PolyZen Devices for EOS Protection in LED Applications

Introduction

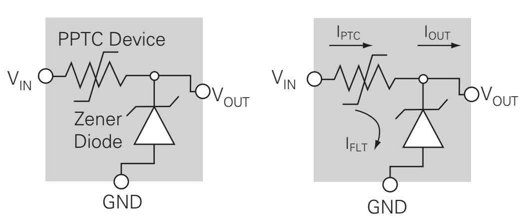
With today's growing demands for increased energy savings and reduced power consumption, light emitting diodes — or LEDs — have become the solution of choice for the next generation of lighting applications. As a result, more and more attention is being paid to protecting against damage from EOS (electrical overstress) events, which, specifically, refer to any undesirable voltage, current or power that the LED application can be subjected to.

LED applications are vulnerable to damage when the EOS event exceeds the maximum requirements of the design's specifications. EOS events are typically transient; meaning they occur for a short period of time, typically less than one second, and are often referred to as spikes (e.g., current spikes or voltage spikes). However, EOS events can be permanent, such as inserting a battery backward into a battery-powered LED flashlight. Any single EOS event, long or short in duration, or any number of events, have the potential to cause damage to the LED. This damage can be exhibited either as an immediate failure or a failure that occurs many hours after the EOS event.

This paper describes how Littelfuse PolyZen device helps provide an efficient, cost effective, space-saving solution for protecting LED applications from damage from EOS faults. It also presents actual tests by in which harsh EOS signals were generated to simulate their effects on LED devices. The experiments are evaluated to show how PolyZen devices can help suppress the impact of EOS faults to achieve effective circuit protection.

The PolyZen Integrated Approach

The PolyZen device integrates a precision Zener diode and a PolySwitch PPTC (Polymer Positive Temperature Coefficient) device, which are thermally bonded. In essence, the PolyZen device provides a thermally protected Zener diode that offers multiple benefits in a single package. The PolyZen series of products includes two families of devices, with the part number ending in either "LS" and/or "YC/YM" Each family offers combinations of different Zener voltages (Vz), PPTC hold currents (I_{HOLD}), and input voltage ratings (Vintmax – referred to as V_{IN}) options. This range of options offers designers a variety of devices that can be used in a wide range of practical applications requiring overcurrent/overvoltage protection. A PolyZen product schematic and related definition of terms is shown in Figure 1.



Definition of Terms

I_{PTC}	Current flowing through the PPTC portion of the circuit
I_{FLT}	RMS fault current flowing through the diode
I_{OUT}	Current flowing out the V_{OUT} pin of the device
Trip Event	A condition where the PPTC transitions to a high resistance state, thereby significantly limiting I_{PTC} and related current.
Trip Endurance	Time the PPTC portion of the device remains in a high resistance state.

Figure 1: PolyZen product schematic and related definition of terms

PolyZen Devices for EOS Protection in LED Applications

PolyZen devices can be used for space-constrained designs. Their thermally protected precision Zener diode can help protect electronics against the failures caused by voltage transients, reverse-bias, overcurrent, and the incorrect use of power supplies. Key benefits include the availability of multiple devices, a small form factor, a single surface-mount component, resettability, and providing multi-functional protection that exceeds the performance of discrete devices.

As a protection device that integrates both a high-performance Zener diode and a PPTC overvoltage/overcurrent protection device, the PolyZen device exceeds the performance of existing discrete solutions that employ a separate fuse, Zener diode or other passive element. For example, commonly used transient voltage suppression (TVS) devices, although capable of voltage clamping, are limited in their ability to provide short-duration impulse protection. In a typical TVS application, a clamping diode will rise in temperature during an overvoltage fault and subsequent breakdown. If the fault is not eliminated and the overvoltage impulse is applied to the circuit for an extended period of time, a high-energy TVS device is needed to protect the circuit; otherwise, the TVS device itself can be permanently damaged from thermal degradation. However, adding a high-energy TVS device is costly and its large package size consumes valuable board space. Additionally, this scheme only provides overvoltage protection and does not address overcurrent protection.

