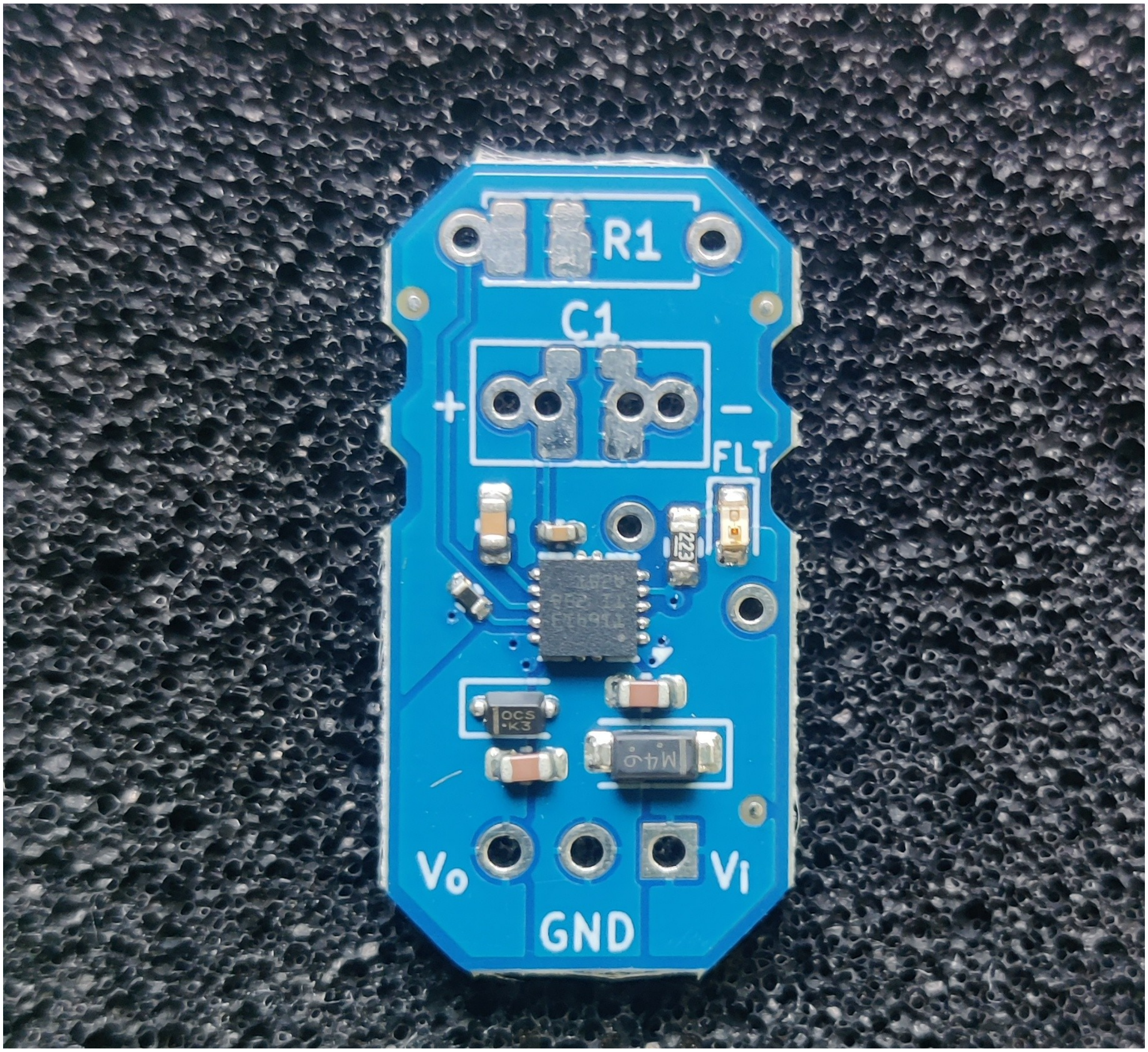
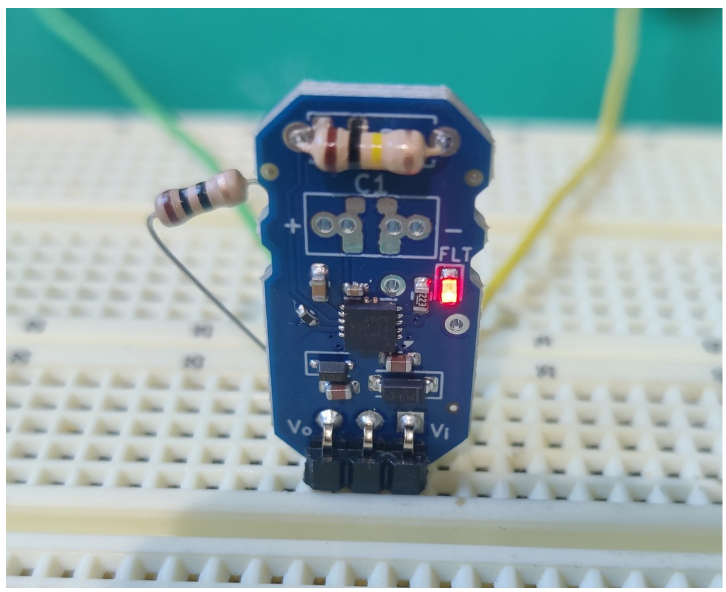


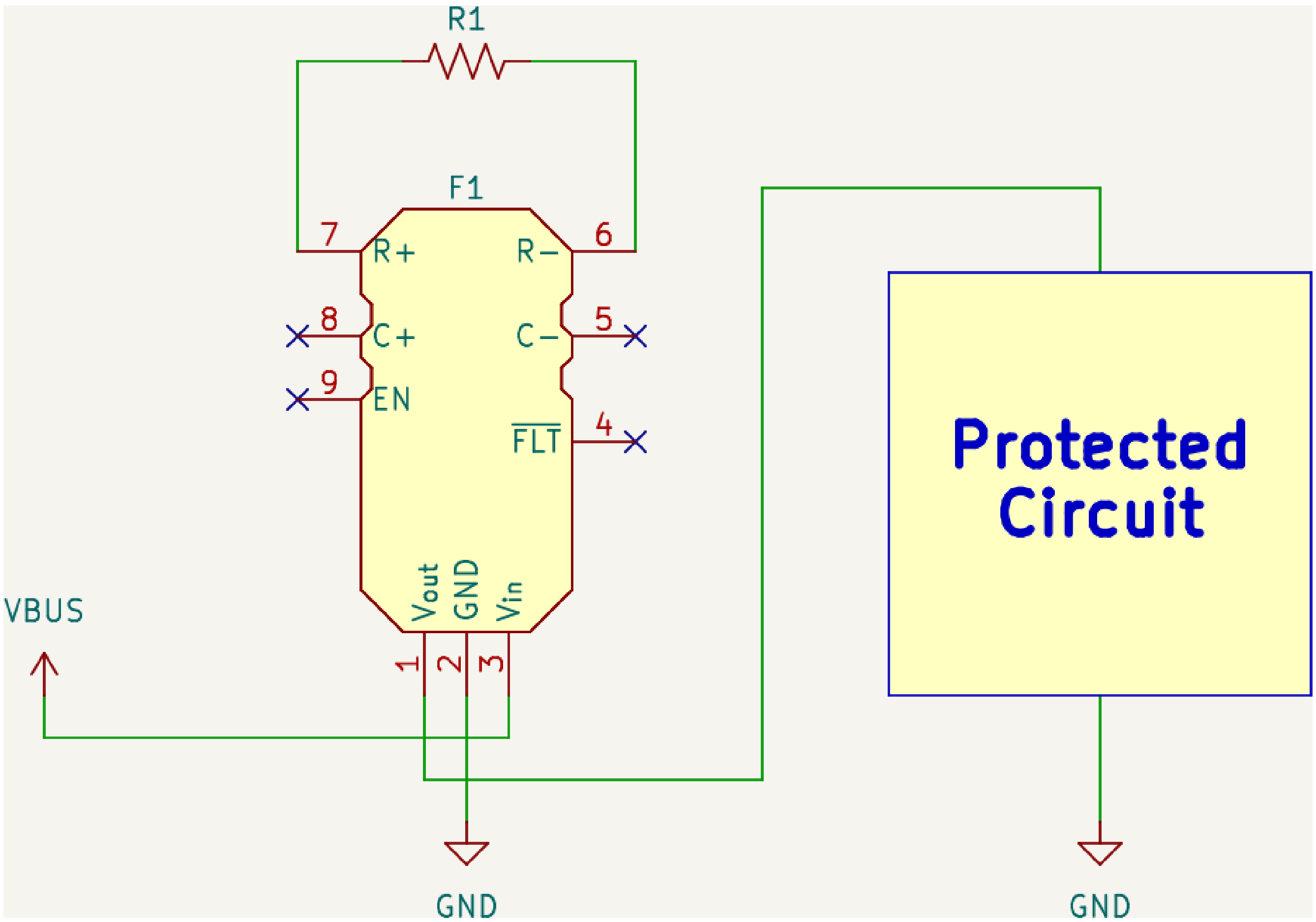
You control voltages with regulators, DC-DC converters, and specialized diodes. Traditional fuses and Positive Thermal Coefficient (PTC) fuses can help you control currents, but there is a catch: they only trip when they get too hot. This can also be dangerously slow - while the fuse is heating up, so is something else in your circuit! Because on their reliance on temperature, they may also trip prematurely during summer, or fail to trip during winter. What if you need something faster and more accurate?

