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**Lab 7: Common Emitter Amplifier**

## Introduction

The purpose of this lab is to become familiar with implementing an NPN transistor in a circuit and analyze how it works. The circuit created in this lab is shown in Figure 1. Although not shown in the figure, RE2 was placed in series with the emitter capacitor.

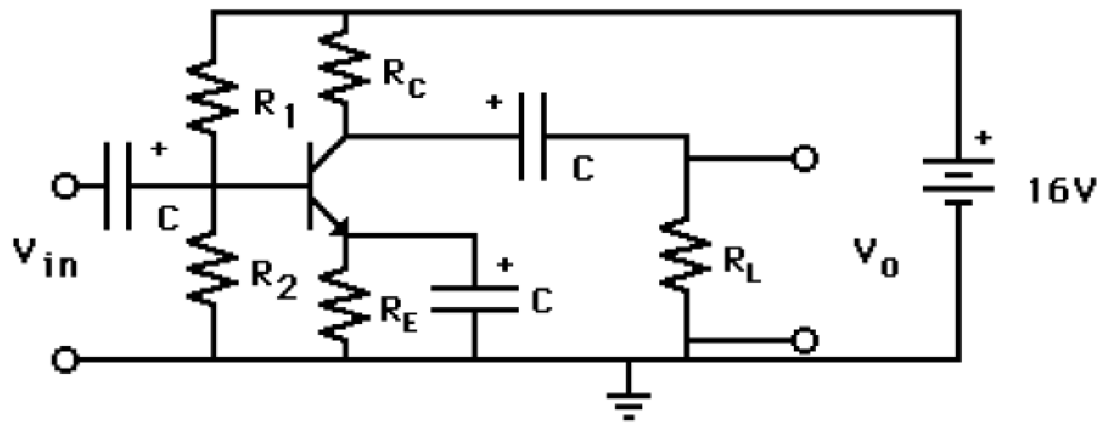


**Figure 1. Circuit schematic with NPN transistor (Monty, lab handout, 2019).**

## Methodology

Transistors are semiconductor devices frequently used for applications including switching and amplification. In this lab, we explored the amplifying properties of a bipolar junction transistor in the common-emitter configuration.

A transistor consists of three layers of doped semiconductor, with adjacent layers alternating between p-type and n-type. In some sense, they could be described as back-to-back diodes. As in a diode, depletion regions form at the interfaces between the n- and p-type layers. The electric field in the depletion regions create a potential barrier, preventing charge from flowing; this is a transistor in its "off" state.

When a voltage is applied to the middle layer, known as the base, one of the pn-junctions becomes forward-biased while the other is reverse-biased. This allows a small current to flow between the base and emitter, and a much larger current to flow between the collector and emitter. When the transistor is properly biased, the collector-emitter current is directly proportional to the base-emitter current by a factor of $\beta$, which is typically on the order of 100.

For this reason, the transistor acts as a current-controlled amplifier; a small current at the base controls a much larger current at the emitter.

We began our lab by characterizing the DC component of our amplifier circuit. Beginning with a theoretical analysis, we found the voltage at the transistor's base by treating $R_1$ and $R_2$ as a voltage divider. Then, because the base-emitter junction was forward-biased, we found the emitter voltage by subtracting 0.7v from the base voltage. Next, assuming the collector and emitter currents to be equal, we used Ohm's law to find the voltage at the collector. Finally, we used the current and the collector-emitter voltage to find the power dissipated by the transistor.

For our analysis of the AC component of the amplifier circuit, we set our input to a frequency of 5 kHz and an amplitude of 0.100v. Using the oscilloscope, we calculated the voltage gain and sketched the input and output waveforms, which are included in the discussion section. Our measured gain values were compared to the theoretical values using the following equation:

$$gain = \frac{-1}{R_E}(\frac{R_L R_C}{R_L + R_C})$$

We then increased the input voltage to 1.100v, which resulted in a severely distorted waveform.

After reverting the input voltage to its initial value, we removed the capacitor and resistor $C_E$ and $R_{E2}$ and measured a lower gain. The gain depends inversely on the AC impedance at the emitter; the capacitor provided a low-impedance path to ground, so its removal caused the impedance to increase, lowering the gain.

