

A driving scheme to reduce AC LED flicker

Jianchuan Tan and Nadarajah Narendran*

Lighting Research Center, 21 Union Street, Troy, NY, USA 12180

ABSTRACT

Light flicker is a common but unwelcome phenomenon in conventional lighting applications. In solid-state lighting, driving or dimming methods also give rise to light flicker. AC LED products in today's marketplace suffer from flicker, which stems from the arrangement of the micro-LEDs and the driving method. Research has shown that light flicker can be a health hazard to humans. Several solutions have been proposed to reduce light flicker in solid-state lighting applications; however, most have drawbacks in terms of power and other performance. This paper proposes a circuit design to reduce light flicker from AC LEDs while maintaining a normal power factor and high power efficiency. The circuit is composed of one resistive branch and one capacitive branch, and each branch drives a load which is made up of high-voltage LEDs. Percent flicker, power factor, and power efficiency were selected as three metrics, and their benchmarks were set to evaluate the performance of this circuit. Phase shift between the two branches was selected as a factor that could determine the circuit performance. The variations of percent flicker, power factor, and power efficiency as a function of phase shift were identified by theoretical analysis and were verified by experiments. The experimental results show that an optimal solution can be achieved for this circuit design at proper phase shift, where the benchmarks of the three metrics are reached.

Keywords: AC LED, phase shift, percent flicker, power factor, power efficiency

1. INTRODUCTION

Since its introduction to the lighting industry in 2005, the alternating current (AC) light-emitting diode (LED) has experienced rapid development. Presently, there are three types of AC LED packages, including anti-parallel connection, Wheatstone bridge, and Schottky barrier diode.¹ Not needing a driver to convert AC to direct current (DC) to power the LED is a distinct advantage that the AC LED has over the DC LED. The absence of a driver could mean potentially higher system efficiency, fewer failure components, smaller system envelope, and lower system cost. However, one of the main drawbacks of the AC LED is light flicker.² Because it is directly driven by AC line voltage, which oscillates at 60Hz (or 50Hz), the AC LED produces light flicker at twice the frequency of the AC line frequency (e.g., 120Hz in North America). According to past research, light flicker can cause negative health effects, and also the perception of light flicker is undesirable in lighting applications.³⁻⁵ Several solutions have been proposed to reduce light flicker, such as increased drive frequency and reduced percent flicker.⁶⁻⁸ These solutions can effectively reduce light flicker, but they introduce new problems to the lighting system, such as lower power factor or low power efficiency.^{9,10} In a lighting system, a good solution should reduce light flicker without sacrificing power factor and power efficiency.

The objective of this study was to find a solution that reduces light flicker by reducing percent flicker while maintaining normal power factor and high power efficiency.

2. BACKGROUND

2.1 Perception of light flicker

Human perception of light flicker is affected by frequency, percent flicker (also called modulation depth), duty cycle, waveform shape, and correlated color temperature (CCT), among which, frequency and percent flicker are the two major factors.¹¹ In a light waveform, shown in Figure 1, percent flicker is defined as the difference between the maximum and

*Corresponding author: +1 (518) 687-7100; narenn2@rpi.edu; <http://www.lrc.rpi.edu/programs/solidstate/>

minimum values divided by the sum of them, as in Eq.(1). Based on this definition, the percent flicker of a commercial AC LED product is measured to be 100%.¹³

$$\text{Percent Flicker} = \frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}} \times 100\% \quad (1)$$

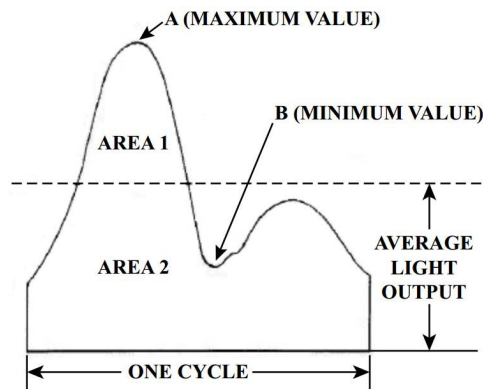


Figure 1. A light waveform with flicker.¹²

Light flicker can be perceived through stroboscopic effects, which occurs when a continuous movement is represented by a series of short samplings. Bullough *et al.* reported that the detection and acceptability of stroboscopic effects depend mainly on frequency and percent flicker.¹⁴ It was also reported that, by decreasing percent flicker from 100% to 33%, perception of stroboscopic effects can be statistically significantly reduced.¹¹

In this study, one goal was to reduce the percent flicker from AC LED to below 33%.

2.2 Power issues of a lighting system

The power issues discussed in this study include power factor and power efficiency.

