International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

The use of Pulse Width Modulation "PWM" Technique in LED Lighting Systems

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Abstract: ***This paper introduces PWM technique in lighting systems , PWM technique is popular method used in the most of LED driving systems.PWM is powerful in LED dimming circuits.***

Keywords: Pulse Width Modulation (PWM)

1. Introduction

LEDs are becoming the choice in most lighting applications, the applications of LEDs are rapidly increased, so technologies combine together to improve lightening control system and power reducing ,PWM is a powerful technique for LED brightening control.

LEDs have a lot of applications: Devices, medical applications, clothing, toys, Remote Controls (TVs, VCRs), etc.. LEDs have a number of advantages over incandescent, fluorescent, and High Intensity Discharge bulbs. LEDs produce a better quality light, last 25 times longer , consume less energy than compact fluorescent light bulbs, and even use less energy to make. [1]

LEDs are good in applications where dimming is required, LEDs do not change their colour tint as the current passing through them is lowered, unlike incandescent lamps, which turn yellow. [2]

2. LEDs in lighting system:

Light Emitting Diodes are low-voltage light sources, requiring a constant DC voltage or current to operate optimally. Operating on a low-voltage DC power supply enables LEDs to be easily adapted to different power supplies, permits longer stand-by power, and increases safety. Individual LEDs used for illumination require 2-4V of direct current (DC) power and several hundred mA of current. As LEDs are connected in series in an array, higher voltage is required.

During operation, the light source must be protected from line-voltage fluctuations. Changes in voltage can produce a disproportionate change in current, which in turn can cause light output to vary, as LED light output is proportional to current and is rated for a current range. If current exceeds the manufacturer recommendations, the LEDs can become brighter, but their light output can degrade at a faster rate due to higher temperatures within the device which leads to a shorter useful life.[3]

3. Pulse-Width modulation (PWM) Technique

PWM Technique is a very efficient way of providing intermediate amounts of electrical power between fully on and fully off.

A simple power switch with a typical power source provides full power only when switched on. PWM can be used to reduce the total amount of power delivered to a load without losses normally incurred when a power source is limited by resistive means. This is because the average power delivered is proportional to the modulation duty cycle, The duty cycle *D* that is a part of PWM period and describes the proportion of on time to regular interval. Figure (1) describes the duty cycle.

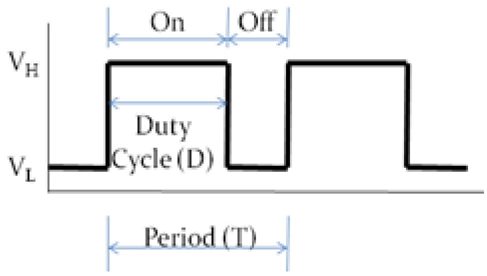

Figure 1: PWM signal

Equation (1) :describes the duty cycle:

$$Duty\ Cycle = \frac{On\ Time}{Period} \times 100\%$$

Equation (2),describes the average signal:

$$V_{AVG} = DV_H + (1-D)V_L$$

V_L is taken as zero volts for simplicity.[4,5]

The reason PWM is popular is simple. Many loads, such as resistors, integrate the power into a number matching the percentage. Conversion into its analog equivalent value is straightforward. LEDs are very nonlinear in their response to current, give an LED half its rated current you still get more than half the light the LED can produce. With PWM the light level produced by the LED is very linear. Motors, which will be covered later, are also very responsive to PWM.

One of several ways PWM can be produced is by using a sawtooth waveform and a comparator. As shown below(Figure.2) the sawtooth (or triangle wave) need not be symmetrical, but linearity of the waveform is important. The frequency of the sawtooth waveform is the sampling rate for the signal.
[5,6]

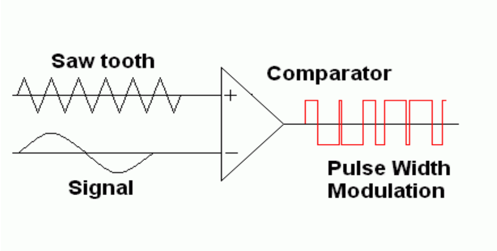

Figure 2: Principle of PWM generation

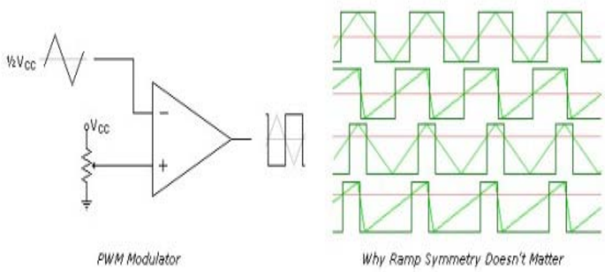

Figure 3: Wave form of Sine PWM

4. PWM Matlab Simulink Model

Simulink, developed by The Math Works, is a commercial tool for modeling, simulating and analyzing dynamic systems.[7]

We used Matlab R2012a for generating PWM signal. In figure.4 the model consists of: signal generator, the output signal equation (the equation from simulink signal generator block parameters, Matlab R2012a):

$$Y(t) = Amp*Waveform(Freq, t) \quad \text{Equation (3)}$$

Amplitude(Amp)=5,frequency(Freq)=1 Hertz .

