Lab Two
Fundamentals of Electronics
EECE2412/3

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Abstract

The goal of this laboratory experiment is to introduce the performer to several different types of pn-junction diodes, which include silicon/germanium junction diodes, light-emitting diodes (LEDs), and zener diodes. A custom circuit is then designed to turn on/off various LEDs at specified voltages.

KEYWORDS: pn-junction, diode, silicon/germanium, LED, zener

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1 Equipment

Available equipment included:

- Basic Circuit Components (Capacitors, Resistors, Inductors, etc.)
- Keysight EDU36311A Dual DC Power Supply
- Keysight EDU33212A Function Generator
- Keysight DSOX1204G Digital Oscilloscope
- BNC Cables
- A Variety of Diodes (1N914 Si Diode, 1N34A Ge Diode, 1N4735A Zener Diode, etc.)

2 Performing the Experiment

2.1 Basic Diode Test

We begin with the construction of a simple circuit to test a 1N914 Si Diode:

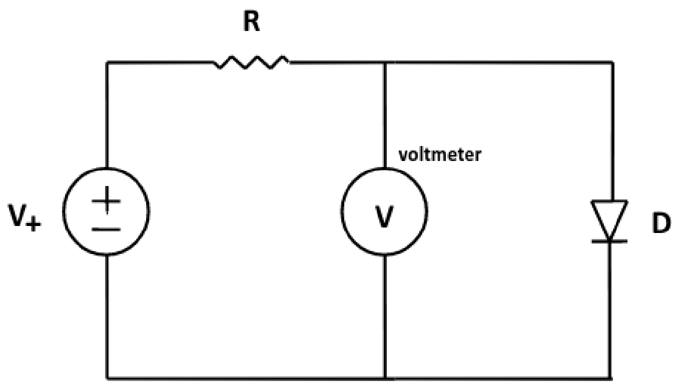

Figure 1: Circuit Schematic for Part 1

The physical construction is shown in Figure 2 below:

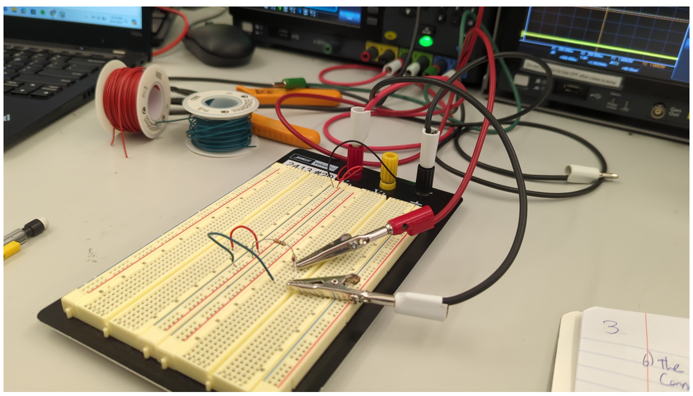

Figure 2: Physical Circuit Construction

Then testing this circuit, the **voltage across the forward-biased diode is measured as** .6[V]**, and** 9.99[V] **for the reverse-biased diode.** We can then measure the value of the resistor to confirm it is within specification (the gold band indicates a ±5% tolerance). The **measured resistance is** 9.938[kΩ], which is within the tolerance. Finally, we **measure the voltage readout as** 10.007[V], which is close to the expected value of 10[V]. We may now proceed to calculate the reverse currents (I_s) from the taken measurements:

$$I_D = \frac{V_s - V_D}{R} \rightarrow \begin{cases} \dfrac{10.007 - .6}{9.938k}[\text{A}], & \text{in Forward-Bias} \\ \dfrac{10.007 - 9.99}{9.938k}[\text{A}], & \text{in Reverse-Bias} \end{cases}$$

$$\boxed{I_D = \frac{V_s - V_D}{R} \rightarrow \begin{cases} .9466[\text{mA}], & \text{in Forward-Bias} \\ 1.7106 \cdot 10^{-6}[\text{A}], & \text{in Reverse-Bias} \end{cases}}$$

We know that the current measurement is inaccurate, as it should be 0. Thus, the current that was calculated above must be the leakage current.

