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COST REDUCTION OF COLOR CHANGING LAMP BY ADOPTION OF ANALOG CIRCUIT

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ABSTRACT
The consumers are gradually shifting to LED lamps from the traditional incandescent and CFL lamps as the LED lamps not only are more efficient than the conventional light sources but their lifetime is also more.With growing demand,there have been several developments in the field of LED lighting to suit the consumer needs and the color changing lamp is one of them. LED lamps are available in two colors, warm white and cool white. A consumer may prefer a particular color or the other depending on his choice. The color changing lamp allows the user to switch between the two colors in the same lamp instead of using two different lamps. The color changing lamp which is currently available in the market uses a microcontroller to switch between the colors, hence has a higher cost which limits its use.One way of making the lamp popular is to reduce the cost. This paper examines switching from microcontroller based circuitto analog circuit to achieve the change of color in the lamp, thereby reducing the cost of the lamp.

KEYWORDS: Color Changing, Analog Circuit, Cost Reduction, Color Temperature, Color Rendition Index, Warm White, Trichromatic, Bichromatic

INTRODUCTION
There are several kinds of LED lamps available in the market, ranging from bulbs to tube lights. The lumen output of these lamps varies from 250lm to 2100 lm for bulbs and 600lm to 2100 lm for tube lights. The length of tube lights vary from 2 feet to 4 feet.

From the time of the introduction of LED lamps in the market, several developments have been made in the field of LED lighting. With time their lumen output, efficiency and life time have been on a constant rise. The Hue lamps made by Philips and the color changing lamp are also the examples of the advancements in the field of LED lighting.

The major reason behind their failure and why these lamps to attract the masses and make them shift to LED lighting is the high cost of the LED lamps as compared to the conventional light sources.

WORKING OF THE LED LAMP
Since LED lamps run on DC power supply, the provision of a rectifier circuit is made in the driver circuit of the lamp so as to convert the AC current to DC current. The LED lamps are adversely affected by high temperatures, therefore heat sinks are attached to the LEDs so as to maintain the LEDs at lower temperatures when in use.

The driver circuit present in the LED lamps, drives the LED by supplying them with regulated DC current with the help of a rectifier present in the driver. Several parameters like luminance, illuminance, luminous flux, luminous intensity, color temperature and color rendition index are considered while designing the driver circuit of a LED lamp. The most important parameters in designing the LED lamp driver circuit are the color rendition index and the color temperature.

The Color Rendition Index (CRI) is the quantitative measure of the ability of the light source to reveal the colors of various object faithfully in comparison to the colors of the similar objects in natural light. Light sources with high CRI are desirable in color critical applications like photography and cinematography.

The CRI value ranges from 100 to values in the negative. The highest value of CRI, i.e. 100, can be achieved is for a black body. Conventional light sources like low pressure sodium lamps have their CRI's in the negative. CRI for fluorescent lamps is around 50 and LED lamps have CRI greater than 80. There are three aspects of color rendering which are relevant to light source selection and application. These include accurate rendering of colors so that they appear as they would under natural light, rendering of colors such that the objects appear more pleasing and lastly the ability of the source to allow a subject to distinguish between large varieties of colors when viewed simultaneously.

Fig. 1 Color Rendition Index

Fig. 2 Zoomed in CRI Graph depicting temperatures

The second most important aspect is the color temperature. It can be defined as the measurement that indicates the hue of a specific light source. The color temperature of a light source is measured in degree Kelvin. Color temperature basically characterizes how cool (bluish) or warm (yellowish) the white light would appear. Correlated Color Temperature (CCT) relates the appearance of a light source to the appearance of a theoretical black body heated to high temperatures. As the temperature of a black body rises, it turns red, orange, yellow, white and then finally white. The CCT gives us the temperature of the black body radiator at which it would most closely match the color of the light source.