The output of two constant blocks is added by sum block, Constant value is "1" in constant block 1 and is"4" in the constant block 4.The sum output is added to sum block2 with signal from signal generation block. The output from this sum in to compare to zero block(Determine how a signal compares to zero).The output is PWM signal shown in figure.5 on oscilloscope block. From oscilloscope to the load (we used generic LEDs block as a load)

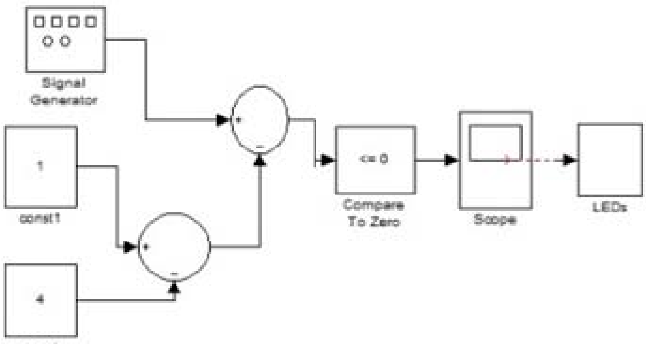

Figure 4: PWM generation using simulink

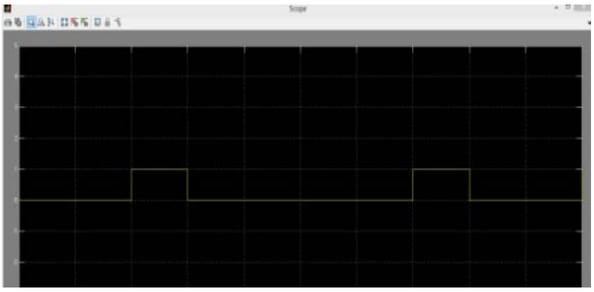

Figure 5: PWM signal (simulink oscilloscope)

5. LED brightness control:

LED brightness control has two basic principles:

5.1 Analog Dimming

Analog dimming simply controls the drive current fed to the LEDs. Full brightness uses the full drive current, and the current is linearly reduced to achieve dimming, reaching zero in the off condition. the current is proportional to the LED brightness within a certain range .LED analog dimming of each cycle of the LED current to be adjusted. More simply put, it is to constantly adjust the LED current. Analog dimming in figure(6).

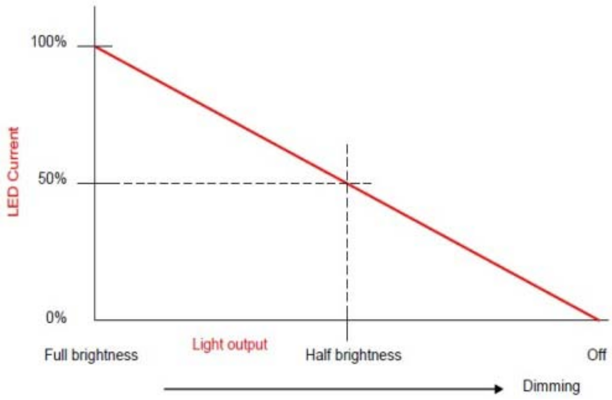

Figure 6: Analog dimming

This type of dimming can be simple to implement but may not be able to deliver the best overall performance, because the colour temperature of the light output may change as the drive current varies.[8,9]

5.2 PWM dimming:

Pulse Width Modulation (PWM) uses digital signals to control power applications, as well as being fairly easy to convert back to analog with a minimum of hardware.

The LEDs are driven with full amplitude pulses of current, the width of the pulses is varied to control the apparent brightness. This type of dimming relies on the capability of the human eye to integrate the average amount of light in the pulses. Provided the pulse rate is high enough, the eye does not perceive the pulsing at all but only the overall average. PWM dimming may be implemented in the power supply or in the driver the pulse rate must be high enough so that the eye perceives only the average light intensity.

