CG1111 Engineering Principles and Practice I

DC Circuit Principles I - Characterizing IV of LEDs

(Week 3, Studio 1)

Time	Duration (mins)	Activity
0:00	10	Briefing on Activity
0:10	70	Activity #1: Characterizing the I-V characteristics of the Red, Green, and Blue LEDs within an RGB LED Lamp (graded lab report)
1:20	10	Discussion on Activity #1, and briefing on Activity #2
1:30	60	Activity #2: Biasing the Red, Green, and Blue LEDs with appropriate resistors to achieve a desired colour (graded lab report - continued)
2:30	5	Final discussions and wrap-up

Introduction:

- These days, it is quite common to see huge LED displays outside shopping malls, such as the one shown in the picture below. They are bright, colourful, and can be seen from far.
- An LED display like this consists of a large matrix of LED Lamps. Such LED displays are controlled by computer electronics, which dictate what colour each LED pixel shows. Have you ever wondered how each pixel is controlled to show the desired colour?
- In this studio, you will be working with one such LED Lamp. You get to understand how it works, and see how electrical circuit principles are applied to control the displayed colour.
- When you take a closer look at the LED Lamp, you'll notice that it contains three colour LEDs inside - Red, Green, and Blue (RGB). These are the three primary colours of light!
- Each pixel's colour as perceived by the human eyes depends on the relative intensity ratios of R:G:B. They are in turn controlled by the amount of current passing through each of the internal RGB LEDs.
- In this studio, you will characterize the current versus voltage characteristics of each of the internal RGB LEDs. You will then apply basic circuit principles to calculate the necessary resistors for biasing the LEDs in order to achieve a desired colour.

Notes:

1. A diode is a polarized device that allows current to flow in only one direction. The positive side "+" is called the anode where current enters, and the negative side "–" is called the cathode where current leaves. An LED (Light Emitting Diode) is a type of diode. The given RGB LED Lamp houses three colour LEDs inside the lens, namely, Red (R), Green (G), and Blue (B). The RGB LED Lamp has a common cathode (pin 2 – the longest pin). The other pins, 1, 3, and 4, are the anodes ("+") of the respective colour LEDs as indicated in Figure 1 below. Notice the symbolic drawing of a diode, which consists of a triangle and a line. The triangle in the symbol points to the forward direction in which the current flows.

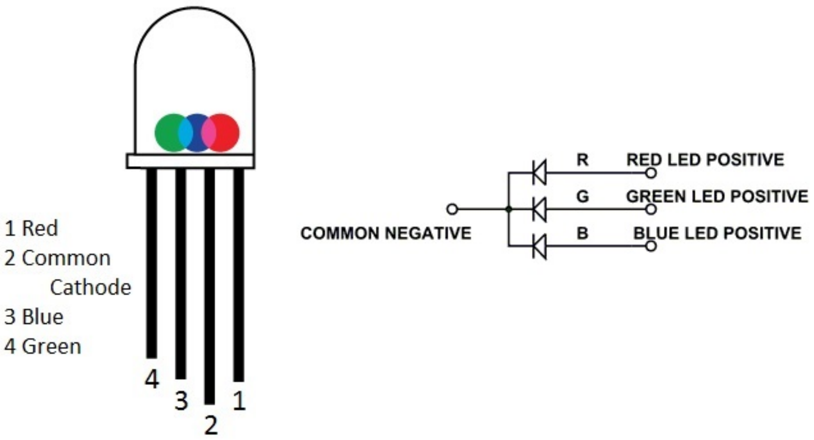

Figure 1: The pin configuration of the given RGB LED Lamp.

2. When a positive voltage is applied across the LED (i.e., the anode has a higher voltage than the cathode), the LED is "forward-biased". Only when this voltage exceeds a threshold, the diode starts to conduct current. The current grows exponentially with incremental voltage beyond this threshold. **As the LED will burn out when the current gets too large, we <u>must not</u> connect a voltage source <u>directly across</u> the LED.** Instead, a common practice is to connect a **resistor** in series with the LED to limit the current (hence called a "current-limiting resistor").

