# Lab 9 Report

Ty Davis

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## 1 Introduction

In this lab we are studying the DC biasing of an NPN transistor. Refer to Figure 1 to see the circuit that we are building today. Via analysis of the circuit we will select resistor values that allow us to force this transistor to operate in the active and saturation regions.

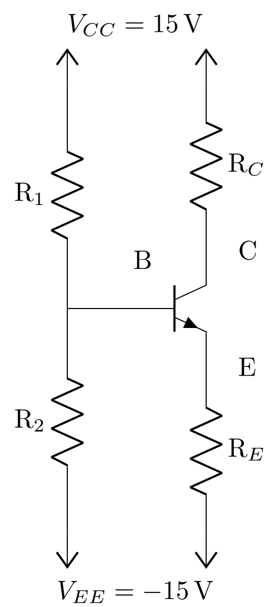


Figure 1: NPN Transistor Circuit

## 2 Active Region

We are tasked to design the circuit such that it follows the requirements shown in Figure 2.

| | |
|---|---|
| $I_C$ | 1 mA |
| $V_B$ | 0 V |
| $V_C$ | 5 V |

Figure 2: Table showing required values for NPN transistor in the Active Region.

## 2.1 Hand Calculations

Using the value for $\beta$ that we got in the last lab ($\beta = 161.02$) we are able to determine the relationships between some currents through the transistor. We found $i_B$ by using the equation $i_B = \frac{i_C}{\beta} = 6.21\,\mu\text{A}$. These leaves the equation $i_E = i_C + i_B$. $i_E = 1.006\,21\,\text{mA}$.

We now have enough information to determine the values of $R_C$ and $R_E$. Using Ohm's Law over the resistors, and knowing that the values of $V_C$ and $V_E$ are 5 V and $-0.7$ V respectively, we could calculate the resistor values. $R_C = 10\,\text{k}\Omega$ and $R_E = 14.211\,\text{k}\Omega$. I used a script that I wrote to find resistors values that are within 1 percent of the required values using a combination of resistors available in the lab.

After an analysis of the left side of the circuit, we can find the resistor values that allow close to $6.21\,\mu\text{A}$ of current to flow through the base terminal of the transistor. We selected a resistor $R_1$ that allows a current about 200 times the size of the base current through $R_1$. The selected resistor value was $12.077\,\text{k}\Omega$, and this was done so that small variations in the current through $R_1$ will still result in enough current to flow through the base of the transistor.

Using KCL and some algebra we are able to find an expression for $R_2$ in terms in $R_1$.

$$R_2 = \frac{15\,\text{V} R_1}{15\,\text{V} - 6.21\,\mu\text{A} R_1}$$

Using our selected value for $R_1$ we can find a value for $R_2$. We selected $R_2 = 12.138\,\text{k}\Omega$. Because the values for $R_1$ and $R_2$ are very close together (within the tolerance of the resistors available to us in the lab), controlling the amount of current going through the base will be difficult, and we can basically achieve the same result by selecting identical resistors within the same order of magnitude. Because of that we selected a resistor value of $15\,\text{k}\Omega$ because there were plenty available in our lab.

## 2.2 Multisim Analysis

With all of those values selected we were able to build our circuit and analyze it. First we built the circuit in Multisim and did a digital analysis of the circuit to check the voltages and verify that the circuit was operating in the Active region. You can see that simulation in Figure 3.

