PRACTICAL METHOD FOR MEASUREMENT OF AC-DRIVEN HIGH-POWER LEDS

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ABSTRACT

Alternating-current (AC) driven high-power LEDs are available and used in SSL products. AC LEDs operate directly from a mains supply and thus have advantages in simplifying product design, increasing product reliability, and extending product lifetime. Accurate measurement of AC high-power LEDs is required for quality control and product qualifications such as US Energy Star. We have developed a simple, robust method for measurement of high-power LEDs at any specified junction temperature under a normal AC operating condition. In addition to optical quantities, the measurement of an AC LED also indicates the thermal resistance between the LED junction and the heat sink.

Keywords: AC LED, High-Power LED, Junction temperature, Measurement method

1. INTRODUCTION

High-power light-emitting diodes (LEDs) are commonly used in solid-state lighting (SSL) products. High accuracy measurements of high-power LEDs are required in quality control, SSL product design, research, and government regulations (such as the US Energy Star). However, accurate measurements of high-power LEDs are often difficult because LEDs are highly sensitive to thermal operating conditions. We have developed and presented a practical method for measurement of direct-current (DC) driven high-power LEDs at any specified junction temperature to acquire reproducible results [1].

Alternating-current (AC) driven high-power LEDs were developed recently and are rapidly being introduced into SSL products [2]. Unlike conventional DC-driven LEDs, which operate at a constant DC current, AC LEDs operate at a constant AC voltage and can operate directly from a mains supply (e.g., 120 V, 60 Hz AC in the USA) without the need for any electronics (LED drivers) to convert AC power to constant DC current. AC LEDs have obvious advantages for general lighting applications in SSL product design, reliability, and lifetime. Similar to DC LEDs, accurate measurements of AC high-power LEDs are also difficult because an LED's high sensitivity to its thermal operating condition. In addition, the forward voltage and the forward current of an AC LED change rapidly, which makes measurement even more difficult. The method we developed for DC high power LEDs [1] could not be applied to AC LEDs directly.

In response to industrial need, we have developed a simple, robust method for measurement of AC high-power LEDs, with which AC LEDs can be operated at any specified junction temperature for optical measurement in a thermal equilibrium condition with reproducible results.

2. PRINCIPLE

Although AC LEDs have various designs, depending on the manufacturers, the principle can be simplified (for the measurement purpose) as that shown in Figure 1. An AC LED is composed of two DC LED arrays, which work alternatively in a complete AC power cycle. The sum of forward voltage of the LED array is equal to the instantaneous voltage of the AC power supply, and the LED array does not turn on until the instantaneous voltage reaches the threshold "on" voltage. Figure 2 shows the instantaneous forward voltage and the forward current of a 110 V, 60 Hz AC LED during a complete AC power cycle. The total "on" time of an AC LED is approximately 50 % of a complete AC power cycle time, and the light output frequency is 120 Hz.