3. When a negative voltage is applied across the LED (i.e., the anode has a lower voltage than the cathode), the LED is "reverse-biased". Note that the LED will break down and be **permanently damaged** (there will be burning smell and you will be pretty embarrassed!) when the reverse-biased voltage is beyond a limit. **Hence, be careful with the polarities when you connect the voltage supply.** From the datasheet of the given RGB LED Lamp, you will see that its reverse voltage limit is –**5V**.

4. Each of the R, G, and B LEDs inside the Lamp has *different* current versus voltage (I-V) characteristics which you will determine experimentally. As R, G, and B are the three primary colours of light, we can visualize different colours by varying the intensities of these three LEDs.
   (Note that the R, G, and B LEDs have different luminous intensities for the same currents flowing through them. According to the datasheet of the RGB LED Lamp, their relative intensities have approximately the ratio 2:4:1 for R:G:B when the current is 20 mA. Hence, you cannot obtain white colour by passing the same current through each LED!)

Objectives of studio:

- Determine the I-V characteristics of each of the R/G/B LEDs for the given RGB LED Lamp
- Determine the appropriate resistance values to bias each of the R/G/B LEDs so as to achieve a desired colour outcome for the RGB LED Lamp
- Able to apply Ohm's Law and Kirchhoff's Laws
- Learn how to use a variable resistor
- Able to calculate power consumption

Materials:

- Breadboard and connecting wires
- USB breakout cable + your own USB charger
- Digital multimeter
- 5% tolerance resistors {150 Ω, 330 Ω, 560 Ω, 820 Ω, and 1500 Ω}
- Common-cathode RGB LED Lamp with diffused lens
- Dome-shaped silicon cap for reducing the glare of the RGB LED Lamp
- 2 kΩ variable resistors (3 per student)
- Trimming tool for adjusting the variable resistors

Activity #1: Characterizing the I-V characteristics of the Red, Green, and Blue LEDs within an RGB LED Lamp (70 mins)

Note: Both Activity #1 and #2 will be assessed. Students are required to submit individual lab reports (upload in PDF format to submission folder) before the studio ends.

Procedure:

1. The RGB LED Lamp can be very bright. To reduce its potential risk of harming your eyes, **always remember to cover the RGB LED Lamp using the dome-shaped silicon cap provided before you light up the LEDs**.

2. Each of the R, G, and B LEDs inside the Lamp has different current vs. voltage (I-V) characteristics, which you will determine experimentally. Figure 2 shows the circuit setup that you will be using for this purpose. The idea is to obtain five sets of current vs. voltage data points for each of the R, G, and B LEDs, so that we can use them to plot I-V graphs using Microsoft Excel. To reduce the experimental measurements that you need to perform, an easier approach is to **measure the voltage across the LED, and then indirectly (see hints below) calculate the LED current using circuit laws**. For example, for the Red LED in Figure 2, if R_R is known, you can indirectly compute the current I_R after measuring V_R. Take some time now to derive the equation that expresses I_R in terms of V_R, R_R and your DC supply voltage. Make sure you include the derivation in your lab report.

   Hint 1: The current flowing through resistor R_R is also the current entering the Red LED.
   Hint 2: You need to apply both KVL and Ohm's Law to calculate the LED current. **Do not try to use Ohm's Law for LEDs because they are not resistors!**

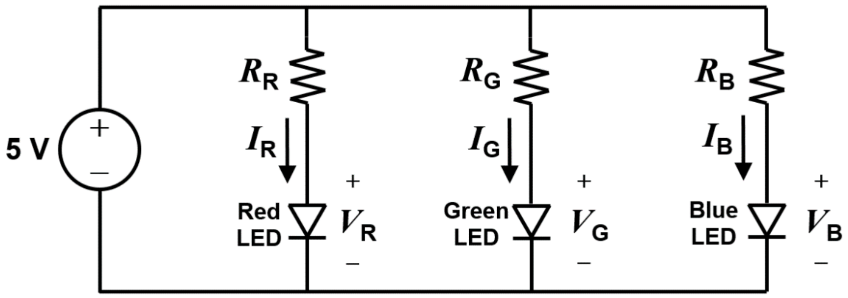

Figure 2: Circuit for characterizing the I-V relationship of each colour LED inside the Lamp.

