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Advantages of eFuses Versus PTC Resettable Fuses

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APPLICATION NOTE

Introduction

Overcurrent protection is a basic necessity for electrical devices. While many people are familiar with fuses and household circuit breakers, few are intimately familiar with the kinds of overcurrent protection devices that are found in electronics.

Though not a comprehensive list, there are basically three types of overcurrent protection devices in electronics. In order of increasing sophistication they are:

- One-shot fuses
- Positive Temperature Coefficient (PTC) resettable fuses
- Electronic fuses (eFuses)

Comparison of technologies

One shot fuses, which are based on melting of a metal link, must be replaced after a single high current event. They are commonly found in applications like LED bulbs where a simple device makes sense. For LED bulbs the solution to a blown fuse is just to purchase another bulb. It is a small expense and the fault leading to the open fuse likely requires replacement of the bulb anyway.

PTC resettable fuses are a step-up from one shot fuses. When a short circuit occurs, they heat up and transition from a low resistance state to a high resistance state. Allowing them to cool down (typically by removing the power) resets them to the low resistance state.

PTCs come in both ceramic (CPTC) and polymer (PPTC) types. Ceramic types are used in sensitive application spaces such as telecom where the resistance must not change much after tripping. The polymer type is used in many general electronics applications and is sometimes called alternatively a resettable fuse, or polyswitch. In this article, a polymer type is compared against an eFuse.

eFuses utilize a completely different operating principle than one-shot or PTC fuses. Instead of limiting current based entirely on heating, eFuses actually measure the current and turn off an internal switch if the current exceeds a specified limit.

Also, since eFuses are semiconductor integrated circuit devices they have a rapid (typically less than 10 μs) response to short circuits as well as a plethora of features that may be included:

- Ability to operate over temperature with minimal shift in parameters
- No degradation after a fault; the on resistance does not depend on how many faults have occurred
- Programmable current limit
- Enable pin, to turn on or off the device
- Fault pin, to signal that something has gone wrong to control logic or other power rails
- Soft-start, to limit inrush current
- Voltage clamp, to prevent voltage spikes from reaching the load
- Choice of latch-off or auto-retry, so that everything will reset if the load recovers, but without needing to turn off the power
- Reverse current blocking

However, the eFuse arguably also has a few disadvantages such as having more terminals and requiring bias current to operate.

At the most basic level, an eFuse requires at least three terminals due to its architecture. These are input, output, and ground. In some cases it would be better to have a two-terminal device to make layout routing easier. For example, there is no need to connect a PTC to the ground plane.

Also, since the PTC does not require a ground pin, current only flows from input to output. This means that no bias current is required at all. This is an obvious advantage for battery-powered applications. However, the latest eFuses have reduced bias current considerably. For example, when the NIS5452 is turned off, its bias current is less than 100 μA. Its predecessor, the NIS5135 has a bias current about 10 times higher.

While it is true that the eFuse is more complicated due to its semiconductor architecture, advances in semiconductor technology have significantly reduced the size, and therefore expense, of eFuses. For example, one of the first eFuses from ON Semiconductor is the NIS5112 with 30 mΩ $R_{DS(on)}$ in the SOIC−8 (5 × 4 × 1.75 mm) package. By contrast the upcoming NIS5020 is in a much smaller (3 × 3 × 1.0 mm) DFN10 package and has half the $R_{DS(on)}$.

eFuse vs. PTC Test Setup

To compare eFuse and PTC fault response an eFuse (ON Semiconductor NIS5132MN2) and a polymer PTC with similar characteristics were chosen to provide fault protection on a 12 V power rail. The eFuse R_{limit} resistor was chosen as 37.4 Ω to match the current limit specifications. Table 1 provides a brief comparison of the devices.

