# General Study for using LED to replace traditional lighting devices

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**Abstract –High power LED provides a high luminous and high efficient for using as a lighting source. Because of the advent for LED as lighting device, LED lighting becomes one of the new trends in the lighting industry. In this paper, the power circuit design based on the constant current flyback and the heat distribution matter are discussed. The aims of the work are provide a solution for using LED to replace the traditional lighting device.**

## 1. INTRODUCTION

With the rigid growth of technology in semiconductor, it is believed that using LED as a lighting device will be one of the new trends in the coming years. For instance, the luminous per watt of LED has increased from 0.1*lm*/W to 20 – 25*lm*/W. Recent researches also show that the lumen per watt will be increased to 130*lm*/W[1]. There is no doubt that, with such exponential growth on LED technology, using LED as a lighting device is no longer a myth.

This paper will first discuss the possibility that using LEDs to replace the traditional lighting device in accordance with energy saving sector and will propose a possible circuit design based on the flyback topology in order to maximize the LEDs' operation life by an intelligent control of the operating temperature.

## 2. COMPARISON FOR DIFFERENT LIGHTING TECHNOLOGY

It is interested to find out rather using LED to replace traditional lighting device is beneficial and cost effective. Traditionally, the lighting devices commonly use the HID, incandescent light and fluorescent lamp [5]. Fig.1 shows the famous used lighting device.

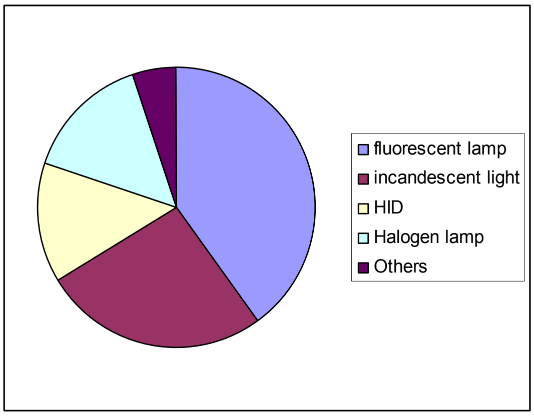


Fig.1 Common lighting device

According to DigiTimes, it shows that currently the fluorescent lamp is the predominant lighting devices of choice. It is interested to find out whether LED can replace them. In this session, it will discuss the feasibility for using LED to replace the traditional lighting device by comparing their luminous, energy saving aspect, etc.

**Power Consumption**

According to Audi, the first car manufactory use LED as headlights, they announce that using LED as the low beams to produce equal amount of light that can draw less current than the traditional halogen or xenon bulbs. Typically, a high power high flux LED required only 4V 700mA LVDC supply. By using the Audi A8 as the example, they just use five LEDs for the low beams, that's means the power used is just around 14W. By comparing with the traditional D2s Xenon HID, which needs 35W for the low beam lamp, hence it shows that using LED can save up to 60% power then use the HID. For the 34W incandescent lamp, it operate at 130V 0.3A with overall 2.1% luminous efficiency. Fluorescent lamp, operates at 120V AC with 30% more efficient than the incandescent lamp.

Fluorescent lamp when it is operated under car battery voltage, an additional DC-DC converter is needed to step up the low car voltage to high voltage for the fluorescent lamp, therefore the net energy saving is not very prominent using fluorescent lamp in automotive applications. On the other hand, HID lamp ballast circuit may not have high efficiency as the voltage is also needed to step up from car voltage to tens of thousand voltage during ignition and to hundred voltage for running, the efficiency of circuit is therefore limited due to the circuit design have to meet 2 to 3 voltage condition. However, for LED, the DC voltage circuit is simple and no high voltage conversion ratio is needed, the power conditioning circuit is usually of high efficiency

**Working Topology**

Incandescent lamp creates light by heating a thin filament to a high temperature above 2500°C and then turns the heat to the visible light. Hence, over 90% for the energy is transfer to the invisible infrared light or heat.

To let the fluorescent lamp and the halogen lamp glow up, firstly the energy is used to produces ultraviolet light and then the electricity is passed across the tube through the mercury vapor to make the phosphor coating glow or fluorescent. Hence, the efficiency for the fluorescent lamp will be decreased during the process of the generation of the ultraviolet light, and converting the ultraviolet light to the visible light.