Enter electronic fuses, or eFuses. Instead of waiting for the something to overheat, eFuses actively monitor current and cut it off quickly when needed. Unfortunately for hobbyists, eFuses come only in surface-mount packages, which makes them a hassle to use on breadboards.

The eFuse Module TPS16413 takes care of that hassle for you and delivers the accuracy and speed of an eFuse in a breadboard-friendly package. The TPS16413 eFuse from Texas Instruments has a 6% current limit accuracy (effectively 11.3% if you use 5% resistors) and works with better consistency over a wide range of ambient temperatures, with a default time to trip of only 19.5 milliseconds. When it trips, an on-board Fault LED lights up, informing you that it tripped. No need for an infrared thermometer or burned fingertips!



To use it, all you have to do is add a resistor for a current limit of your choice and a header. If you expect significant inrush current spikes, the eFuse Module TPS16413 also features a footprint for a timing capacitor to prevent the eFuse from working *too* fast. For advanced users, Enable and $\overline{\text{Fault}}$ test points offer more control over the module.

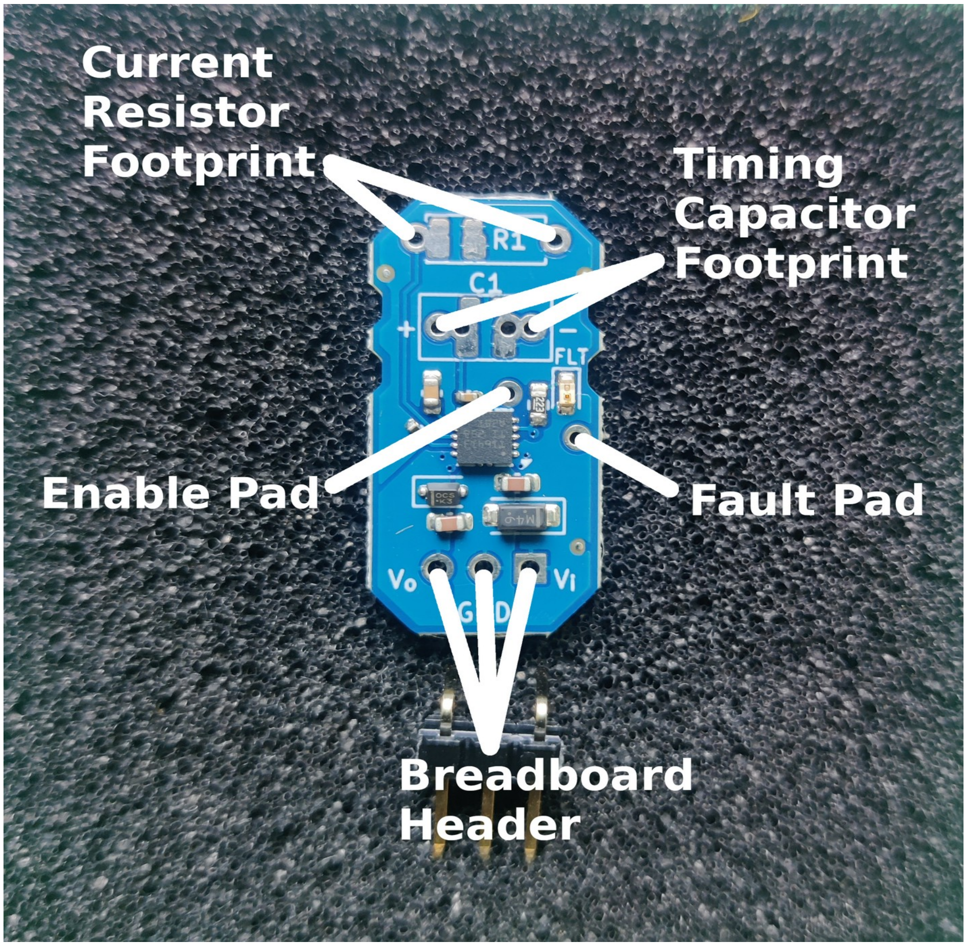


Technical Details

eFuse Module Specifications:

- eFuse: Texas Instruments TPS16413
- Operating voltage: 2.7 V - 24 V
- Range of adjustable current limit: 30 mA - 1800 mA
- Time to trip: 19.5 ms *(but can be higher with a timing capacitor)*
- eFuse current limit accuracy: 6% *(plus the tolerance of your current-limit resistor)*
- eFuse internal resistance: 0.152 Ω
- Maximum input circuit inductance: 100 uH
- Power-on slew rate: 1.00 V/ms ±40%

Pinouts



Breadboard Header

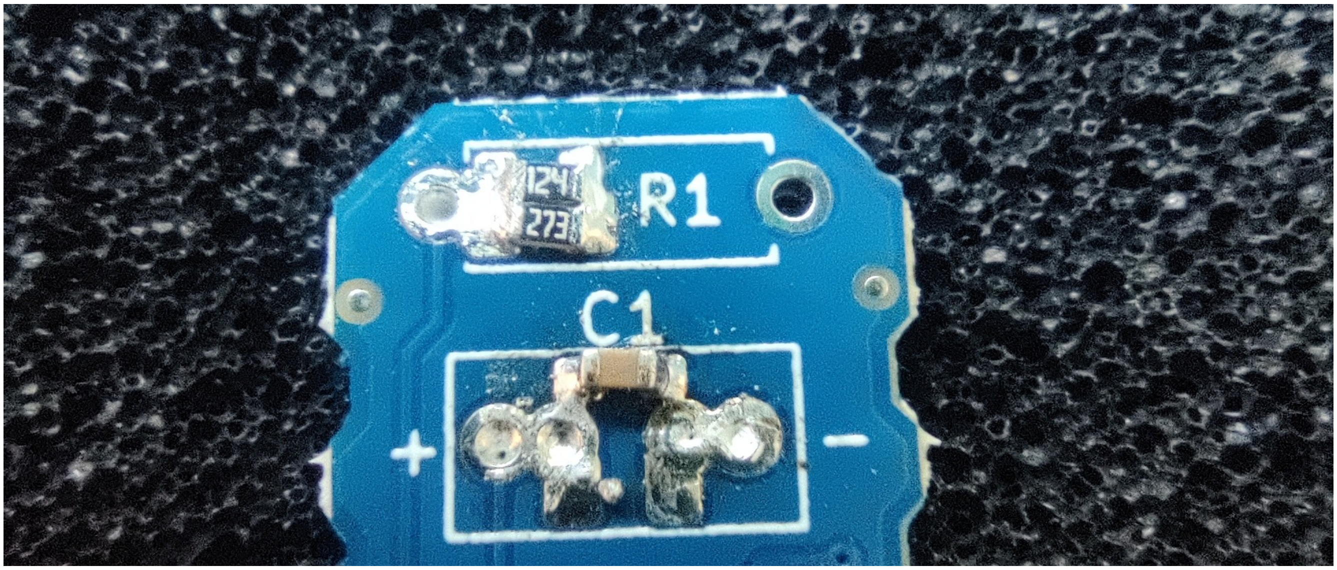
These are the eFuse Module's main connections. In order from left to right:

- **V$_{out}$**: Where checked current comes out to power your circuit.
- **GND**: The ground connection.
- **V$_{in}$**: Where unchecked current comes in from the power supply. To avoid damaging the eFuse Module, input circuit inductance must not exceed 100 μH and input Voltage must be positive.