2.1.1 Calculating I_s and n

We can use the Shockley equation, or:

$$I_D = I_s e^{\frac{V_D}{nV_T}}$$

Note: the added 1 term can be dropped, as it does not make a significant difference to the large magnitudes we are dealing with. Thus, we can use our original measurement, as well as an additional one taken at 5[V] input. Thus, we obtain:

Input #	Input Voltage	Diode Voltage	Diode Current
Input 1	10.007[V]	.6[V]	.9466[m]
Input 2	5[V]	.577[V]	.4451[m]

We may now set up the equations:

$$\left(.9466 \cdot 10^{-3}\right) = I_s e^{\frac{.6}{(.025)n}}$$

$$\left(.4451 \cdot 10^{-3}\right) = I_s e^{\frac{.577}{(.025)n}}$$

Solving these, we find:

$$\boxed{n = 1.22 \quad \text{and} \quad I_s = 2.675 \cdot 10^{-12}[\text{A}]}$$

2.1.2 Temperature Dependence

We now proceed to spray the diode with an aerosol refrigerant. After spraying the diode, we found that the voltage became .76[V]. From our room temperature measurement, we know that the voltage is .6[V] at approximately 20[°C]. Thus, we may find the constant:

$$6 = -.002(20) + C$$

$$C = .64[\text{V}]$$

We can now calculate the temperature response, with V_r as the response voltage, using:

$$V_r = -.002T + .64$$

Therefore, with an output of .76[V], the **temperature must be**:

$$.76 = -.002(T) + .64$$

$$T = -(.12/.002)$$

$$\boxed{T = -60[^\circ\mathrm{C}]}$$

Applying heat by holding the diode, we **find the body temperature voltage to be** .595[V], which gives us:

$$.595 = -.002T + .64$$

$$T = .045/.002$$

$$\boxed{T = 22.5[^\circ\mathrm{C}]}$$

2.2 Using Different Diodes

2.2.1 Energy Band Gaps and Diodes

Using a 1N34A instead of the 1N914, we measure:

$$V_D = \begin{cases} .34[\mathrm{V}], & \text{In Forward-Bias} \\ 9.912[\mathrm{V}], & \text{In Reverse-Bias} \end{cases}$$

Repeating similar measurements with Green and Red LEDs, respectively, we see:

$$V_{D(grn)} = \begin{cases} 1.858[\mathrm{V}], & \text{In Forward-Bias} \\ 9.992[\mathrm{V}], & \text{In Reverse-Bias} \end{cases}$$

$$V_{D(red)} = \begin{cases} 1.626[\mathrm{V}], & \text{In Forward-Bias} \\ 9.992[\mathrm{V}], & \text{In Reverse-Bias} \end{cases}$$

Thus, we may conclude that the Red LED has less energy band gap, which results in less V_{drop} when in forward bias mode. Similarly, we can conclude that, for the germanium diode, the energy band gap is the least by far.

2.2.2 Implementing Zener Diodes

We now swap the LEDs with a 1N4735A Zener Diode. Measuring the Diode's voltage response, we get:

V^+[V]	0	1	2	3	4	5	6	7	8
V_D[V]	0	.999	1.999	2.999	3.999	4.969	5.671	5.927	6.017

9	10	11	12	13	14	15
6.06	6.084	6.1	6.111	6.119	6.128	6.131

We may see that the implementation of a zener diode can provide useful voltage limitation properties to a circuit, oftentimes for circuit protection.

2.2.3 The 1N4744A and 1N4735A

The breakdown voltage **was measured as roughly** 15.2[V]
Experimenting with the 1N4735A, we dissipated 5[W] of power; however, the maximum current of the diode can be found as:

$$\frac{1[W]}{10[V]} = .1[A]$$

This is less than the passed .5[A], which caused the diode to break down. Adding a LED, we found that it began glowing once the current was greater than the .1[A], indicating that too much voltage is dissipated in the resistor, so the zener diode must go into breakdown to supply the needed current to the LED. Still, it was quite dim, meaning it most likely needs more current than it was receiving (it would need more than .1[A]).

