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Head: **Sizing Up Circuit Protection for LED Strings**

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As LEDs find their way into more outdoor applications they are at higher risk for ESD and other electrical transients. High-brightness LEDs (those with sapphire or SiC substrates and in the future AlN and GaN substrates) are especially susceptible, and when the first LED in a string fails, the whole string goes dark. Few engineers know all the considerations of specifying circuit protection for LED strings. For example, a recent category of devices, called open LED protectors, are now available, and are not well understood. When to apply them, how to size them, and how to save cost by protecting multiple strings with a single device, will be discussed.

**Introduction**
High-brightness LEDs are showing up in outdoor applications everywhere you look. More and more car and truck taillights are made up of clusters of LEDs, chosen because they don't burn out and are resistant to vibration and shock. They're used in street lights, traffic lights and airport runway markers because they cut costs for replacement and electricity. Billboards use them in giant video screens because of their high reliability and rapid response.

As low-voltage devices (forward voltage typically ranges from about 2.7 volts for red to approximately 4.1 volts for blue) high brightness LEDs are generally connected in series strings and fed by a constant-current supply. A string can contain anywhere from five to 20 individual LEDs. LEDs connected in series share a common current, which means there's more uniform LED-to-LED brightness, and it's easier to control the brightness of the group.

But LEDs have three major weaknesses:

- They can be damaged by temperature cycling. Thermomechanical stress on the internal wire bonds can degrade them, eventually causing the LED to fail open. Vibration can contribute to this.
- They're electrically fragile. Electrostatic discharge (ESD) or surges induced by nearby lightning can destroy them — and ESD and lightning are common in outdoor applications. Most LEDs in this type of application are powered by

switch-mode power supplies, which tend to offer only limited protection against incoming surges (in fact they generally need protection themselves).

- If one LED in a string shorts out internally it will go dark and the rest of the string will stay lit but that shorted LED will typically have thermal accumulation that eventually leads to an open circuit condition due to failure of the wirebond connection.  However, if the LED fails open then it will act like a bulb on an old-fashioned string of holiday lights: one open LED causes the entire string to go dark. This is unsightly on a billboard but can be a safety hazard in a traffic light or airport runway marker. What's more, many of these outdoor applications are remote and hard to reach without lift equipment, driving up the cost of string replacement.

**Keeping the lights on**

LEDs can be protected against damage due to ESD and induced surges with MOVs or TVS diodes, and against overcurrents with fuses, but these devices cannot keep a single open LED in a string from shutting down the entire string. To do that requires an open LED protector, which is connected in parallel with each LED (Fig. 1) — or group of up to four LEDs — in the string. If an LED fails open, the voltage across it will increase to the compliance voltage of the supply; the protector will detect the voltage rise and turn on at its breakdown voltage $V_{BR}$ (Fig. 2) to shunt the current around the failed LED and keep the rest of the string operating. Some open LED protectors also protect against ESD and reverse voltages.

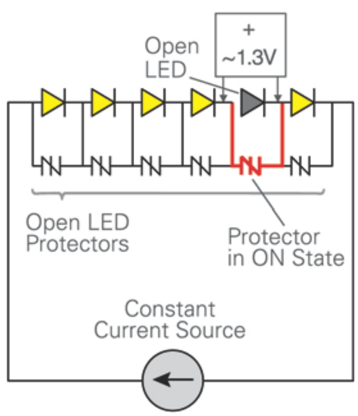


*Fig. 1: If an LED fails open the voltage across it will increase to the compliance voltage of the supply; the protector will detect the voltage rise, trigger, and shunt the current around the failed LED to keep the remaining LED string operating.*

Many LED driver ICs have built-in open-LED protection, but this is intended only to keep the output voltage of the driver from reaching damaging levels if the load current falls to zero (as it would if an LED in the string opens); it does nothing to keep the other LEDs in a string operating. Similarly, ESD protection built into the driver or the LED is not sufficient for the HBM (human body model) form of ESD that can reach as high as 15 kV (see IEC 61000-4-2).

If the power supply is connected backwards to the LED string, the open LED protector's built-in reverse protection diodes will turn on to protect the LEDs. The LEDs will not illuminate until the power supply polarity is corrected.

Some designers may try to use an SCR or a zener diode in place of an open LED protector, but this is short-sighted. SCRs tend to be large; they provide no ESD or reverse polarity protection; they typically require a resistive voltage divider network to set the trigger voltage; and their variation of triggering voltage vs. temperature is quite large. A zener diode (either external or built into the LED) provides no protection against open circuits or reverse polarity, and if the LED opens then the zener diode will conduct all the current and the heat generated may shorten the life of the zener diode and nearby LEDs.

