Extend the life of LED lighting systems with thermal management

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With light emitting diodes (LEDs) at the forefront of new residential and commercial fixtures, engineers and designers often struggle with ways to protect LEDs from premature failure due to thermal issues. LEDs permanently lose their brightness when thermally stressed and will degrade much quicker than the manufacturer intended. The additional cost of the emitters should be balanced with the thermal design to provide not only an elegant lighting solution, but the long life promised by solid state lighting.

Today, roughly 20% to 50% of the electrical energy produced worldwide is used for lighting. With the world population growing there are only two alternatives, generate more electricity by building new power plants or work more efficiently with what is already being produced. Even if new power stations are built, the power lines connecting them to where the energy is needed can take many years to plan and install. Improving efficiency is one solution to mitigate the rising trend of power consumption and has the focus of the lighting industry. LEDs came on the scene commercially around the 1970’s as a replacement for incandescent bulbs used as indicators. Today, LEDs have efficacies over 100 lumens per watt and are finding their way into a large selection of general lighting applications. One of the earliest issues converting fixture designs from incandescent bulbs to LEDs is the difference in thermal characteristics. LED manufacturers actually publish life curves for their emitters as a function of temperature... something fixture designers may have never seen before.

The problems with LEDs

Incandescent bulbs could be referred to as heaters that emit some visible light. Around 90% of the light emitted from an incandescent bulb falls into the infrared region beyond 700 nanometers - invisible to humans but not imperceptible (See Figure 1).
Figure 1. Emission spectrum of an incandescent bulb.

The infrared “heat” can be felt if near incandescent bulbs – a common problem with task lighting over kitchen counters where the wasted IR light will heat food sitting below the lamps, which may promote premature spoilage.

LEDs however suffer a different problem. Their light is produced as electrons cross a forbidden energy zone called the “band-gap”. As the electrons combine with electron “holes” or the absence of electrons, they lose energy crossing the barrier. This energy is tailored by adjusting the band-gap to produce various frequencies of light. Traditional “white” LEDs initially generate intense blue or ultraviolet light which is used to excite a phosphor placed in the optical path. The process of converting electrons to photons in the junction of the LED is not perfect. The majority of the photons created in the junction is never emitted and ultimately recombine producing waste heat. Additionally, the phosphor used to shift the frequency of the LED emission to produce the white light depends on a phenomenon called the Stokes Shift. Both of these mechanisms produce waste heat that must be conducted away from the LED junction or severe damage will occur.

LEDs rarely fail catastrophically like their incandescent predecessors. They slowly degrade affecting the photon emission resulting in a dimming of the emitter. There are two industry end-o-life metrics; one is the L70 or Life to 70% of original emission and the L50 point – or 50% emission point. Typically the L70 point is used as the useful life of an LED fixture or bulb. The U.S. Department of Energy is actively engaged with standards organizations such as NIST and ANSI and has already released several standards such as ANSI C78.377-2008, Specifications for the Chromaticity of Solid-State Lighting Products. However, standards for life estimation such as TM-21, Method for Estimation of LED Life are still in development. The bottom line is that the lower the operating temperature of the LEDs, the longer their life span.

Solutions to Thermal Issues

The secret to a successful LED fixture design is proper thermal management. There are several factors that affect the thermal performance of any fixture including the ambient air temperature, but LEDs specifically suffer from improper thermal design. Conducting away the waste heat produced by LEDs is paramount and can separate the winners from the losers quickly in this emerging industry. Two markets exist; one is the retrofit or existing infrastructure of Edison base bulbs, “can” and low voltage halogen fixtures as well as task lighting. The other is new construction and
commercial applications where reliability and overall cost of ownership take on greater importance. Both applications lack proper thermal management in the current infrastructure.

Addressing the retrofit market has additional hurdles including cost as well as dealing with the poor thermal characteristics of existing fixtures. One method to fix the thermal and cost issues is using passive cooling. This requires the fixture or bulb to have a large heat-sink engineered into the design that provides a low resistance path for the heat to flow away from the LED. Like electrical current any thermal resistance in the heat path causes a temperature increase. Thermal impedance is traditionally measured in degrees per watt (°C/W) and uses the symbol “θ” (theta) to denote the value. For instance, the value of θsa equal to 20°C/W refers to the heat-sink (“s”) to ambient air thermal impedance and will cause a temperature rise of 20 degrees for every watt of power dissipated. Figure 2 shows a passive thermal PAR38 (flood light style) design from LedEngin, Inc. and is commercially available today.

![Figure 2. PAR38 dimmable LED replacement bulb from LedEngin, Inc.](image)

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For more demanding applications where thermal conduction is limited due to elevated ambient air temperature or limited space, active cooling may be the solution. With the life span of LEDs exceeding 35,000 hours rotating fans become the weak link in the system. A company called Nuventix has invented a novel active cooling system based on a hydrodynamic principle called entrainment. They produce high speed air-jet pulses that pull in or “entrain” the air around it. This produces a flow vector in the direction of the jet causing continuous air flow. The SynJet® product has only small diaphragms that produce the jets and have an L10 lifespan of over 100,000 hours—well within the lifespan of the LEDs in the fixture. Figure 3 shows a Nuventix MR16 cooler that
provides extremely low thermal impedance between the sink and the ambient air – depending on model anywhere from 2.0 to 3.25 °C/W. In many cases active cooling may be the only method for maintaining the correct LED temperature to extend the life of the fixture.

Figure 3. Nuventix MR16 active cooler

One additional method that may be combined with the two above is called thermal fold-back. To provide thermal fold-back, an LED driver needs to incorporate an additional control loop that senses the temperature of the LED. If for any reason the LEDs’ temperature increases beyond safe limits (i.e. blocked cooling path, elevated ambient temperature, etc.), the driver will sense the increase in temperature and “fold back” the current driving the LEDs. This in turn will reduce the power dissipation of the LEDs and reduce the temperature. The brightness will also decrease, but the LEDs will be protected from damage and maintain their useful life. Once the thermal problem is corrected, the driver will once again increase the current returning the LEDs to their original brightness. An example of a driver that has this function built-in is the Texas instruments LM3424 LED driver.

The Future

There are companies such as Luminus Devices, Inc. that are pushing the luminous intensity of LEDs by incorporating wave-guide technology directly into the die. These LEDs are based on photonic crystals – some of which occur naturally such as opal – that channel subsurface photons so they can be emitted instead of absorbed which reduces heating. As the efficacy of the LEDs continues to increase, less power will be lost to heat mitigating some of the issues with thermal management. Additionally, government standards for efficiency will continue to push the envelope in solid-state lighting, which ultimately will displace the humble incandescent bulb as well as all other current lighting sources.
Conclusion

When designing LED fixtures care must be taken to ensure the thermal management is well designed and maintains the minimum temperature possible to extend the life of the emitters. Good thermal design either passive, active or employing thermal fold-back will not only extend the life of the fixture or bulb, but also provide added value to the end product further satisfying consumers as they make the switch to solid-state lighting.

See related information: High-power LED driver features multiple dimming control modes

About the Author

Rick Zarr is a technologist at Texas Instruments. He is actively engaged in research of energy related technologies and applications utilizing semiconductors. He has more than 30 years of practical engineering experience and has published numerous papers and articles worldwide. He received the National Semiconductor Applications Engineer of the Year Award in 1994 for his work on battery charging and has lectured on energy management related topics at various industry events both in the United States and Asia. Zarr holds a bachelor’s of science degree in electrical engineering from the University of South Florida, is a member of the IEEE and a patent holder.