In comparison, the PPTC device component integrated in the PolyZen device helps designers provide necessary overcurrent protection quickly and effectively, as would a standalone PPTC device. As a result, designers are offered an alternative to integrating and testing space-consuming discrete devices or employing expensive IC solutions for combination overvoltage/overcurrent protection.

The PolyZen Device: How It Works

When an overvoltage fault occurs in an application using a PolyZen device, the device's Zener diode and PPTC operate in conjunction to help provide protection. The protection occurs because as the Zener approaches a clamp voltage, the current flowing in the Zener causes it to rise in temperature. Since the PPTC is thermally bonded it also is exposed to the increase in temperature. This causes it to trip, or go into a high-resistance state. The device's I_{OUT} and I_{FLT} will be greatly reduced, protecting not only the PolyZen device but the downstream electronics as well.

The overvoltage fault protection occurs when the Zener clamps, whether the diode is forward- or reverse-biased. Littelfuse utilizes a precision Zener in the PolyZen device based on its ability to permit current flow in either direction.

As referenced in Figure 1, when a positive voltage on V_{IN}, with respect to GND, approaches the Vz value of a particular PolyZen device, it will reverse-bias the diode and the current I_{FLT} will flow in the direction as shown, which is through the PPTC and into the cathode and out the anode (GND). While shunting the current, the diode will clamp at Vz of the particular PolyZen device, generating heat within the Zener and transferring the heat to the PPTC, thus causing it to trip.

If there is a reversal of voltage polarity from V_{IN} to GND, the current I_{FLT} will flow in the opposite direction (forward-biased) as it approaches a clamp voltage. In a forward-bias the Zener will clamp at the diode-drop of the particular PolyZen device instead of at Vz. The current flowing in the Zener will create heat, transfer the heat to the PPTC, thus causing it to trip. As mentioned above, I_{OUT} and I_{FLT} will be greatly reduced, thereby protecting both the PolyZen device and the downstream electronics. Reverse-polarity protection is thus provided as well.

In the case of an overcurrent fault, where current is flowing from V_{IN} to V_{OUT} (I_{PPTC} or I_{OUT}) and the Zener is not clamped, the PPTC will respond just as any standalone PPTC device would. The PPTC has an I_{HOLD} specification, and if it is exceeded, the PPTC will also "trip" to a state of high resistance, rapidly cutting off excessive current at I_{OUT}. (More details on the PolyZen device's Zener and PPTC parameters are included in the individual PolyZen specifications.)

Whether or not an overvoltage and/or overcurrent EOS event causes the PPTC to trip, the protection provided by the PolyZen device is resettable, unlike providing one-time protection, such as using a fuse as an overcurrent protector with a discrete Zener or TVS device. The unique feature of utilizing a Zener diode bonded to a PPTC device allows the PolyZen device to withstand much more energy than other protection solutions, despite its smaller package size. Additionally, the device is reset whether the Zener clamped when tripping the PPTC or if the PPTC device is tripped without the Zener by cycling power.

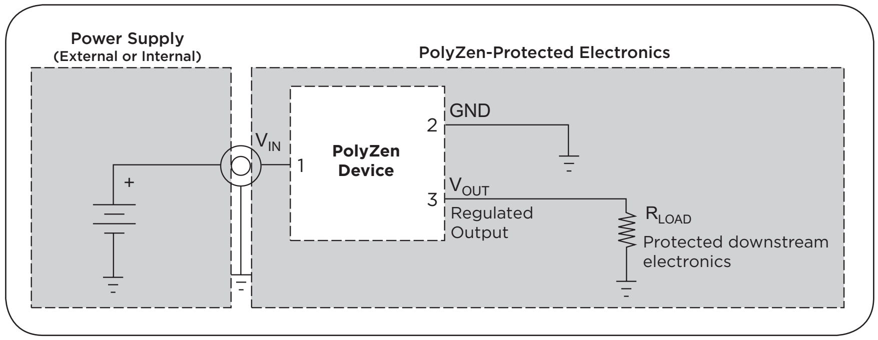


Figure 2: Typical application block diagram of a PolyZen device

An application block diagram of a generic PolyZen device is shown in Figure 2.

