Lab Three
Fundamentals of Electronics
EECE2412/3

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Abstract

The purpose of this laboratory experiment is to familiarize ourselves with bipolar junction transistor (BJT)-based amplifiers and the underlying concepts. This includes sensitivity to clipping, the frequency response of the gain, and the construction of a stable amplifier. This is all synthesized to then design a stable amplifier with high gain.

KEYWORDS: BJT, amplifier, clipping, frequency response, gain

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1 Equipment

Available equipment included:

- 2N3904 Bipolar Junction Transistors
- Basic Circuit Components (Wires, Inductors, Capacitors, etc.)
- Keysight EDU36311A Dual DC Power Supply
- Keysight EDU33212A Function Generator
- Keysight DSOX1204G Digital Oscilloscope
- BNC Cables

2 Experimental Procedure

We begin by constructing the following Common-Emitter Amplifier circuit:

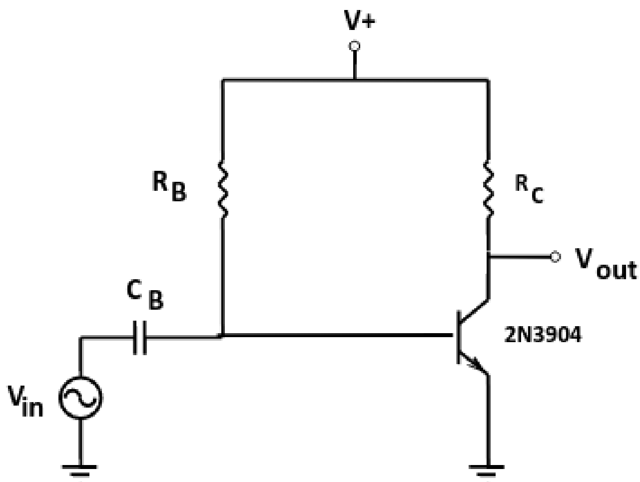

Figure 1: Common Emitter Amplifier with: $R_B = 309[\text{k}\Omega]$, $R_C = 1[\text{k}\Omega]$, $C_B = 1.5[\mu\text{F}]$, $V^+ = 10[\text{V}]$, and $V_{in} = 10[\text{mV}_{0p}]$

Physically, this looked like:

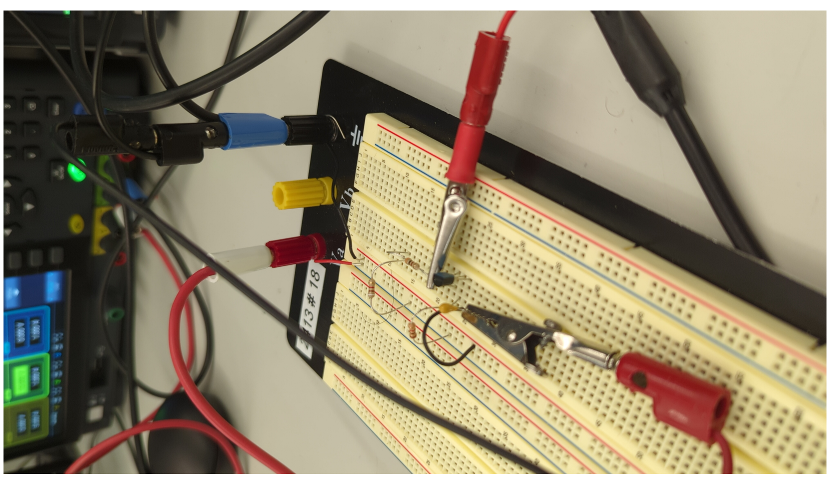

Figure 2: Constructed Amplifier (Unstable)

2.1 Confirming Active State

Based on the parameters described in Figure 1, we measure: $V_{CE} = 2.75[\text{V}]$ and $V_{BE} = .715[\text{V}]$. Given that $V_{CE} > V_{BE}$, we conclude that the above amplifier is biased in the forward active region.