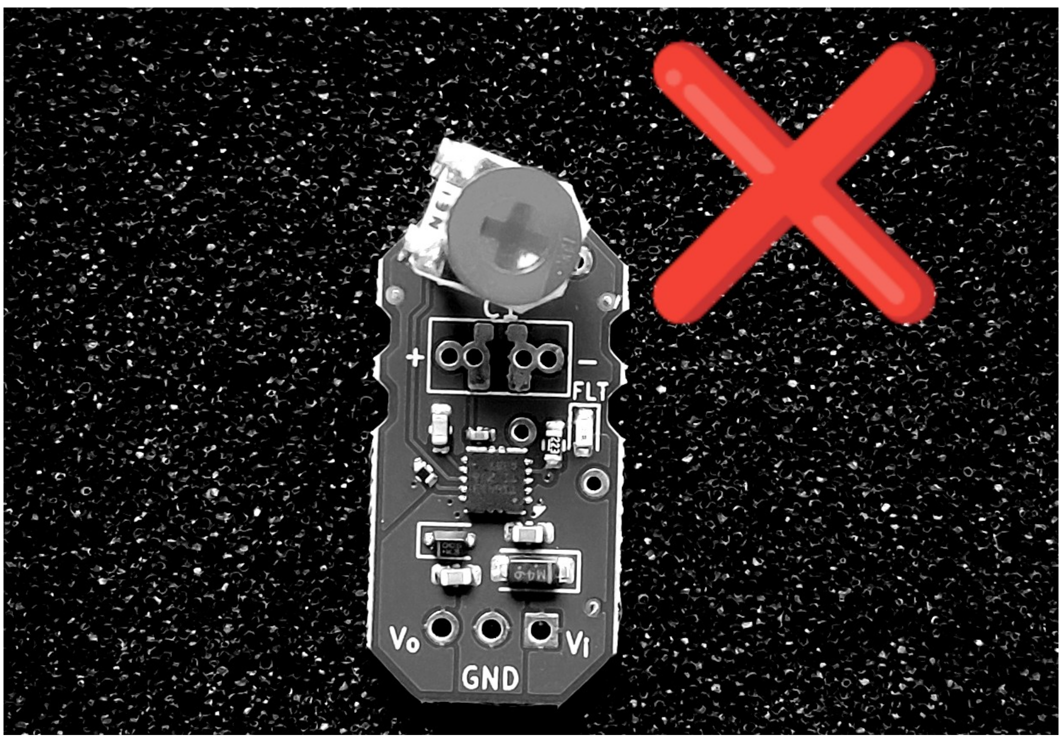
Resistor Footprint

This is where you solder a resistor to set the eFuse Module’s current limit. This is explained in greater detail in the **Current Limit** section on page 14.

In case you prefer to use SMD resistors, the eFuse Module has 0805 and 0603 SMD pads just for this. Both SMD and through-hole resistor footprints are connected in parallel.

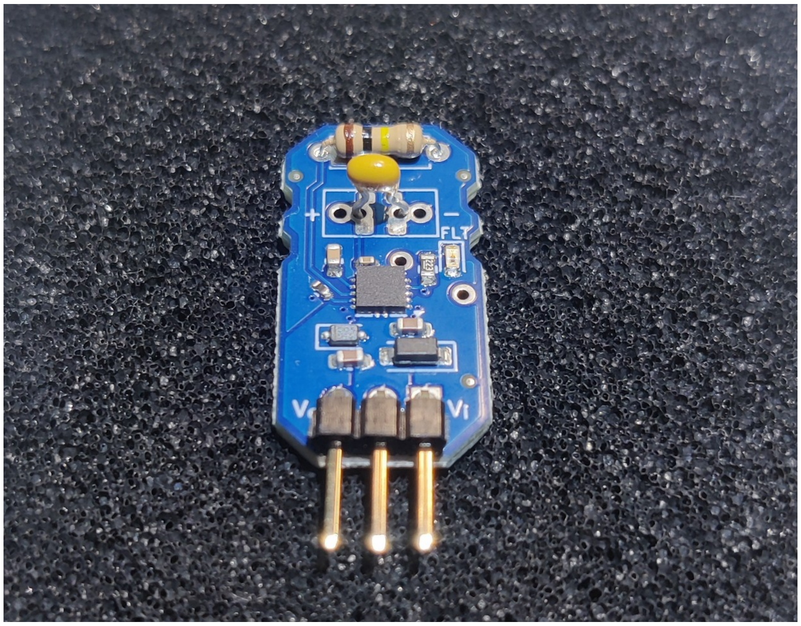


Nothing stops you from soldering a small in place of this resistor to make the fuse adjustable during operation, but we do not recommend it. When you cannot see the resistance, you cannot see how much current the eFuse module will actually tolerate. That makes it very easy to damage something that you thought was protected!



Capacitor Footprint

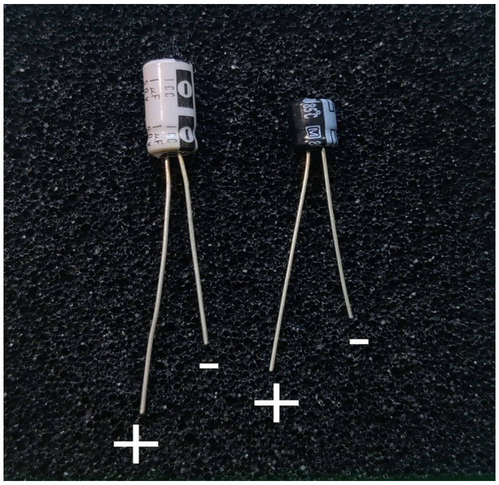
This is where you solder a capacitor to make the eFuse module slower if you find it too fast for your needs. Selecting the capacitance is explained in greater detail in the **Delay Time** section on page 20.



When selecting a capacitor, please keep in mind that the distance between its pins must be between 2.54 and 5.04 millimeters (one and two breadboard-position-distances, respectively.) Ceramic capacitors can be fragile. Bending their leads too aggressively can cause fractures in their internal structure, which can cause the capacitor to fail. The capacitor footprint has extra holes specifically to reduce the need to bend the capacitor’s pins.

Just as with the current-limit resistor footprint, the eFuse Module has 0805 and 0603 SMD pads for timing capacitors. Both SMD footprints and through-hole capacitor footprint are connected in parallel. A capacitance of 12 nF is already connected in parallel with the timing capacitor footprint, for a default time-to-trip of 19.5 milliseconds.

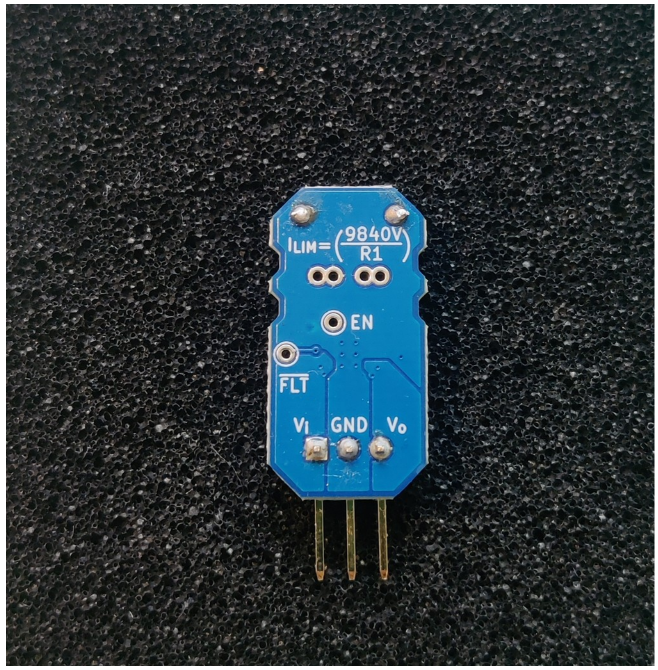
If you need a long enough delay to justify the use of polarized capacitors, then you will need to pay attention to polarity when you install them. The silkscreen denotes the positive position with a **+**. Electrolytic capacitors have a longer positive pin and a stripe near their negative pin.