- (1) Power factor: The ENERGY STAR[®] program sets requirements for solid-state luminaires in terms of power factor: luminaires with input power $\leq 5\text{W}$ should have power factor ≥ 0.5 ; luminaires with input power $> 5\text{W}$ should have power factor ≥ 0.7 for residential products and ≥ 0.9 for commercial products.¹⁵ In this study, another goal is to maintain the power factor of the AC LED lighting system to be over 0.7.
- (2) Power efficiency: The power efficiency of an electrical system with loads (e.g., LEDs in a solid-state lighting system) is defined as the ratio of the output active power dissipated on the loads to the input active power, as shown in Figure 2. The typical power efficiency of LED drivers ranges from 70% to 95%, mainly around 85%.¹⁶

In this study, another goal was to maintain the power efficiency of the AC LED lighting system to over 85%.

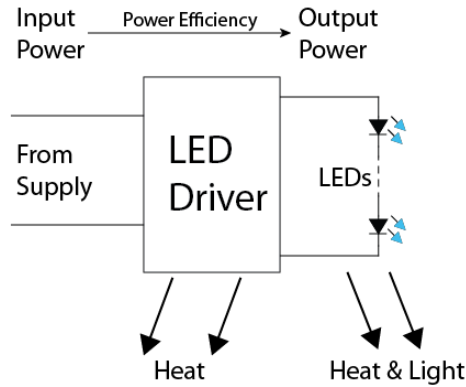


Figure 2. Power efficiency of an LED lighting system with driver.

3. METHODOLOGY

In electronics, it is a basic principle that when a capacitor is driven by voltage of sine wave, the waveform of the current through the capacitor leads the waveform of the voltage. By making use of this principle, a circuit with two branches (one resistive and one capacitive) is proposed, as shown in Figure 3. The resistive branch (R-branch) drives Load 1, and the capacitive branch (C-branch) drives Load 2. Both loads are AC LED modules composed of high-voltage (HV) LEDs.

For simplicity of theoretical analysis, there are three assumptions and one restriction for this circuit design:

Assumption (1): Load 1 and Load 2 are purely resistive.

Assumption (2): In the C-branch, the capacitor C_2 is purely capacitive.

Assumption (3): The voltage and current waveforms are all sinusoidal (i.e., there is no distortion in the circuit).

Restriction: The amplitudes of light output from Load 1 and Load 2 should be equal.

Resistors R_1 and R_2 as well as the capacitor C_2 can be changed. With the change of R_1 , R_2 and C_2 , the percent flicker, power factor, and power efficiency of this lighting system will also change. Therefore, the methodology of this study is to investigate the variation of percent flicker, power factor, and power efficiency as a function of phase shift between both branches, so that an optimal solution can be identified.

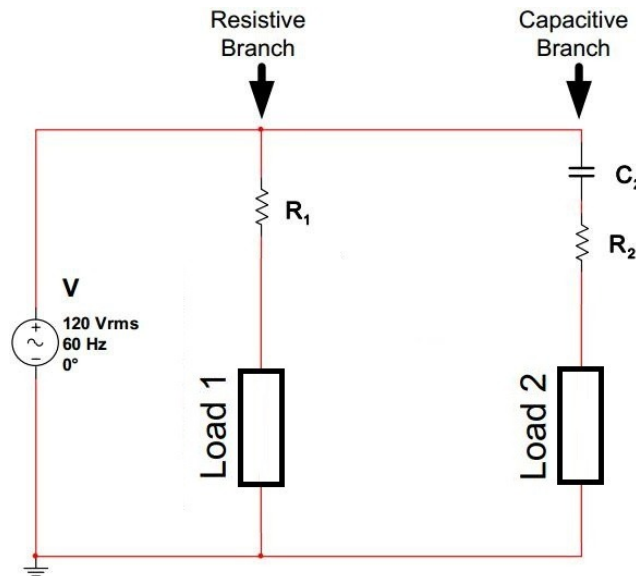


Figure 3. The circuit design proposed in this study.

4. THEORETICAL ANALYSIS

Based on the circuit design and assumptions, a theoretical simulation shows that the percent flicker ($\%F$), power factor (PF), and power efficiency (η) can be expressed as a function of phase shift (ϕ), as presented in Figure 4. Three simulation results can be identified that when ϕ increases, then $\%F$ decreases, PF decreases, but η increases.

