Get more operating life from LED-based bulbs

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Replacing incandescent lighting mandated by the largest countries around the world is powering a paradigm shift to solid-state lighting. LED lighting offers significant advantages over alternative lighting technologies, especially as the lumens per watt increases and the cost per lumen decreases. One of the main benefits with these replacement technologies is the actual life time of the bulb and its cost per watt-hour compared to traditional incandescent bulbs. While a traditional incandescent bulb has a life expectancy of 1000 hours\(^1\), LED bulbs offer the promise of up to 50,000\(^2\) hours of operating time, while consuming only approximately 20% of the power for equivalent light output. But without the right precautions, the lofty promise of nearly 25 years without changing a light bulb may fall short.

With the acceptance of LED technology as a cost-effective replacement for incandescent lighting, the design approach presents challenges that can lead to a reduced lifetime for the LED-based bulb. The complexity and reliability of the driver circuit compatibility with legacy dimmer technology and the LEDs themselves are areas of concern that need to be addressed in order to maximize operating life.

The robustness of solid state-lighting technology compared to relatively fragile incandescent and halogen bulbs, is one of the key features that attracts the consumer. However, LEDs require DC current for proper operation and need to be driven by a circuit, which converts the standard AC line voltage down to a usable level. In order to make LED-based bulbs compatible with standard light sockets the driver circuit needs to be integrated into the bulb, which increases potential failure mechanisms unless dealt with properly. The legacy LED driver technology previously available for LED bulbs required large numbers of external components, costly isolation components and special design considerations to avoid long-term degrading of key components (such as electrolytic capacitors) when interacting with dimmers, commonly used in homes across the world.

The integration of the driver circuit inside the bulb now makes the bulb susceptible to reliability issues, such as infant mortality or degraded MTTF (mean time to failure) rates. MTTF, the measure of the amount of time until first failure, is normally calculated based on the number of components and the type of components, using the FIT rates (failures in time, measured relative to 1,000,000,000 hours) of each component in the circuit. Since the driver circuit transforms a high AC-voltage (100V\(_{AC}\)/220V\(_{AC}\)) down to a DC voltage that can be used to power the LEDs, electrical isolation is necessary for safety reasons. In a typical electrically isolated AC-DC converter, feedback is provided from the secondary side to the controller on the primary side via an opto-isolator (or optocoupler), a discrete component that converts an electrical signal to light, sends that signal across an isolation barrier and then converts it back to an electrical signal. Figure 1 shows a generic representation of this type of circuit.
Since opto-isolators have higher FIT rates compared to semiconductor components, they reduce the MTTF rating for the overall circuit. Additionally, the opto-coupler’s current transfer ratio can change over time and temperature, due to aging effects. This can affect the loop stability of the power supply thus reducing the life of the LED driver circuit. While many LED lamps and luminaires may operate at an elevated PCB temperature, the weak links must be eliminated in order to achieve the desired long lifetime.

Figure 2 shows primary-side digital control technology that allows for sensing of the LED current via the primary side of the isolation transformer using real-time waveform analysis. This eliminates the need for direct feedback from the output while maintaining very tight constant current regulation for the LED string. An important, additional benefit of the technology is internal feedback loop compensation, simplifying the design and removing external components. By reducing the external components count and eliminating the opto-isolator (the component with the highest FIT rate), the reliability of the LED driver circuit goes up, improving the overall reliability of the entire bulb.

The LED bulbs being manufactured today need also to be backward compatible with home lighting technology already in place in family homes today. Dimmers are used to provide ambience to the home and one benefit of LED lighting as an alternative to incandescent bulbs is that the LEDs can easily be dimmed to match the incandescent bulb characteristics, whereas a compact fluorescent cannot. The LED driver needs to manage several factors to support the dimmer function, including dimmer detection, compatibility and light flicker. However, to optimize the operating life of the bulb,
the main concern is the durability of the dimmer when used with an LED driver. The typical A-lamp incandescent bulb is purely resistive. When a dimmer is used to control the brightness of an A-lamp, the resulting load on the dimmer is also purely resistive and the current through the dimmer is constant and controlled.