3 Diode Circuit Construction

We now proceed to construct the circuit we designed in the Pre-Lab. This circuit is shown below:

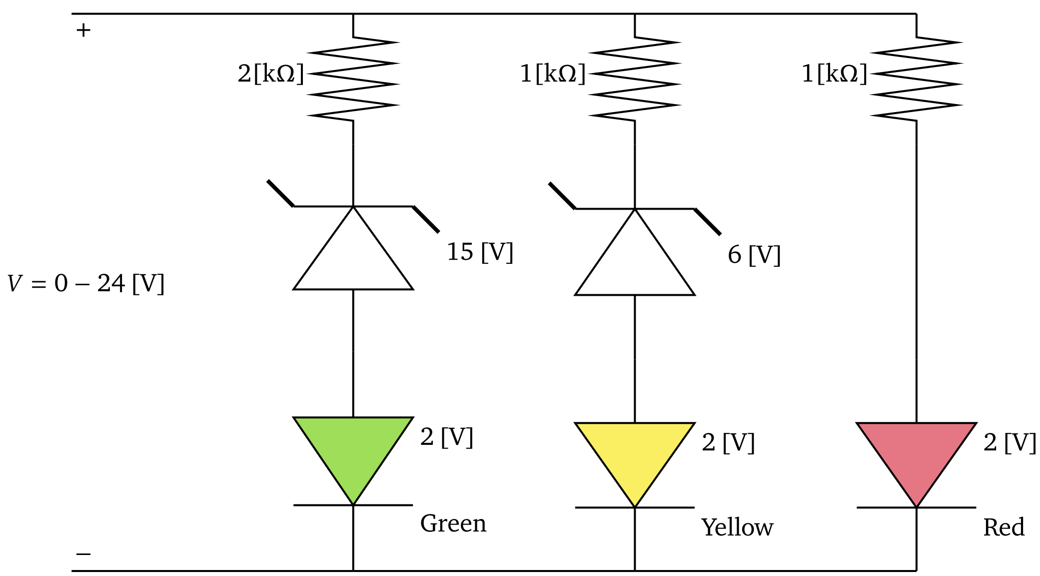

Figure 3: Constructed Circuit Schematic

The physical construction turned out as shown in Figure 4 below:

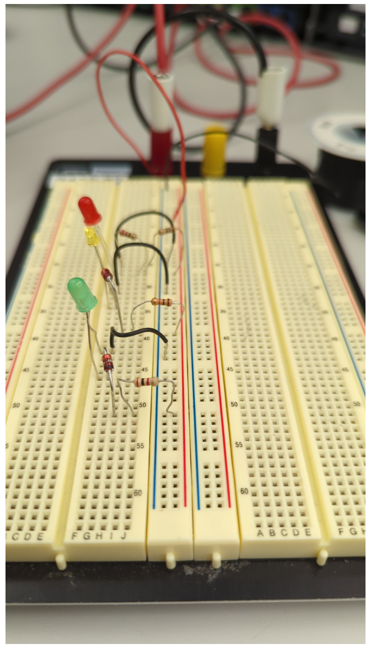

Figure 4: Physical Circuit

When tested, the circuit behaved as expected. The behavior can be viewed below:

Figure 5: Scan to View Behavior (link)

The response was constructed according to the following table:

Voltage Range/Color	0 – 2[V]	2 – 8[V]	8 – 17[V]	17 – 24[V]
Red LED	off	on	on	on
Yellow LED	off	off	on	on
Green LED	off	off	off	on

3.1 Virtual Simulation

3.1.1 Forward/Reverse Diode Response

We begin by simulating with the following circuit:

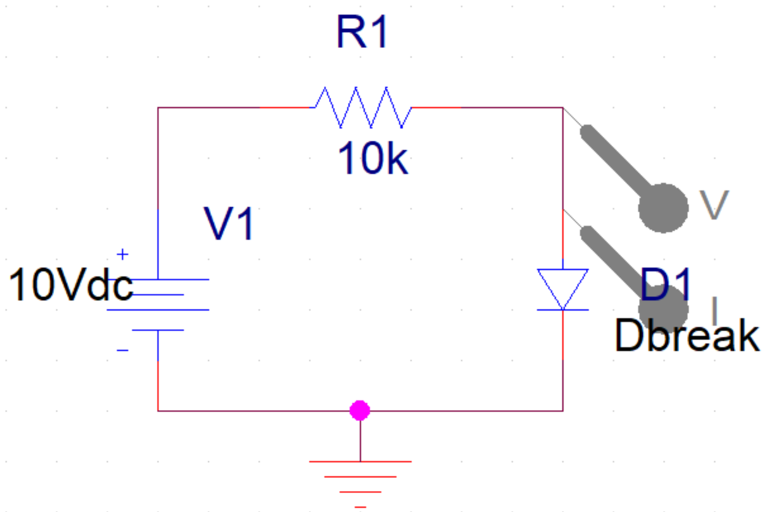

Figure 6: Circuit Schematic

From here, we may obtain the current and voltage values, respectively, for the forward bias:

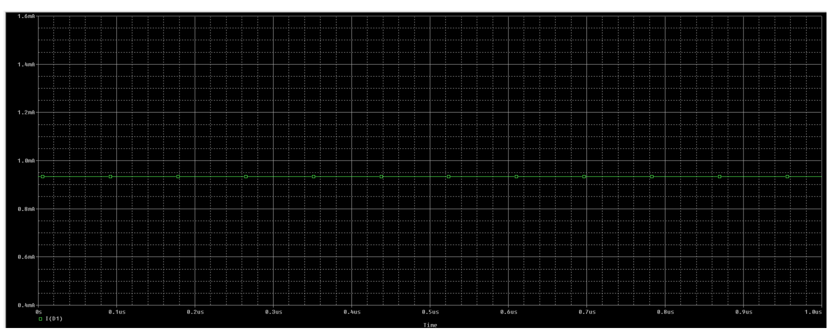

Figure 7: Forward Bias Current

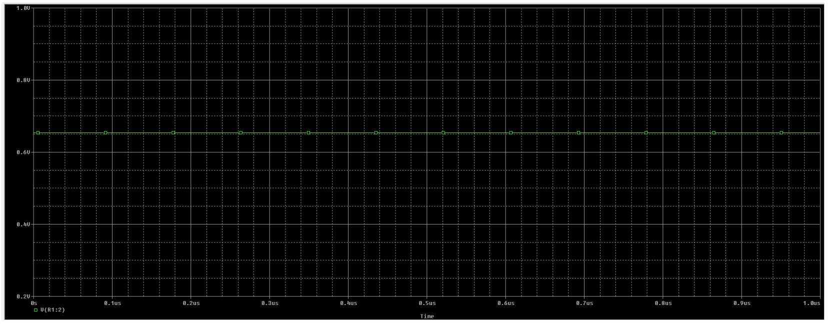

Figure 8: Forward Bias Voltage

And the reverse bias:

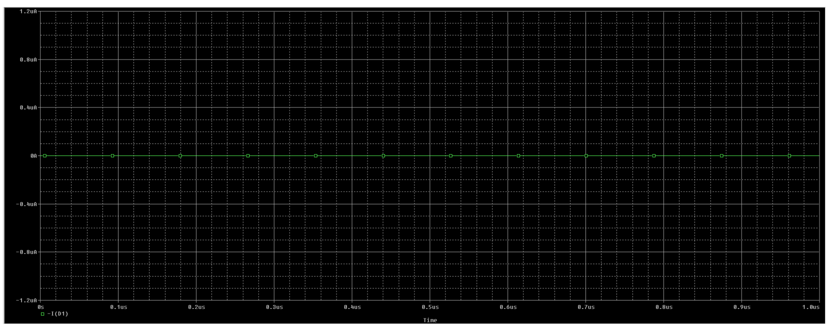

Figure 9: Reverse Bias Current

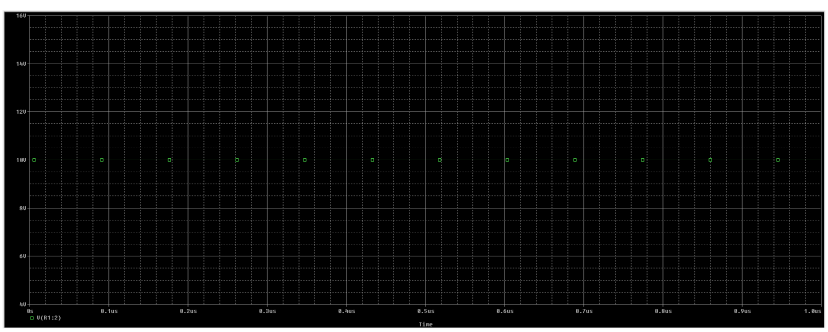

Figure 10: Reverse Bias Voltage

3.1.2 Finding I_s and n

Similar to the physical circuit, we may find I_s and n by obtaining diode forward bias response values at a different voltage. We will simulate at 5[V] once again, using the schematic shown in Figure 6:

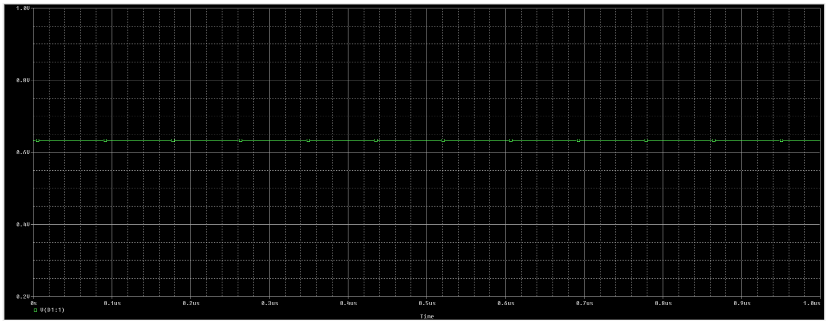

Figure 11: 5[V] Input Voltage Response

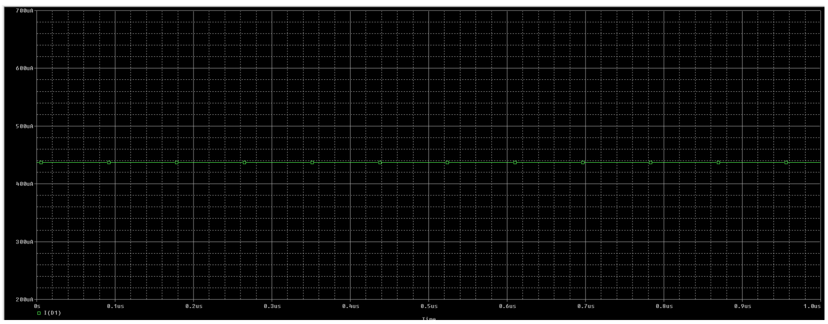

Figure 12: Equivalent Input Current Response

From Figures 7 and 8, we take $I_{D1} \approx .93[\mathrm{m}]$ and $V_{D1} \approx .66[\mathrm{V}]$. Similarly, from Figures 11 and 12, we get $I_{D2} \approx 435[\mu\mathrm{A}]$ and $V_{D2} \approx .62[\mathrm{V}]$. Thus, we set up:

$$\left(.93 \cdot 10^{-3}\right) = I_s e^{\frac{.66}{.025n}}$$

$$\left(.435 \cdot 10^{-3}\right) = I_s e^{\frac{.62}{.025n}}$$

Solving the system, we find:

$$\boxed{n = 1.2157 \quad \text{and} \quad I_s = 3.45 \cdot 10^{-13}[\mathrm{A}]}$$