3. Connect the USB breakout cable to the breadboard. The red wire is the '+' terminal, while the black wire is the '–' terminal. Connect the red wire to the top row of your breadboard, and the black wire to the bottom row of your breadboard. Next, connect your USB cable to a USB charger. Measure the **actual voltage** between the breadboard's top and bottom rows using the multimeter, and **use this actual value** in your calculations later on (instead of using the nominal '5 V' value).

4. Using the breadboard, construct the circuit shown in Figure 2 for **just the Red LED first**. Vary the resistance R_R, according to the values given in Table I {i.e., 150 Ω, 330 Ω, 560 Ω, 820 Ω, and 1500 Ω}. For each resistance value, measure the voltage V_R and calculate the current I_R using the expression you have derived in Step 2. Note that **you should be using the measured value of resistance R_R in your calculation**, not its nominal value. Tabulate your readings using the format given in Table I, and include them in your lab report.

   Hints:
   1) You can use the **formula** feature in Microsoft Excel to help you calculate the various current values automatically upon entering the measured voltage values. **Do some preparation and create the Excel file before attending the studio.** After entering the experimental data into your Excel spreadsheet, you can simply copy the table into your lab report.

   2) You can bend the common cathode pin (longest pin) away from the other 3 pins, so that the 3 RGB anodes are on the top half of the breadboard, while the common cathode is on the bottom half (see Figure 3 below). Note: the pin sequence is RBG, not RGB.

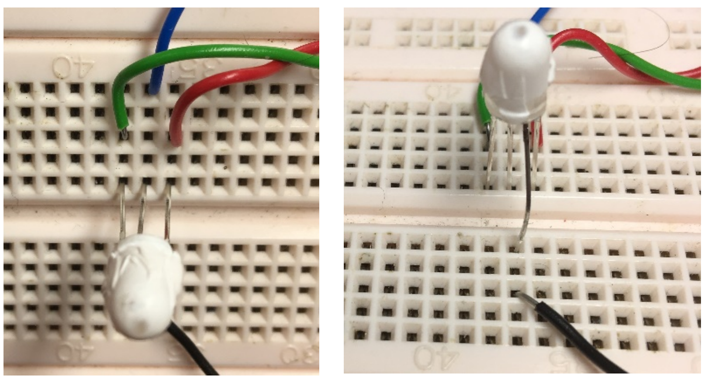

Figure 3: Example of how to insert the RGB LED Lamp into the breadboard.

5. Repeat the experiment for the **Green** and **Blue** LEDs inside the LED Lamp.

Table I

		Resistance Values for R_R, R_B, and R_G				
Nominal resistance →		150 Ω	330 Ω	560 Ω	820 Ω	1500 Ω
Measured resistance →						
Red LED	Measured Voltage V_R (V)					
	Calculated Current I_R (mA)					
Green LED	Measured Voltage V_G (V)					
	Calculated Current I_G (mA)					
Blue LED	Measured Voltage V_B (V)					
	Calculated Current I_B (mA)					

6. From the data you have collected in Table I, plot (using Microsoft Excel) the I-V graphs for each of the colour LEDs. Choose the "polynomial" trendline option for the line fitting. <u>Copy and paste the graphs from Microsoft Excel into your report. Compare your graphs with those provided in the datasheet for the RGB LED Lamp, and write down your observations. Are the graphs linear? Are the values exactly the same as the datasheet? If not, explain whether your graphs would become closer to the graphs' values in the datasheet if you have obtained more data points (e.g., by using > 5 resistance values per graph).</u>

<u>Activity #2: Biasing the Red, Green, and Blue LEDs with appropriate resistors to achieve a desired colour (60 mins)</u>

Note: This part is also assessed, and must be included in your lab report for submission as well.