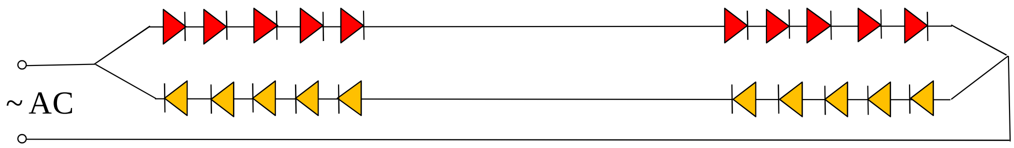

Figure 1. Illustration of the design of an AC LED

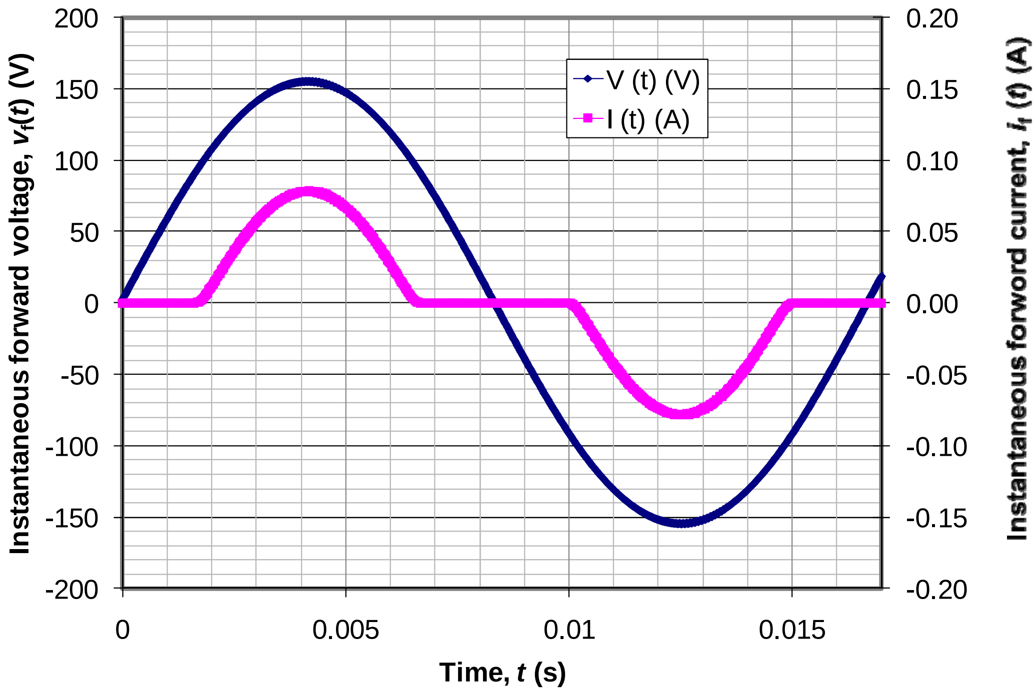

Figure 2. Instantaneous forward voltage, $v_f(t)$, and forward current, i_f (t), of a 110 V AC, 60 Hz LED.

For an AC LED at a fixed instantaneous forward voltage, the forward current increases as the AC LED junction temperature increases. Thus, an instantaneous forward current at a fixed instantaneous forward voltage can be used to monitor the change of junction temperature of an AC LED. In theory, by simply replacing the forward voltage of a DC LED with the instantaneous forward current of an AC LED as the feedback parameter for controlling the junction temperature, the same method developed for the measurement of DC LEDs [1] can be used to measure AC LEDs. In practice, however, this method does not work with AC LEDs. During operation of an AC LED, its electrical/optical values and the thermal condition (e.g. the junction temperature) change constantly. The measurement errors are too large for the instantaneous forward current of an AC LED. The large measurement errors mainly come from three sources: 1) the synchronization error between the voltage measurement and current measurement, which is critical because the applied voltage changes rapidly, 2) the noise on the AC voltage of the power supply. Note that voltage noise is amplified many times to current noise due to the LED's steep voltage versus current characteristics (the V-I curve), and 3) the digital multimeter; the faster the measurement speed, the larger of the measurement errors.

To overcome the difficulty in measuring the instantaneous forward current, $i_f(t)$, we choose to measure the root mean square (RMS) forward current, $I_f(n)$, averaged over half of an AC power cycle to monitor the change of the RMS junction temperature of the AC LED. Because the AC LED has only approximately 50 % "on" time, the RMS forward current, $I_f(n)$, can be easily measured without the need to synchronously measure the instantaneous LED forward voltage.

The principle of the simple method for measurement of AC LEDs is shown in Figure 3. The measurement procedures of this method are as below: (1) mount the AC LED on a temperature-controlled heat sink (with a TE cooler) by using a metal core printed circuit board (MCPC board) or any other thermal connection techniques, (2) set the temperature of the heat sink equal to the desired junction temperature, T_j , and wait for the LED (not turned on yet) to stabilize thermally, (3) apply the specified AC voltage from zero phase to the AC LED and measure the first half-cycle RMS forward current, $I_f(0)$, (4) as the LED is operated on the AC power and is heated up, adjust (lower) the heat sink temperature, T_s, so that the measured RMS forward current, $I_f(n)$, equals to initial $I_f(0)$ obtained in step (3) and thus the same T_j is maintained when the LED reaches the thermal equilibrium, (5) measure the electrical, radiometric, photometric, and colorimetric quantities of the AC LED, and (6) power off the AC LED to finish the measurement. Using a programmable temperature-controlled heat sink, the entire measurement procedures can be fully automated.

