

## **Profitably Powering Solid State Lighting**

Due to the rising environmental concerns, the world is now replacing billions of conventional incandescent light fixtures. While a significant percentage of the applications are moving to compact fluorescent, the concerns over the mercury content of the CFL lamps as well as the potential for even greater energy savings are causing more and more users to move to solid state lighting (i.e. LED lamps). The newest LED lights consume approximately 80% less energy than incandescent lamps and contain no toxic materials. The market research firm iSuppli expects the LED related global sales to continue a pattern of strong growth, estimating the market to be approximately \$14.6 billion in 2013 despite the slow global economic recovery.

LED Lamps typically cost more than other technologies at present. Almost every business case to justify the additional cost hinges on two key attributes of the product; improved energy savings and lower maintenance costs. There are two key components of the energy savings. The first is the result of an improved efficacy as measured in lumens per Watt (lm/W). For the power electronics this translates into higher power conversion efficiency. The second is more intelligent control resulting from the ability to dim the product when higher light levels are not required. This requires that the power electronics has means to easily dim based on input from occupancy sensors, daylight harvesting sensors and/or other control systems. Lower maintenance costs result from longer product life. In addition to the cost of replacement lamps there is the cost of the labor to remove and install the lamps. This costs can vary significantly depending on whether the product is within easy reach (i.e. desk lamp) or requires heavy equipment (i.e. a bucket truck for servicing streetlights). For the power electronics lower maintenance costs are derived from improved reliability and longer life. While it is well within the capability of properly designed power electronics to last as long as the light engine (i.e. 50,000 hours or more), many poorly designed products have tarnished the reputation of LED lighting failing long before the expected payback period of the lamp. Without proper attention to the power electronics the profitability of a solid state lighting application can be seriously affected.

### **Life and Reliability**

It is important to understand that product lifetime and product reliability are two very different, although not unrelated, concepts. Unfortunately, because they are both often expressed in hours they are frequently confused. Lifetime refers to the length of time a user can expect single product to work properly before a known wearout mechanism renders the product unfit for use. Reliability deals with the random failure rate of a population of products. It may be expressed as a failure rate such as FITs (failures in  $10^9$  hours) or as the inverse, MTBF (Mean Time Between Failures). A lifetime of 50,000 hours implies that one would expect any give product to last up to 50,000 hours before failing. An MTBF of 50,000 hours implies that for a population of 1000 units, one could expect to see a random failure every 50 hours (i.e. every 50,000 hours of unit operation). Both concepts are important to understand and manage for a successful implementation of LED lighting.

Life Time Estimating the life of any product is primarily a matter of identifying all known wearout mechanisms and then identifying the shortest lived component in the system that will render the product inoperable. For most electronics power supplies, including LED drivers, that component will be an electrolytic capacitor. The electrolyte in the capacitor will vent over time as a function of the operating temperature of the capacitor. That temperature is a function of case temperature as well as the internal heating caused by ripple current in the capacitor. While it may vary somewhat for different manufacturers or part numbers, the typical equation for the life of an electrolytic capacitor takes the following form:

$$L_x = k \cdot L_o \cdot 2^{\frac{T_s - T_a}{10}}$$

Equation 1: Life of an Electrolytic Capacitor

where,

$L_x$  is the lifetime result,

$k$  is the factor determined by capacitor's RMS ripple current and operating voltage, it is provided as either a value or a function,

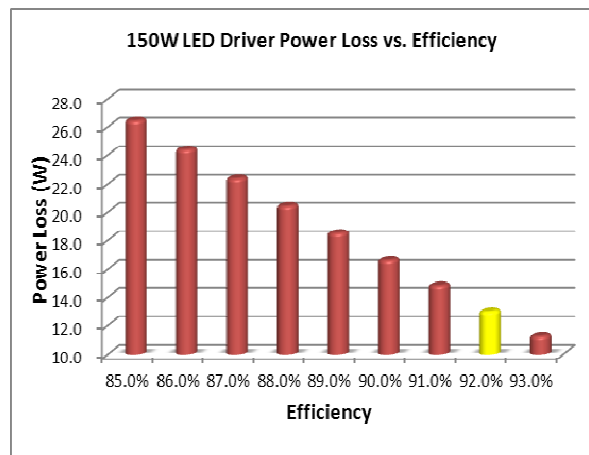
$L_o$  is the lifetime value tested in standard condition provided in the datasheet,

$T_s$  is the rated case temperature,

$T_a$  is the operating case temperature.