Replacing the capacitor and shorting across resistor $R_{E2}$ had the opposite effect, increasing the gain dramatically and causing significant clipping of the output waveform. Since the resistor was counteracting the low impedance of the capacitor, removing it created a much lower impedance at the emitter, and by extension a much greater gain.

**Results**

The expected and measured values for the resistors in the circuit analyzed are in Table 1. Calculations were carried out with the measured values to represent the circuit accurately. Measured and calculated voltage across the base and emitter are shown in Table 2 along with the measure voltage across the base. The measured and calculated current for the cand voltage across the base and emitter is in Table 3. Power dissipated by the transistor was calculated using the measured and calculated values of the voltage across the collector and emitter and current for the collector is in Table 4. When incorporating a function generator into the circuit, the voltage gain is shown in Table 5. One leg of the capacitor was pulled out of the circuit to determine how the voltage gain changed, which is in Table 6. $R_{E2}$ was shorted by adding a wire and the voltage gain for this scenario is shown in Table 7.

**Table 1. Measured and expected values for each resistor in the circuit displayed in Figure 1.**

| Component | measured value | expected value |
|---|---|---|
| $R_E$ | 467 Ω | 470 Ω |
| $R_{E2}$ | 47.2 Ω | 47 Ω |
| $R_C$ | 2.169 kΩ | 2.2 kΩ |
| $R_L$ | 2.186 kΩ | 2.2 kΩ |
| $R_1$ | 67.4 kΩ | 68 kΩ |
| $R_2$ | 9.85 kΩ | 10 kΩ |

**Table 2. The measured and calculated $V_{BE}$ using the measured $V_B$.**

| $V_{BE}$ measured | $V_B$ measured | $V_B$ calculated | percent difference for $V_B$ |
|---|---|---|---|
| 0.700 V | 1.920 V | 2.04 V | 6.07 % |

**Table 3. Calculated and measured $I_C$ and $V_{CE}$.**

| $I_C$ calculated | $I_C$ measured | percent difference for $I_C$ | $V_{CE}$ calculated | $V_{CE}$ measured | percent difference for $V_{CE}$ |
|---|---|---|---|---|---|
| 2.61E-03 A | 2.56E-03 A | 1.97 % | 9.11 V | 9.05 V | 0.699 % |

**Table 4. The measured and calculated power dissipated by the transistor.**

| measured power dissipated by the transistor | calculated power dissipated by the transistor | percent difference |
|---|---|---|
| 0.023 W | 0.024 W | 2.67 % |

**Table 5. The measured voltage gain for the circuit shown in Figure 1 with the addition of a function generator.**

| $V_{IN,PP}$ | $V_{O,PP}$ | $V_{gain}$ |
|---|---|---|
| 0.2 | 3.88 | 19.4 |

**Table 6. The voltage gain when one leg of the capacitor is disconnected from the circuit.**

| $V_{IN,PP}$ | $V_{O,PP}$ | $V_{gain}$ |
|---|---|---|
| 0.2 V | 0.456 V | 2.28 |

**Table 7. The voltage gain when RE2 is shorted.**

| $V_{IN,PP}$ | $V_{o,PP}$ | $V_{gain}$ |
|---|---|---|
| 0.2 V | 15,82 V | 79.2 |

**Discussion**

In general, our theoretical predictions matched closely with our measurements. However, they are slightly off due to assumptions we made about the circuit. Specifically, we assumed the collector and emitter currents to be equal, but in reality, there is a small current between the base and emitter as well that we did not take into account. As a result, our measured values for the base voltage, collector current, and power were slightly lower than our predictions. Still, with this source of error in mind, our results agree closely with theory.

For the initial configuration of the circuit, we measured an absolute voltage gain of 19.3. Using the equation given in the methodology section, we calculated a theoretical gain of about 25. Our prediction was significantly higher than the measured value, but it was at least within reason. With the capacitor removed, we measured a gain of 2.28; this time our prediction was much more accurate, with a gain of 2.33.

Finally, replacing the capacitor and shorting across the adjacent resistor yielded a gain of 79.2. In contrast, our calculations predicted a gain of over 600. This value is certainly large, as expected, but it is very far from the actual measured value. This is likely a limitation of the circuit; with an input peak-to-peak voltage of 0.200v, our theoretical output would be over 120v, which is not possible with our 16v DC power supply. This is further supported by the fact that the actual output had a peak-to-peak value of 15.84v (ignoring the distortion), which is very close to the DC supply voltage.