A typical fault response of a specific PolyZen device is shown in Figure 3. In this example, PolyZen device integrates a 5.6V Zener diode (Vz), a 1.3A I_{HOLD} PPTC, and a 24V V_{IN} (specified as Vintmax but shortened to V_{IN}). V_{IN} is connected to a 24V, 10A current-limited power source and I_{OUT}=0. As fault current passes through the system under a 24V overvoltage (V_{IN}) fault, the PolyZen device's precision Zener diode clamps the output voltage at the Zener clamp voltage Vz (~5.6V) in order to protect the load circuit. At the same time the PPTC device trips, cutting off the current to help protect the Zener diode as well as the entire circuit.

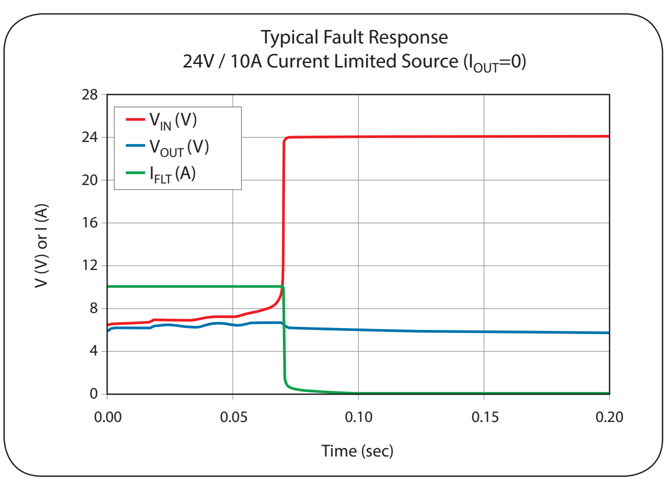


Figure 3: Typical fault response of a PolyZen device

EOS Faults in LED Applications

Typical scenarios in which EOS faults can originate in LED applications are from instability in power supply output, noise generated by overvoltage/overcurrent conditions, component degradation, and from current inrush in hot-swap applications.

As previously described, EOS faults are typically transient, but they can also be permanent. Basically, when the energy of the voltage or current spike (i.e., EOS fault) exceeds the LED's specified design values, the LED can be damaged. EOS faults can cause the immediate breakdown of the LED or, in some cases, can cause failure only after the EOS event has been present for a period of time.

EOS Fault Test Examples

A basic test platform was set up to simulate the EOS fault signal in an LED application. The complete test-platform circuit diagram as well as a diagram of the actual test are shown in Figures 4 and Figure 5, respectively.

A Keithley Model 2410 SourceMeter was used as the source of the output voltage/current in the test system. In the circuit, a switch was connected in series for on/off switching of the complete circuit. A commercially available LED was selected to evaluate the impact of EOS. The rated capacity of the LED for surge current is shown in the red rectangle in Table 1.

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Forward current (min.) (T_S = 25°C) (max.)	I_F I_F	100 800	mA mA
Surge current $t \leq$ 50ms, D = 0.016, T_S = 25°C	I_{FM}	2000	mA
Reverse voltage (T_S = 25°C)	V_R	not designed for reverse operation	V

Table 1: LED-rated parameters

The transient power, which can result in LED failure, can be calculated according to the following Formula 1:

$I^2tD = 2^2 \times 0.016 \times 0.05 = 0.0032(A^2s)$ ------ Formula 1

I: Current - peak value, t: Time - duration of current,
D: Duty cycle of current

Thus, the LED device can be damaged if the energy of the transient spike in the output of the test system power supply exceeds this value.