Table 1. PTC AND EFUSE SPECIFICATION COMPARISON

Specification	Polymer PTC	eFuse
Max Voltage	16	25
Hold Current	1.5 A	1.7 A
Trip Current	3.0 A	3.0 A
On Resistance	40 to 110 mΩ	44 mΩ
Package	1210	3 × 3 DFN
Length (mm)	3.2	3
Width (mm)	2.5	3
Height (mm)	0.55	1

The test circuit board is shown in Figure 1. It has coaxial connectors to measure input voltage, output voltage, current (voltage over a 20 mΩ resistor), and eFuse enable pin voltage. It also has a Zener diode and 10 μF input capacitor to suppress inductive spikes due to V = L(di/dt) transients on the power cable.

There are also switches to change between the eFuse and PTC and to short the output to ground. Furthermore, it has an onboard multimeter to read input voltage and output current. Standard eFuse peripheral components such as the R_{limit} and the output capacitor were included too. Generally eFuses do not require output capacitors for functionality, but it is a good idea to have them if large inductive voltage spikes are possible in the application.

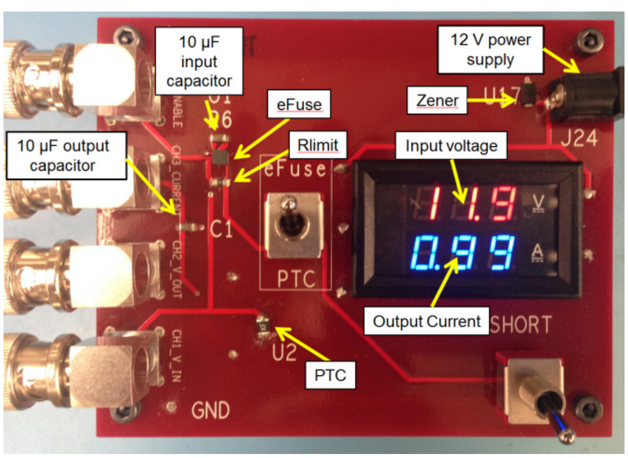

Figure 1. The Circuit Board Used for Comparing the eFuse to the PTC

A 12 ohm load is connected from output to ground. Since both the eFuse and PTC have their current limits above 1 A, in normal operation 1 A is allowed to flow.

The behavior of the PTC depends on the current capability of the power supply. To test this, three different supplies were used:

- Small wall adapter, CUI INC model SMI24−12, which supplies 12 V and up to 2 A DC. It has a cut off and auto-retry feature in the event of a fault
- Benchtop DC power supply, GW Instek SPS−606, capable of 60V and 6 A
- Desktop computer power supply, Dell model NPS−250KB F, capable of 16 A on the 12 V rail

The test scenario was the same for all cases: a 1 A load is running and then suddenly the output is short circuited to ground. The current limit device is tasked with limiting the current as soon as possible in order to maintain a stable supply rail voltage. In a real-world application, the supply rail staying high is important in case other parallel loads running off the same supply need power.

Small Wall Adapter Power Supply

Figures 2 and 3 show what happens while using the small wall adapter supply. Referring to Figure 2, when a short circuit occurs with the PTC, over 4 A passes through for 50 ms, and then the power supply itself shuts off the current. The PTC never actually trips, resulting in the power supply shutting down.

In Figure 3, the eFuse responds to the fault. The input voltage is able to stay up because the power supply current limit does not activate. Subsequently the eFuse attempts to turn on again but recognizes that the output is shorted. The eFuse limits the current so quickly that other loads could continue to operate on the same power line if needed.