For HID – high intensity discharge lamp, the light is emitted from the arc discharge between two closed spaced electrodes hermetically sealed inside a small quartz glass tubular envelope capsule [6]. To make it glow, ballast is needed to supply a high open circuit output voltage which is over 300V and most properly 400V or 450V to force the arc to establish. For the D1 and D2 type of HID, they operate at 35W and the ballast need to limit the current from 0.5A to 2A to prevent the arc to draw extra current and make the damage of the parts. For the Xenon and Mercury type of HID, the efficient to produce the visible light is lower than the metal halide type.

The working topology for LEDs is much simple. The simplest topology is use a current limit resistor to control the current passing through the LEDs. Developing the DC-DC converter with current regulation can make the power circuit more reliable.

**Efficiency**

According to Kohtaro Kohmoto, most compared with the other lighting device, LEDs do not provide UV radiation and IR radiation, the only loss for LED is the heat loss. Table 1 shows the losses for the common used lighting device.

Table 1 Losses for different lighting device

| Light Source | Loss in Radiation [%] | Heat loss [%] |
|---|---|---|
| Incandescent Lamp | 81 – 86 | 5 – 6 |
| Fluorescent Lamp | 30 - 32 | 44 |
| HID (mercury) | 62 – 65 | 16 – 22 |
| HID (metal halide) | 57 – 74 | 7 – 20 |
| HID (sodium) | 47.3 – 63.3 | 10 – 23 |
| LED | 0 – 0.2 | 80 – 88 |

Form the table above, the efficiency for the incandescent lamp is 8 – 14%, for the fluorescent lamp is 24 – 26% for the HID(mercury) is 13 – 22%, for HID(metal halide) is 6 – 36% for HID(sodium) is 13.7 – 42.7% and for LED is 11.8 – 20%.

**Dimming Options**

The possible dimming methods for the lighting devices are as follow:

Incandescent Lamp and LED– use high-current rheostat or use the PWM to control dimming

Fluorescent Lamp – As the fluorescent lamp can only glow at the workable temperature, hence if just reduce the voltage and it will possibly reduce the filaments' temperature and this may make the fluorescent lamp go out. Hence to reduce the power given to the FL will only dim to 20 – 30%. To get a major dimming of FL, a more advance technology should be used, for example, to use some impedance-varying means, current-varying means or PWM method with properly heating the filaments during the operation.

High Intensity Discharge Lamp – Traditionally, dimming the HID is impossible. By applying the constant-wattage autotransformer magnetic ballast topology can make the dimming becomes possible. By using the (CWA) magnetic, it will reduce the voltage supplied to the HID lamp in order to reduce the light output about 60%. However, the disadvantages for using this method are the power quality is not good and it will also affect the lamp and the ballast performance [8]. To dim the HID lamp continuously, a variable reactor can be used to change the lamp current without affecting the input voltage and this will allow around 30% of dimming. Also, use the solid-state components to change the waveforms of both the current and voltage can also dim the HID to 50%.

**Color rendering index and color temperature**

The color rendering index rating from 0 to 100 which is used to describe how the light source makes the color appears to human eyes. And the higher CRI rating is the better. Table 2 shows the CRI index for different kind of devices.

Table 2 CRI index for lighting device

| Light Source | CRI index |
|---|---|
| Fluorescent Lamp | 52 – 95 |
| Incandescent Lamp | ~100 |
| HID(Mercury) | 15 – 55 |
| HID(Metal halide) | 65 – 80 |
| HID(Low pressure sodium) | 0 (monochromatic light) |
| HID(High pressure sodium) | 22 – 75 |
| LED | 0(mono-color LED) – 80(high flux LED) |

Color temperature is the index to indicate how warm the light source is. The lower the color temperature, the warmer the light source is. For a 40W incandescent lamp, the CCT is 2800K. Halogen Lamp: 3200K, compact fluorescent Lamp is around 2700K – 6000K. HID's car headlight CCT index is 3900K – 4200K and the daylight white is 5000K – 5500K. For the LED cold white 6500K and warm white is 3300K and for the RGB package can produce the CCT index from 1000K – 10000K depending to the color mixing for Red, Green and Blue value.