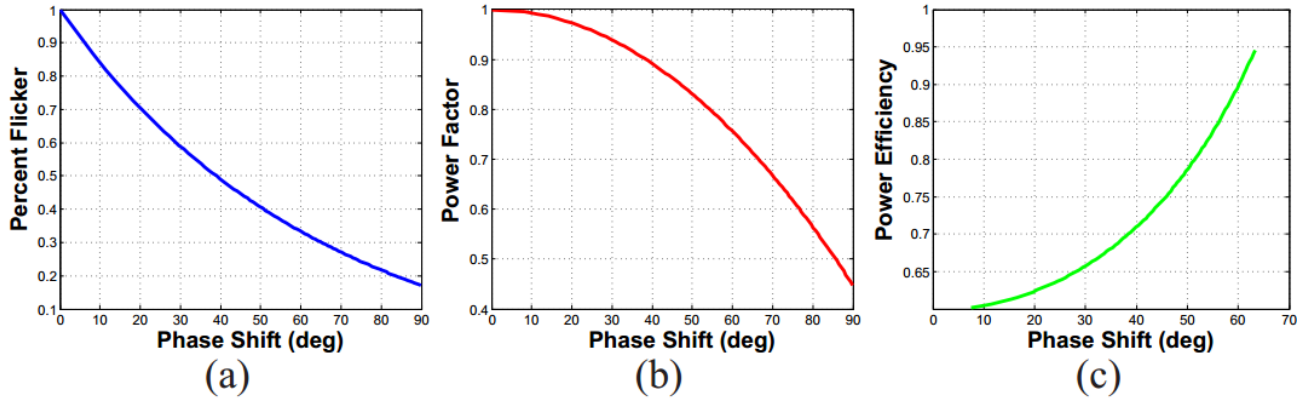


Figure 4. The theoretical variations of (a) percent flicker $\%F$, (b) power factor PF , and (c) power efficiency η as a function of phase shift ϕ .

5. EXPERIMENTAL RESULTS

An experiment was conducted to verify the theoretical predictions, as well as to investigate if an optimal solution could be achieved with this circuit design. The setup of this experiment is shown in Figure 5.

The experimental results are shown in Table 1. A phase shift ϕ in the range of (66° , 68°) corresponds with percent flicker $\%F < 33\%$, power factor $PF > 0.7$, and power efficiency $\eta > 85\%$, meaning all three goals were met, and thus an optimal solution for this circuit design could be achieved.

Table 1: Experimental data of $\%F$, PF and η .

Phase shift ϕ (deg)	Percent Flicker $\%F$	Power Factor PF	Power Efficiency η
55.0	27.8%	0.824	75.3%
62.1	23.0%	0.747	81.2%
66.7	19.7%	0.714	87.2%
68.5	18.5%	0.692	88.0%

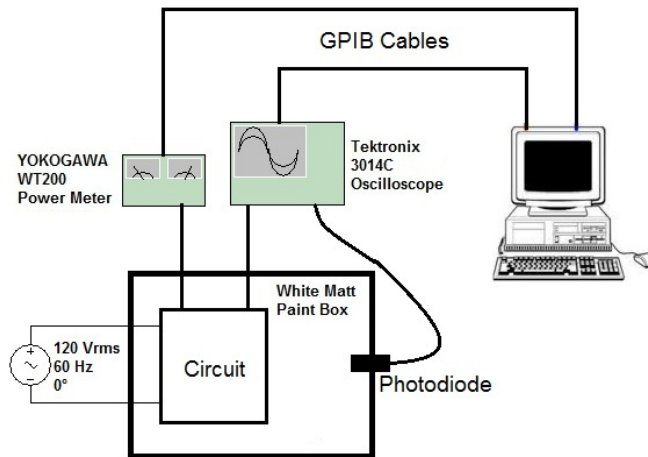


Figure 5. The setup of the experiment.

6. DISCUSSION

6.1 Pros and cons

The pros of this circuit design include:

- The performance can be better than existing AC LED products in the market, especially in flicker reduction.
- The AC LED modules only need some resistors and one capacitor to drive, thus the reliability can be higher than the existing DC driving circuits.
- The capacitor and resistors in this circuit design are inexpensive (less than US\$1 total) and they can be integrated to be a separate driver for Load 1 and Load 2. If the driver fails but the loads remain operational, the driver can be easily replaced at a low cost.
- Because HV LEDs need low driving current, the power loss during current conduction, such as in wires and in soldering, is less than low voltage and high current design topologies.

The cons are that the emitting area can be large, which requires large optics to redistribute light to yield uniform light distributions.

6.2 Future study

This study makes use of only one type of HV LED; therefore, it is difficult to generalize the results of this study to other types of HV LEDs with different forward voltages. An additional study can be conducted by building a simulation model in computer software, such as PSpice, to predict the performance of similar circuits with different HV LEDs and then verified with the experimental results.

7. CONCLUSION

By building loads with high-voltage LEDs and by combining the light outputs from a resistive branch and a capacitive branch with a certain phase shift, the percent flicker of the total light output is significantly reduced and more acceptable than that of existing AC LED products, while maintaining normal power factor and high power efficiency.

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