The LED's are basically available in two colors, warm white and cool white. As the names themselves suggest warm white LEDs render yellowish light and cool white LEDs render whitish light. The reason for the difference of colors between the two LEDs is because of the temperatures at which the colors are achieved. Warm white color is achieved at temperatures ranging around 3300K whereas cool white color is achieved at temperatures greater than 5000K.
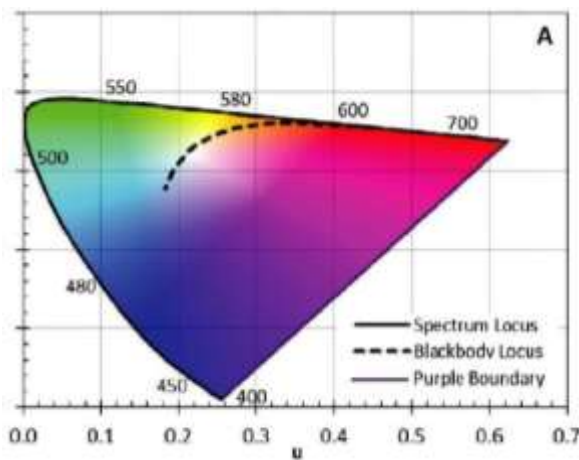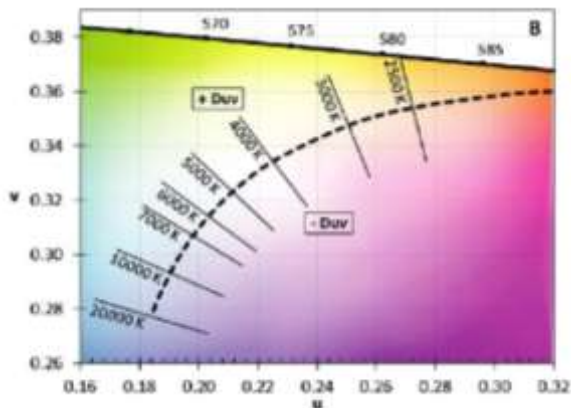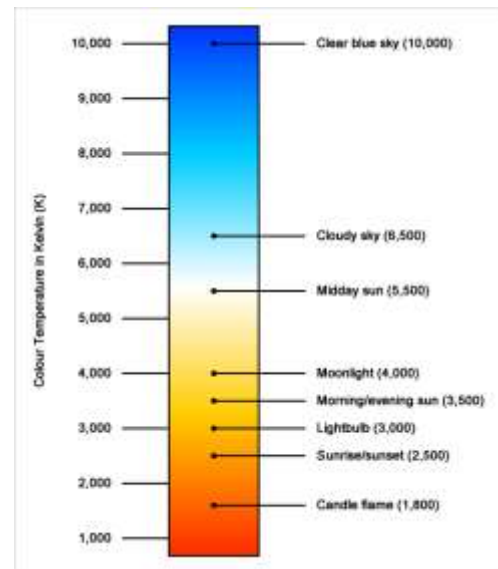

Fig. 3 Color Temperature Chart

CREATING WHITE OR YELLOW LIGHTWITH LEDs

There are several methods to generate white light. Trichromatic and bichromatic are the most commonly used methods.

The trichromatic method or RGB method combines red, green and blue colors to generate white light. Though high efficacy, vivid and saturated colors can be obtained with this method, it has its own disadvantages. Color shadows are observed behind the object and the color rendering property is at best, moderate.

Fig. 3 The RGB Color Combination

Bichromatic method utilizes phosphor conversion. A coating of phosphor is applied on the blue LED die. Indium – Gallium – Nitride present in the die renders the blue color. It is grown on a Gallium – Nitride (GaN) buffer on a transparent substrate like Sapphire or Silicon Carbide. The LED die is a semiconductor material which is a mix of Gallium Nitride and Indium Nitride. The ratio of In/Ga is usually between 0.02/0.98 to 0.3/0.7. The InGaN when coated with phosphor, converts some of the blue color into yellow color, which in turn combine to generate white light in the LED. The wavelength of the light emitted from the LED is dependent on the GaN/InN ratio. The thickness of the InGaN layer ranges from 2-3nm.

In order to generate yellow color, more phosphor or a combination of phosphor on the InGaN is used. This would convert some of the blue light into red light, which would in turn combine to generate yellow light.

COLOR CHANGING LAMP

Most of the times we would find people having lamps of both colors i.e. warm white and cool white in their rooms. The color changing lamp was introduced in the market as the solution to the problem of having to use two different lamps in the room. The color changing lamp allows the user to switch between the two colors whenever they feel like, in the same lamp with the help of an external trigger (the switch for the lamp in this case). The user can change between the two colors by toggling the switch, provided the toggle is made in

a particular time frame. Using the color changing lamp helps the user in saving money. Even though the color changing lamp helps the user to save money they have not been successful in the market because the cost of the lamp is greater than the single color LED lamps.

