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An Optimum power control and current balancing scheme for High-Power LED Lighting.

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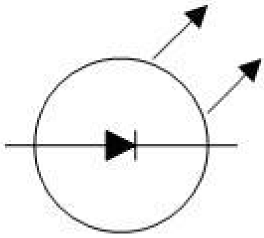
Abstract: ***High-power LEDs (HPLEDs) or high-output LEDs (HO-LEDs) can be driven at currents from hundreds of mA to more than an ampere, compared with the tens of mA for other LEDs. Some can emit over a thousand lumens. LED power densities up to 300 W/cm2 have been achieved. Since overheating is destructive, the HPLEDs must be mounted on a heat sink to allow for heat dissipation. If the heat from a HPLED is not removed, the device will fail in seconds. This paper proposes a PWM current balancing scheme which adaptively minimizes the on-time current within the PWM averaged-current control to optimize the LED luminous efficacy. Applying an independent current balancing control in each LED string often increases the control complexity, but the precise dimming can be easily incorporated into this scheme without additional circuitry. This paper provides solution as a better current balancing scheme with optimum power utilization compared to previous methodologies.***

Keywords: LEDs, Power, PWM, Heating, Current balancing, high luminous efficiency.

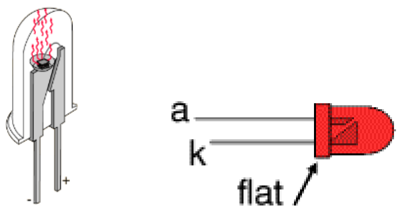
Introduction:

A light emitting diode (LED) is essentially a PN junction opto-semiconductor that emits a monochromatic (single color) light when operated in a forward biased direction. LEDs convert electrical energy into light energy. They are frequently used as "pilot" lights in electronic appliances to indicate whether the circuit is closed or not.



Schematic of LED

The most important part of a light emitting diode (LED) is the semi-conductor chip located in the center of the bulb as shown at the right. The chip has two regions separated by a junction. The p region is dominated by positive electric charges, and the n region is dominated by negative electric charges. The junction acts as a barrier to the flow of electrons between the p and the n regions. Only when sufficient voltage is applied to the semi-conductor chip, can the current flow, and the electrons cross the junction into the p region.



Physical LED

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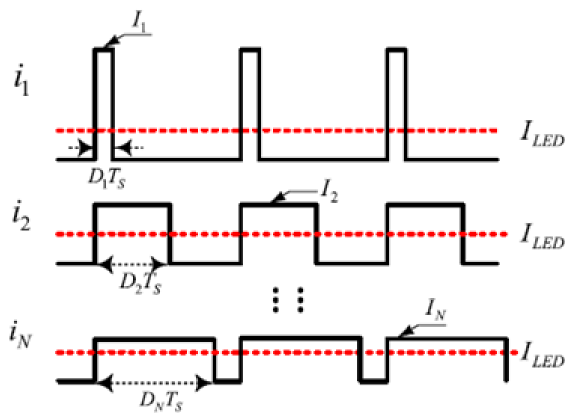
Concept of The Current Balancing

The concept of the current balancing scheme using PWM is to maintain a constant averaged LED current via the tuning of the duty cycle of each LED string shown in Fig, where N LED strings are connected to a common output terminal with dc bus voltage Vo, which is used to control the duty cycle of each switching regulator to provide the required power of each LED string.

Denote the instantaneous current of each LED string as in which is modulated by the current balancing switch with on time current In , where n = 1, 2, . . . ,N. The current waveforms are illustrated in Fig below with a common averaged current of ILED.