2.2 Calculating Transconductance Gain

We now calculate the collector current as:

$$I_C = \frac{V_{CE} - .7}{1k}$$
$$I_C = \frac{2.75 - .7}{1k}$$
$$\boxed{I_C = 2.05[\text{mA}]}$$

Since we know that, at room temperature, $V_T = 26[\text{mA}]$, we may calculate:

$$g_m = \frac{2.05}{26}$$
$$\boxed{g_m = 78.896[\text{mS}]}$$

2.3 Calculating the DC Gain (β_{DC})

We may experimentally determine the gain by finding:

$$I_B = \frac{.715 - .7}{1k}$$
$$\boxed{I_B = 15[\mu\text{A}]}$$

Which gives us:

$$\beta_{DC} = \frac{I_C}{I_B}$$
$$\beta_{DC} = \frac{2.05}{.015}$$
$$\boxed{\beta_{DC} = 136.67}$$

2.4 Calculating r_π

We may use our obtained values from above to find:

$$r_\pi = \frac{\beta}{g_m}$$
$$r_\pi = \frac{136.67}{.078846}$$
$$\boxed{r_\pi = 1733.4[\Omega]}$$

2.5 Calculating the Voltage Gain

We may obtain the voltage gain using:

$$A_v = -g_m R_C$$
$$A_v = -(.078846)(1k)$$
$$\boxed{A_v = -78.846}$$

Note that the measured voltage gain was approximately −80, which is in line with the calculated gain.

2.6 Experimentally Obtaining Voltage Gain

Measuring the input voltage, we find that, zero-to-peak, it is a nominal 7[mV], while the output was 560[mV], and phase shifted by 180°. This gives us an experimental gain of:

$$A_v = \frac{-560}{7}$$
$$\boxed{A_v = -80}$$

When $r_b = 200[\Omega]$, the voltage gain meets a slight division, which gives us:

$$A_v = -g_m \left(\frac{r_\pi}{r_b + r_\pi}\right)$$
$$A_v = -(.78846)\left(\frac{1733.4}{200 + 1733.4}\right)$$
$$\boxed{A_v = -70.69}$$

We may observe that, in such a case, the voltage gain is slightly reduced.

2.7 Output Clipping

Experimentally, we observe clipping at .15[V] and 0[V]. We may explain the minimum because there is no negative voltage swing with the BJT. In the other hand, there is a maximum because the voltage gain times .15[V] is greater than the supply voltage (as experienced with operational amplifiers).

2.7.1 Gain Sensitivity to Supply Voltage

Changing the supply voltage to 8[V], we see the voltage gain become:

$$A_v = -\frac{4.8}{.053}$$
$$\boxed{A_v = -90.566}$$

Changing the input to the 12[V], we see the gain magnitude increases to:

$$A_v = -\frac{5.6}{.047}$$

$$\boxed{A_v = -119.15}$$

We may determine that the amplifier is sensitive to changes in the supply voltage because the collector current depends on the collector-to-emitter voltage, and the collector-to-emitter voltage, in turn, depends on the supply voltage. Because the transconductance gain of the amplifier depends on the collector current, a change in the collector-to-emitter voltage results in a change in the gain, which depends on the transconductance gain.

2.8 Frequency Response of the Gain

We may observe that the upper corner frequency occurs at, approximately, $f_{crit} = 730[\text{kHz}]$. On the other hand, the lower corner frequency occurs at, approximately, $f_{crit} = 14[\text{kHz}]$. According to these values, though not ideal, this amplifier is best suited for an AM Radio. It can operate at a lower frequency by using a different capacitor value, which we observed by increasing the capacitance value.

2.9 Stabilizing the Amplifier

After introducing the changes to the amplifier, we see that the voltage gain is:

$$A_v = -4.7$$

and, thus, it is insensitive to changes in V^+. As expected, the gain decreased. Calculating the gain, we find that $A_v = -4$, which is just a bit lesser in magnitude than the value above. Introducing refrigerant increased the magnitude of the gain to $A_v = -21$, with the peak-to-peak output voltage going from $8.2 \rightarrow 8[\text{V}]$, and the input voltage remaining at .44[V]

2.10 Constructing A Stable Amplifier

With values derived in the pre-lab, we construct a stable amplifier as follows:

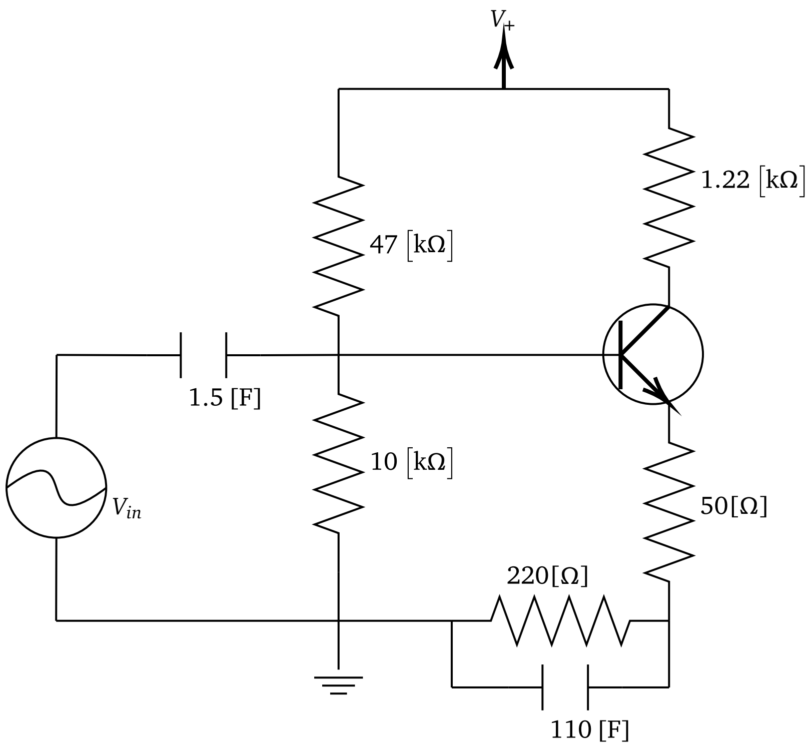

Figure 3: Stable BJT Amplifier

Physically, the circuit was constructed as shown below:

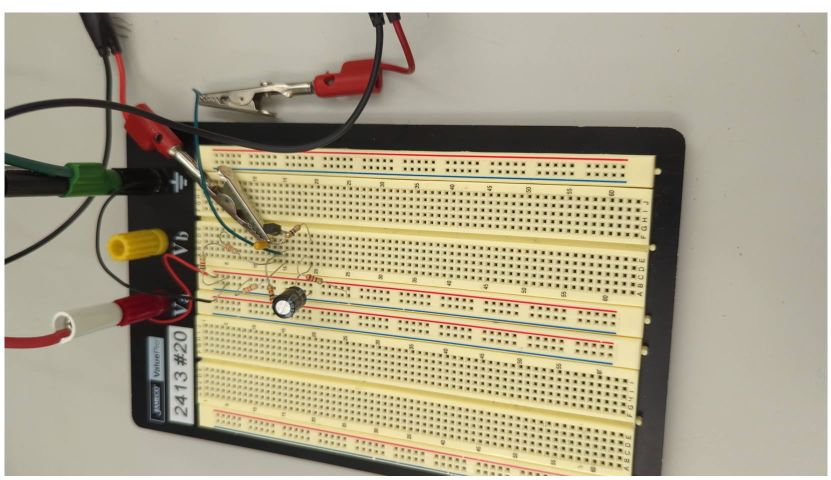

Figure 4: Constructed Amplifier

The output for $V^+ = 8, 10$, and $12[V]$ is shown in Figures 5-7:

Figure 5: Stable Amplifier, $V^+ = 8[V]$

Figure 6: Stable Amplifier, $V^+ = 10[V]$

Figure 7: Stable Amplifier, $V^{+} = 12[V]$

We may see that, though at a lower supply voltage there is slight clipping (which is to be expected), the amplifier meets the performance requirements.

2.11 Virtual Simulation

2.11.1 Part 1

We simulate the following circuit:

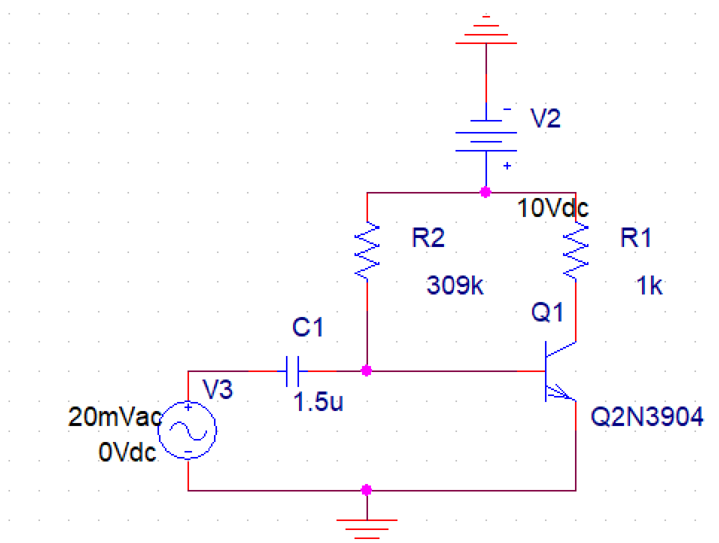

Figure 8: Part 1, Initial Circuit Schematic

This produces the following responses:

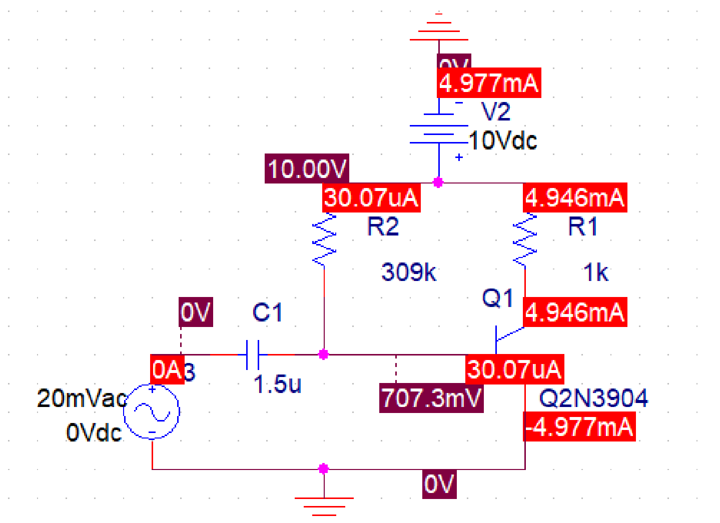

Figure 9: Part 1, DC Response

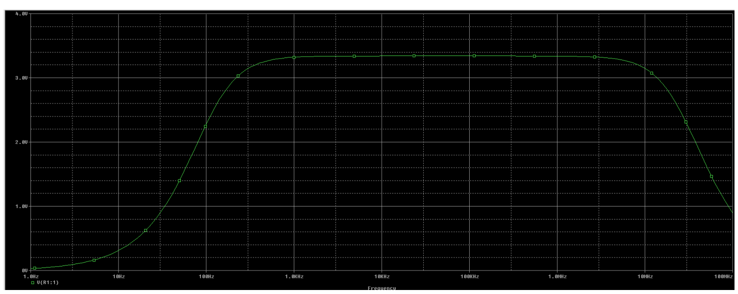

Figure 10: Part 1, AC Response

Notice the corner frequencies and bandwidth in the plot above. We can then observe voltage clipping:

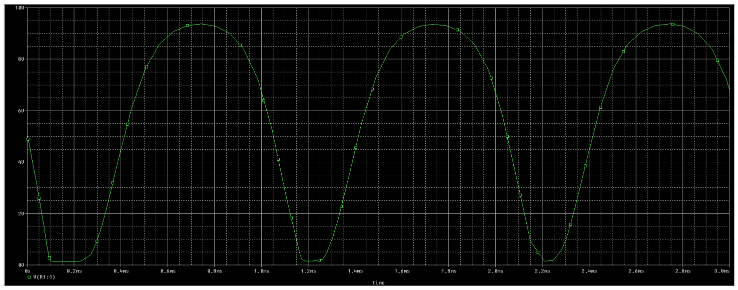

Figure 11: Part 1, Clipping at just Above .15[V_{0p}]

The values agree with those measured and calculated. We now proceed to check the influence of the supply voltage:

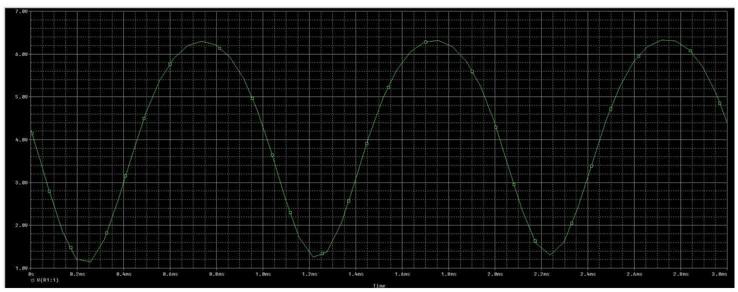

Figure 12: Part 1, 8[V] Supply Voltage

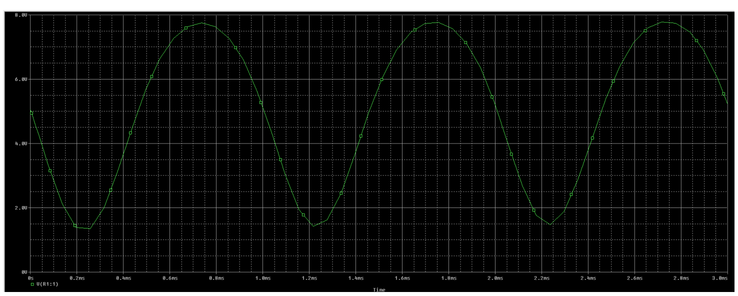

Figure 13: Part 1, 10[V] Supply Voltage

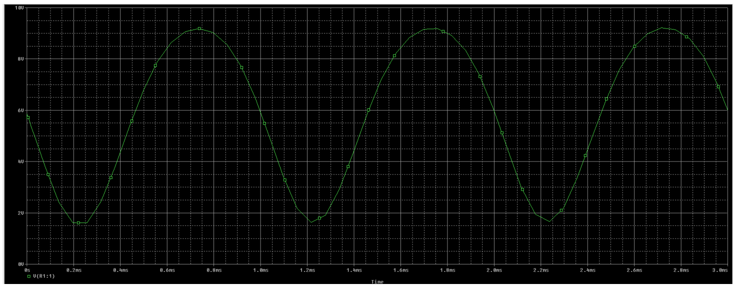

Figure 14: Part 1, 12[V] Supply Voltage

We may observe that the supply voltage has a strong affect on the gain; that is, a higher supply voltage generates a greater gain. This is similar to the measurement observed in the physical circuit. Now, let us add a stabilizing resistor to create a circuit whose gain is (more so) independent of the supply voltage. This gives us the following schematic:

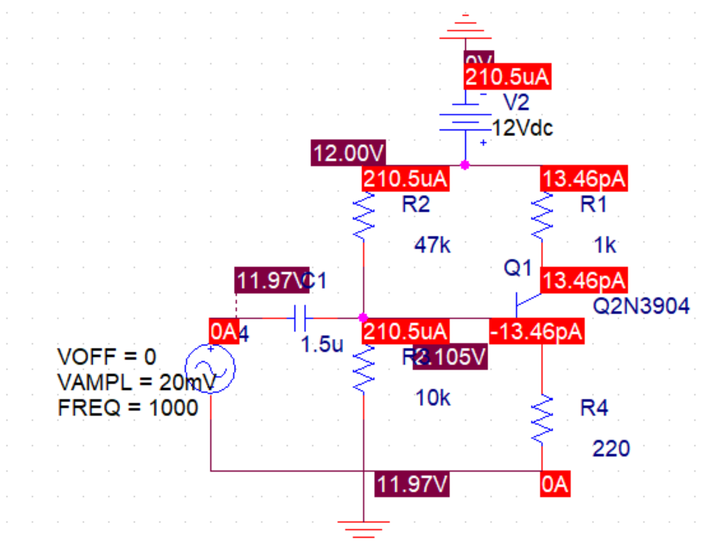

Figure 15: Part 1, Stable Schematic

The stabilization can be seen by re-running the 8,10, and 12[V] supply voltage runs to get:

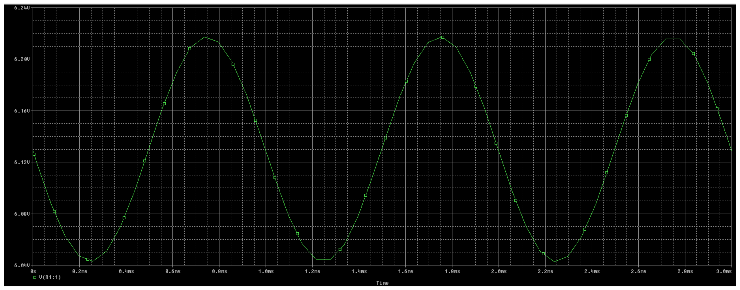

Figure 16: Part 1, 8[V] Supply Voltage (Stable)

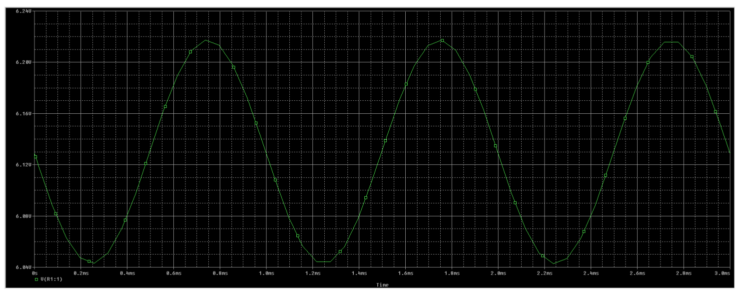

Figure 17: Part 1, 10[V] Supply Voltage (Stable)

