Developing an Accelerated Life Test Method for LED Drivers

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Developing an Accelerated Life Test Method for LED Drivers

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ABSTRACT

Although light-emitting diodes (LEDs) have the potential for long life, LED luminaires may experience a much shorter life for the system as a whole because of the driver. Past studies show that the electrolytic capacitor used in switch-mode power supplies often has the shortest lifetime, and thus determines the electronic driver lifetime. This study demonstrated an accelerated life test method for LED drivers that use electrolytic capacitors at the output stage by monitoring the output current ripple trends at different elevated operating temperatures.

Keywords: LED driver, electrolytic capacitor, life test, reliability

1. INTRODUCTION

LED lighting systems are beginning to experience widespread use in many lighting applications. One of the promises offered by LED lighting systems is long operating life. An LED lighting system is composed of many components, including a driver to convert unregulated AC mains voltage to DC constant current output. Even though an LED light source's lifetime can be very long, the LED driver lifetime can be shorter, and therefore shorten the lifetime of the complete system. The goal of this study was to gain better understanding of the failure modes of LED drivers, and to study what factors influence the failure modes of LED drivers. This study mainly focuses on stand-alone LED drivers and develops an accelerated test method that can be used for predicting the useful life of an LED driver.

LED driver topologies differ considerably depending on the specific application requirements, such as the input and output voltages, the overall power consumption, isolation for UL safety requirement, power factor correction for harmonics compliance and ENERGY STAR requirements[1], and dimming function.[2] Some of the current control methods include the use of current limiting resistors, linear voltage regulators, buck converters, boost converters, buck-boost converters, SEPIC converter, flyback converters, and resonant converters.[3]

Two types of off-line constant current LED drivers were considered in this study. One is a standard flyback topology converter, and the other one is a single-stage PFC-based flyback converter. These drivers commonly use an output capacitor to maintain constant current to the LED. The topologies of LED drivers are similar to those of switch-mode power supplies.[3] Most of the breakdowns in switch-mode power supplies are attributed to the failure of electrolytic capacitors.[4–11]

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An electrolytic capacitor is composed of cathode aluminum foil, electrolytic paper, electrolyte, and an aluminum oxide film acting as the dielectric, which is formed on the anode foil surface. The region between the anode and the electrolyte, and the region between the cathode and the electrolyte each constructs a capacitor, respectively. At the anode side, the aluminum oxide film is the dielectric, which provides high resistance to current flow. At the cathode side, the dielectric is the naturally formed oxide layer. The total capacitance is the series capacitance of these two capacitors and mainly decided by the capacitance of the anode side.[12] The equivalent series resistance (ESR) is the sum of electrolytic resistance, dielectric loss, and electrode resistance.[13] The major wear-out mechanism of electrolytic capacitors is evaporation and deterioration of electrolyte due to elevated ambient temperature or internal temperature. Elevated ambient temperature or internal temperature will accelerate the vaporization of electrolyte. A basic rule of thumb for estimating an electrolytic capacitor's life states that life doubles for every 10 degrees Celsius lower than the rated temperature at which the capacitor operates.[12, 14–16] As the output electrolytic capacitor degrades, its capacitance will drop and its ESR will increase[13, 14, 17-20], both of which cause an increase in the output current ripple[21], which will affect the output power to the LED and the light output and efficacy of the LED system.

2. EXPERIMENT

None of the past studies have tried to experimentally investigate the degradation process of LED drivers at elevated ambient temperature conditions. Therefore, the objective of this study was to study the degradation process of LED drivers represented by the output current parameter shift, and to develop an accelerated test method that could be used for predicting the useful life of an LED driver at nominal operating conditions.

Since the electrolytic capacitor at the output stage is assumed to be the weakest link in the whole LED driver system, it is desired to understand the impact of the degradation of the electrolytic capacitor on the LED driver's performance. The shift of the output current parameters is assumed to be a good indicator of the degradation level of the electrolytic capacitor, which limits the actual lifetime of the LED driver.

The experiment was designed to establish the relationship between the pin temperature of the electrolytic capacitor and the useful lifetime of the LED driver. The pin temperature of the electrolytic capacitor is indicative of the core temperature of the capacitor, which is found to be the critical factor to the lifetime of the capacitor.[14] It is suggested that the end-of-life criterion can be defined considering light output or efficacy derating due to the increase of current ripple. The useful lifetime of a given LED driver is then calculated using the proposed end-of-life criterion. Three samples of LED driver A and LED driver B from two different manufacturers were selected for the experiment.