For example, at 50% brightness the LEDs are driven with pulses where the ON-time and OFF-time are equal, as shown in Figure 7 the pulse rate must be high enough so that the eye perceives only the average light intensity. The pulse rate of approximately 200Hz is high enough to achieve this objective, without any visible flickering. This corresponds to a period of 5ms per pulse. [9,10]

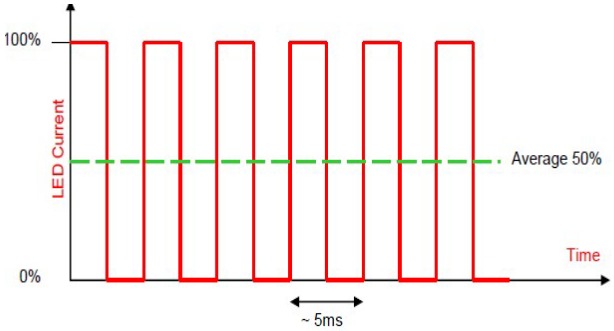

Figure 7: PWM dimming at 50% brightness

For 25% brightness, the LEDs are driven with pulses where the ON-time is equal to 25% of the pulse.

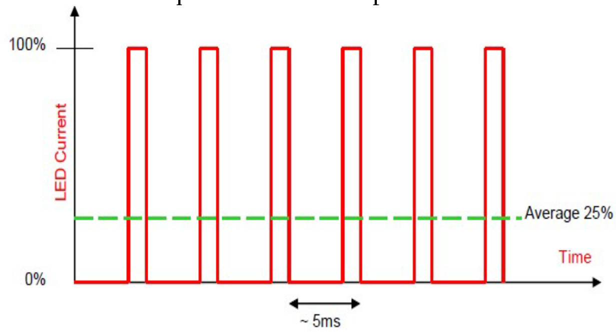

Figure 8: PWM dimming at 25% brightness

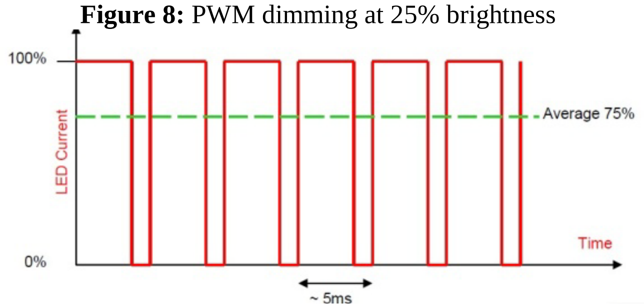

Figure 9: PWM dimming at 75% brightness

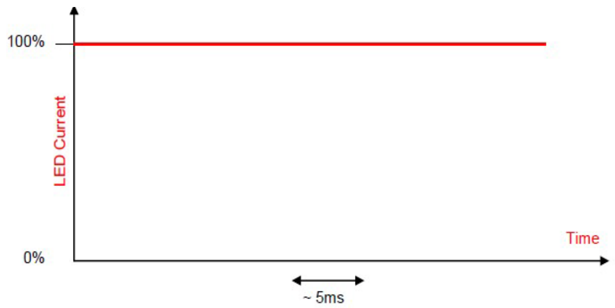

Figure 10: PWM dimming at 100% brightness

This technique independent control of color and intensity is possible. In place of control the forward current, the duty cycle of the switch is control to vary the brightness across LED. Figure (11) shows the schematic diagram of the PWM technique. The current for the LED load is switches periodically and this current is controlled form low value to its high value using switch. Using this technique peak value of the current remains fixed where as only average value is changed which is required for dimming. However the slew rate of PWM technique and continuous ON-Off of the switch creates oscillation in the current signal which causes heat loss in the circuit. Figure 5 shows the waveform of the LED current using PWM technique[11].

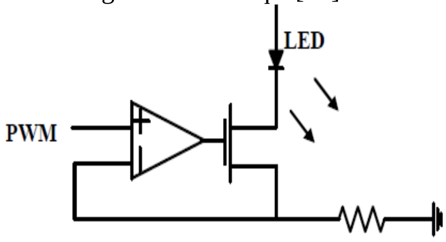

Figure 11: PWM dimming

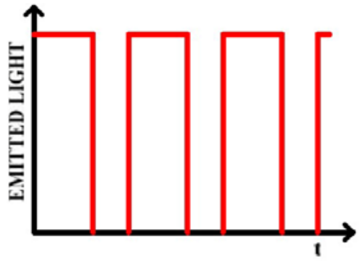

Figure 12: Associated Waveforms

6. PWM LED Driving

LEDs require a device that can convert incoming AC power to the proper DC voltage, and regulate the current flowing through the LED during operation. The driver converts 120V (or other voltage) 60Hz AC power to low-voltage DC power required by the LEDs, and protects the LEDs from line-voltage fluctuations.

