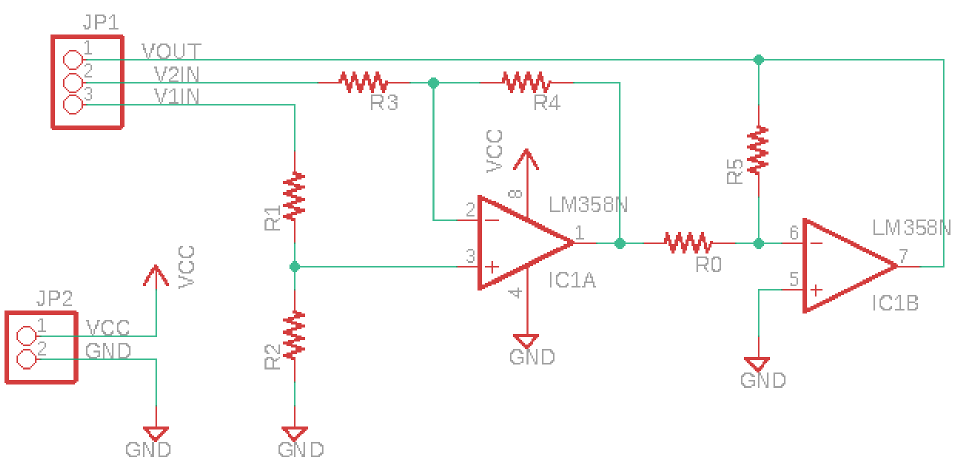
Instructor: Aiku Shintani

EE 143 Section 08
T 6:10-9PM

Experiment 3

R, V & I Measurement
Ohm's Law, KCL and KVL
Accuracy and Precision
Reverse Engineer a PCB



Written by Astrid Yu
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Introduction

The purpose of this experiment is to learn how to read resistors and use a multimeter. An additional purpose is to learn about accuracy an resolution, to verify electrical laws (such as Ohm's Law, KCL, and KVL), and to understand open circuits and shorts, as well as to understand what a node is and to draw a schematic from a PCB.

Analysis

1. Accuracy and Precision

Figure 1: A Neoteck NT8233D Pro.

a) The multimeter used is a Neoteck NT8233D Pro, pictured in Figure 1. According to the manufacturer's website, the multimeter has the following precision steps:

Table 1: Neoteck NT8233D Pro precision steps. (Source: `http://www.neoteck.cn/index.php/2017/03/16/ntk017/`)

Measurement Type	Steps
Voltage	$200mV, 2V, 20V, 200V$
Current	$200\mu A, 2000\mu A, 20mA, 200mA, 10A$
Resistance	$200\Omega, 2k\Omega, 20k\Omega, 200K\Omega$

It has an auto-ranging feature, which is its only mode of ranging (no manual ranging).

b) This step was skipped because the multimeter only has auto-ranging.

c) A 470Ω resistor was measured, with results in the table below.

Table 2: Measurement of a $470\Omega \pm 5\%$ resistor

Best Precision Range	Auto Range Readout (Ω)
$2k\Omega$	$0.459k\Omega$

d) The resistance of the leads was measured to be 0.0Ω on the 200Ω range (the smallest).

2. Body Resistance Measurement

a) Probes were held between the thumb and forefinger of each hand, and the resistance of Astrid's body was measured.

b) This was repeated again after moistening the thumb and forefinger.

Table 3: Measurement of body resistance

Name	Body Resistance, Dry Fingers	Body Resistance, Moist Fingers
Astrid	$0.805M\Omega$	$0.317M\Omega$