## 3. POTENTIAL FOR USING LED AS THE LIGHTING SOURSE

In the previous sessions, it generally describes the lighting characteristics between some common lighting devices Data. They show that the potential for LED to replace the traditional lighting devices is high. As LEDs use LVDC source, hence it can use a simple topology to drive. Besides, as the topologies used to drive the LEDs are simple hence it can be easily to color the brightening level and the dimming effect can be controlled easily. Moreover, by the wide range of the lighting index such as the CRI and CCT index, LED can produce the same light pattern for the entire traditional lighting source.

Besides the discussion above, below have the description for the other advantages to use LED to replace the traditional lighting devices.

**Wide color range**
The wavelength for the LED range from produces large scales. As LED have different wavelength, by using a multiplexing technology to control the RGB LED package, it can generate a full color scales. Fig. 2 below shows the color generated from a third color LED. With this advent for the LED technology, it is widely used for signaling, advisement, outdoor information display, and to embellish the building appearance etc.

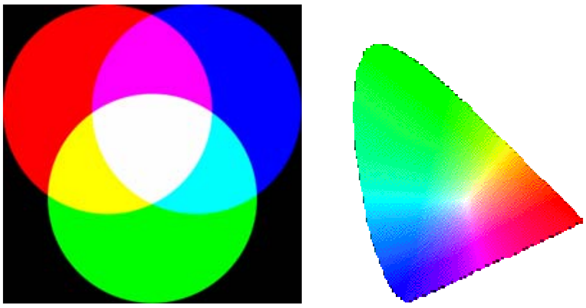

Fig.2 Full colour range generated from RGB colour

**Small size**
The size for LEDs is small and it can be rearranged to any pattern for the different applications. The sizes for the LEDs are varying from the smallest OLED to 1 cm type. By such a small package size, it gives a wide area for the lighting engineers to design their own applications.

**Easy to control**
LED, operates at low voltage and DC source. Hence, the lighting intensity can easily be driven digitally by using high-frequency pulse width modulation (PWM).

Table 3: Summary for the characteristic for common lighting device [9][10]

| | FL | IL | HL | HID | LED (5units) |
|---|---|---|---|---|---|
| Power conditioning | 130V AC | 120V AC | 12 – 24V DC | 500V DC for starting | 5*4V DC |
| Topology | C | S | C | C | S |
| Dimming Option | C | S | C | C | S |
| Lm/W | 33-83(T8) | 6.7 – 20.7 | 30 | 100 | 20 – 130 |
| Starting time | 1sec | instant | <0.4sec | 15 – 20sec | instant |
| Life | 6K | 750 – 1K | 2K | 8K | 100K |
| Cost (US$/klm) | 0.73 | 0.6 | 1 | 1.27 | 55 |
| CCT(K) | 2700 - 6000 | 2800 | 3200 | 3900 - 5500 | 1000 - 10000 |
| CRI | 52 – 95 | ~100 | - | 0-80 | 0-80 |

* FL – fluorescent Lamp
* IL – Incandescent Lamp
* HL – Halogen Lamp
* C-Complex
* S-Simple

## 4. Challenge for using LED as the lighting sourse

It seems that there is a high potential for using the LED to replace the traditional lighting device. The challenges for such replacement are discuss as follow:

**Cost**
According to table 3, the cost for using LED is high. In order to produce the same amount of luminous, using LEDs' cost is much higher than using the traditional bulbs.

**Thermal management**
LEDs produce a high temperature during the operation especially for the high power LED. When working at the full power condition, high power LED will generate around 100° C. In order to maximize the operating life for LED and protect the power circuit ICs, to have a proper thermal management strategy is needed.

**Power Circuit Design**
The traditional devices are commonly worked HVAC power source. To let the LEDs lamp completely adaptable to the traditional working environment

## 5. Proposed Driving circuit for the power LEDs

To replace the traditional lighting devices with LED units, first works to be done is to change the AC voltage to DC voltage and followed with the power factor correction circuit. Finally, use a DC-DC converters to pull down the high voltage to the special value that required by the LED units. However, as the best way to drive the LEDs are using the Vo with current regulation, hence a special design for the LED driver should be used in order to maximize the LED units. Fig.3 shows the block diagram for the ballast for lighting up the LEDs. For the application that the LEDs are driven by Car battery system for automotive applications, the AC rectifier is not necessary and only DC-DC converter is needed.