To achieve current balancing, the turn-on current amplitude In and turn-on duty cycle Dn of string n should satisfy

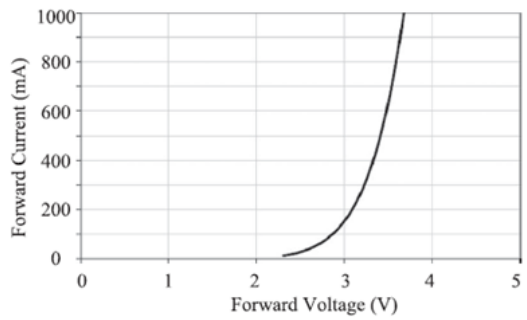
$$I_{LED} = InDn, n = 1, 2, . . . ,N$$



Current waveform in each LED string with PWM

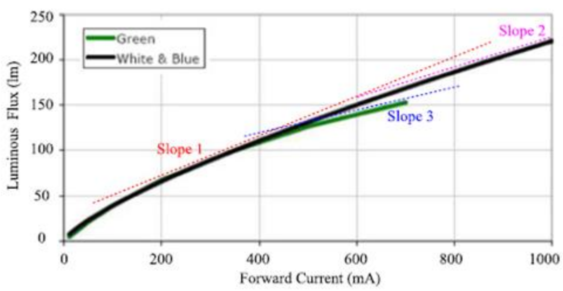
In the subsequent analysis, Xn will be used to describe the property X of LED-string n, where n = 1, 2, . . . ,N. From (1), In is determined by VO and the characteristic of the LED string.

The PWM current balancing scheme controls a constant ILED by adjusting Dn. Intuitively, VO must adjust to be no smaller than the accumulative voltage drop of any LED string to guarantee sufficient on-time current. LEDs are nonlinear components with the typical exponential V–I curves shown in Fig below. A slight voltage difference in Vo will result in a large on-time current variation in In.



Typical forward voltage versus forward current of Cree Xlamps XR-E LEDs at *Tj* = 25 ◦C

A typical relationship of the luminous flux versus the driving current is illustrated in Fig above. The emitted luminous flux is not linear with the driving current and slowly decreases when the driving current is increasing due to higher junction temperature as a result of more heat dissipation.



Typical luminous flux versus forward current of Cree Xlamps XR-E LEDs at *Tj* = 25 ◦C

Normally, the normalized forward voltage varies insignificantly compared with the normalized forward current, and thus can be assumed constant. Therefore, the slope at a particular point of the curve in Fig above can reflect the trend of luminous efficacy = (luminous flux)/(VLEDILED))at that specific position.

Therefore, the maximum of Dn is unity and the string with unity Dn has best luminous efficacy among other LED strings having duty cycle smaller than unity. Hence, Vo should better be just above the maximum of

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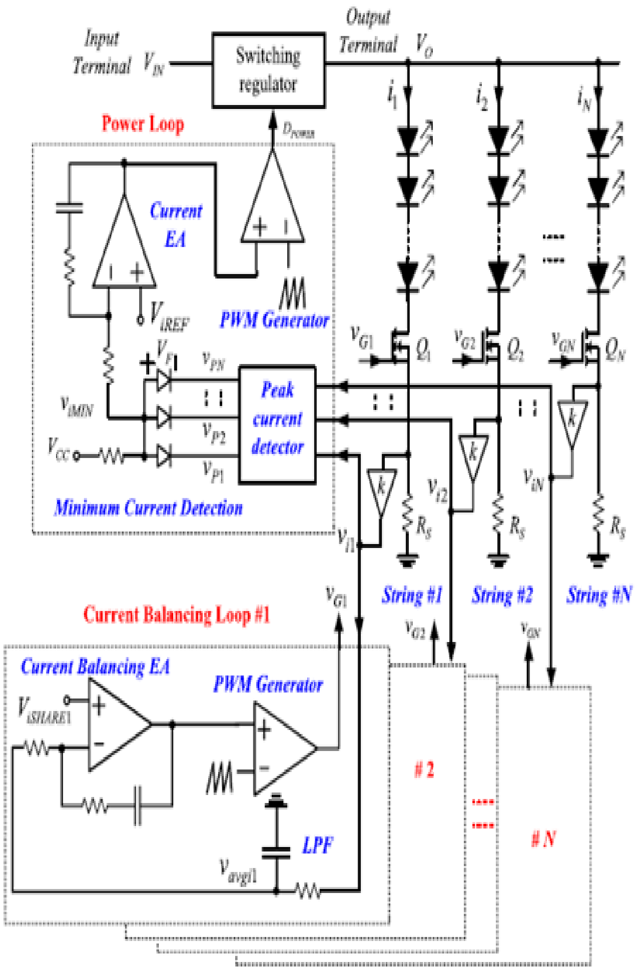
all the LED-string voltage drops to produce a set of ILED with maximized Dn (n = 1, 2, . . . ,N) and minimized In (n = 1, 2, . . . ,N). Then, the high luminous efficacy of LED sources is achieved.