Knowing this equation, it becomes fairly straightforward to optimize the designs. The first priority is to select a high quality, long life capacitor. Second, the designer should strive to reduce the capacitors RMS ripple current and operating voltage relative to its rating. This involves both minimizing the ripple current and voltage while also selecting capacitors with sufficient design margin. Over specifying the capacitors will result in a larger and more costly product than necessary.

Under specifying can significantly compromise the life of the product. The last and most effective method is to decrease the case temperature of the capacitor. The temperature of the capacitor will be a function of the ambient operating environment of the driver, the ability of the driver to conduct or convect heat into the surrounding environment and the amount of power dissipated in the driver itself. For a given case design and application, the primary contributor to temperature will be the power dissipated in the driver which is directly a function of the efficiency of the driver. In other words, high efficiency and a low thermal resistance design can significantly improve the lifetime.

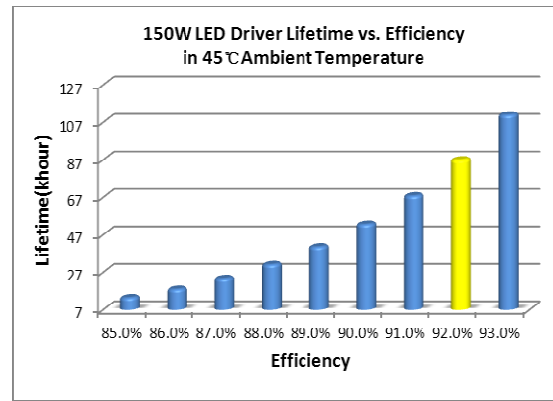


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Efficiency has a much greater impact than many people realize. For example, moving from 95% efficiency to 85% is not a 10% change in the amount of power dissipated. Rather, it increase the heat dissipated by a factor of 3.3X. Inventronics is devoting great efforts to improving the LED drivers' efficiency. Take the

popular EUC-150S (150W constant current output) series for example, the 220VAC full load efficiency reaches up to 92%, resulting only 13W loss. As the output power becomes higher, only 1% efficiency difference can see quite different loss. Figure 1 shows the relation between the efficiency and loss.

Since products of different designs can have significantly different efficiencies, therefore, the temperature inside the enclosure can be greatly different. As was shown in Equation 1, a 10 degree lower temperature doubles the lifetime. Even assuming the thermal design is the same, which means the thermal resistance from the bulk capacitors to air is the same, drivers with different efficiencies will result in different  $T_a$ , and therefore yield very different lifetimes. Figure 2 shows efficiency versus lifetime still using a 150W product as an example.



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Even if a driver maintains high efficiency, without good heat conduction and/or convection the limited power loss can generate high temperatures inside the driver. Utilizing a good thermally conductive potting compound inside and a robust aluminum case with ample surface area can greatly reduce the thermal resistance from device to ambient. This particular driver achieves 87,000 hours operating in a 45C ambient. This is better than most LED light engines and will contribute greatly to the profitability of LED lighting projects.

Reliability In general, reliability deals with the failure rate of a population of products operating within their rated conditions and within their operational life. A common way of expressing the reliability of a product is a metric known as MTBF or Mean Time Between Failures. Even though Reliability and Life are both often expressed in terms of hours, the concepts are still quite different and that difference should be understood. Equation 2 expresses the very simple concept of MTBF. It is the total operational time in hours of a population of product divided by the number of failures.

$$MTBF = \frac{TotalTime}{Failures}$$

Equation 2: Mean Time Between Failures (MTBF)

As an example, a population of 1000 products operating around the clock will accrue 24,000 hours of operation per day. If this population or products operates for one month and produces 4 failures then the MTBF would be (1000 units x 24 hours/day x 30 days)/ 4 failures. This would be 720,000 / 4 or 180,000 hours. To provide another example, if a product is found to have a 300,000 hour MTBF then a population of 1000 of these products would likely exhibit a failure about every 300 hours on average. A population of 10,000 of these products would exhibit a failure about every 30 hours on average.

To be clear, a product with a 300,000 hour MTBF does NOT mean that any given product would

be expected to last for 300,000 hours. The MTBF only holds for the operational life of the product. That is to say before any known wearout mechanisms could be expected to occur.

Perhaps a better way to understand reliability is to look at it in terms of failure rate. Equation 3 shows that failure rate is simply the inverse of the MTBF. However, because these number can be quite small, it is common to multiply this number by  $10^9$  and talk in terms of failures in  $10^9$  hours or FITs.

$$FailureRate = \frac{1}{MTBF}$$

Equation 3: Failure Rate

When determining the life of a product, it is only necessary to identify the shortest lived component and calculate its life. However, when determining the reliability of a product it is required to understand the failure rate of every component that can cause the product to fail and look at the combined failure rate.