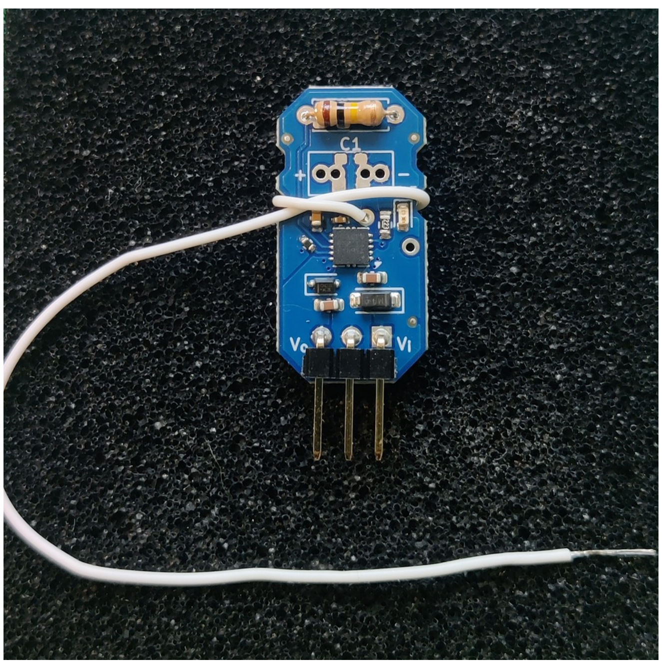


Advanced Connections

The eFuse module also features test points for the Enable and Fault signals.

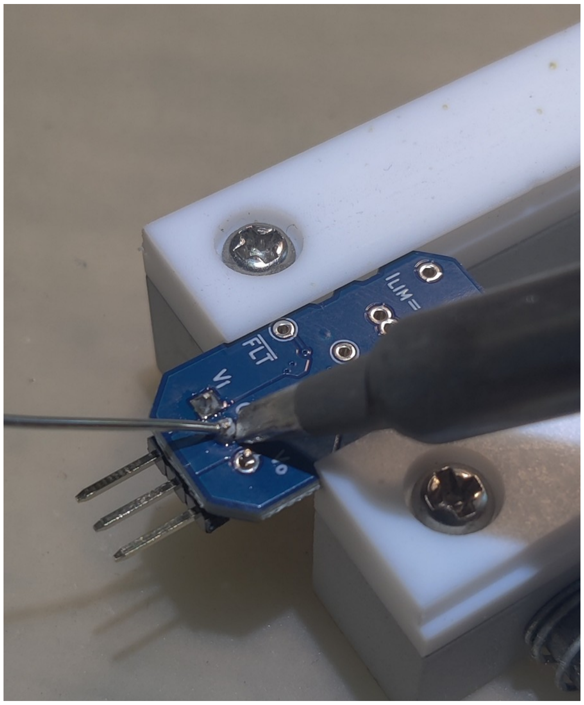
- **Enable:** marked **EN** on the silkscreen, this signal pulls itself high when left floating. Pulling it down shuts off the flow of current through the eFuse.
- **Fault:** marked $\overline{\textbf{FLT}}$ on the silkscreen, this active-low open-drain signal is pulled to ground when something (in most cases, excessive current) caused the eFuse to switch off. Current into this pin needs to be less than 3 mA and it is already pulled up with a high-efficiency LED circuit, so we recommend using a high-input-impedance device (such as a MOSFET) to buffer this signal.

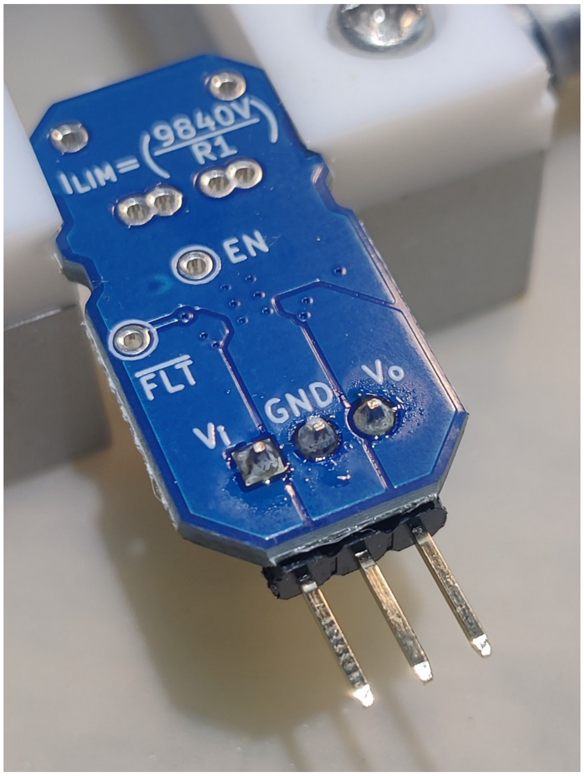




If these are needed, thin silicone-insulated or magnet wire can be soldered directly to pads without melting the wire's insulation. To prevent the core of the wire from breaking from too much bending at the same point, you can tie the wire around the notches in the sides of the circuit board. This way, when the wire is handled and moved around, deformation is spread out away from the solder joint.

Header Soldering

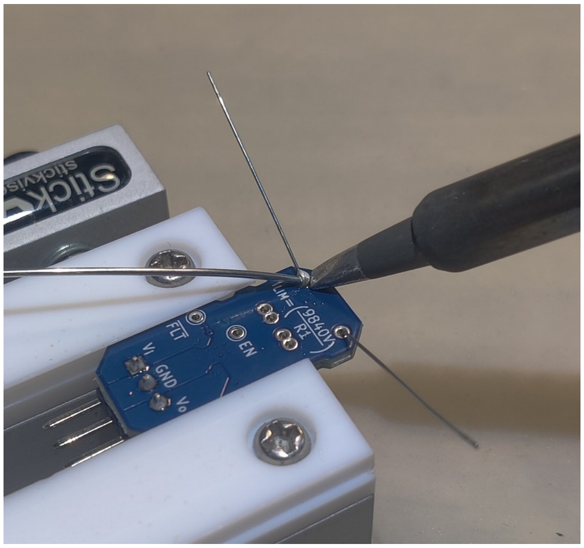


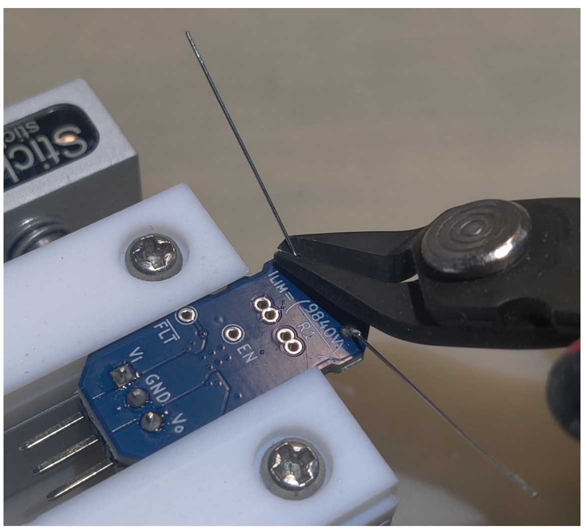


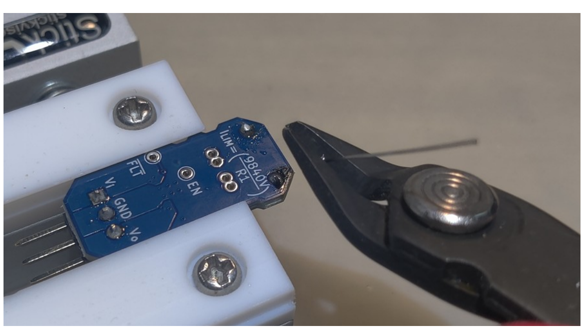
This product guide assumes that you are already proficient in soldering. If not, then you may want to consult another guide first.

To use the eFuse Module on a breadboard, you will need to solder a header to it.

Resistor Soldering







To have the eFuse module permit any load current at all, you will also need to install the current-limit resistor. For detailed information on selecting the right current-limit resistor, please see the **Current Limit** section on page 14.

Current Limit

Basic Resistor Selection

To program the current limit, you solder a resistor onto the footprint labeled **R1**. To determine the value of the resistor you need, the easiest approach is to divide 9840 Volts (a constant) by the desired current limit I_{LIM}. This constant is written down on the module's rear silkscreen to make it easier to remember.