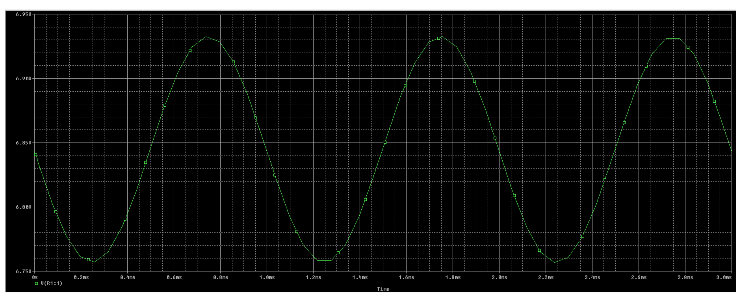

Figure 18: Part 1, 12[V] Supply Voltage (Stable)

We can see that, though there is still a correlation, the influence of the supply voltage is drastically reduced. Finally, we may add a gain-boosting capacitor to get:

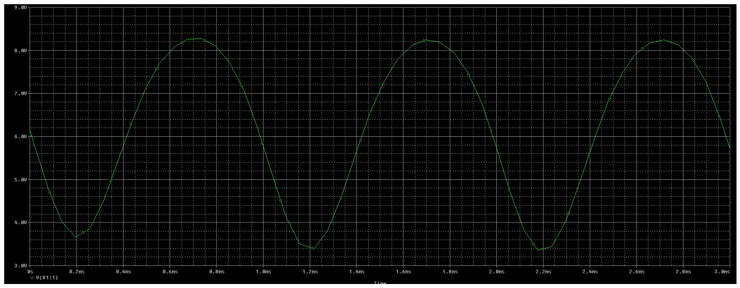

Figure 19: Part 1, Gain-Boosting Capacitor

We may notice that the gain is greater here than the previous plots. We finally may proceed to Part 2, and generate our custom design:

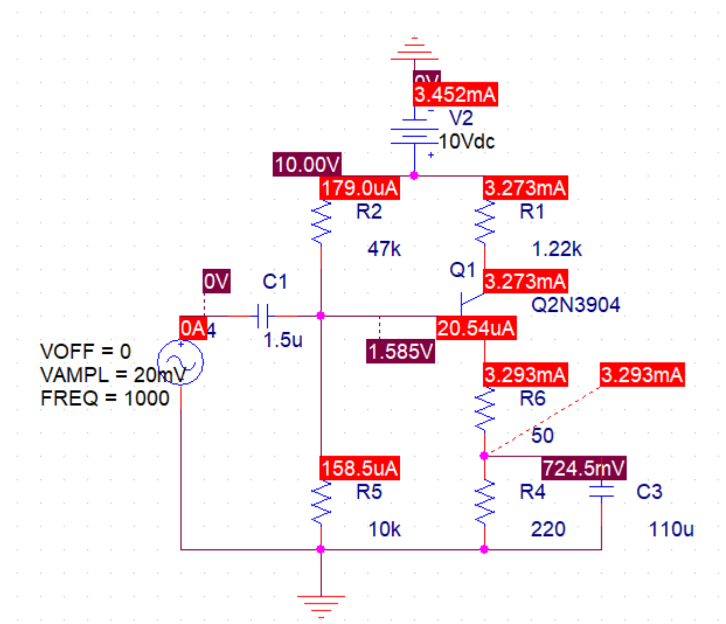

Figure 20: Part 2, Custom Schematic with DC Response

This allows us to see the following output response:

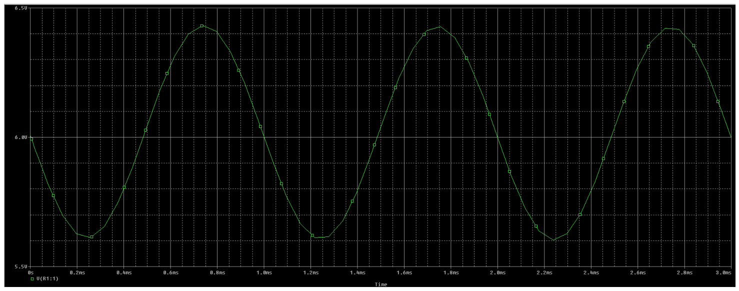

Figure 21: Part 2, Output

3 Conclusion

Throughout this laboratory experiment, we observed the function of a common-emitter. This includes, but is not limited to: how to isolate the gain from supply voltage influence, how to isolate the output from DC offset, and understanding why the gain clips at certain voltages.