3.1.3 Zener Diodes

We can now plot the reverse breakdown voltage, using available diodes. To model the 4744, we use two 750s in series, and a single 750 for the 4735. This gives us:

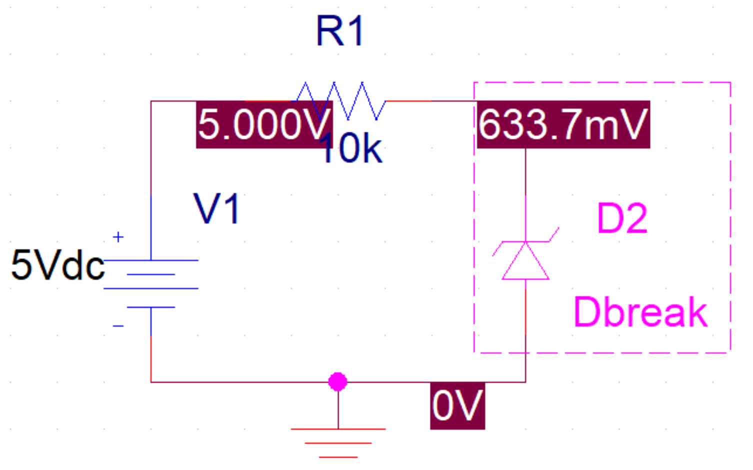

Figure 13: Circuit 2 Schematic

Simulating the circuit for the two ("equivalent") diodes, we get:

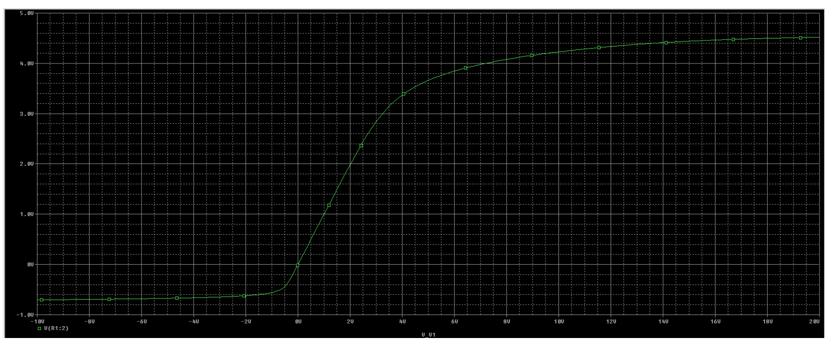

Figure 14: 4735 Response

We see that the breakdown voltage is, approximately around 5[V] (note that for an actual 1N4735, this would be around 6[V]).

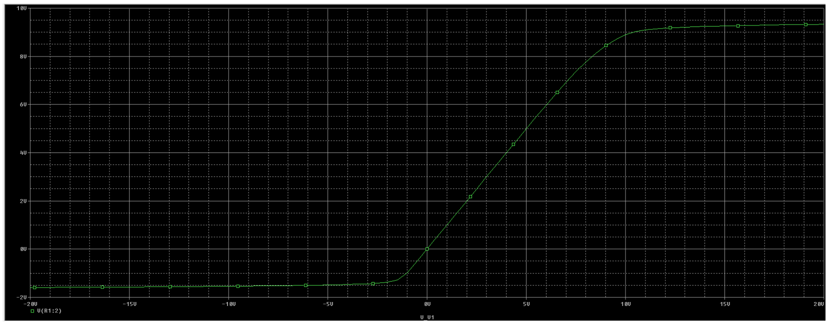

Figure 15: 4744 Response

We see that the breakdown voltage is, approximately around 10[V] (note that for an actual 1N4744, this would be around 15[V]).