"An LED driver is the power supply for an LED system. LEDs are easily integrated with circuits to control dimming and color-changing so that these functions can respond to preset commands or occupant presence or commands. Most LED drivers are compatible with commercially available 0-10V control devices and systems such as occupancy sensors, photocells, wall box dimmers, remote controls, architectural and theatrical controls, and building and lighting automation systems.[12]

7. PWM LED Dimming Driver

PWM driving methods is used in LEDs driving circuits, as shown in Figure(13),the ideal LED current waveform based on this driving method, where the current is periodically switched between a constant level IOH and zero level at a period of Td. The duty cycle of the period output current, controlling the dimming level ,rang from zero to one. Since the output current changes with time, the current time function can be represented by equation(4).

$$i_O(t) = I_{OH} \sum_{n=1}^{+\infty} [u(nt) - u(nt - nT_d D_d)]$$

Equation (4)

U(t) is a unit step function ,Dd is the dimming duty cycle, D of the power converter, dimming frequency fd as defined by

1/Td is the number of cycles that the current waveform repeats per second. The current switches either to *IOH* or zero repeatedly, the luminance intensity emitted from LEDs would switch also. If the dimming frequency is not fast enough, flickering problem may exist ,this flickering problem can be alleviated by increasing the dimming frequency.[13]

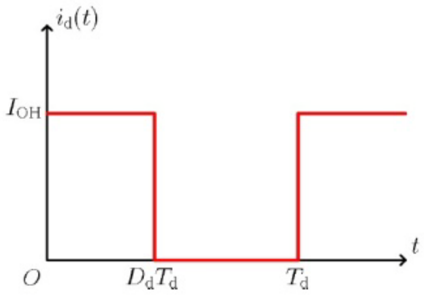

Figure 13: ideal LED forward current timing waveform under PWM driving method

8. PWM LED Driving Circuit

Buck converter is one of PWM dimming methods ,high efficiency LED driver based on Buck converter, which could operate under a wide AC input voltage range (85 V - 265 V) and drive a series of high power LEDs, Buck converter shown in figure(14).

During the time interval of state 1, the metal oxide semi-conductor field effect transistor (MOS-FET) S is turned on, current flows through MOS switch S, input inductor L, storage capacitor C, the load LED strings and sampling resistor Rs. The power supply stores energy in the inductor L, the storage capacitor C and the free-wheeling diode.

D is off at the moment. During the time interval of state 2, the MOS switch S turns off. The LED strings power is provided by the storage capacitor C, and the energy stored in inductor L flows through the free-wheeling diode D simultaneously. Then the circuit proceeds back to stage 1 when the MOS switch *S* turns on again.

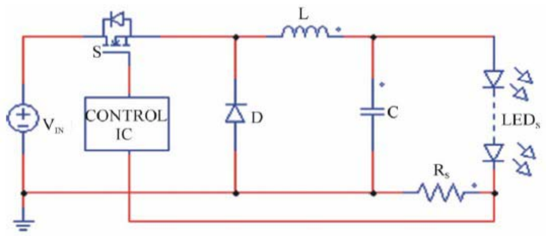

Figure 14: Circuit diagram of Buck converter

To avoid colour variation and get accurate current control over full range, PWM dimming regulators in which the pulse current is kept constant, the power dissipation on the power switch *S* is described in following Equation (5):

$$P_{S(on)} = I_O^2 \times R_{S(on)} \times D$$

Equation (5)

RS (on) is conduction resistor of MOS switch, *Io* is the LED strings current and *D* is the duty cycle of the power switch.
In fact, there is still some power dissipation in the MOS switch when it operates in high frequency. Especially when LED constant current driving circuit is working in frequency more than 100 kHz, this power dissipation is quite substantial. Equation(6)

$$P_{S(high-freq)} = Q_{gs} \times V_{GS} \times f_s + \frac{1}{2} \times V_{IN} \times I_O \times (t_r + t_d) \times f_s$$

Equation(6)

Qgs MOS gate-source charge and V*GS* is the MOSFET gate drive voltage *VIN* is the input voltage ,*tr* , *td* are the needed time of MOS turn-on and turn-off respectively, *fs* is the switching frequency. From the Equation (6),that the power dissipation is proportional to the switching frequency. Combining Equation (6) together with Equation (5).[14]

$$\begin{aligned} P_S &= P_{S(on)} + P_{S(high-freq)} \\ &= I_O^2 \times R_{S(on)} \times D + Q_{gs} \times V_{GS} \times f_s \\ &\quad + \frac{1}{2} \times V_{IN} \times I_O \times (t_r + t_d) \times f_s \end{aligned}$$

Equation (7)

9. Conclusion

In this article ,PWM technique in LED systems is being introduced, Matlab is being used for PWM signal generation.

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