3. Reverse Engineering a PCB Layout

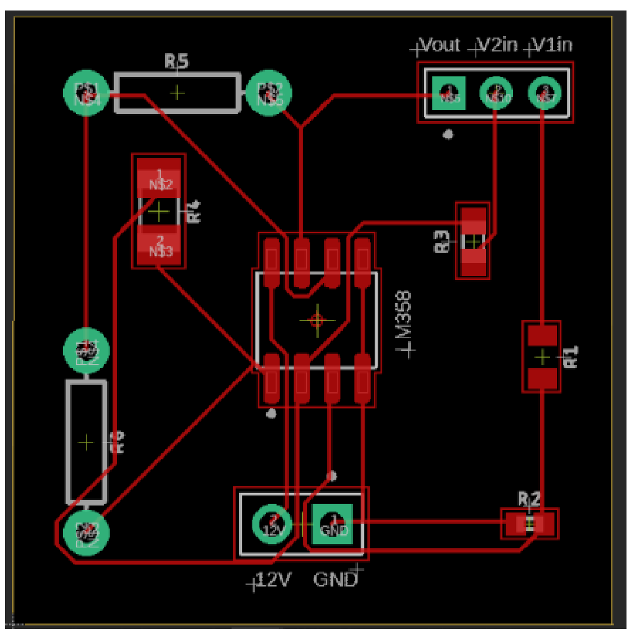


Figure 2: The PCB that was reverse engineered.

The PCB layout in Figure 2 was analyzed and reverse-engineered. The in Figure 3 was produced in EAGLE

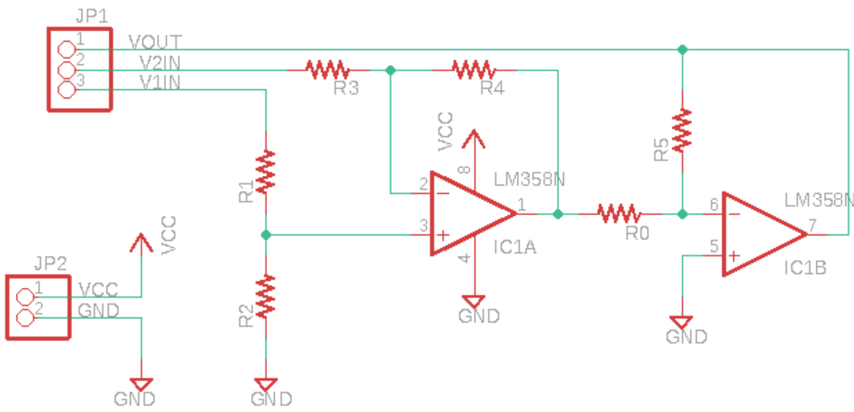


Figure 3: Reverse-engineered schematic made in EAGLE. The LM358 symbol only had one pair of VCC and GND, which is why they only exist on one op-amp.

4. Verification of Kirchhoff's Circuit Laws

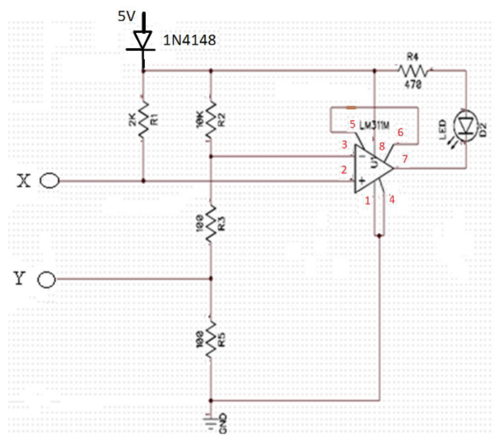


Figure 4: The continuity tester schematic.

a) The circuit pictured in Figure 4 was reproduced on a breadboard, as seen in Figure 5. An Arduino was used as the power supply, and the basic functionality of the continuity tester (LED lighting up when connected, and shutting off when disconnected) was verified.

b) Next, X and Y were shorted together.

c) A voltmeter was used to verify KVL along Loop 1 and Loop 2. The voltage drops are listed in Tables 4 and 2 respectively, and the mathematical verification of KVL is in equations 1 and 2 respectively.

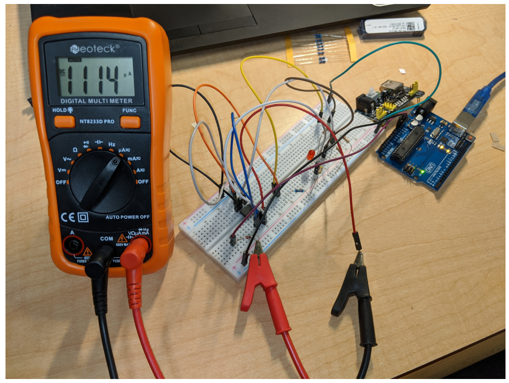


Figure 5: The experimental setup used to test the continuity tester.