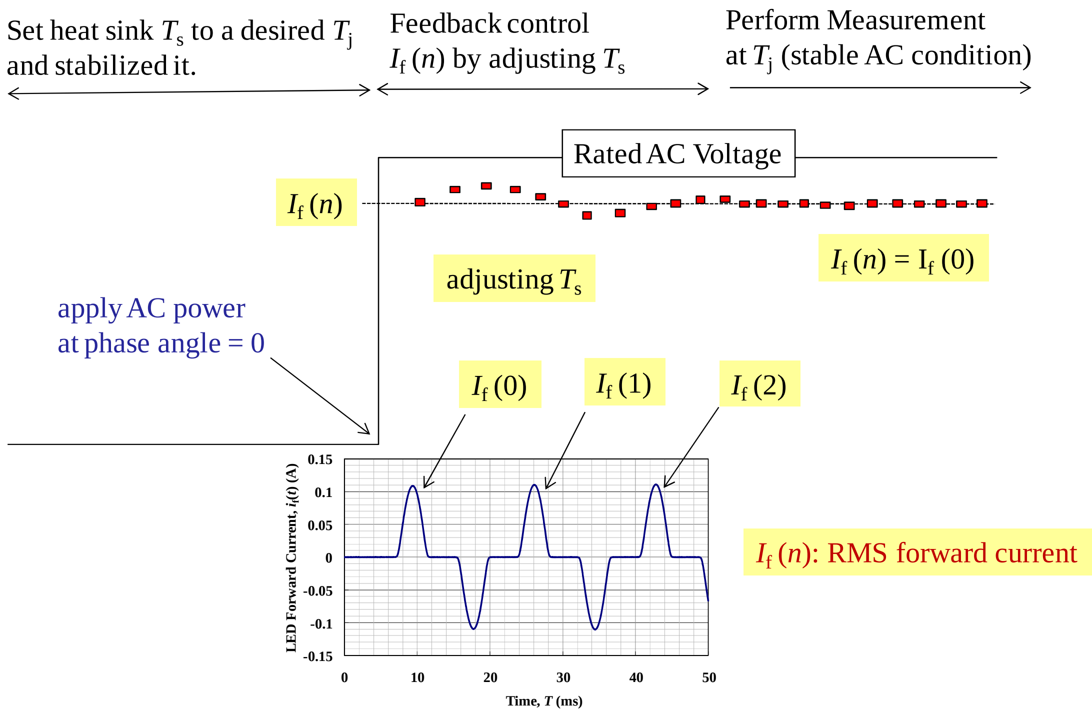

Figure 3. Principle of the simple method for measurement of AC LEDs

The above procedure used for setting and controlling the junction temperature of an AC LED is similar to that used for the measurement of a DC LED [1]. A temperature-controlled heat sink is used to set and control the AC LED to a specified junction temperature, T_j , and all electrical and optical quantities of the AC LED are measured in a steady AC operation under a thermal equilibrium condition. Once the AC LED is stabilized in this condition, various photometric measurements can be made with the existing measurement facilities used in the lighting industry, such as those used for measurement of discharge lamps, including integrating spheres, gonio-photometers, and spectroradiometers (array or scanning type).

Fast measurement is required only for the electrical quantity, $I_f(n)$, which is used for calibration and control for each AC LED immediately before the optical measurement. Therefore, individual variation of the $I_f(0)$ vs. T_j relationship and changes over time do not matter. The AC LED mounting method and the thermal contact between the AC LED and its heat sink are also largely irrelevant to the measurement results because the junction temperature is controlled. Furthermore, the thermal resistance between the AC LED junction and its heat sink surface is obtained, which is often of great interest.

3. EXPERIMENTAL MEASUREMENT RESULTS

Several LEDs from two different manufacturers are measured to validate the measurement method. Figure 4 shows an example of the relationship between the RMS forward current, I_f, and the heat sink temperature of an AC LED from 25 °C and 45 °C. The I_f is a linear function of the heat sink temperature within the temperature range and also a linear function of the

LED junction temperature assuming both the thermal resistance and the LED efficacy are constant within this temperature range.