If you want to be especially detail-oriented, you can take into account that most resistors have a tolerance of 5% and the TPS16413 eFuse has a current limit accuracy of 6%. In most cases you will not find resistors of an exact value and have to settle for an approximation. When you choose a higher resistance, the current limit will be lower, and vice-versa.

$$R1 = 9840\ V / I_{LIM}$$

As an example, if you want a current limit of 0.5 Amps like a basic USB port, then 9840 Volts divided by 0.5 Amps equals 19680 Ω. With a 5% resistor, the total inaccuracy is:

$$(100\% + 6\%) * (100\% + 5\%) - 100\% = 11.3\%$$

If you want to be absolutely sure that the eFuse trips at 0.5 Amps, then increase the calculated resistance by that 11.3%, and then select the next higher common resistor value:

$$19680\ \Omega * (1 + 0.113) = 21903.84\ \Omega \rightarrow 22\ k\Omega$$

Similarly, if the objective is to ensure that the eFuse *does not* trip at currents up to 0.5 Amps, then decrease the calculated resistance by that same amount, and then select the next lower common resistor value:

$$19680\ \Omega * (1 - 0.113) = 17456.16\ \Omega \rightarrow 15\ k\Omega$$

When the desired resistance is known and a resistor is selected, the resistor can be soldered into place. Pads are provided for a through-hole resistor, as well as for 0805 and 0603 SMD resistors.

Please keep in mind that, even though the TPS16413 eFuse has a maximum current limiting specification of 1.8 A, most breadboards cannot handle more than 1 A.

It is also worth mentioning that electronic component distributors (such as DigiKey and Mouser) also offer resistors in a wide variety of values, tolerances, and forms.

To continue the example, if you want to guarantee that the eFuse trips at 0.5 Amps and you are working with 5% resistors, we have calculated the desired resistance to be:

$$19680\ \Omega * (1 + 0.113) = 21903.84\ \Omega$$

There are 22kΩ resistors available and for many practical applications that would be close enough. For the sake of this guide, however, suppose those are not available.

The equivalent conductance is:

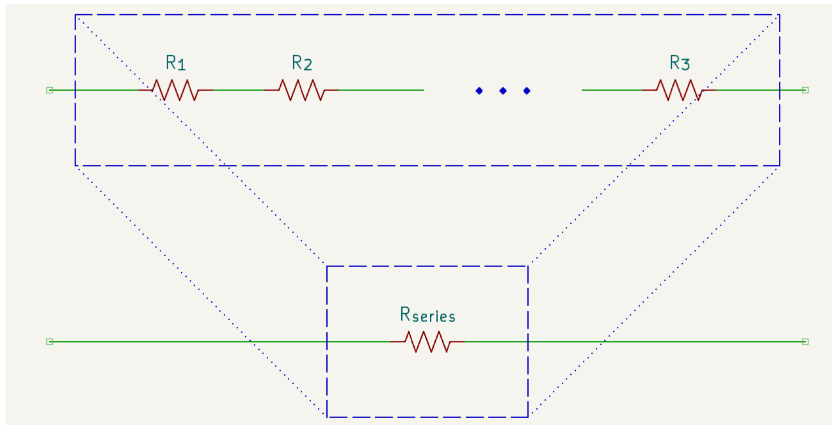
$$1 / \ 21903.84\ \Omega = 0.000045654\ \mho = 45.654\ \mu\mho$$

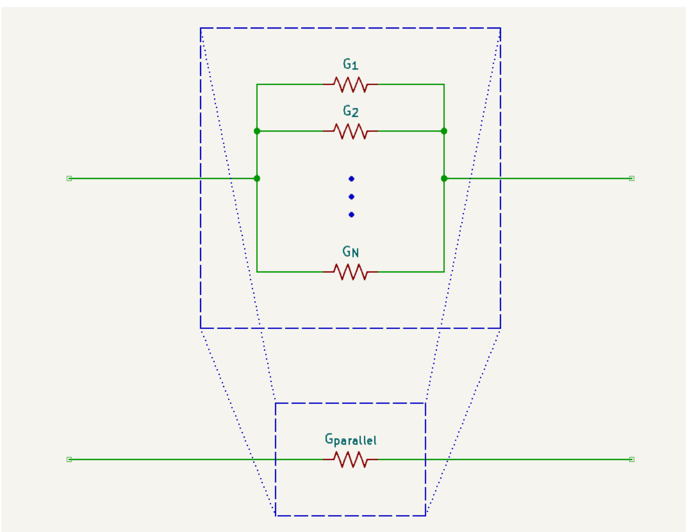
Advanced Resistor Selection

When exact resistor values are not available, finer control can be achieved by connecting multiple resistors in series or in parallel.

When resistances are connected in series, they accumulate because electrons have to flow through each and every one of them:

$$R_{series} = R_1 + R_2 + \ldots + R_N$$





On the other hand, when conductances are connected in parallel (like the **R1** pads on the eFuse Module,) they accumulate, because each of them is just another path through which the electrons can flow:

$$G_{parallel} = G_1 + G_2 + \ldots + G_N$$

Conductance (G) is the reciprocal of resistance:

$$R = 1 / G$$

$$G = 1 / R$$

The SI unit for conductance is the Siemen (S) but because it is reciprocal of resistance, the same unit is sometimes called the Mho (℧) for its intuitive representation of the Ohm (Ω) inverted.

Below is a table of resistance and conductance of some common resistors values. Please keep in mind that, due to the TPS16413's current range of 0.03A – 1.8A, some of the resistors listed here are only usable as the current limiting resistor **R1** in combination with other resistors. We do not recommend using resistances below 5.1k or above 348k, as this sets the TPS16413's current limit to a value outside of its specifications.

R (Ω)	G (μ℧)	Usable as R1 by itself?	Current Limit (A)
5,100	196.078	barely	1.929
6,800	147.059	yes	1.447
8,200	121.951	yes	1.200
10,000	100.000	yes	0.984
12,000	83.333	yes	0.820
15,000	66.667	yes	0.656
20,000	50.000	yes	0.492
22,000	45.455	yes	0.447
27,000	37.037	yes	0.364
33,000	30.303	yes	0.298
43,000	23.256	yes	0.229
47,000	21.277	yes	0.209
51,000	19.608	yes	0.193
68,000	14.706	yes	0.145
82,000	12.195	yes	0.120
100,000	10.000	yes	0.098
120,000	8.333	yes	0.082
150,000	6.667	yes	0.066
200,000	5.000	yes	0.049
270,000	3.704	yes	0.036
330,000	3.030	barely	0.030

Although the closest conductance (22kΩ resistor) is unavailable for the sake of the example in the previous section, the next lower conductance on the table above is 37.037μ℧ (27kΩ.) That leaves 8.617μ℧ (116.050kΩ.) From the table above, the closest conductance available is 8.333μ℧ (120kΩ.) Combined in parallel, the 27kΩ (37.037μ℧) and 120kΩ (8.333μ℧) resistors' conductance adds up:

$$37.037\mu℧ + 8.333\mu℧ = 45.370\mu℧$$

The equivalent combined resistance is:

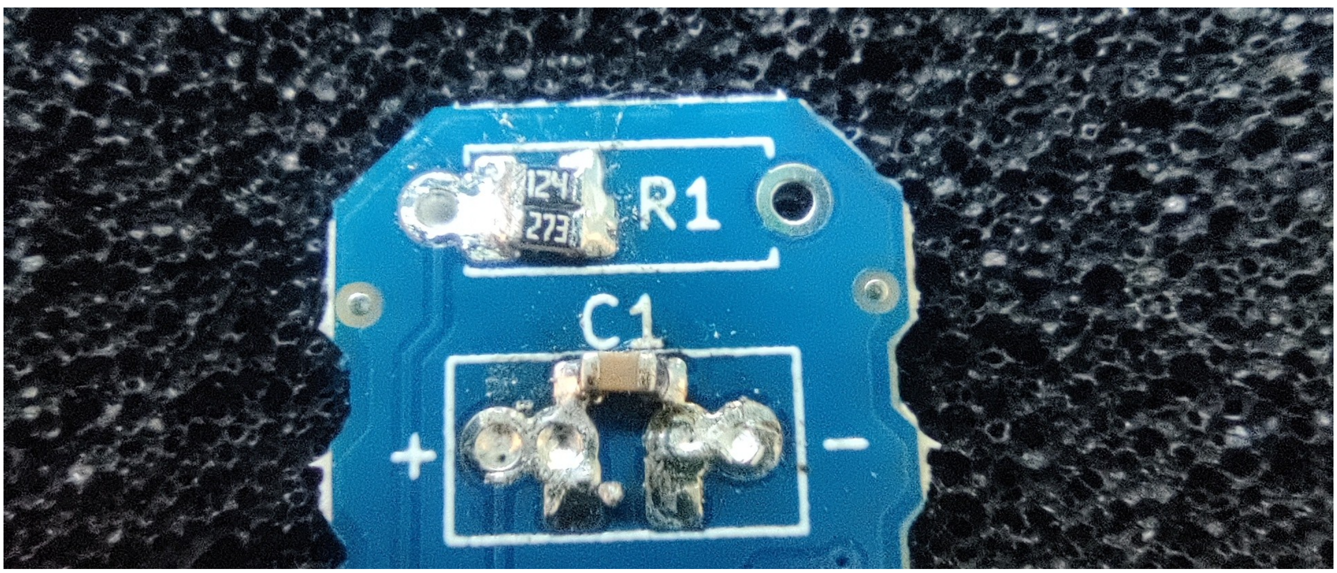
$$1 / 45.370\mu℧ = 0.022040M\Omega = 22.041k\Omega$$