Table 4: Voltage drops along Loop 1 when X and Y are shorted

V($5V$ source)	V(diode)	V(R2 = $10k\Omega$)	V(R3 = 100Ω)	V(R5 = 100Ω)
$4.99V$	$0.723V$	$3.84V$	$193.5mV$	$0.234V$

Equation 1 demonstrates that KVL holds true for Loop 1.

$$\begin{aligned} & V(5V\text{source}) - V(\text{diode}) - V(R2 = 10k\Omega) - V(R3 = 100\Omega) \\ & - V(R5 = 100\Omega) \\ = & 4.99V - 0.723V - 3.84V - 193.5mV - 0.234mV \\ = & 233.266mV \\ \approx & \mathbf{0V} \end{aligned} \tag{1}$$

Table 5: Voltage drops along Loop 2 when X and Y are shorted

V($5V$ source)	V(diode)	V(R4 = 470Ω)	V(LED)	V(Pin 7)
$4.99V$	$0.723V$	$2.19V$	$1.918V$	$155.1mV$

Equation 2 demonstrates that KVL holds true for Loop 2.

$$\begin{aligned} & V(5V source) - V(diode) - V(R4 = 470\Omega) - V(LED) - V(Pin7) \\ = & 4.99V - 0.723V - 2.19V - 1.918V - 155.1mV \\ = & 3.9mV \\ \approx & \mathbf{0V} \end{aligned} \tag{2}$$

d) An ammeter was used to verify KCL at node A for when there is both an open and a short between X and Y. The currents entering and leaving are listed in Table 6.

Equation 3 demonstrates that KCL holds true for Node A when X and Y are disconnected.

Table 6: Current entering and exiting Node A

X and Y	I(diode)	I(R1 = $2k\Omega$)	I(R2 = $10k\Omega$)	I(R4 = 470Ω)	I(Pin 8)
Disconnected	3.12mA	$0.0\mu A$	1922 μA	$0.0\mu A$	1112 μA
Connected	9.49mA	403 μA	1873 μA	4.74mA	2.40mA

$$\begin{aligned} &I(diode) - I(R1 = 2k\Omega) - I(R2 = 10k\Omega) - I(R4 = 470\Omega) - I(Pin8) \\ =&3.12mA - 0.0\mu A - 1922\mu A - 0.0\mu A - 1112\mu A \\ =&86\mu A \\ \approx&\mathbf{0A} \end{aligned} \tag{3}$$

Equation 4 demonstrates that KCL holds true for Node A when X and Y are connected.

$$\begin{aligned} &I(diode) - I(R1 = 2k\Omega) - I(R2 = 10k\Omega) - I(R4 = 470\Omega) - I(Pin8) \\ =&9.49mA - 403\mu A - 1873\mu A - 4.74mA - 2.40mA \\ =&74\mu A \\ \approx&\mathbf{0A} \end{aligned} \tag{4}$$

Discussion

Section 1

1. *Generally, which multi-meter range yields the best precision?*

   The range with the smallest limits yields the best precision.