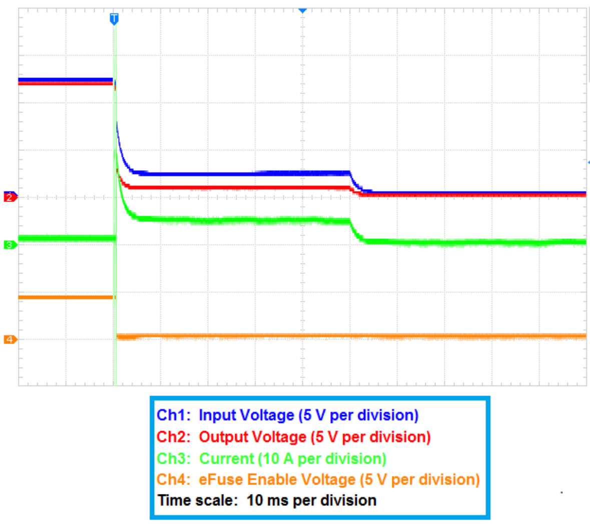

Figure 2. At the beginning the PTC is conducting 1 A. The input and output voltage are both about 12 V. The power supply is the small wall adapter unit made by CUI Inc. When a short on the output occurs, the power supply provides about 4 A until its protection circuit shuts off the current and the input voltage drops to zero

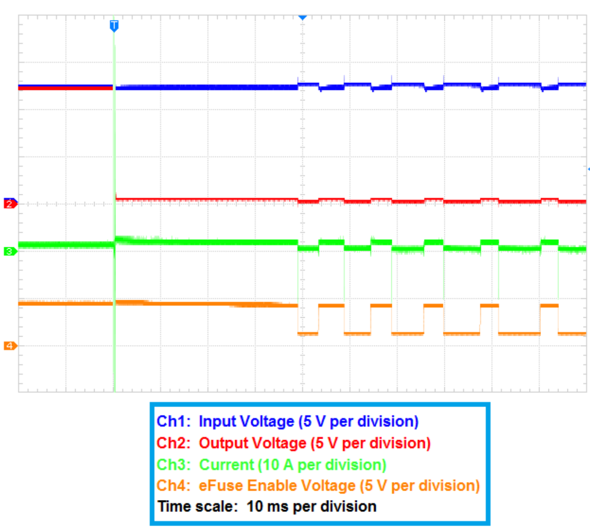

Figure 3. Here the eFuse responds to the same scenario as in Figure 2, and the power supply does not need to shut down. The eFuse's auto−retry feature attempts a restart but the output is still shorted so it does not return to 12 V. The input voltage stays up. The ripple on the input voltage line is caused by inductive voltage spikes and may be dampened by using ceramic decoupling capacitors

Benchtop DC Power Supply

The benchtop supply has a 6 A limit but does not have a shut off. It supplied 6 A until the PTC tripped, but it took about 30 ms (see Figure 4). In that time period the power supply voltage was quite low. As shown in Figure 5, the eFuse responded just like in the wall adapter supply case: very quickly and allowing the input voltage to stay high.

Figure 4. In this case the PTC trips after the short circuit has been present for about 30 ms. Note the large drop in the input voltage until the PTC trips

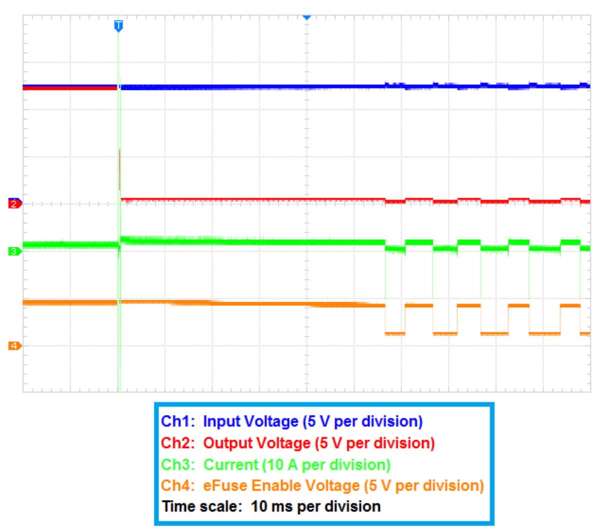

Figure 5. The eFuse responds to the fault quickly, keeping the input voltage up

Desktop Computer Power Supply

The high current capability of the desktop computer supply allowed the PTC to trip quickly (see Figure 6). Clearly, the PTC performs much better with this supply than with the others; the input voltage trace is much more stable. As Figure 7 shows, the eFuse responds in a similar manner as with the other supplies, but even in this case the eFuse results in less disruption of the input voltage than with the PTC.