With this resistance, the worst-case scenario (with 11.3% inaccuracy) is that the eFuse trips at:

$$(1 + 0.113) * 9840\ V / 22041\Omega = 0.497\ A$$

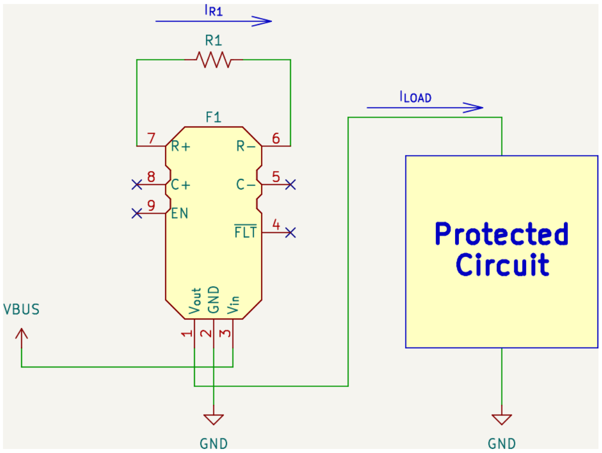
In other words, before the current reaches 0.5 Amps, the eFuse is guaranteed to trip at 0.497 Amps. Please keep in mind that, with the configuration in this example, the eFuse could just as easily trip at:

$$(1 - 0.113) * 9840\ V / 22041\Omega = 0.396\ A$$



Inner Workings

(and why you should not be worried that the 9840 Volt constant will deliver an electrical shock)



The virtual 9840 Volt constant is not physically present anywhere within the module. It exists only to simplify calculations. When voltage is applied to the TPS16413 eFuse, a reference current of a known magnitude is permitted to flow through the current limit resistor.

This creates a voltage across the resistor according to Ohm's Law:

$$V_{ILIM} = I_{R1} * R1$$

This resulting voltage is much lower than 9840 Volts. The eFuse also measures output current by means of its built-in circuitry, generating a voltage signal proportional to output current.

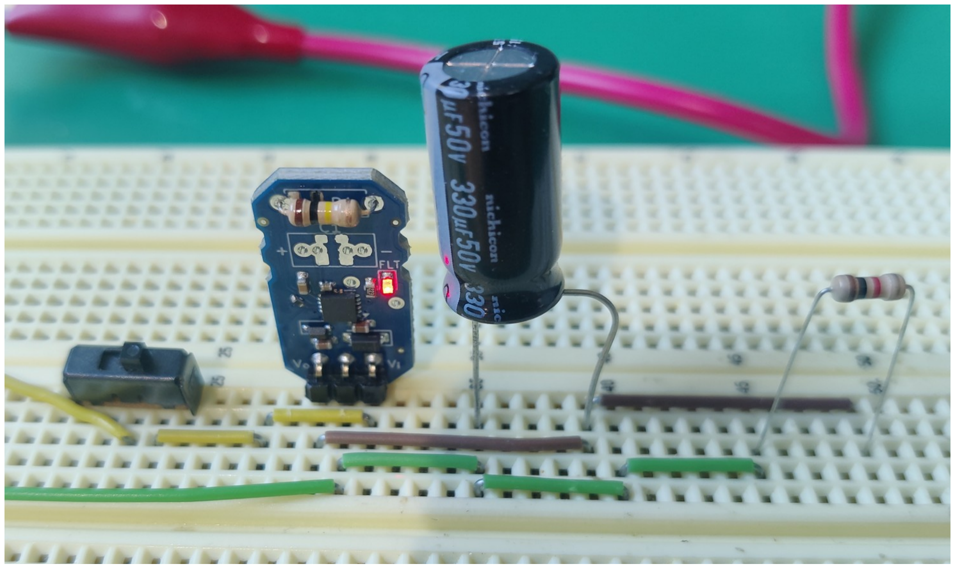
$$V_{ILOAD} = I_{LOAD} * R_{INTERNAL}$$

These voltages are compared by an internal comparator. If the voltage from measuring the output current (V_{ILOAD}) is higher than the voltage across **R1** (V_{ILIM},) then the eFuse trips (see the section **Timing In Detail** on page 23 for more information on the modes in which the eFuse can trip.) The product of the reference current I_{R1} that flows through the current-setting resistor **R1**, the internal output-current-sensing resistance $R_{INTERNAL}$, and the ratio of gains on both sides of the comparator, just happens to be approximately 9840 Volts.

Delay Time

So you power up your circuit, or your circuit tries to power up its load, and the eFuse trips instantly. You have done the calculations and measured the current through the circuit, and you know that it does not consume enough steady-state current to trip the eFuse. So what could be the problem?

If you have a large electrolytic capacitor protecting your circuit from brown-outs, then chances are, it draws a lot of current to charge itself up when you first turn on your circuit. If this takes longer than 19.5 ms, then it can trip the eFuse.



Alternatively, if your circuit is trying to power up a motor, then it takes a split-second for the motor to accelerate to its full speed. While the motor is accelerating, its back-EMF is significantly lower than when it runs at full speed, so the current drawn by the resistance of its windings is significantly higher. This, too, can trip the eFuse.

In both cases, the problem is that the eFuse is working *too* quickly. One solution is to add a timing capacitor, and the eFuse will tolerate the inrush current a little longer.

Basic Capacitor Selection

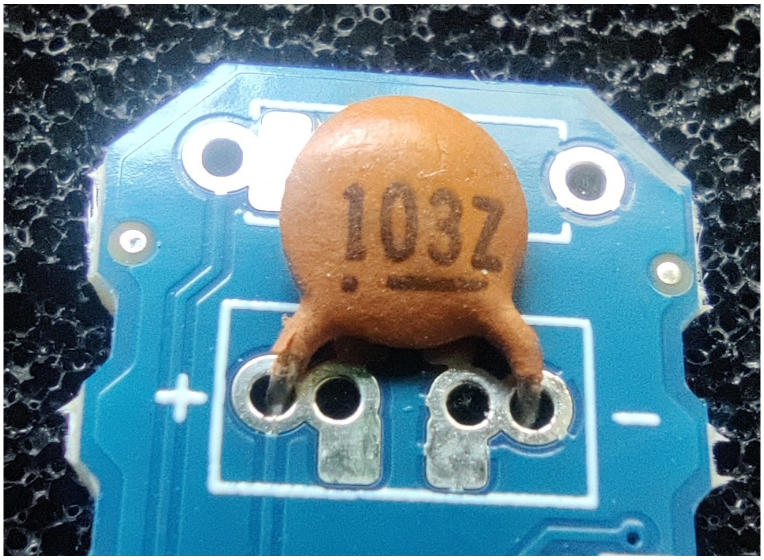
If you know the time-to-trip **t** that you want, and it is greater than 19.5 ms, then here is how to find out the capacitance that you need:

$$C1 = (t - 0.0195\ s) * 615\ (nF/s)$$

For example, if you want a delay of 35 milliseconds or 0.035 seconds, then

$$(0.035\ s - 0.0195\ s) * 615\ (nF/s) = 9.5325\ nF$$

Most capacitors on the market have a capacitance 10% - 20% lower than their nominal value, so the next highest common value will usually work. In this example, this value is 10 nF.