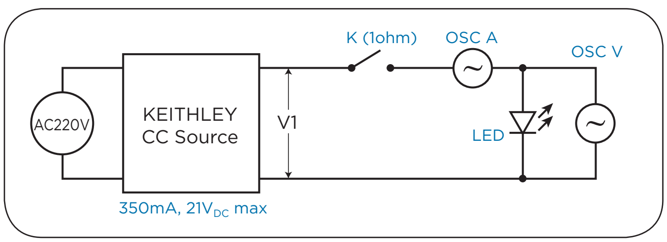

Figure 4: Block diagram of EOS simulation test platform

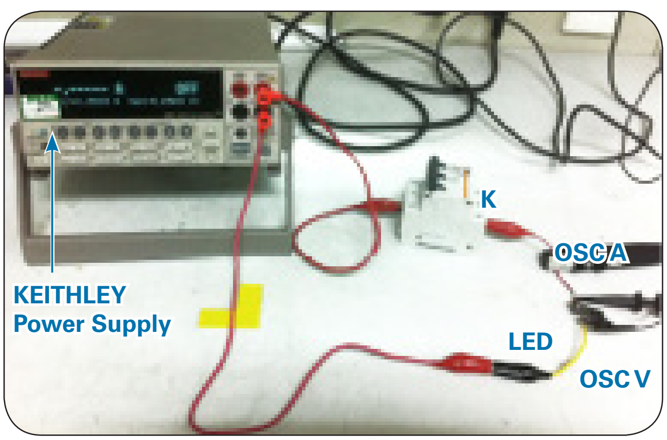

Figure 5: Diagram of experimental test system

Figure 6 shows the results of the circuit when the test was started. In this figure, the oscilloscope captures the transient voltage/current waveform of the test system as it begins operation. Here, the spike voltage = 4V, the spike current = 1.5A, and time duration = 340µs.

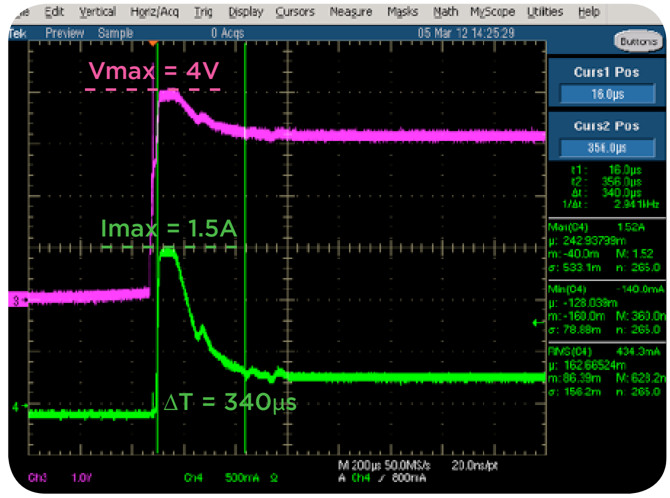

Figure 6: The transient impulse waveforms from the Keithley SourceMeter test

In this situation, where the waveform is similar to a triangular wave, EOS energy can be calculated using the following Formula 2:

$0.5I^2t = 0.5 \times 0.15^2 \times 0.00034 = 0.00038(A^2s)$ ------ Formula 2

I: Current - peak value, t: Time - duration of current,

Based on the data derived from Formula 2, the noise energy of the spike is below the rated limit of a surge that would damage the LED device; which means the LED is safe under this condition. But this test uses the Keithley SourceMeter, which is able to deliver a high-quality voltage/current that actually assists in the protection of the LED from EOS damage. However, in real-world applications, engineers would have to spend additional time and cost in the design and construction of the type of high-quality LED power supply that is required to protect against EOS faults. In most markets, adding extensive cost to the power supply is not a practical solution, and therefore compromises must be made.

The next test simulates the harsh conditions of power supplies in actual day-to-day applications. Based on the Figure 4 test platform, a capacitor (rated at 220µF/450V) is inserted in the output of the voltage source to deteriorate the quality of the Keithley output, thus introducing EOS type signals. This also provides a more real-world response based on what an LED application would be subjected to.