The setup for the experiment is shown in Figure 1. A sealed container was used to create an equivalent local oven environment for the electrolytic capacitor. The temperature of the case of the local oven was kept constant by a temperature controller in each temperature case. A thermocouple was connected to the end of the positive pin of the electrolytic capacitor as an indicator of the temperature of the electrolyte. This temperature value at the positive pin was sampled by a DAQ. Also, the output current parameters were sampled by a powermeter. A Labview program running on a PC controlled the automatic data sampling and recording operation. The recorded data was then analyzed and the lifetime was calculated using certain end-of-life criterion.

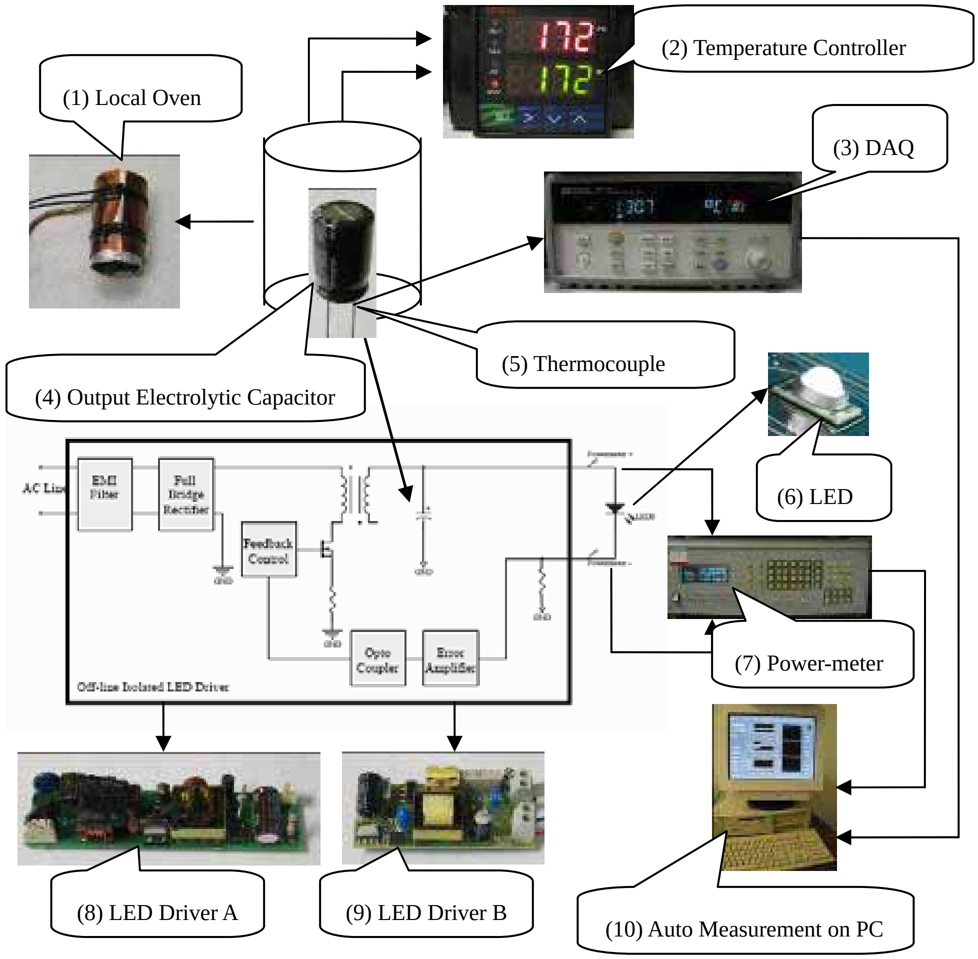

Figure 1: Setup Diagram of the Experiment

3. RESULTS

Figure 2 shows the output current parameter drift through degradation process for sample #3 of LED driver A when the average temperature of the positive pin of the output electrolytic capacitor was 179°C. The point when current ripple reaches 300% of its initial value was selected as the end-of-life criterion for LED driver A. This value was selected because at this point, the output current mean value drops to 90% of its initial value, which is out of its rated range, and results in light output drop by 10%. Additionally, this is the "knee point" of the curve of the current ripple trend. Using the same treatment at different temperature conditions, a set of current ripple trends of this sample #3 of LED driver A can be obtained, as shown in Figure 3. The useful life of LED driver A can then be calculated using the end-of-life criterion at each different temperature case. Figure 4 shows LED driver A's lifetime profile using a logarithmic vertical scale by combining all three samples' lifetime data at different temperature conditions. The useful lifetime of LED driver A shows an exponential decay as capacitor temperature increases. At around 190°C, the lifetime curve bends, suggesting possible existence of multiple failure mechanisms at such extremely high temperature conditions. This means that in this case, the temperature values have to be kept below 190°C when accelerating this type of driver.