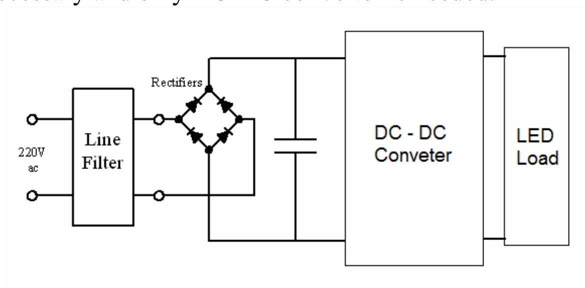


Fig.3 Block diagram for LED power circuit

The configuration for a constant power flyback circuit to drive 12 high power LEDs is shown in Fig.4. The input voltage for the LED driver is 12V and the output voltage is 4V in order to provide the voltage drop across the LEDs. By using the Isense in the primary side, it controls and provides the maximum current protection to the circuit and by using the voltage feedback, it can help to regulate the output voltage in order to provide the constant power regulation to the LEDs..

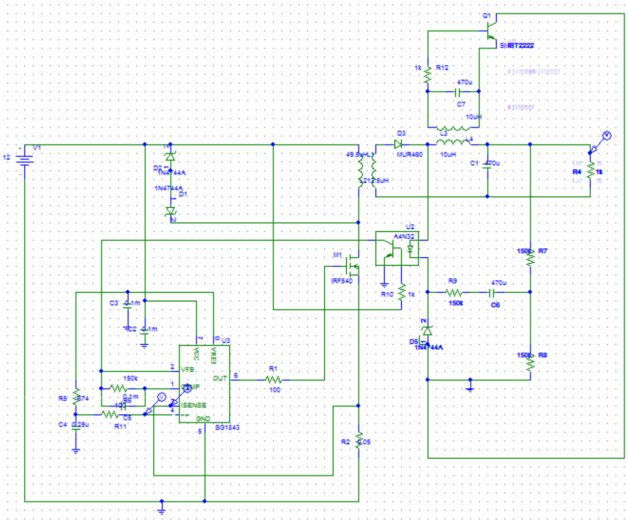

Fig.4 DC-DC converter based on Flyback topology

The power circuit use the current mode control to modifying PWM and control the duty cycle for the switching. During the off stage, the energy stored in the transformer windings is transferred to the diode. And the voltage regulation rate is defined according to the following equation:

$$DV_{in} = \frac{V_o}{N}(1-D) \longrightarrow \frac{V_o}{V_{in}} = \frac{ND}{1-D} \qquad (1)$$

where D is the duty ratio of the main transistor, N is the secondary to primary turns ratio, Vo is the output voltage to the lamp load and $V_{in}$ is the input voltage to the circuit., And as the voltage ripple can be calculated using the following equation,

$$\frac{\Delta V_o}{V_o} = \frac{DT_s}{RC} \qquad (2)$$

In order to make the calculation more easily, the discontinuous mode is used and the ripple current under this condition. And the primary and secondary side inductor ripples are calculated by using the following equation:

$$\Delta i_p = \frac{V_o}{L_p N}\delta T_s \qquad (3)$$

$$\Delta i_s = \frac{\Delta i_p}{N} \qquad (4)$$

And the magnetizing current for the primary and secondary side are shown as follow:

$$I_{mp} = I_{ms} N \qquad (5)$$

To make the flyback working at the discontinuous mode, the relationship between the electronic components is as follow:

$$\frac{V_o}{V_{in}} = \frac{D}{\sqrt{k}} \text{ where } k = \frac{2L_p}{RT_s} \qquad (6)$$

By using the above relationship the PSIM simulation result shown for the proposed circuit are shown as Fig 5 and 6. It is noted that the voltage applied to the LEDs can be regulated through the PWM control The switching frequency for the PWM is selected to be large enough to avoid the audio range.