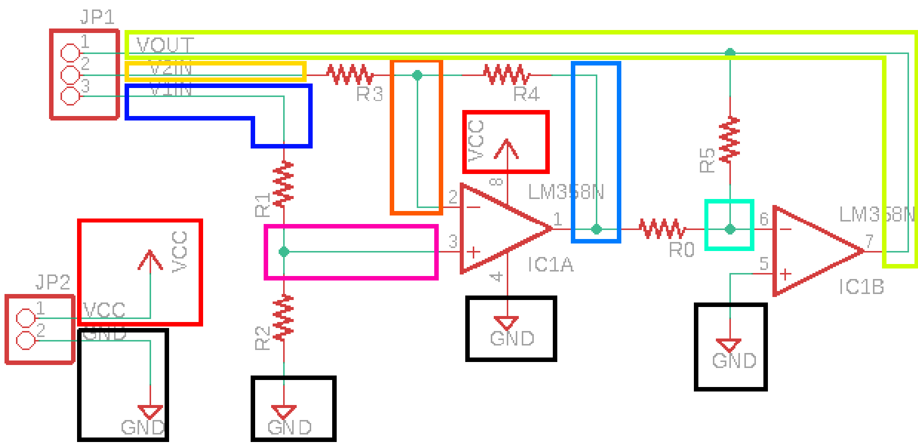
Section 2

2. *Contrast your body resistance with dry fingertips compared to your body resistance with damp fingertips. For a given amount of voltage, when are you more susceptible to serious injury due to electricity? Use Ohm's Law to support your answer. ($6mA$ causes painful shock and $50mA$ is fatal.)*

   By Ohm's Law, $I = \frac{V}{R}$, to maximize I and cause injury for a constant V, R must be decreased. According to Table 3, Astrid is a better conductor when her fingers are moist, so she is more susceptible to injury when wet than dry.

Section 3

3. *Draw a box/rectangle around each of the nodes on your schematic. Insert a picture of schematic here.*



Each color is its own node. The 12V and GND ports are all connected together and thus each count as a single node.

4. *How many nodes are there in the schematic?*

   There are 9 nodes in the schematic.

Section 4

5. *Explain the difference in diode current when there's an open in the continuity-tester leads and when there's a short between the leads.*

   The LED is not being powered, so there is less voltage being supplied to the circuit through the diode.

6. *Write the KVL equation for the loop containing the* $5V$ *source, diode, and* $2k\Omega$ *resistor when there is an open between the continuity leads. What is the voltage across the open?*

   The op-amp is in an open-loop amplifier configuration, so the voltage difference between the positive and negative leads *is not* negligible.

   Let ΔV = the voltage across the open between X and Y. The KVL equation is the following:

$$V(5V source) - V(diode) - V(R1) - \Delta V - V(R5) = 0 \tag{5}$$

   The following values are known:

$$\begin{aligned} V(5V source) &= 5V && \text{By definition} \\ V(diode) &= 0.7V && \text{Assumed} \\ V(R1) &= 0V && \text{Only attached on 1 end} \\ V(R5) &= 5V\frac{100\Omega}{10k\Omega + 100\Omega + 100\Omega} && \text{Voltage divider} \\ &\approx 9.80mV \end{aligned} \tag{6}$$

   Substituting these values into equation 5 and rearranging:

$$\begin{aligned} 5V - 0.7V - 0V - \Delta V - 9.80mV &= 0 \\ \Delta V &= \mathbf{4.29V} \end{aligned} \tag{7}$$

7. *Using the data from procedure steps c and d, how much power is expended by the LED when lit?*

   The LED and R4 are connected in series. Therefore, $I(R4) = I(LED)$.

$$\begin{aligned} I(LED) &= I(R4) = 4.74mA && \text{(see table 6)} \\ V(LED) &= 1.918V && \text{(see table 5)} \\ P(LED) &= I(LED) \times V(LED) \\ &= (4.74mA)(1.918V) \\ &= \textbf{9.09mW} \end{aligned} \tag{8}$$

8. *In step (e), did the LED glow brighter or dimmer after the* 470Ω *resistor was replaced with a* $20k\Omega$ *resistor? Explain with your knowledge of Ohm's Law.*

   The LED was dimmer after the resistor was replaced with a stronger one. By Ohm's Law, resistance is inversely proportional to current for constant voltage. With more resistance, there is less current flowing, which results in less power delivered to the LED.

Conclusion

This experiment was successful. The error of a resistor and a multimeter was observed, human body resistance was quantified, a PCB was reverse-engineered and analyzed, and Kirchhoff's current and voltage laws were verified multiple times.

The measured voltage drops and current flows were underestimates, as shown by equations 1, 2, 3, and 4 all having positive residuals before being rounded down to zero. In the case of equations 1 and 2, the KVL equations, this is because there is lead resistance creating a voltage divider and reducing the observed voltage. In the case of equations 3 and 4, the KCL equations, even though the multimeter's resistance is small, it is still somewhat present, reducing the amount of current flowing through the individual branches.