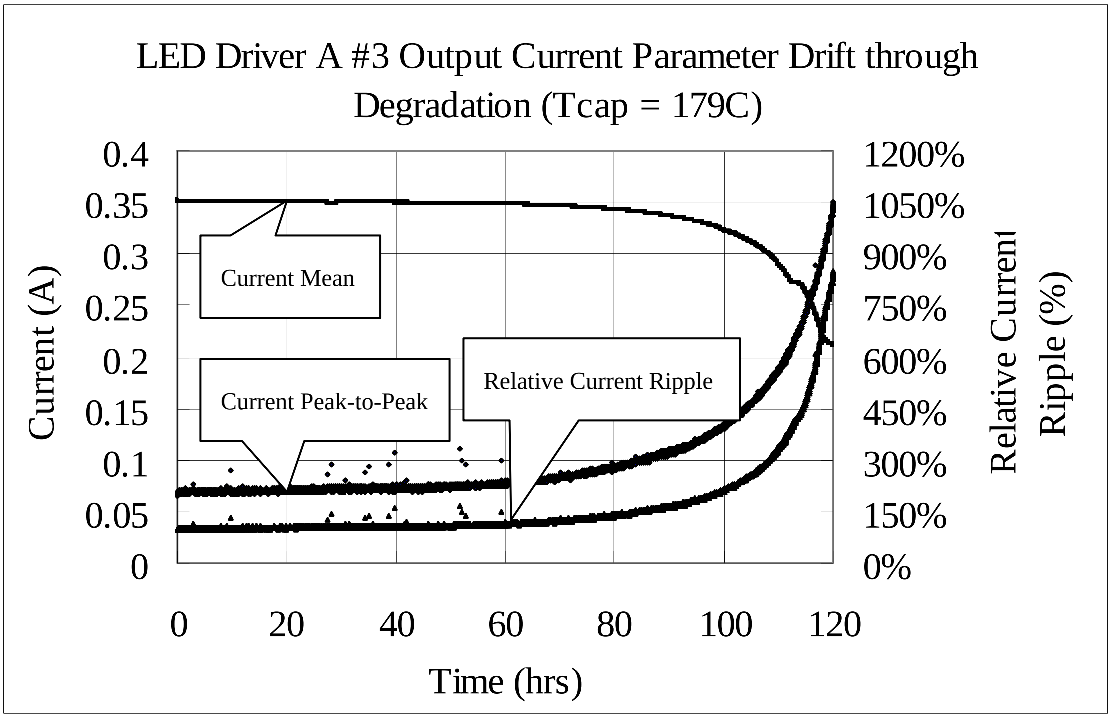

Figure 2: LED Driver A #3 Output Current Parameter Drift through Degradation (Tcap = 179°C)