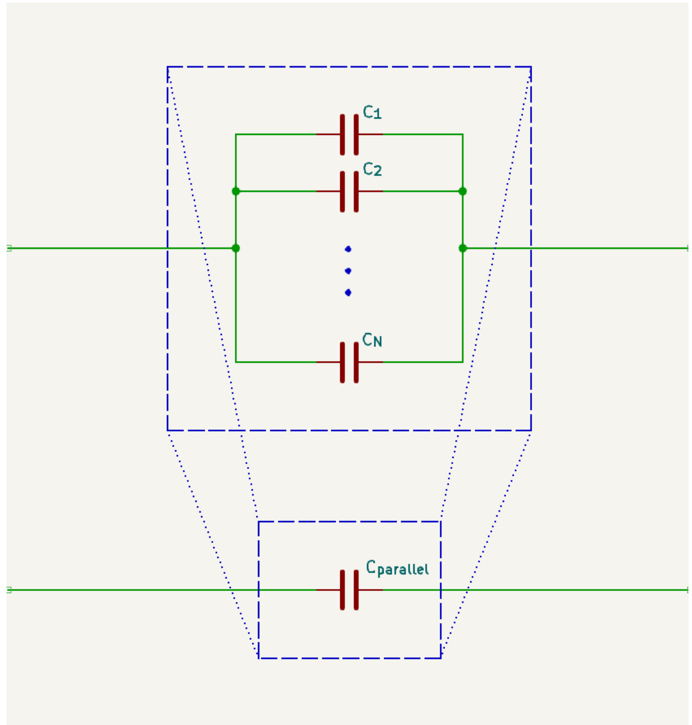
The eFuse Module has a 12 nF ±5% capacitor pre-installed in parallel with **C1**, hence the subtraction of 19.5 milliseconds. This is to prevent the TPS16413 from defaulting to a delay of 155 ms, which happens in the absence of a timing capacitor. For more information, please see the section **Without Timing Capacitance** on page 25.

Advanced Capacitor Selection

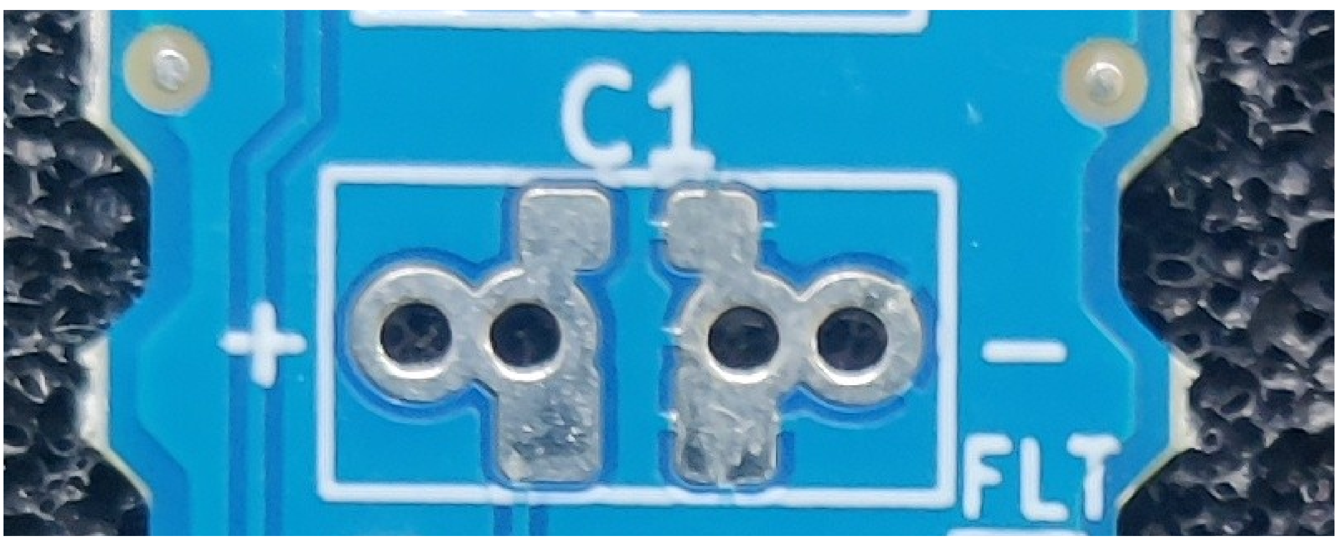
Like resistors, capacitors can be combined in parallel and in series. Unlike resistors, capacitance values add up together when capacitors are connected in parallel, whereas the inverse of capacitance accumulates when capacitors are connected in series. Also unlike resistors, higher capacitance values usually increase the cost of the component, which makes it more economical to combine capacitors in parallel as opposed to in series.

$$C_{parallel} = C_1 + C_2 + \ldots + C_N$$

Combining capacitors in parallel is also safer: differences in leakage current between capacitors connected in series may cause an uneven distribution of charge leading to differing voltages. Capacitors connected in parallel, on the other hand, share the same voltage.



The eFuse Module has two SMD capacitor pads and a multiple-pitch through-hole footprint connected in parallel in case you need to combine multiple capacitors to get the capacitance (and more importantly, the time-to-trip delay) that you want.

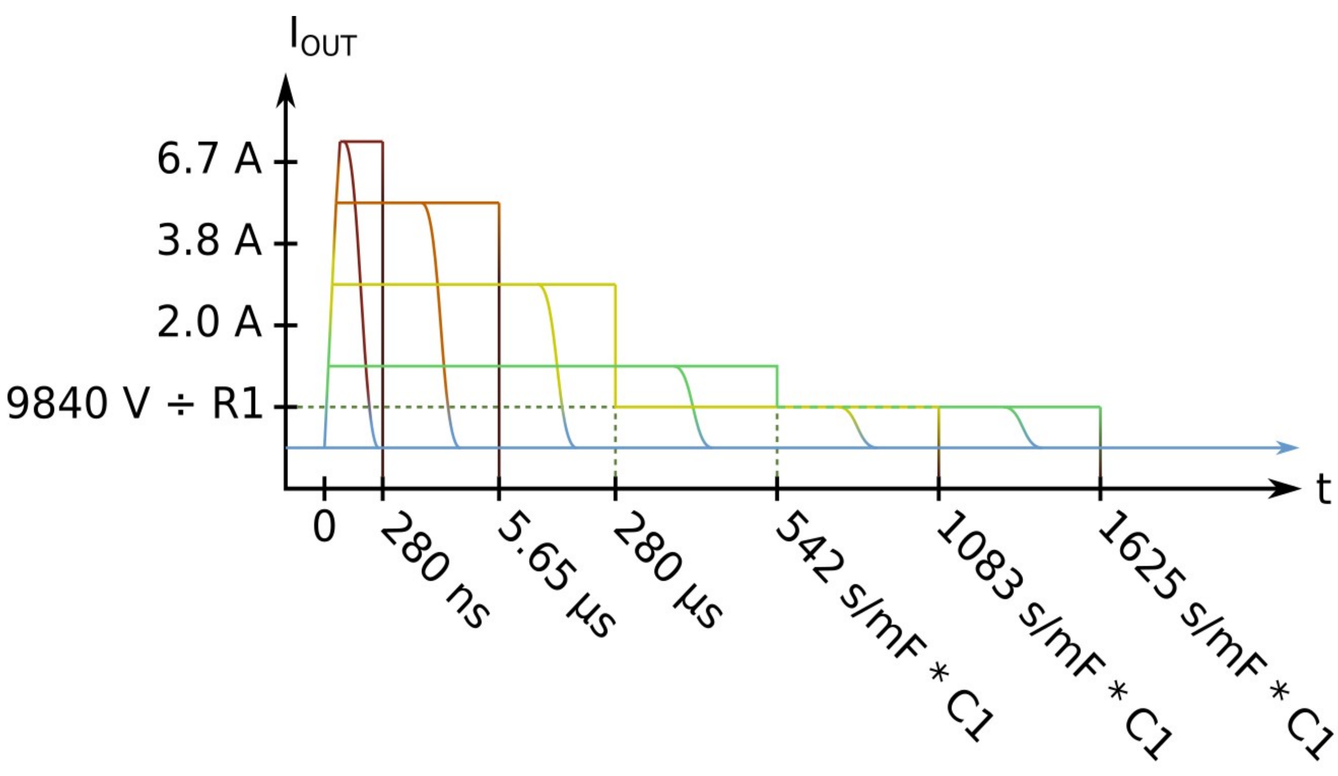


Timing In Detail

The TPS16413 eFuse exhibits different modes of current protection depending on different intensities of current. Most of these are irrelevant to most projects. They are, in order of current highest to lowest:

Mode	Load Current Draw		Response		
	Min	Max	Blanking Period	Limiting Period	Trip
Short Circuit Protection	6.7 (A)	N/A	280 (ns)	0	Yes
Fast Trip	3.8 (A)	6.7 (A)	5.65 (µs)		
Over-Current Protection	2.0 (A)	3.8 (A)	280 (µs)	1083 (s/mF) * C1	
Current Limiting	9840V÷R1	2.0 (A)	542 (s/mF) * C1		
Normal Operation	0	9840V÷R1	N/A	N/A	No

The official, most authoritative source on the fault behavior of the TPS16413 eFuse is the [TPS1641x datasheet](). Having said that, the general idea is that higher levels of current trip the eFuse faster.