In this part of the activity, the objective is to determine the appropriate values for the resistances R_R, R_B, and R_G, so as to achieve a desired colour outcome. **Each student will be assigned <u>one</u> particular mystery colour by the TA**, for which its corresponding current values I_R, I_B, and I_G are given in Table II below.

Table II

Mystery Colour	Current I_R	Current I_G	Current I_B
A	20 mA	2 mA	2 mA
B	20 mA	1.5 mA	0 mA
C	20 mA	0 mA	1.5 mA
D	3 mA	13.5 mA	1.5 mA
E	2.5 mA	0 mA	1.5 mA
F	2 mA	1.5 mA	12.5 mA

Procedure:

1. For the mystery colour assigned to you, calculate the appropriate values for the resistances R_R, R_B, and R_G. Remember to include in your report how you obtained their values from circuit laws.

   Hint: Use the I-V plots for the respective R, G, and B LEDs, as well as Ohm's Law and Kirchhoff's Voltage Law.

2. After determining the required resistance values for R_R, R_B, and R_G, you will construct the circuit, using the three 2 kΩ variable resistors to obtain R_R, R_B, and R_G. The pin layout of the variable resistor is shown in Figure 4 below. The resistance between pins 1 and 3 is fixed at 2 kΩ. Pin 2, on the other hand, is connected internally to a part that slides between pins 1 and 3 when you rotate the white circular disc on top using the trimming tool (from your toolkit box). To use it as a variable resistance that you can tune, you can choose to use either (i) pins 1 and 2 only, or (ii) pins 2 and 3 only. Suppose we use pins 1 and 2 only, and leave pin 3 disconnected (unused). You can now turn the white disc to vary the resistance between pins 1 and 2 to obtain any desired value between 0 and 2 kΩ!

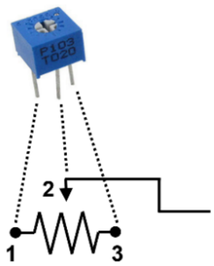

Figure 4: Pin layout of variable resistor.

3. When measuring the resistance between pins 1 and 2, you should place the variable resistor in a different part of your breadboard away from the rest of the circuit (see Figure 5 below). **Never measure the resistance while it is still plugged into the rest of your circuit, because they affect your measurement.** Only after trimming it to the desired resistance value, then you can move it into your circuit.

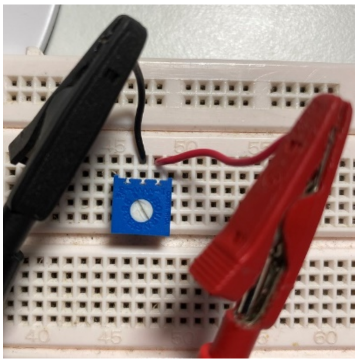
Figure 5: Measuring resistance on a **different part** of breadboard away from circuit.

Important: Do not trim the variable resistor while it is connected to the LED Lamp circuit. If you turn all the way to one end such that the resistance is 0, your LED will be fried. Since this is a graded studio, you don't want to end up in that situation.

4. Demonstrate the colour you have obtained to the TA. Take a picture of your entire circuit with the LED showing the mystery colour, and include the picture in your lab report.

5. Analyze how much power is consumed by the respective R, G, and B LEDs, and how much power is lost in the current-limiting resistors R_R, R_B, and R_G (work done vs energy lost). Thereafter, calculate the efficiency of biasing each of the R, G, and B LEDs this way. Here, we define the efficiency for each R, G, and B LED as

$$\text{Efficiency } \eta = \frac{P_{LED}}{P_{LED} + P_{Loss}} \times 100\%$$

   Remember to include all the above calculations in your report.
   (Note: Ignore the efficiency calculation for a particular R, G, or B LED if its current is 0.)

END OF STUDIO SESSION