Plenty of time has been spent on research of estimating reliability of electronic equipment. The most common of these methods is MIL-HDBK-217<sup>[2]</sup>, which is considered to be the standard reliability prediction method and is the method used by Inventronics. Another fairly common method is the Telecordia Reliability Prediction Model<sup>[3]</sup>. Typically the military result is more conservative and produces a lower number than the second commercial method of Telecordia. Either of these will be referred to as calculated reliability numbers as opposed to demonstrated reliability which is actually measuring the failure rate of a population of products. While comparing two products using the same methodology proves to be a very valid comparison, comparing the reliability of products using different methods is virtually meaningless.

The challenge is to produce the most reliable product possible given certain size and cost constraints. There are several key considerations when designing for reliability. First is the topology selection for the power stage design. A semiconductor's reliability is usually dependant on the operating junction temperature. Soft switching topologies like ZCS flyback and LLC half bridge can be utilized to minimize the switching loss of power switches, thus improving the thermal condition of both the semiconductors and the whole driver. Second, the selection of high quality component yielding adequate component stress margin should be considered. For instance, 20% operating voltage margin for electrolytic caps and 10% voltage margin for semiconductors are always a must for a reliable design. Third, protection circuits can help products survive from various kinds of abnormal conditions including over current, over/under voltage, over heated and short circuit. Also, surge suppression circuits should be used to prevent the driver from being damaged by lightning. The fourth point brings us back to the issue of efficiency and thermal design as stated previously. Heat has a direct and significant impact on the reliability of semiconductors like MOSFETs, ICs and opto-couplers. Figure 3 shows how efficiency affects the MTBF of 150W products.

One final important issue regarding reliability is understanding and eliminating infant mortality – the initial early failures of a product coming off the production line. As mentioned earlier, the concept of product reliability is valid only during the useful life of the product. It no longer applies when the product reaches any of several possible wearout mechanisms. It should also be noted that it only applies after the initial phase of infant mortality. Shown below in

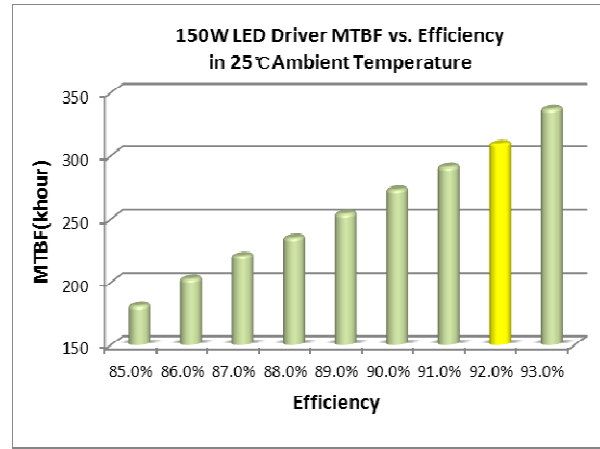
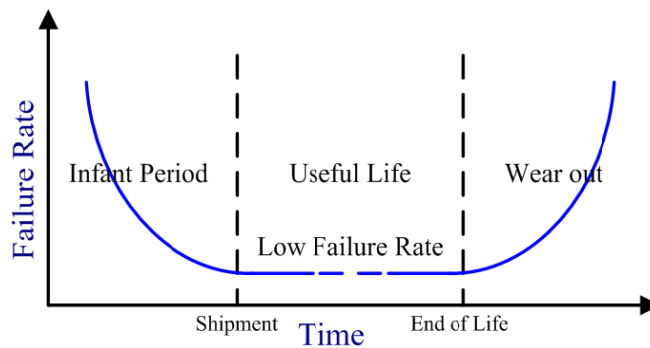


Figure 4 is the the initial failures or the well-known bathtub curve. On the Y-axis of this graph is the failure rate of the product.

This is plotted versus time on the X-axis. Most electronic products will demonstrate an initial higher failure rate referred to as infant mortality. The product then enters its useful life – the flat bottom portion of the curve. Finally, failure rates begin to rise as the product reaches some certain wearout mechanism. The challenge of the manufacturer is to ensure that those products destined for premature failure never leave the factory. In order to screen out these failures

Inventronics utilizes a robust dual burn-in process on 100% of its products. Every product is put through a burn-in process prior to potting for 1 to 2 hours. Then, after final assembly, all products are powered up under heavy load and high temperature and run for anywhere from 4 to 12 hours. It is then subject to a final suite of functional tests. The objective here is to eliminate early field failures that not only reduce the profitability of LED lighting installations but damage the perception of the lighting manufacturer.