The following graphs are sketches of the oscilloscope output at four different configurations of our circuit. The graphs show the output voltage in phase with the input; however, they should be 180° out of phase. This is most likely due to experimental error. One of the oscilloscope outputs may have been shifted horizontally, or we might have simply sketched the output graphs incorrectly.

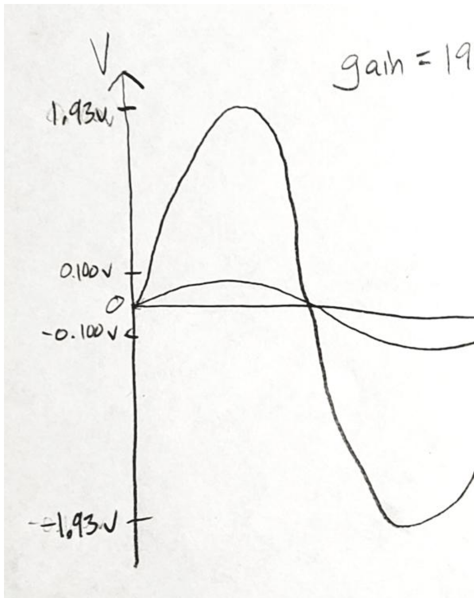


**Figure 2. Input and output of amplifier circuit with standard common-emitter configuration as shown in Figure 1. Note that the waveforms are drawn in phase, when they should be 180° out of phase.**

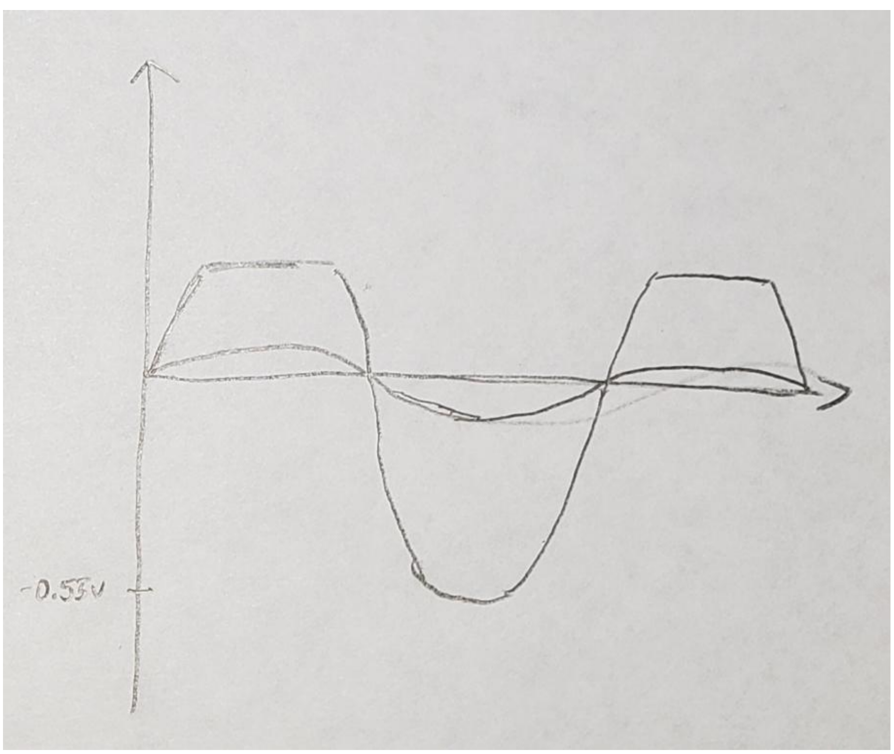

Figure 3. Input and output of circuit in the same configuration as Figure 2.
The input voltage is increased to 1.10v peak-to-peak, causing significant distortion.