An LED driver is effectively a current source and its input looks highly capacitive to the dimmer, which on start-up will see a large spike of in-rush current to charge up that capacitive load prior to stabilizing the current at a much lower level. This in-rush current is potentially damaging to a standard dimmer and needs to be reduced so that the lifetime of the dimmer circuit is not compromised when driving an LED-based A-lamp replacement bulb. Get more operating life-

An elegant solution to the dimmer in-rush problem is to use a two-step approach to driving the LEDs. Instead of using a straight flyback converter that has the highly capacitive input impedance, using an initial stage to reduce that impedance to a manageable level reduces the in-rush current and provides the safety and protection necessary for the dimmer. The LED driver in Figure 3 uses a two stage approach with an initial boost converter whose function is two-fold, first to provide the necessary impedance to load the dimmer, reducing the in-rush current, and second to bring the input current back into phase with the line current, improving the power factor of the overall circuit. This allows a bulb that not only lasts longer, but can provide high power factor along with it.

The digital control block that provides the primary-side control also contains algorithms for detecting and operating with virtually all dimmers available in the market, giving the device a very broad compatibility with existing dimmer technologies. The same algorithms also control the chopping circuit such that it optimizes the dynamic input impedance of the chopping circuit to increase power factor and reduce the in-rush current.

An equally important concern with the operating life of LED-based bulbs is the expected lifetime of the LEDs. Like any other semiconductor component, the higher the operating junction temperature of the LED, the lower the expected lifetime of the device. One method to ensure long operating life is to de-rate the current driving the LED and simply use more LEDs to generate a specific light output, resulting in less heat generation per LED and therefore a lower junction temperature. This approach serves to extend operating life but at the cost of more LEDs and it does not accommodate external factors, such as the physical properties of the light fixture, which may contribute to higher than expected heat.
A second method is to optimize the maximum LED current then establish a desired maximum junction temperature at which the LEDs current needs to be reduced in order to prevent degradation. There are now digital controllers for LED driving that implement a two-stage protection scheme that allows the designer to program the maximum LED temperature by using a single external device. An NTC (negative temperature coefficient) resistor can be placed physically near the LED cluster and acts as a temperature monitor. The NTC resistor is connected to the LED driver IC, which then uses that temperature feedback device to protect the LEDs. The device pictured in Figure 3 uses an NTC device to protect the LEDs in an LED bulb.

In the event that the maximum programmed temperature threshold is reached, the controller reduces the LED current by 10% increments until the temperature stabilizes. If the temperature drops, the LED current steps back up to its maximum programmed value in equal and opposite 10% increments, with an appropriate amount of hysteresis to prevent oscillations. There is also a fail-safe mode where the current through the LEDs reduces to 1% of programmed output current in the event of a major failure event. This over temperature protection (OTP) topology offers flexibility in the design of the LED bulb and peace of mind that the bulb will be fully protected under extreme operating conditions.

LEDs have evolved to the point where cost and light output have equalized across competitive solutions and are now gaining momentum as a realistic replacement for incandescent bulbs in the home. The key to the success of this new technology is in the implementation of the driver. Besides the obvious parameters of efficiency and cost that each designer strives to optimize, the additional factors of temperature, dimming control and reliability, are the true keys to guaranteeing the long operating life promised by LEDs.

References:

Osram Classic A Incandescent Bulb - Family Data Sheet

“Osram Sylvania – Ultra Aline Dimmable Technical Specifications”

About the Author

Scott Brown joined iWatt in October 2011 with over 20 years experience in the analog semiconductor industry. Scott has broad experience in all forms of semiconductor marketing from hands-on tactical to high-level strategy, he also has many years experience in semiconductor business and functional management. Scott has extensive global experience and a deep knowledge of the Power Management market. Prior to iWatt Scott held marketing and management positions at National Semiconductor, Micrel, ON Semiconductor, Catalyst Semiconductor and Semtech. He holds a BSc in Electrical and Electronic Engineering from Brunel University in the UK.