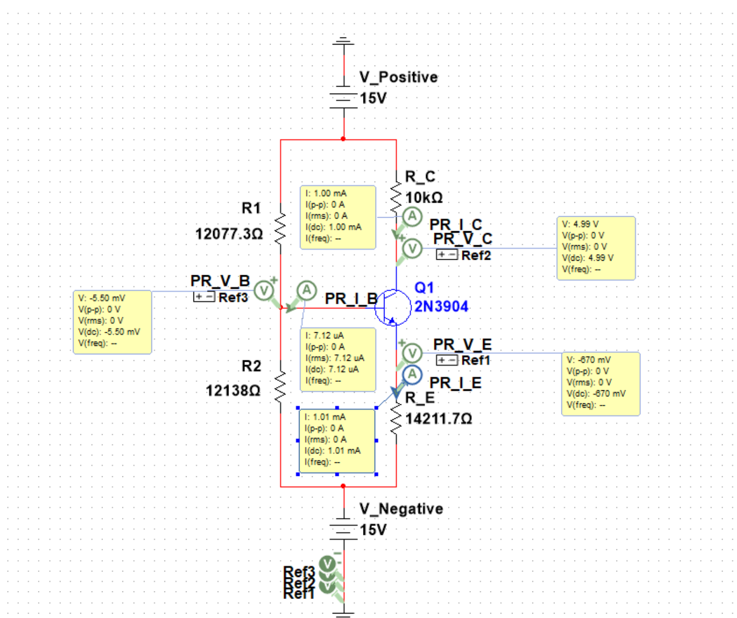


Figure 3: Multisim Simulation for NPN transistor in the Active Region

In the simulation results you can see that the voltages and currents are in line with our calculations.

| | |
|---|---|
| $V_C$ | 4.99 V |
| $V_E$ | −0.67 V |
| $V_B$ | −5.5 mV |
| $I_C$ | 1.00 mA |
| $I_E$ | 1.01 mA |
| $I_B$ | 7.12 $\mu$A |

Figure 4: Table of Multisim simulated values

Notably: $V_E = -0.67\,\text{V}$ and $V_B = -0.006\,\text{V}$, which are within tolerance to be the values that we calculated. Figure 4 is a table enclosing all of our values that we simulated.

## 2.3 Prototyping and Measurement

Using the earlier noted resistor values and a transistor we built the circuit and made measurements of our own to analyze the behavior of an NPN transistor in the Active Region. Figure 5 shows the values that we measured from the physical circuit.

| | |
|---|---|
| $V_C$ | 5.308 V |
| $V_E$ | −0.713 V |
| $V_B$ | −52.4 mV |

Figure 5: Table of measured voltages

These values are well in line with the calculated values considering the variations in transistors and resistor values.

## 2.4 Post-Measurement Exercise

$V_{BE}$ resulted in a value of 0.66 V. $V_{CE}$ resulted in a value of 6.021 V. These values are close to our calculated values, $V_C$ was a little high which resulted in a skewed $V_{CE}$ as well, but both still suggest operation in the Active Region.

Using our measured resistor values we found the following currents shown in Figure 6.

| | |
|---|---|
| $I_C$ | 1.003 mA |
| $I_E$ | 0.998 mA |
| $I_B$ | −0.005 mA |

Figure 6: Table of measured currents

From the measured currents we can see that the base current is in the wrong direction, but that can be concluded from the tolerance of the resistors. It still operates in the active region regardless.

# 3 Saturation Region

We are tasked to design the circuit such that it follows the requirements shown in Figure 7.

| | |
|---|---|
| $I_C$ | 1 mA |
| $I_E$ | 1.2 mA |
| $V_C$ | 2 V |
| $V_{CE}$ | 0.2 V |

Figure 7: Table showing required values for NPN transistor in the Saturation Region.

## 3.1 Hand Calculations

Knowing that the value of $V_{CE}$ is 0.2 V, the value for $V_E$ is 1.8 V. Using the constant drop model for $V_{BE} = 0.7\,\text{V}$ we find that the voltage of $V_B$ is 2.5 V. This allows us to calculate the values of $R_C$ and $R_E$ because we know the currents that have to flow through those resistors.

The values that we found for $R_C$ and $R_E$ were $13\,\text{k}\Omega$ and $14\,\text{k}\Omega$ respectively. We once again used the script that I wrote to select resistors networks to match those values.