Life, Reliability and Warranty. It seems that many people will improperly use warranty as a substitute for understanding life and reliability. It is important to understand that warranty does not directly correlate to life or reliability and is in fact a very different issue altogether. A driver with a five year warranty is not necessarily a better product than a driver with a three year warranty and, in fact, may be significantly less reliable. Warranty is simply an economic hedge by the seller that the additional margin accrued by offering the warranty will be greater than the cost incurred by drivers that are actually returned. The seller may therefore offer a longer warranty for a price premium even though no changes have been made to improve the life and reliability of the driver. It is important to understand that the seller only incurs the cost if the products are returned – not simply because unit fails. The probability of the driver making its way back to the manufacturer once it has been installed in the field is surprisingly small. The

longer the driver has been in the field the lower that probably becomes. Warranty is therefore a very poor substitute for understanding life and reliability when calculating ROI. It is also important to note that the replacement cost of the driver is usually only a very small fraction of the cost of maintenance in the event of a failure. The profitability of an SSL installation is dominated by the actual life and reliability of the product irrespective of the warranty. The issue here is not that warranty is unimportant. It is simply that warranty is a very poor proxy for actual life and reliability.

### **Efficiency**

As we have seen, efficiency has a triple impact on the profitability of solid state lighting. First of all, higher efficiency power supplies use less energy and thus the energy savings component of the ROI equation is greater. More of the energy from the ac source is transmitted directly to the light engine and less is dissipated in the driver. The overall efficacy of the lamp is improved directly with an improved efficiency in the driver. The second and third effects are directly related to the fact that less power is being dissipated in the driver. For each watt dissipated in the driver the temperature of the driver increases. The increased temperature translates directly into both shorter life and lower reliability. Both of these impacts increase the maintenance cost component of the ROI equation.

### **Control**

The initial impetus in the market for converting to solid state lighting is based simply on the energy savings and reduced maintenance costs of directly replacing either incandescent, fluorescent or other technologies with LED lamps on a direct basis. However, because of the ease with which solid state lighting may be controlled, the addition of intelligent lighting controls is having a profound impact on the return on investment. LED lamps may be dimmed either by directly reducing the amount of current sources through the LEDs or by rapidly turning the LEDs on and off at a frequency greater than that which can be detected by the human eye and modulating the pulse width to create a dimming effect. While each method has its advantage the critical issue here is that the energy savings are significant from dimming the lights when full brightness is not required. This ability to dim is primarily a function of the power electronics and is an important aspect of the driver. The ability to easily interface to common sensors and systems is important. While there are a variety of ways to signal the driver to dim the LEDs perhaps the most versatile is a simple 0-10V analog signal. This input can be easily produced by a 0-10V dimmer, a resistive network, a DALI or DMX converter or any number of other schemes. The 0-10V interface is also easily adapted to accommodate a variety of sensors. Two of the most common implementations include occupancy sensors (dimming the light output when no one is within a given proximity to the lighted area) and daylight harvesting sensors (dimming the light output in proportion to the amount of sunlight allowed into the lighted area. Other schemes include adjusting the light output based on time of day, day of week or inputs from a security system.

Whatever the scheme, intelligently controlling the light output can lead to significant energy savings. The added benefit is that the lower thermal and electrical stress on the driver and light engines while the product is dimmed also adds to the life and reliability of the installation. The impact to ROI is therefore multiplied by the thoughtful implementation of intelligent controls.

## Summary

Understanding the drivers for both life and reliability are critical to designing a product that will perform as expected in the field. This is especially true of projects such as LED lighting where payback is measured in years, long warranties are required conditions for doing business and where a reduction of maintenance costs forms a significant portion of the return on investment. While there are many factors which must be considered we see here the importance of efficiency and its use as a key metric in evaluating LED drivers. While LED drivers can be designed to meet the requirements of today's lighting projects, it takes a great deal of care and analysis to ensure that these objectives are met.

## [Reference]

[1] Arne Albertsen, Electrolytic capacitor lifetime estimation.

[2] MIL-HDBK-217F, MILITARY HANDBOOK, Reliability Prediction of Electronic Equipment, December 1991.

[3] Telcordia, SR-332, 2006. Reliability Prediction Procedure for Electronic Equipment, Issue 2, September 2006.

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