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A schematic circuit diagram and a photograph of the test set up are shown in Figures 7 and Figure 8, respectively. This experiment evaluates how PolyZen devices help to mitigate EOS faults. As shown in Figure 7, the PolyZen device ZEN056V130A24LS, which integrates a Zener diode rated at 5.6Vz, 1.3A I_{HOLD} PPTC = and 24V V_{IN}, was placed after the capacitor. The first portion of the experiment shows the response of the circuit with the capacitor inserted and the second portion shows the response with the capacitor and PolyZen inserted.

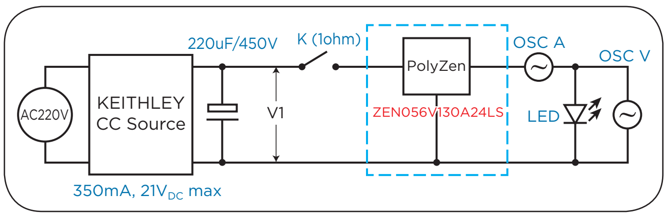

Figure 7: EOS simulation test platform diagram with PolyZen protection (with added capacitor to deteriorate the EOS signal)

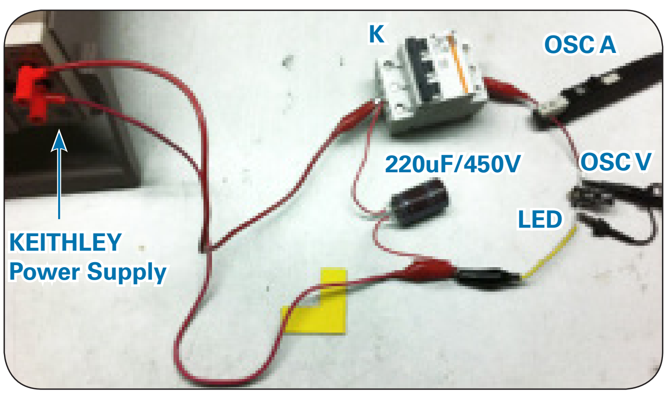

Figure 8: Experimental test system diagram without PolyZen protection (with added capacitor to deteriorate the EOS signal)

In the first part of the test, the capacitor has been inserted into the circuit, and shows what happens when a PolyZen device is not used to protect the circuit. After switching on the power, the current/voltage transient impulse waveform, illustrated by the oscilloscope used for Figure 9, shows the following: Spike voltage = 23.2V, Spike current = 12.8A, time duration = 200μs. The energy of this EOS waveform is calculated according to the following Formula 3:

$0.5I^2t = 0.5 \times 23.2^2 \times 0.0002 = 0.054(A^2s)$ ------ Formula 3

I: Current - peak value, t: Time - duration of current,

According to Formula 3, 0.054A²s of the EOS energy can be obtained, which exceeds the rated LED surge current. The LED lifetime will be shortened, and the LED will probably sustain direct damage if it operates under these power-supply conditions for an extended period of time.

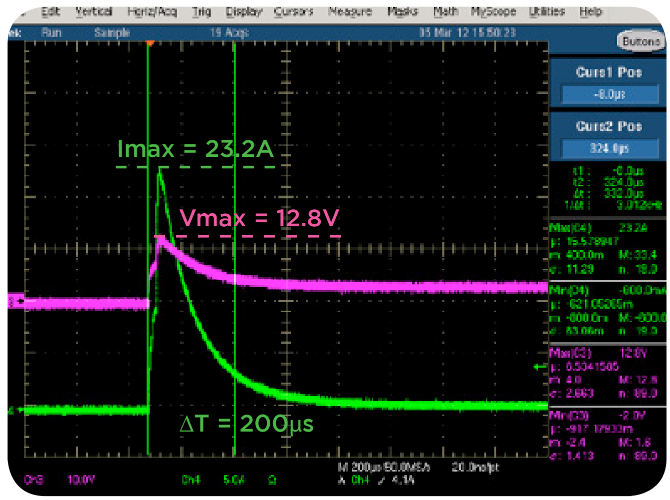

Figure 9: Transient impulse waveform from Keithley Sourcemeter (with added capacitor to deteriorate the EOS signals)