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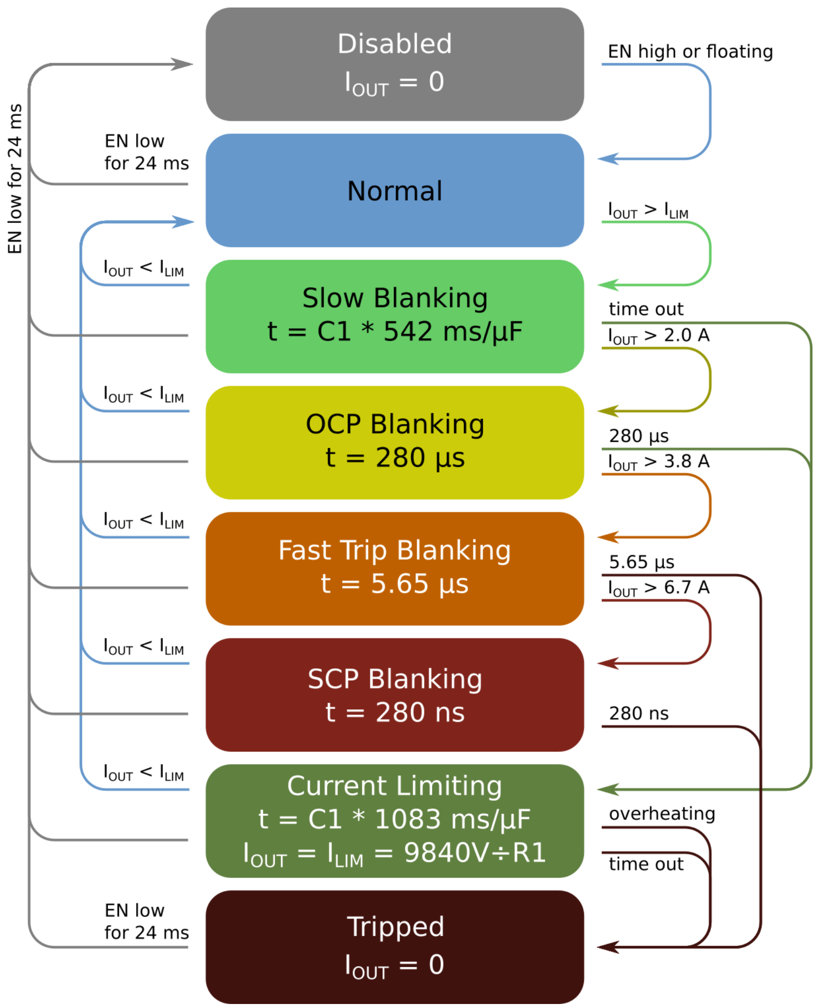


The eFuse trip behavior is divided into two parts: first Blanking, followed by Current Limiting.

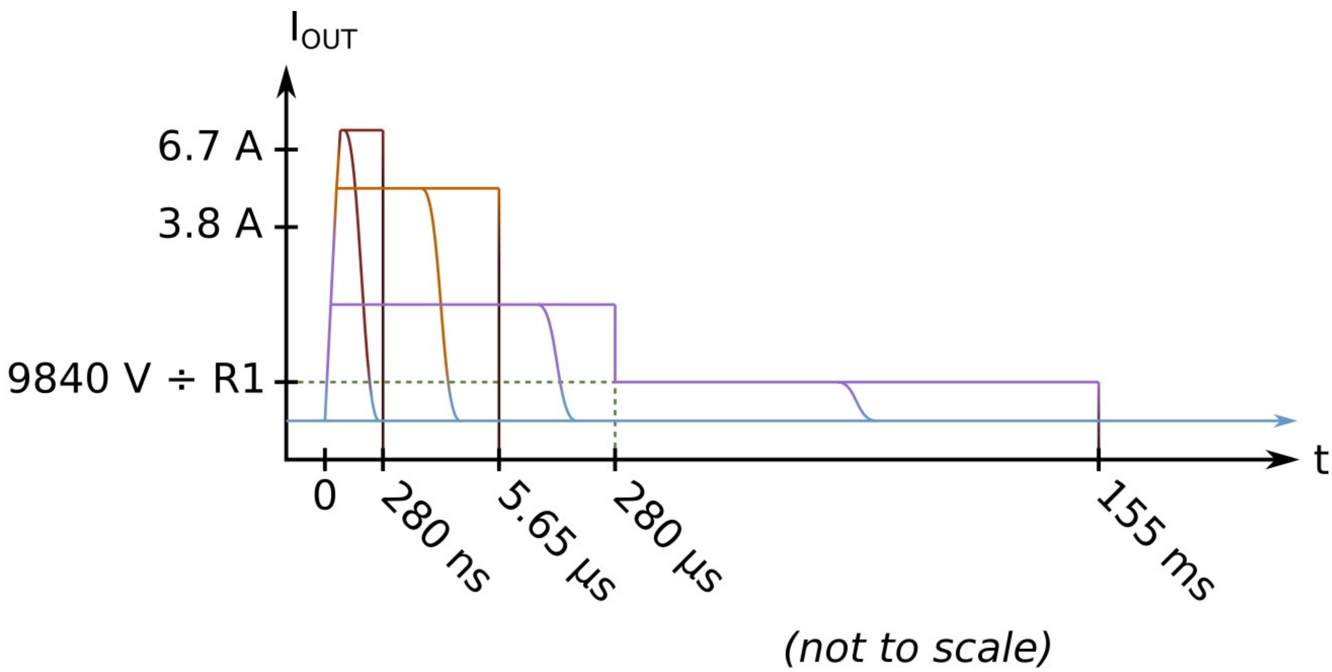
During Blanking, the eFuse “blanks out,” exhibiting no immediate outward reaction. After Blanking, depending on the current draw, the eFuse may either enter the active current limiting period, or just trip.

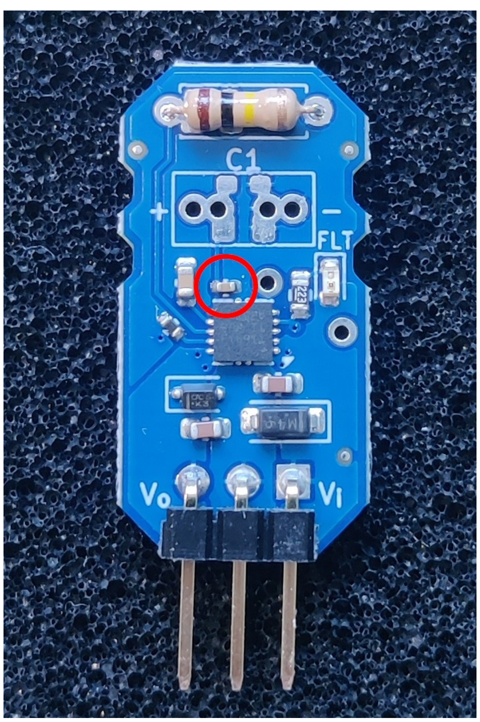
For Current Limiting, the eFuse limits the output current to the value of I_{LIM} (see **Basic Resistor Selection** on page 14.) If the current draw through the eFuse does not fall below I_{LIM} for the entire duration of Limiting, then the eFuse trips and cuts off the current. As current limiting dissipates energy, the eFuse will also trip if its junction temperature exceeds 155°C.

Without Timing Capacitance

If the timing capacitance is less than the minimum of 12 nF recommended by the datasheet, or is shorted to ground, then the eFuse uses the Over Current Protection value for blanking time and a built-in value for current limiting time:

- Blanking time: 280 µs
- Current limiting time: 155 ms





To prevent this behavior from occurring by default, the eFuse module comes with the recommended minimum capacitance of 12 nF pre-installed in parallel with **C1**.

You can bypass this measure and achieve the behavior described above by shorting the timing capacitor footprint **C1** with a jumper or 0Ω resistor.