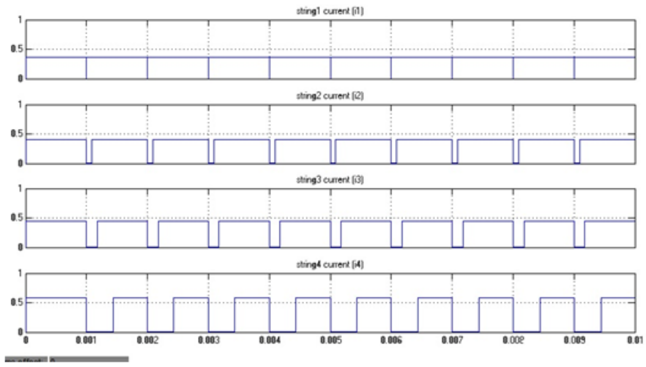
Circuit Design And Implementation

From the aforementioned analysis, independent PWM controls for light dimming and current balancing are required in each LED string. Moreover, the adaptive Vo regulation is realized by the proposed minimum on-time current control via the main switching regulator. There are two cooperative control loops, one being the N-LED-string current balancing loop and the other being the power loop for regulating the terminal voltage Vo.



Schematic of power loop control and current balancing loop control in Each LED string

Results Of Individual Current Balancing Loop

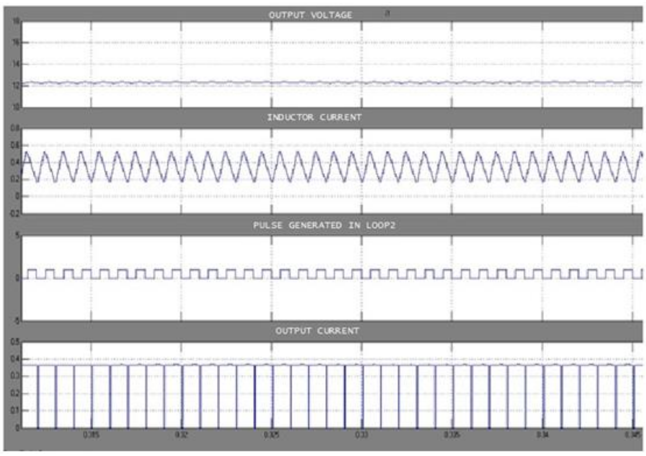


i1=0.3612 i2=0.4051 i3=0.4482 i4=0.5776

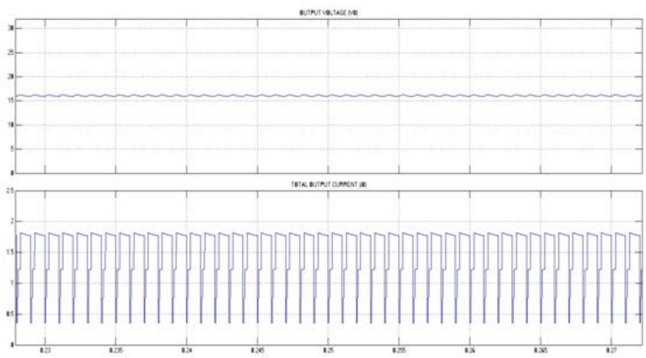
D1 = 0.99 D2 = 0.9 D3 = 0.8 D4 = 0.6

i1D1 = 0.3612 i2D2=0.3645 i3D3=0.3585 i4D4=0.3465

Results Of Single String