The next portion of the experiment (Figure 7) shows the capacitor and a PolyZen device connected in parallel and placed in front of the LED. Because the PolyZen device integrates a Zener diode for comprehensive overcurrent/overvoltage protection, it is able to clamp the output voltage, as well as shunt fault current effectively to protect the load circuit. In this test, a spike voltage/current waveform was obtained, as shown in Figure 10. The results indicate: Spike voltage = 6.4V, Spike current = 6.4A, Time duration = 240μs. The energy of this EOS waveform is calculated according to the following Formula 4:

$0.5I^2t = 0.5 \times 6.4^2 \times 0.00024 = 0.0049(A^2s)$ ------ Formula 4

I: Current - peak value, t: Time - duration of current,

In this test the PolyZen device significantly improves protection from EOS events by decreasing the EOS energy from 0.054A²s to 0.0049A²s. In a real-world application of a power supply exhibiting EOS, the PolyZen device offers protection that is an order of magnitude better than using nothing at all.

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The value obtained in Formula 4 is slightly higher than in Formula 1; however, protection of the LED was maintained. In other words, the PolyZen device effectively reduces the fault current and thus improves EOS event protection by quickly clamping the fault voltage.

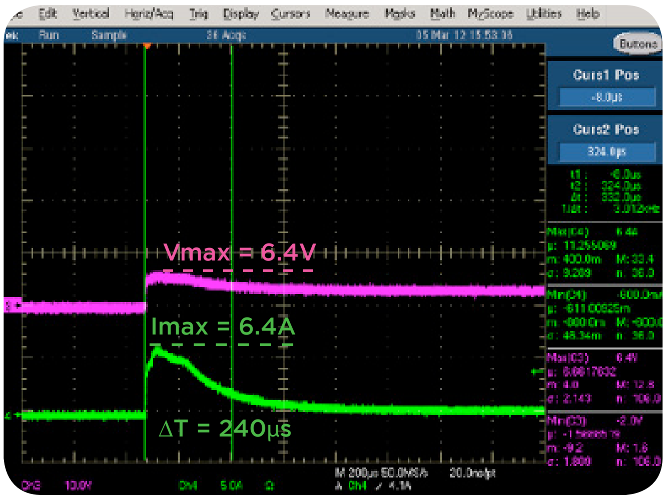

Figure 10: Transient-impulse waveform from Keithley Sourcemeter (with added capacitor to deteriorate the EOS signal and with PolyZen protection)

The next experiment employs a PolyZen device to illustrate a cost-effective solution for helping to protect LEDs that are often used in actual applications. With the goal of protecting two LEDs with a forward voltage (Vf) of 3V, the PolyZen ZEN065V130A24LS device was selected for its Zener diode of 6.5Vz, 1.3A I_{HOLD} PPTC, and 24V V_{IN} rating. The schematic circuit diagram of the test system is shown in Figure 11, and the diagram of the actual test is shown in Figure 12.

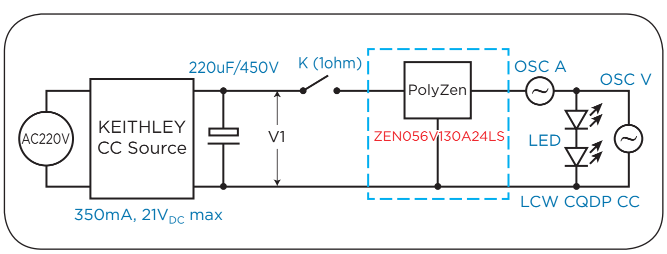

Figure 11: The block diagram of the EOS simulation test platform (one PolyZen device protects two LEDs)