The lamp currently used in the market uses a microcontroller to switch between the two colors when an external trigger is detected by it. This is one of the reason behind the high cost of the lamp. It was thought that an effective way to reduce the cost of the lamp would be to design an analog circuit responsible for detecting the external trigger and changing the color of the lamp.

DESIGN OF ANALOG CIRCUIT

Before the analog circuit responsible for the switch is designed, the basic functioning of the circuit using the microcontroller has to be understood.

The lamp switches between two colors i.e. warm white and cool white when the external trigger is made. The microcontroller is programmed to detect the external trigger and switch between the two colors. The microcontroller would switch between the two colors only if the switch is made within a particular time span

Fig. 4 Analog Circuit for Color Changing Lamp

An analog circuit was designed which would switch the load when externally triggered. The values of the various components was theoretically calculated and then simulated in a software called MULTISIM. MULTISIM is an electronic schematic capture and simulation program which is part of a suite circuit design programs. It allows the designer to design the circuit and check whether the circuit is giving the desired result or not.

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WORKING OF ANALOG CIRCUIT

The working of the analog circuit is similar to the working of the microcontroller based switching circuit. The circuit would change between the colors when an external trigger is detected only if the trigger is made in a particular time frame. If the trigger is not made in that time frame the circuit will return back to its default state. In this case the default state is LED 1, this means that if the external trigger is not made in a particular time frame, LED 1 would glow instead LED 2 when the circuit detects an external trigger.

The MOSFET and the thyristor are used to trigger between the two LEDs. The transistor is responsible for detecting the external trigger and the capacitor C_2 in this case maintains the timing of the circuit.

Initially the circuit is in its default state, when the trigger is made for the first time, a potential drop is generated across the gate and source of the MOSFET (JCS2N65FB) and LED 1 starts glowing as a result of the potential drop across the MOSFET. Resistors R_3 and R_8 act as potential dividers. When the first trigger is made a potential drop develops across them. This potential drop would charge the capacitor C_2 to its maximum value. A potential drop also develops generated across R_1 and R_2, this would generate a potential drop across the base of the transistor. When the supply is turned off, the capacitor C_2 would start discharging through the emitter of the transistor developing a potential drop across it. As a result of turning of the supply the potential drop across R_1 and

R_2 also starts decreasing. As a result of discharging, as soon as the potential across the emitter is greater than the potential across the base of the transistor, the transistor starts behaving like a forward biased diode and starts conducting. The current generates a potential drop across R_6. This potential drop if greater than the minimum gate trigger voltage of the thyristor, the thyristor is triggered. If there is an external trigger in the particular time frame, the current will start flowing through the anode of the thyristor latching it to the ground and completing the circuit. As a result LED 2 will start glowing. Since the anode of the thyristor gets latched, the MOSFET gets grounded as result of which LED 1 would not glow while LED 2 is glowing.

If the external trigger happens after the particular time span the circuit goes back to its default state. This happens because once the external supply/trigger is turned off the capacitor C_2 starts discharging through the emitter, if the trigger is made after a particular time span the capacitor will be fully discharged and there will be no gate trigger voltage, to trigger the thyristor.

CALCULATIONS

Assuming that the capacitance of the MOSFET JCS2N65FB. The maximum V_{gs} for the MOSFET is 30 V. For the MOSFET to work the V_{gs} must be maintained below 30V. Assuming the potential across the ground of the MOSFET and ground is maintained at 15V. When LED 1 is working, R_8 and R_3 act as potential dividers. (A MOSFET with a high value of V_{gs} is preferred because we are supplying gate input to the MOSFET through DC bus, there has to be a buffer between the V_{gs} and the potential across gate of the MOSFET and the ground. A small surge in the DC bus could end up destroying the MOSFET.)

Selection of R_9

Ideally the voltage at input is 2-3V greater than the voltage across the LED's. If the amount of current flowing through the LED is greater than a particular value, the LED will start glowing. When LED1 is glowing there will be a small amount of current that will also be flowing through LED2, now if that current through LED2 is greater than a particular value LED2 will also start glowing and this situation needs to be avoided.

Set the minimum current through LED2 that can turn it on when LED1 is glowing as 0.1mA. Assuming V as 2V, here V is the difference between the potential drop across the LED and the input voltage.

Let V = 2V

$2 = 0.1 * 10^{-3} * R \quad [V = I*R]$ --- (1)

On solving the above equation we get the value of R as 20KOhms.