We are able to find the forced $\beta$ that is being used in this saturation region. $\beta_{forced} = \frac{i_C}{i_B} = 5$

We decided to leave $R_2$ open to allow all the current to flow through $R_1$ and then through the base terminal of the transistor. We selected $R_1 = 62.5\,\text{k}\Omega$. $R_2$ can be any very large resistor, but we just left it open completely.

## 3.2 Multisim Analysis

With all of those values selected we were able to build our circuit and analyze it. First we built the circuit in Multisim and did a digital analysis of the circuit to check the voltages and verify that the circuit was operating in the Saturation region. You can see that simulation in Figure 8.

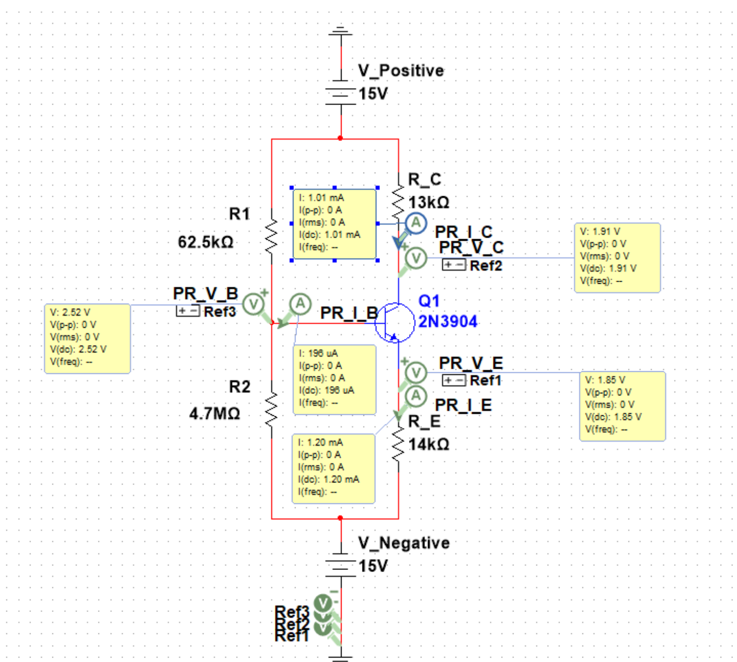


Figure 8: Multisim Simulation for NPN transistor in the Saturation Region

| | |
|---|---|
| $V_C$ | 1.91 V |
| $V_E$ | 1.85 V |
| $V_B$ | 2.52 mV |
| $I_C$ | 1.01 mA |
| $I_E$ | 1.20 mA |
| $I_B$ | 196 $\mu$A |

Figure 9: Table of Multisim simulated values

In the simulation results you can see that the voltages and currents are in line with our calculations. Figure 9 is a table enclosing all of our values that we simulated.

Interestingly, $V_{CE}$ is just 0.06 V, but that still suggests that the transistor is operating in the Saturation Region.

## 3.3 Prototyping and Measurement

Using the earlier noted resistor values and a transistor we built the circuit and made measurements of our own to analyze the behavior of an NPN transistor in the Saturation Region. Figure 10 shows the values that we measured from the physical circuit.

| | |
|---|---|
| $V_C$ | 2.087 V |
| $V_E$ | 2.040 V |
| $V_B$ | 2.717 mV |

Figure 10: Table of measured voltages

Once again we see a smaller $V_{CE}$ than we would expect, but that still suggests operation in the saturation region, and as you'll see the currents are well in line with the requirements as well.

## 3.4 Post-Measurement Exercise

$V_{BE}$ resulted in a value of 0.677 V. $V_{CE}$ resulted in a value of 0.047 V.

Using our measured resistor values we found the following currents shown in Figure 11.

| | |
|---|---|
| $I_C$ | 0.993 mA |
| $I_E$ | 1.19 mA |
| $I_B$ | 0.197 mA |

Figure 11: Table of measured currents

The currents are right in line with the requirements and the calculations completed earlier.

This also leaves a $\beta_{forced} = 5.038$ which is right on top of the calculated value of $\beta_{forced} = 5$ from the hand calculations.