Results For Minimum Current Of I_{MIN}= 0.3594A



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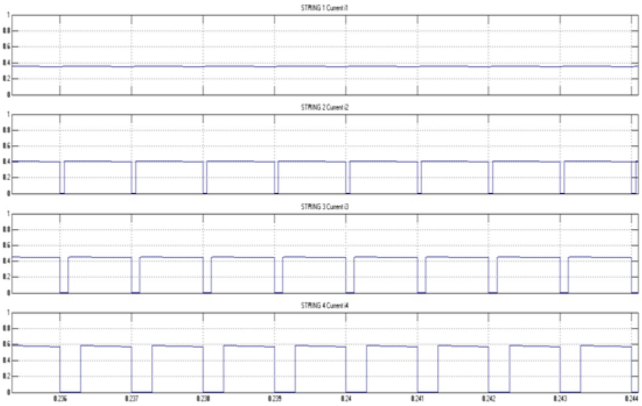
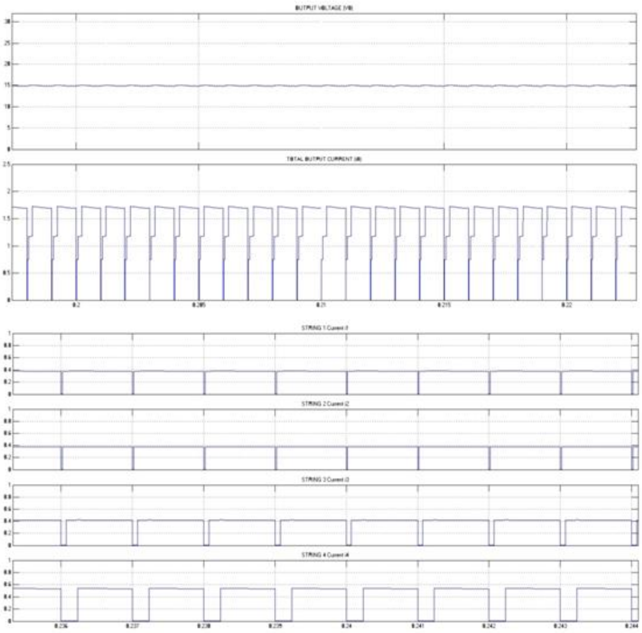
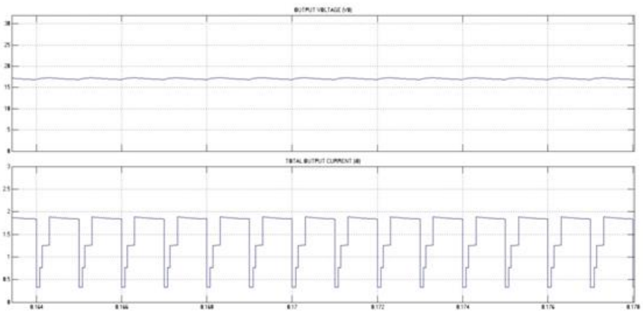
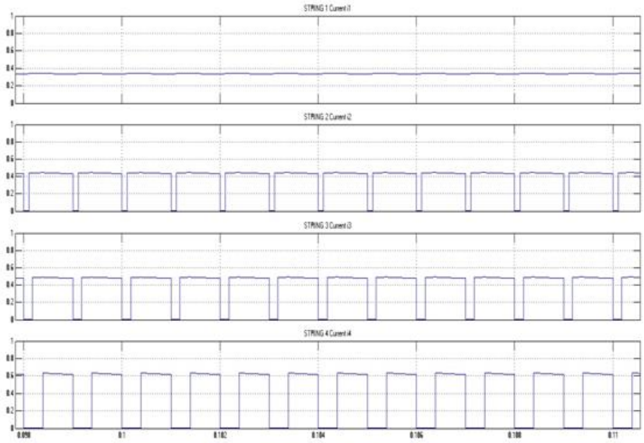


Results For Minimum Current Of I_{MIN}= 0.3696A



Results For Minimum Current Of I_{MIN}= 0.3368A





Conclusion

Current balancing techniques are important in driving multiple LEDs due to device variation and heterogeneous working environment. This project proposes a PWM current balancing scheme which uses an optimal feedback control for maximizing luminance efficacy. Detailed design, analysis, and implementation are provided in this project. The performance of the above proposed LED driver system is evaluated using simulation in MATLAB software.

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