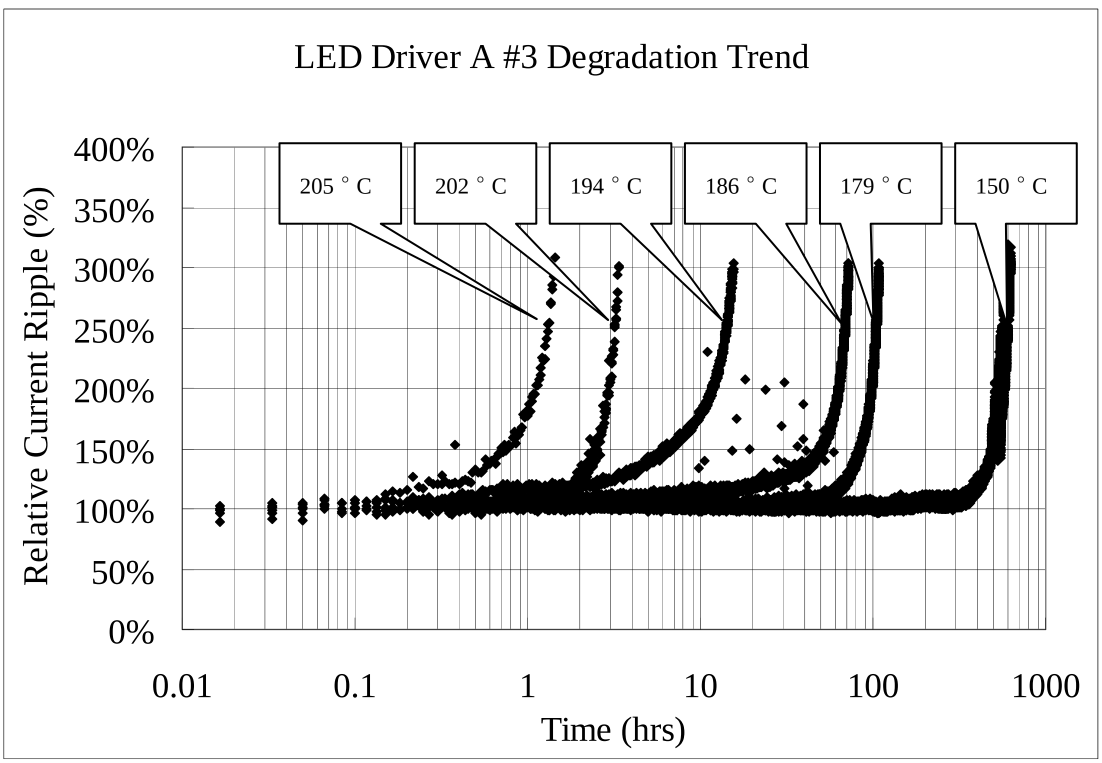

Figure 3: LED Driver A #3 Degradation Trend (T at +pin of the capacitor)

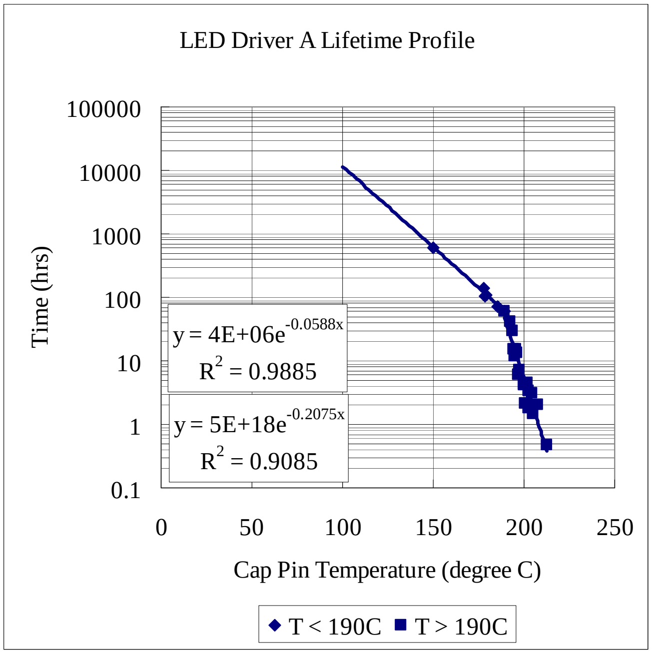

Figure 4: LED Driver A Lifetime Profile

Figure 5 shows the output current parameter drift through degradation process for sample #1 of LED driver B when the average temperature of the positive pin of the output electrolytic capacitor was 174°C. The point when current ripple reaches 130% of its initial value was picked to be the end-of-life criterion for LED driver B. This value was selected because at this point, the output current ripple reaches about 1.4, where the load efficacy drops by about 15% and light output drops by 10% compared to the non-ripple ideal condition. Additionally, this is the "knee point" of the curve of the current ripple trend. Similarly, by using the same treatment at different temperature conditions, a set of current ripple trends of this sample #1 of LED driver B can be obtained, as shown in Figure 6. The useful life of LED driver B can be calculated then using the end-of-life criterion at each different temperature case. Figure 7 shows LED driver B's lifetime profile using a logarithmic vertical scale by combining all three samples' lifetime data at different temperature conditions. The useful lifetime of this LED driver B also shows an exponential decay as capacitor temperature increases. At around 185°C, the lifetime curve also bends, suggesting possible existence of multiple failure mechanisms at such extremely high temperature condition. Here again, the temperature values have to be kept below 185°C when accelerating this type of driver.

