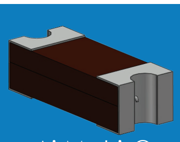
Put Your Guard Up™


AirMatrix®

APPLICATION BRIEF

Protecting LED Lighting From Overcurrent

Light emitting diodes have been in the electronics industry for decades. They've been used as light indicators in electronic devices such as video displays and sensors. They are also being used as backlighting in portable LCD displays for smartphones, tablets and laptops. Recently there has been a demand for energy efficiency in general lighting applications. This has led to the advancement of high brightness (HB) LEDs. Now there is a growing trend to replace traditional incandescent and fluorescent light bulbs with HB LEDs. HB LEDs offer lower energy consumption, high efficacy (lumens per watt), long operating life, compactness and durability. But, this new technology introduces overcurrent and short circuit engineering design challenges. They will be discussed in-depth in this application note.

LED Lighting Overcurrent and Short Circuit Considerations

LED light bulbs are vulnerable to overcurrent and short circuit events. They are commonly caused by electrostatic discharge, lightning strikes, inductive or capacitive load switching. You can add to the list, loss of neutral and incorrect input voltage. All can lead to fires or electrical shock threatening personal safety or causing severe property damage. It is for these reasons the use of overcurrent protection is mandated by international safety standards. However, when selecting appropriate protection devices engineers are faced with several design challenges. These can include elevated operating temperature, in-rush current pulses and voltage surges. In addition, LEDs are constant current devices. To be compatible with the AC main they require AC-to-DC power conversion. A LED driver is also used to provide a regulated supply of current. The driver maintains constant current regardless of variations in load due to fluctuations in temperature. This complex circuitry must fit inside a screw-in type bulb assembly. So, available board space is limited (Figure 1).

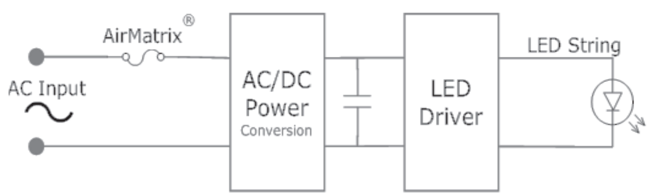


Figure 1. LED block diagram

Temperature Considerations

The majority of heat generated in an incandescent light bulb is dissipated through radiation. In contrast, LEDs dissipate the majority of heat through conduction. Therefore, LED light bulb fixtures can reach internal ambient operating temperatures ranging 65 to 85 degrees centigrade. In some applications temperatures can exceed 100 degrees centigrade. These extreme temperature conditions pose serious design restrictions. This is particularly true for electrolytic capacitors where high temperatures can reduce performance and lifetime. Fuses are positive temperature coefficient devices. So, they experience a rise in electrical resistance as temperatures increase. This change in a fuse's physical properties conversely alters clear time characteristics. Primarily, an increase in DC resistance causes a decrease in I^2t. The I^2t value of the fuse is expressed in units of A^2sec. It is defined as the energy required to open the fuse. The smaller the I^2t, the less energy required to open the fuse, hence a faster clear-time. So, fuses operating in elevated temperatures, (i.e., LED light bulb fixtures) must be properly de-rated or re-rated. This is to prevent nuisance openings. Consider the option of using a 2A rated fuse operating in worst-case 105 degrees centigrade conditions. Next, we can use the temperature de-rating curve (Figure 2). This is usually provided on the manufacturer's product datasheet or catalog. From it, we can see that a de-rating of 80% is required at this temperature. We take into consideration a recommended buffer of 75% or less of the fuse current rating, with a typical operating current of 0.3A. We can determine that a 2A rated fuse can withstand temperature conditions of a LED light bulb. Ensuring no nuisance blowing, the fuse current rating can be determined as follows:

$$I_{fuse} \geq \frac{\left(I_{operating}/_{0.75} \right)}{T_{derating}} \rightarrow I_{fuse} \geq \frac{\left(0.3/_{0.75} \right)}{0.8}$$

$$I_{fuse} \geq 0.5A$$

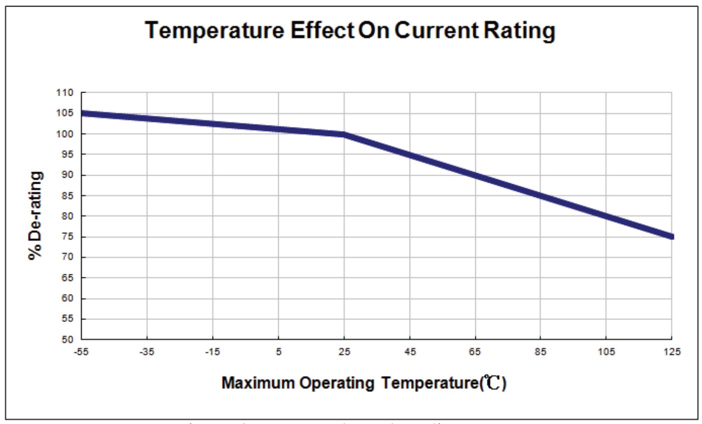


Figure 2. Temperature de-rating curve

In-rush Current Withstanding Capability

Every time the LED light bulb is turned on an in-rush of current is produced. This is a very fast transient condition. It can generate peak current orders of magnitude greater than normal operating conditions. This transient state is the result of charging the large electrolytic capacitor. It's used to remove or "smooth" the AC ripple component at the full bridge rectifier output (Figure 4). Energy contained in the transient event is the time-integral of the pulse waveform. It is given by the relationship:

$$I^2t = \int_0^t [A(t)]^2 \, dt$$

When considering a fuse, the energy of the in-rush pulse must be taken into account. The energy of the fuse shall be greater than that of the in-rush. Of course this is to ensure we don't cause nuisance openings ($I^2t_{fuse} > I^2t_{inrush}$). Let's consider a worst-case scenario in a large capacitor at 90˚ phase angle of a 265VAC sinusoidal wave. Here, a "perfect storm" is capable of generating high in-rush current. Let's take 12A at 1ms for demonstration purposes. Assuming a typical capacitor charging wave form, we can approximate our calculation with equation 1 (Eq 1). We allow for additional pulse cycle de-rating (assuming worst-case, 20% for 100,000 cycles). We factor in temperature from the example above and finally include a 30% safety margin:

$$Eq\ 1: I^2t_{inrush} = \frac{I^2t}{2} = \frac{12^2 \cdot 1ms}{2} = 0.072\ A^2s$$

$$Pulse\ \&\ Temperature\ derating \rightarrow \frac{\left(0.072/_{0.2}\right)}{0.8} = 0.45\ A^2s$$

$$30\%\ safety\ margin \rightarrow \frac{0.45}{0.7} = 0.64A^2s$$

Figure 5 illustrates the average I^2t vs. time curve. We can see the I^2t value of a 2A rated fuse. And, at 1ms it is well within tolerance compared to the I^2t of the in-rush pulse. So, the 2A fuse can sustain numerous in-rush pulse cycles. And, it can provide protection for the expected lifetime of a LED light bulb. We should mention the use of power factor correction (PFC) and EMI filtering can significantly reduce the magnitude and alter the wave shape of the in-rush pulse.

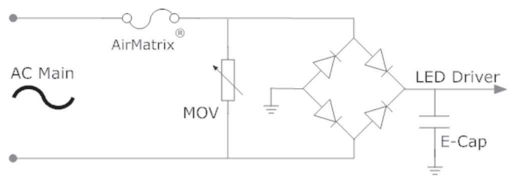


Figure 4. Typical LED power conversion circuit. E-Cap located at the output of the rectifier can generate high in-rush current.

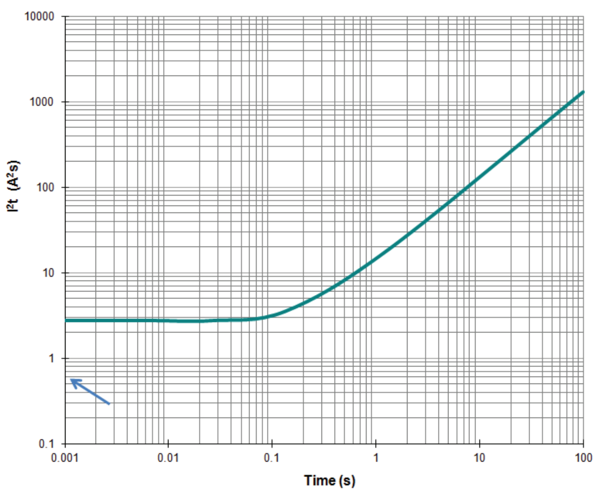


Figure 5. Avg. I^2t vs. Time curve for 2A fuse. Arrow indicates I2t of in-rush pulse.

Voltage Surge Withstanding Capability
Safety standards require LED light bulbs endure high voltage surge testing. A voltage surge in the main power supply can be induced many ways. Commonly they include lightning strikes; tripped circuit breakers; power company malfunctions; and power outages. There are also less common causes. International safety standard IEC61547 outlines specific requirements. A 25W light bulb should withstand a 5 pulse 1.2us/50us waveform at 500V line-to-line and 1,000V line-to-ground. In LED light bulbs a high-energy metal oxide varistor (MOV) is connected across the line and ground. This is to prevent catastrophic damage. MOVs posses non-linear voltage-current characteristics. So, during normal operating conditions the MOV is at high impedance. This blocks current from flowing to the ground. But, during a high voltage surge the MOV becomes low impedance. This provides a so-called "shunt" path directing the current to ground. In turn it dissipates energy as heat thereby protecting sensitive downstream components. As current-sensitive devices, fuses must survive the resultant in-rush current that is produced during such an event.

Space Constraints
LED light bulbs must be cost-effectively interchangeable with traditional Edison screw-in bulb fixtures. So, it's essential that all power conversion and LED driver circuitry fit inside the bulb assembly. Component manufacturers are challenged with the task of reducing package size while maintaining all the electrical requirements. This is true too with a fuse interrupting rating (the maximum current the fuse can safely interrupt). Engineers must overcome physical limitations using a small fuse package. And, the fuses interrupting rating is a function of body size. Furthermore, the mass of the body in combination with the material system matter. This determines arc quenching capability without breaching (the ability of the fuse to extinguish arcing during opening). A fuse with a smaller case size is necessary to maximize board space availability. A surface-mount configuration is also ideal for compatibility with standard pick-and-place technology. This not only reduces assembly cost but lead time as well.

Solution
It has been demonstrated that a 2A fuse can sustain the typical worst-case conditions of an LED light bulb. This includes operating at extreme temperature conditions while surviving pulse cycling through its lifetime, without nuisance opening. In addition, LED light bulbs are susceptible to AC line voltage surges. Therefore, they must pass all standardized surge testing requirements. AEM Electronics offers a 2A 250VAC fuse in its AirMatrix® product family. It complies with all regulatory requirements. The AirMatrix® fuse comes in a compact EIA standard 2410 case size. It is an ideal overcurrent protection solution for LED lighting where board space is limited.