With the simulation, we find that there is .1[A] of current at breakdown, meaning the modeled 1N4735 has a power rating of:

$$P = (5)(.1) = .5[\text{W}] \quad \text{(actual value: 1[W])}$$

Similarly, for the modeled 1N4744, we see that the power rating is:

$$P = (10)(.1) = 1[\text{W}] \quad \text{(actual value: 1[W])}$$

3.1.4 Design Problem

We may now simulate our designed circuit. The circuit looks as follows, but note that, for lack of equivalent diodes in the library, the same substitution as in the section above is used. The schematic below was designed for readability:

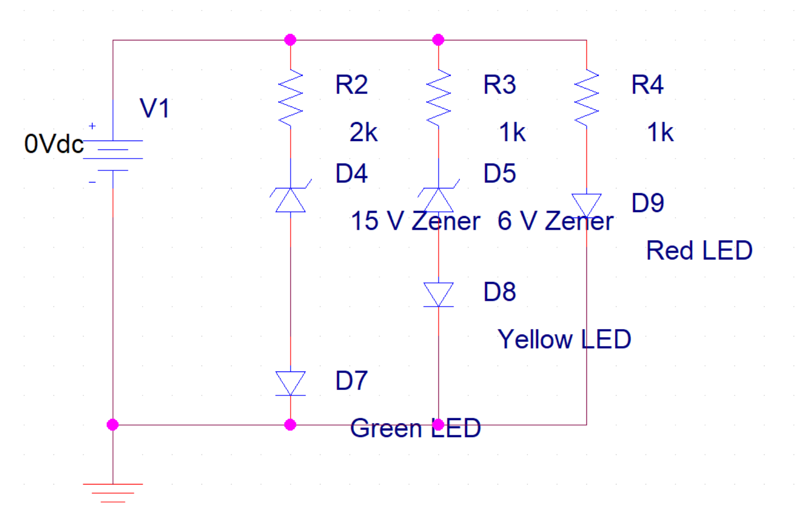

Figure 16: Design Challenge Circuit Schematic

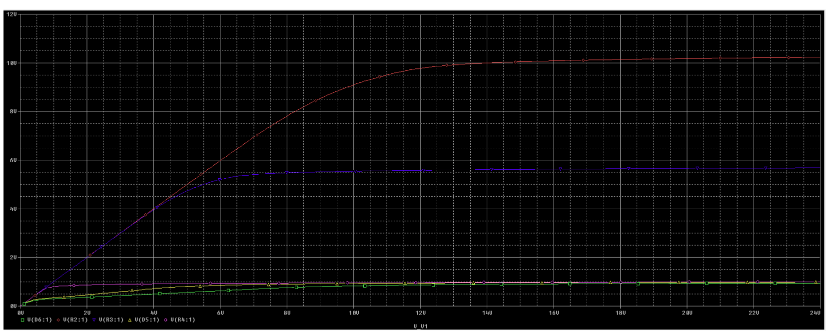

Figure 17: Design Challenge Circuit Response

Note that the colors correspond to: red $\longrightarrow$ voltage across the modeled 1N4744 plus voltage across the Green LED, blue $\longrightarrow$ voltage across the modeled 1N4735 plus voltage across the Yellow LED, pink $\longrightarrow$ voltage across Red LED, yellow $\longrightarrow$ voltage across Yellow LED, and green $\longrightarrow$ voltage across the Green LED.

Given this, we may see that the Red LED is on at about .6[V] (note, this is because we substitute for a 1N914 diode, which has a forward-drop of $\approx$ .6[V] instead of 2[V]). We can then see the Yellow LED is fully on around 6.4[V] (once again due to modeling difference). The Green LED is fully on around 12[V]. Given that we used diodes with different breakdown and forward-drop values, the response shown is, more or less, in line with what we expected.

4 Conclusion

Overall, throughout the laboratory experiment, we were able to gain extensive experience pertaining to diode response. Furthermore, by employing a variety of diodes, include pn-junctions, LEDs, and zeners, we were able to learn more about different types of diodes.