As an example, by extrapolation, the predicted lifetime at 85°C ambient temperature (correlated to 100°C for the capacitor's positive pin temperature) is approximately 11 000 hours for LED driver A, and 14 000 hours for LED driver B. Likewise, the life of drivers can be predicted at any operating temperature if the pin temperature is known.

It is worth noting here that depending on the requirements of specific applications, different end-of-life criterion can be assumed and the value of the predicted lifetime would vary. Also, the usage pattern can impact the useful life of a driver. The above-mentioned test method does not take switching operation into consideration. Additional studies are needed to quantify performance if frequent turning on and off operations exist.

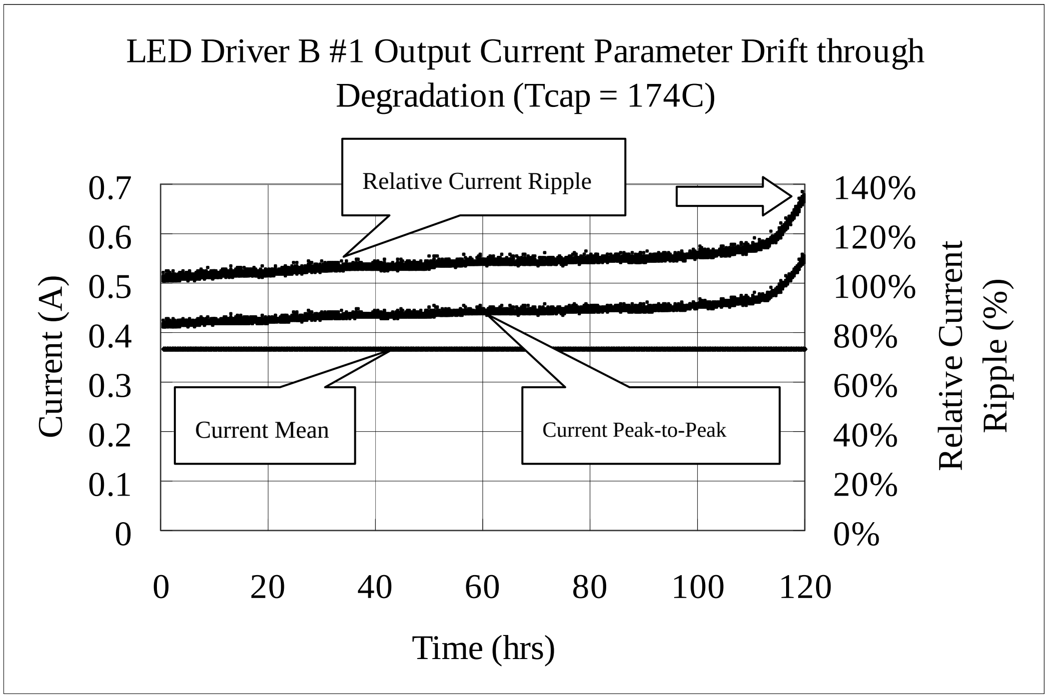

Figure 5: LED Driver B #1 Output Current Parameter Drift through Degradation (Tcap = 174°C)