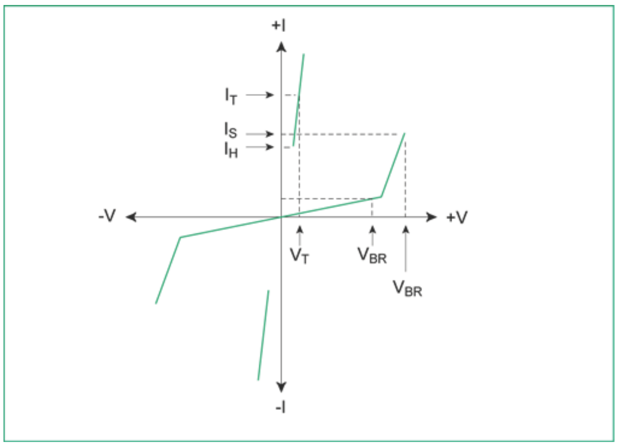


*Fig. 2: An open LED protector turns on at its breakdown voltage $V_{BR}$. Shown is the graph for a Littelfuse PLED6 Series device. Standard operation is quadrant one.*

**Sizing an open LED protector**

The first step in selecting an open LED protector is to define the characteristics of the LEDs to be protected — $V_f$ (forward voltage) and $I_f$ (forward current) — and their connection scheme (protected singly or in groups of two, three or four).

From the number of LEDs in the LED string, calculate the forward voltage drop of the entire string, which will determine the compliance voltage that will activate the open LED protector. The individual LED voltage drop must not exceed the stand-off voltage of the open LED protector. If an open LED protector is used across multiple LEDs, then the combined voltage drop of all parallel LEDs must not exceed the stand-off voltage of the open LED protector.

Check the constant-current source value of the power supply.

Choose the voltage and current characteristics of the open LED protector based on the following:

- The open LED protector turn-on voltage must be less than the power supply compliance voltage, so the device will trigger when one LED opens.
- The open LED protector switching current must be less than current source value, so the device will switch on reliably.
- Make sure the open LED protector's switching current and holding current can be satisfied over the entire expected range of operating temperatures of both the LEDs and the protector (note this is device temperature, not ambient temperature), as well as such things as the LED color and brightness (holding current < LED drive current).
- For cost savings, LED protectors are available to protect groups of two or three LEDs in series. Select the open LED protector accordingly; a device that triggers at 6 volts protects one LED; a 9-volt device can be used with a pair of LEDs (Figure 3); a 13-volt device can be used with three; and an 18-volt device can be used with four. (Note that in this case a failure of one LED will cause two, three or four LEDs, respectively, to go out.)

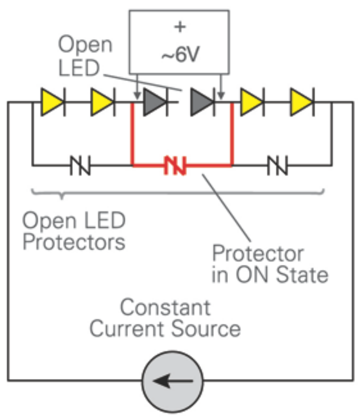


*Fig. 3: Open LED protectors are available to protect groups of two (shown), three or four LEDs. The protector trigger voltage in this example is 9 volts, higher than the normal operating voltage of two LEDs (6 volts).*

Dimming is important in some applications. Some LEDs experience a color shift when the forward current changes, but pulse width modulated (switch-mode) dimming prevents that from happening. Make sure that the open LED protector chosen is compatible with the type of dimming used.

**Packaging and environmental considerations**
Next, choose the open LED protector package to fit the lighting product environment.

Define the ambient temperature of the open LED protector's environment and provide adequate heat sinking if required. In a typical application with a constant current output from the power supply of 350 mA and a drop across the protector of 1.1 V when triggered, the protector will dissipate 385 mW. While this is less than the on-state dissipation of the LED or LEDs to which it is connected, the protector may or may not need a heat sink. For example, the protector in this case, assuming a typical junction-to-air thermal resistance of 100°C/W (with no heat sink), would have a temperature rise of 38.5°C. Assuming a device maximum operating temperature of 85°C, the protector would require heat sinking in any ambient warmer than 46.5°C. For safety that temperature should probably be reduced to about 30°C.

Protector current in the non-triggered mode is generally less than 150 microamps, so temperature rise would be a bit more than 5°C.

**Final notes**
After all calculations, perform testing on the open LED protectors by shunting with the protected LEDs and check the results against the design criteria.

When installing open LED protectors, be sure to follow all soldering guidance for the device packages used.

And finally, note that open LED protectors can be used on individual LEDs or multiple LEDs installed in series strings; they may be suitable for parallel strings driven by a common cathode (in this configuration, the open LED protector prevents excessive current from flowing into the parallel strings) but may not be suitable for matrix arrangements in which there are cross-connections between multiple strings.

**About the authors**
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