At R_9 = 20KOhms the current through LED2 is 0.1mA, hence the resistance value has to be more than 20KOhms.

If R_9 is a very large value, say 90KOhms for instance then,

$I = 2 * 10^{-3} \div 90 = 0.022 mA$ --- (2)

This sufficient high value of R_9 will not allow LED2 to glow as the current through it will be very less. The high value of R_9 is also required because if R_9 is very low the capacitor C_2 will discharge through R_3 at a very high rate.

Since the MOSFET is a voltage controlled device, only a small amount of gate current is required so as to turn the MOSFET on. The resistor value of R_9 should be very high, because if the value of R_9 is very less the potential drop across the gate and source will be less than the desired value of the V_{gs}. Also, the low value of R_9 would obstruct the working of R_8 and R_3 as potential divider. Hence the value of R_9 can be selected something as high as 250KOhms.

Selection of R_8

Since R_8 and R_9 act as a potential divider, the equation of a potential divider is

$V_a = (V_{dc} \times R_8) \div (R_8 + R_9)$ --- (3)

Hence,

$15 = (V_{dc} \times R_8) \div (R_8 + R_9)$ --- (4)

In this case V_{dc}, $V_{in}-V_{R5} = 30V$. (Since potential drop across R_5 is 30V)

Hence V_{dc} is 15V.

$15 = 30 * (90k/(90k + R_8))$ --- (5)

On solving the above equation we get R_8 as 90K.

Selection of R_4 and R_6

The LED 2 will start working only if the emitter voltage is greater than the base voltage. When this happens the transistor would start acting as a diode and conduct, because it would be forward biased. Voltage observed at base is 15 - 0.7 = 14.3V. R4 and R_6 act as a potential divider. For the SCR to work, minimum gate voltage gas to be supplied at the gate of the SCR. The SCR used here was BT169B, the minimum gate trigger voltage that needs to be applied is 0.5V. The 0.5V potential drop at the gate would be observed across R_6.

To find the value of R_4 and R_6

$0.5 = 14.3 * (R_6/(R_6 + R_4))$ --- (6)

On solving the above equation we get

$R_4 = 27.6 R_6$ --- (7)

C1 is applied across R6 so as to avoid mistrigger.

Selection of C_2

Assuming that C_2 will not discharge through the resistor and only through the transistor. The discharge equation is

$V = V_0 e^{(-\frac{t}{RC})}$ --- (8)

Here V is the final voltage and V_0 is the initial voltage. When V across R_6 is less than 0.5, the SCR would not be triggered.

Let the voltage across R_6 be 0.3. At 0.3 the SCR will not be triggered.

Assume R_4 and R_6 to be 100 Ohms and 2.76 KOhms respectively.

Hence,

$0.3 = (x * 100)/(2760 + 100)$ --- (9)

On solving the above equation we get the value of x as 8.58V.

Assuming the discharge time after which the potential falls below a certain value and the gate voltage is not sufficient to trigger the SCR as 0.03 seconds.

$8.58 = 14.3(e^{-\left(\frac{0.03}{2860c}\right)})$ --- (10)

Taking log on both sides, we get

$$\log\left(\frac{8.58}{14.3}\right) = -\frac{0.03}{2860c}$$ --- (11)

On solving the above equation we get the capacitor value to be approximately 9.5uF, hence we can select C_2 as 47uF.

To select R_1 and R_2

Maximum value of potential across R_1 and R_2 is the voltage across LED 1 when all the LED's are glowing.

Voltage across each LED is 6V

Total number of LED's is 6

Hence the net voltage across R1 and R2 is 6*6 = 36V.

The voltage at the base of the transistor has to be greater than the voltage at the emitter of the transistor, so that LED 2 does not glow when LED 1 is glowing.

Assuming we want voltage at the base as 16V

$$16 = ((36 * R_1) \div (R_1 + R_2)) \quad \text{--- (12)}$$

On solving the above equation we get the relation between R1 and R2 as

$$R_2 = 1.25 R_1 \quad \text{--- (13)}$$

Values of R_1 and R_2 can be selected in such a way that it satisfies the above relation.

(NOTE: The values of the components shown in the circuit diagram are different from the values obtained, as the values of the components had to be changed to get the desired output while simulating.)

CONCLUSION

Cost savings are made by adoption of Analog Circuit in place of Microcontroller based circuit in the color changing LED lamps. This has the potential of making the color changing lamp much more popular in the market.

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