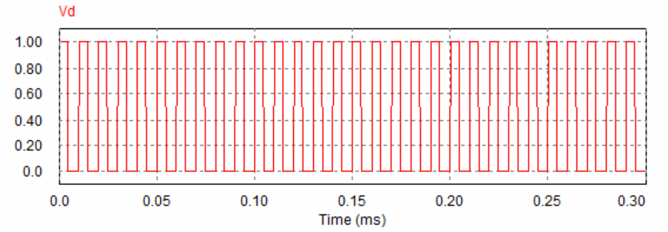


Fig.5 Pulse for adjust Duty cycle

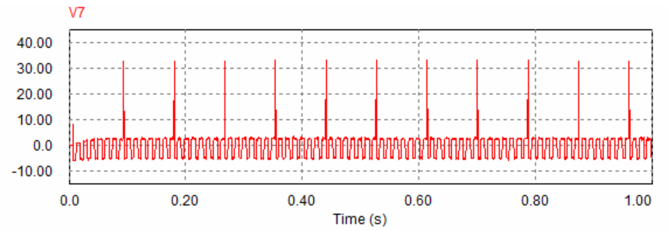


Fig.6 Output voltage across the LEDs

## 6. Proposed Thermo Solution for Driving High Power LEDs

The power circuit for the LED not only needs to conclude the voltage and current pass though the LEDs but also need to conclude the thermo-factors. During the LED's operation, the heat will be given out as shown below in Fig 7 and Fig.8 according to Lumileds' Emitter III data.

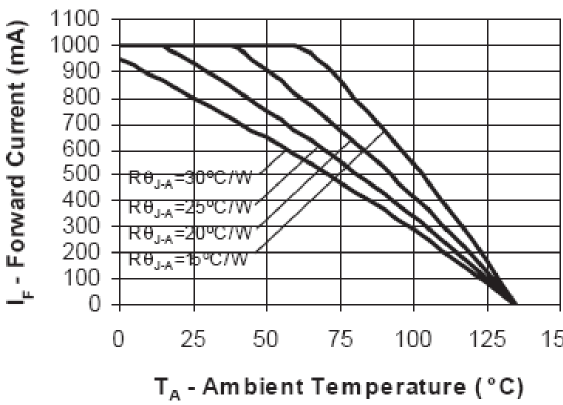


Fig.7 Current Vs Temperature

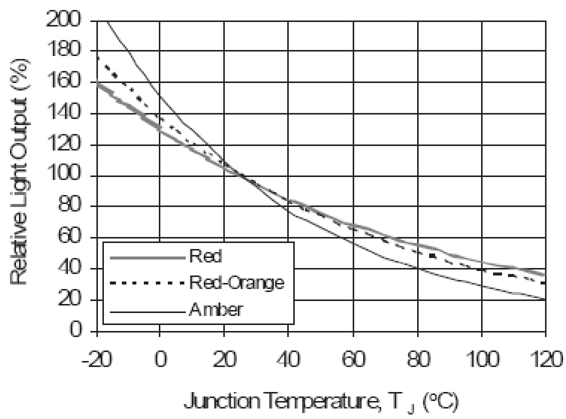


Fig.8 Temperature Vs Light output

Hence, the operating status will be various and depending on the temperature. To again maximize the LED's life and drive the LEDs in the greatest light intensity operation, Fig. 9 shows the proposed thermo protection circuit.

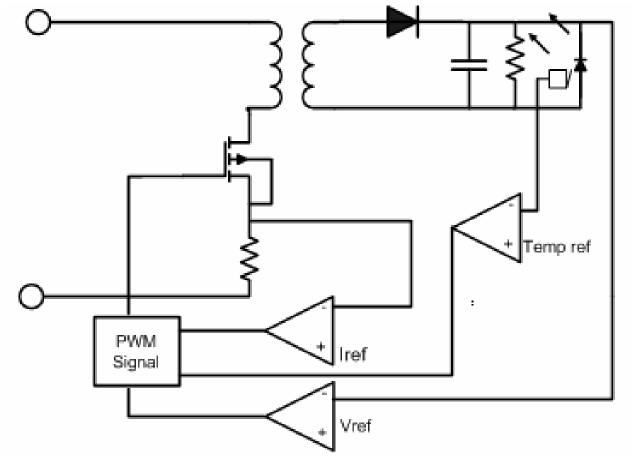


Fig.9 Circuit to add thermal control

By using the thermo-resistant, the resistance will vary by the temperature. Using this as one of the inputs to the PWM control circuit with the current sense input and the voltage feedback input, the PWM can be controlled to give out the utilized duty and give the maximum operation status for the LEDs.

## 7. Conclusion

After comparing the power characteristics and lighting characteristics, it is clear that using LEDs to replace the traditional lighting devices are possible. Protection circuits such as current, voltage and temperature are needed to increase the reliability. In order to make such mission become truth, the first important thing should be done is to lower the unit cost and secondary to have a proper and reliable power circuit. Also suitable optics is needed to control the light pattern from the LEDs including focus, diffusion, reflection, and light amplification.

## Acknowledgement

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