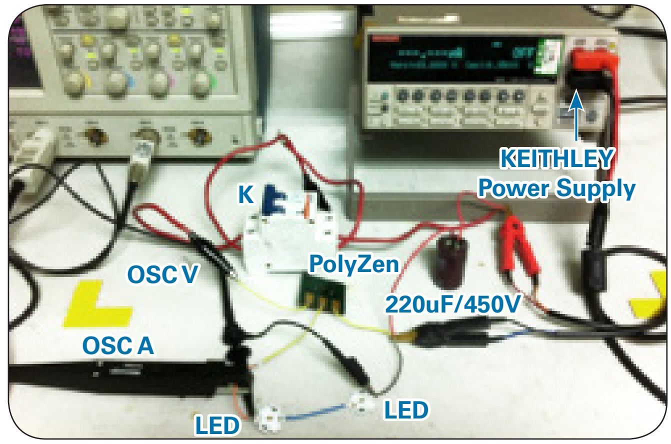

Figure 12: Experimental test system (one PolyZen device protects two LEDs)

The waveform on the oscilloscope is shown in Figure 13, where the spike voltage = 7.4V, spike current = 1.5A, time duration = 400µs. Therefore, the energy of the EOS waveform can be calculated using Formula 5:

$0.5I^2t = 0.5 \times 1.18^2 \times 0.0004 = 0.00027(A^2s)$ ------ Formula 5

I: Current - peak value, t: Time - duration of current,

The EOS energy is less than the value calculated with Formula 1, which can cause LED failure. Therefore the LED can operate safely within this power environment. In this application, EOS protection is provided effectively by the PolyZen device, and the LED is also protected.

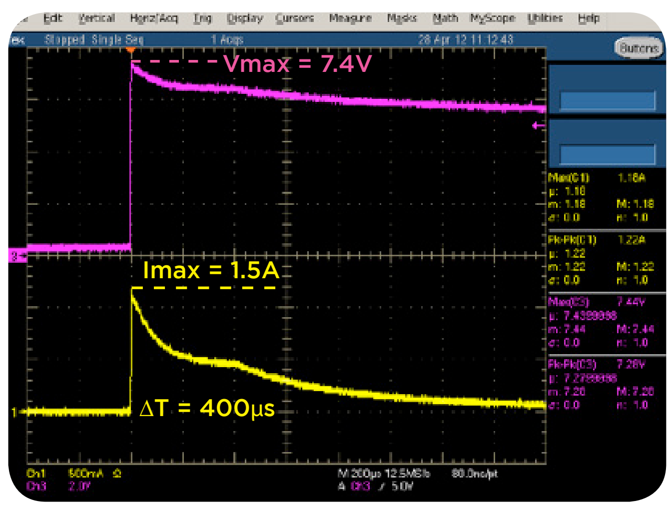

Figure 13: Transient impulse waveform from the Keithley Sourcemeter (with an added capacitor to deteriorate the EOS signal, where two LEDs are protected by one PolyZen device)

PolyZen Devices for EOS Protection in LED Applications

Summary

The results of the experiments presented in this paper show that PolyZen devices can be used to help protect LED applications against EOS faults. According to the results, PolyZen devices can help:

1. Lower EOS energy levels significantly to help protect LED devices and extend their lifetime.
2. Reduce complexity and cost in LED power-supply designs.
3. Provide multi-functional resettable protection against overcurrent/overvoltage conditions and mitigate high energy states.
4. Offer space- and cost-saving alternative to high-power, physically large TVS diodes, as well as other discrete components trying to duplicate the functionality of PolyZen device.

The numerous advantages of PolyZen devices make them a useful solution for the protection of LEDs against EOS faults. Additionally, their slim-profile package and advanced protection features are suitable for helping to protect a wide range of sensitive electronics from damage resulting from overvoltage and overcurrent events. PolyZen devices offer PCB designers a simple overvoltage/overcurrent solution, which ultimately can aid manufacturers in avoiding costly product returns and warranty issues.

For more information on PolyZen-based applications and product details, please visit our website:
www.littelfuse.com