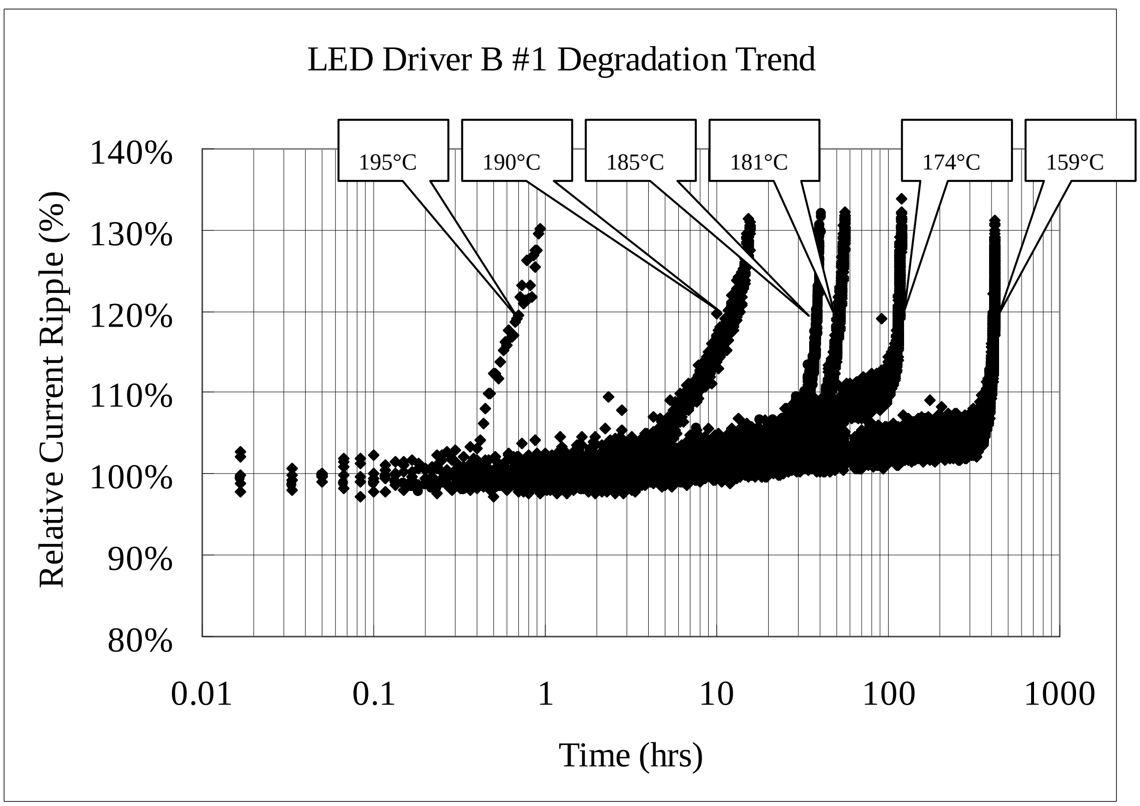

Figure 6: LED Driver B #1 Degradation Trend (T at +pin of the capacitor)

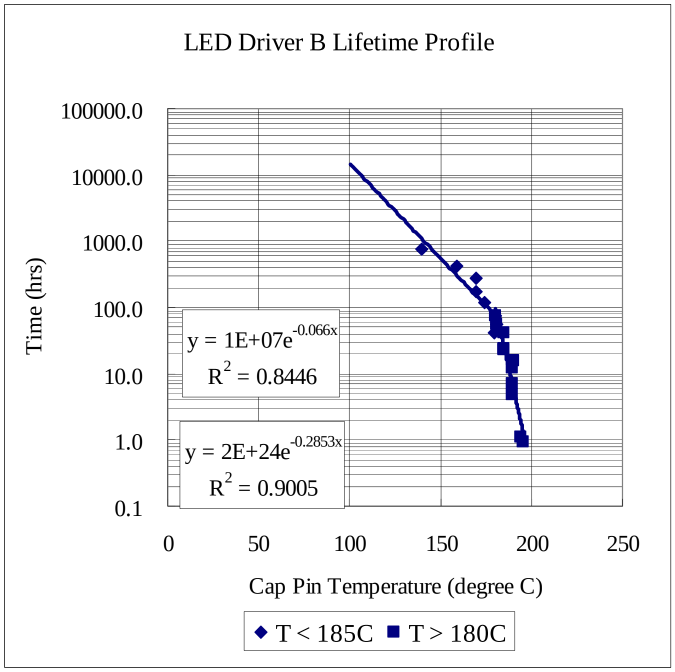

Figure 7: LED Driver B Lifetime Profile

4. SUMMARY

This study demonstrated an accelerated life test method for LED drivers that use electrolytic capacitors at the output stage by monitoring the output current ripple trends at different elevated operating temperatures. Past literature suggests that the electrolytic capacitor used at the output stage of an LED driver is the weakest link among all components, and it defines the useful lifetime of the system. As an electrolytic capacitor degrades, its capacitance decreases and its ESR increases, contributing to the increase of output current ripple of the LED drivers. Thus, the amplitude of the output current ripple is a good indicator of the degradation level of the output electrolytic capacitor. In this study, temperature was selected as the acceleration factor and the relationship between the capacitor's positive pin temperature and the useful lifetime of the LED driver was established using an end-of-life criterion that considers light output and efficacy of the LED. Although this method is not applicable to every LED driver on the market, it begins to identify methods that can be used for predicting the lifetime of LED drivers.

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