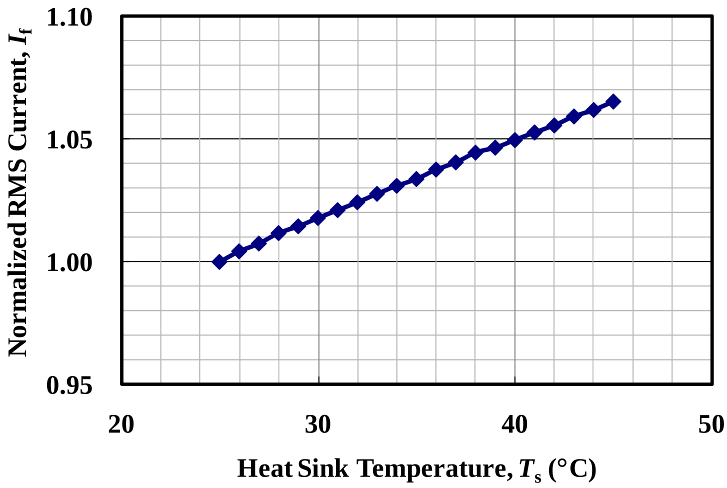

Figure 4. Relationship between the LED RMS forward current, I_f , and the heat sink temperature, T_j

A heating curve of an AC LED operated on a 60 Hz, 110 V AC power is shown in Figure 5. The AC LED is mounted on a 25 °C temperature-controlled heat sink. The voltage and current of the AC LED are measured by using two fast digital multimeters with a measurement speed of 50000 samplings per second. The junction temperature of the AC LED rises rapidly as shown by the rapid rising of the RMS forward current. The junction temperature of the LED rises approximately 25 % of the total rise within the first AC power cycle.

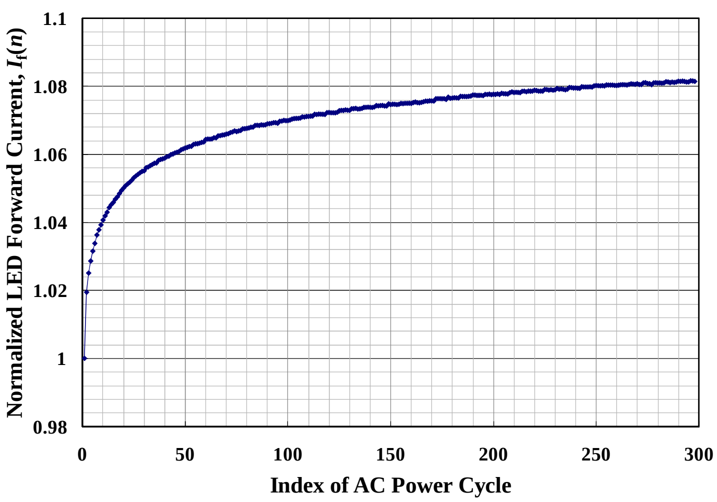

Figure 5. A heating curve of an AC LED.

4. SUMMARY

We have developed a simple, robust method for the measurement of AC-driven LEDs. By using a temperature-controlled heat sink, a fast digital multimeter (or a fast digitizer), and existing AC instruments, AC LEDs can be set at any junction temperature and measured in a steady AC operating condition in thermal equilibrium. This method can be applied to any type of AC LEDs, any LED shapes, any heat sinks, and any mounting techniques. In addition to obtaining optical quantities, the measurement of an AC LED is also used to determine the thermal resistance between the junction and the heat sink. The measurement results are insensitive to measurement noise, and are irrelevant to mounting method and thermal resistance.

The operation of LEDs requires an AC power supply with phase control, and a DC fast multimeter that can determine the RMS current of the first half power cycle. An oscilloscope or a digitizer might also be used to measure the forward current of an AC LED. By using this simple and robust method for measurement of high power AC LEDs, reproducible results with small uncertainties can be achieved.

The junction temperature of an AC LED actually increases during the half power cycle, thus the forward RMS current at the first half cycle does not exactly represent the true junction temperature. However, this method reproduces exactly the same averaged junction temperature, which might be called nominal junction temperature.

Much higher accuracy on junction temperature setting may be achieved if instantaneous forward current can be measured and perfectly synchronized with the AC voltage phase, especially at the early time of the first half cycle phase. This can be made using a so-called "source-measure unit (SMU)", used for measurement of DC LEDs in the method [1]. The SMU can generate AC-wave form power and measure electrical parameters of AC LEDs automatically synchronized. At present time, unfortunately, the speed of existing SMUs in the market are too slow, which limits the generated AC power to be less than 10 Hz. By using the low frequency 10 Hz AC power, additional measurement errors may be introduced even though the measurement result is not sensitive, in general, to the frequency of the AC power.

The measurement uncertainties of AC LEDs will be analyzed and discussed in the future.

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