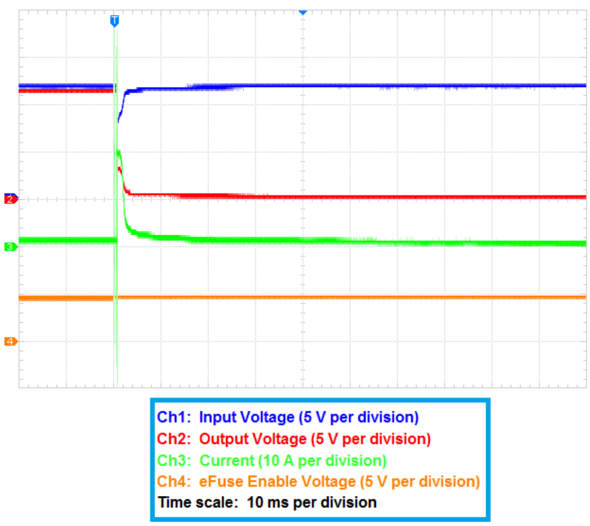

Figure 6. With the desktop computer power supply, there is a dip in the input voltage but the PTC trips in about 3 ms

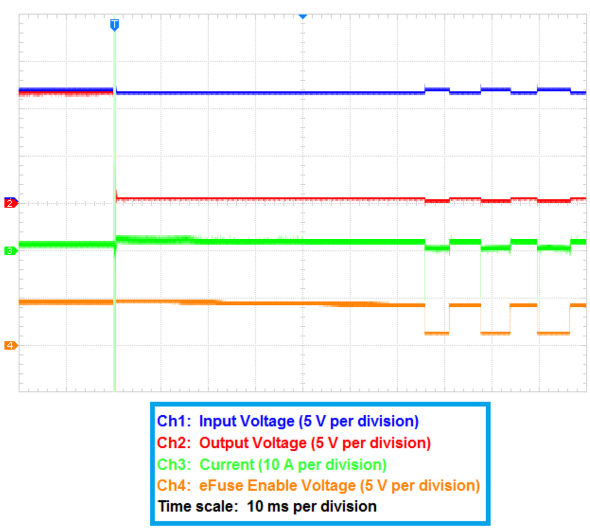

Figure 7. The eFuse responds as it did with the other power supplies. The response is quick and the input voltage stays high

Test Summary

It was observed during the tests that the eFuse responded to faults more quickly than the PTC, allowing the power supply rail to stay up better. The results are summarized in Table 2.

Table 2. FAULT RESPONSE TEST SUMMARY

Supply	PTC Response	eFuse Response
Wall Adapter	Fig 2: Did not trip	Fig 3: ~10 μs
Benchtop	Fig 4: Slow (~30 ms)	Fig 5: ~10 μs
Desktop Computer	Fig 6: Fast (~3 ms)	Fig 7: ~10 μs

Conclusion

In many cases, a PTC may provide adequate protection. Its response should be fast enough to prevent burn damage to wiring. In addition, its ability to maintain voltage levels in response to a fault can be enhanced by choosing a higher current supply, or perhaps even adding decoupling capacitance on the power supply (input) side.

However, in other cases an eFuse is not only a better choice but its superior performance and features are required to satisfy application requirements. The use of an eFuse may also save cost and board space if additional circuitry, needed to prevent inrush currents or to provide overvoltage protection, can be eliminated by using an eFuse. For more information about eFuses, please visit www.onsemi.com or contact your local ON Semiconductor sales representative for evaluation boards and samples.

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