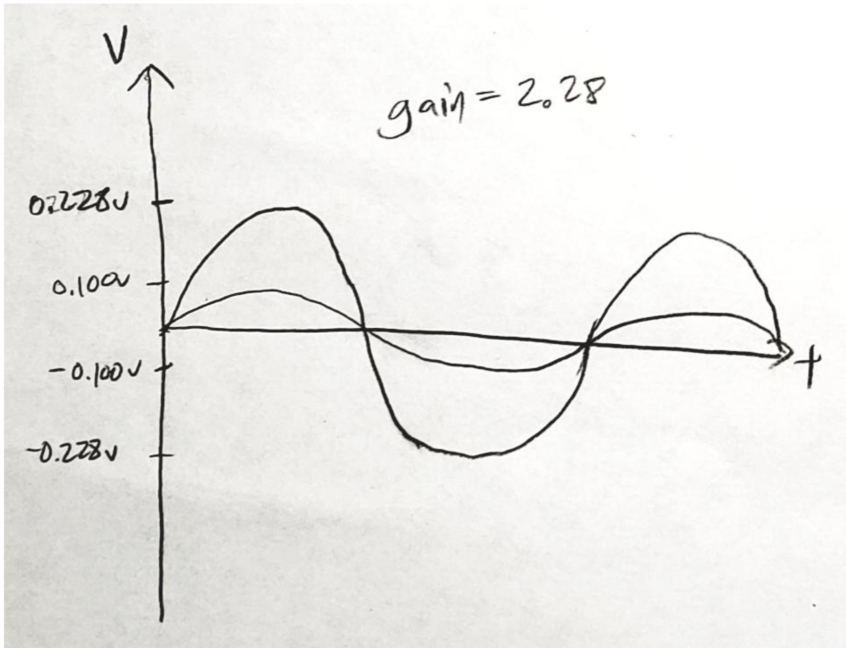


Figure 4. Output of amplifier circuit with emitter capacitor removed.
The gain is significantly lower than the previous configurations.

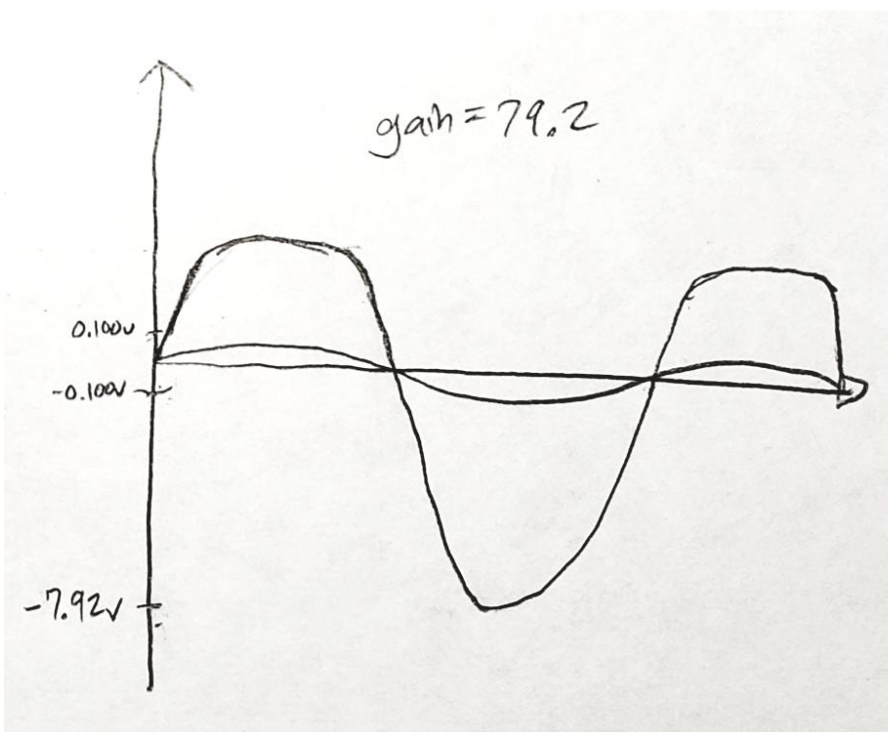


Figure 5. Output of amplifier circuit with resistor $R_{E2}$ removed.

**This allows the gain to increase until the output voltage is at the maximum allowed by the power supply.**

## Conclusion

Transistors must be placed correctly in order for them to function properly in a circuit. By taking our circuit components and modifying them, the gain appeared to change. This demonstrates the importance of the set up.