Lab 9 - BJT DC Biasing

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Introduction

In this lab we are analyzing the DC operating points of an NPN-type BJT. There are three modes of operation for a BJT, namely *active*, *saturation*, and *cutoff*. We are going to analyze the BJT in both the *active* and *saturation* regions of operation.

Fig. 1 shows our circuit. For each mode of operation we will select different resistor values in order to bias the circuit.

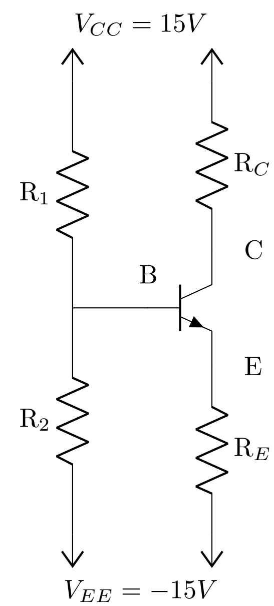

Figure 1: The circuit we use in the lab.

Analysis

Active Mode Operation

For active mode operation we are going to design the circuit such that $I_C = 1$ mA, $V_B = 0$ V, and $V_C = 5$ V.

We can quickly find I_B because we know that β from the data sheet is $\beta = 161.205$. This means that $I_B = I_C/\beta = 6.203$ µA. Knowing that $I_E = I_C + I_B$, we get $I_E = 1.006203$ mA.

With these values we can find $R_C = \frac{15-5}{1 \text{ mA}} = 10$ kΩ. Using the constant drop model, we can assume that $V_E = V_B - 0.7 \text{ V} = -0.7$ V. This leads us to $R_E = \frac{-0.7-(-15)}{1.006203 \text{ mA}} = 14.371$ kΩ.

For the remaining two resistors, the function is not fully specified, but we know that $V_B = 0$ V, and the current through R_1 is equal to the current through R_2 and the current I_B. As such, we can do some brief nodal analysis to find:

$$\frac{V_{CC} - 0}{R_1} + \frac{0 - V_{EE}}{R_2} + I_B = 0$$

Rearranging this to solve for R_1 in terms of R_2 we find this equation:

$$R_1 = V_{CC} \cdot \left(\frac{1}{-I_B - V_{EE}/R_2} \right)$$

That expression allowed us to choose some R_2 and determine a necessary R_1. We chose the value $R_2 = 100$ kΩ, and the corresponding R_1 is found to be $R_1 = 96.028$ kΩ.

Saturation Mode Operation

The Saturation Mode operation is even more straightforward. We are going to design the circuit such that $I_C = 1$ mA, $I_E = 0.2$ mA, $V_C = 2$ V, and $V_{CE} = 0.2$ V.

Knowing I_C and I_B means that we can find $I_E = 200$ µA. Also, we find that $V_E = 1.8$ V because $V_{CE} = 0.2$ V.

With values for V_C and V_E we can find that $R_C = 13$ kΩ and $R_E = 14$ kΩ.

The same method for calculating R_1 and R_2 applies in this circuit as well, so we can select $R_2 = 100$ kΩ and find that $R_1 = 33.333$ kΩ.

The β_{forced} that we found is $\frac{1\text{ mA}}{200\text{ µA}} = 5$.

Simulation Results

Building the circuit in Multisim we recorded the following values:

	Active Mode	**Saturation Mode**
V_C	5.12 V	1.92 V
V_B	-40.0 mV	2.54 V
V_E	-0.704 V	1.86 V
V_{BE}	0.66 V	0.68 V
V_{CE}	5.82 V	0.08 V
I_C	0.988 mA	1.01 mA
I_B	7.02 µA	198.68 µA
I_E	0.995 mA	1.20 mA

Table 1: Simulation results.

Measurement Results

Building the circuit we found that the our analysis and simulation in both active mode and saturation mode operation were very close to the actual performance of the device. Look at Tables 3 and 4 to see the resistor values that we used.

The β_{forced} that we calculated is $\frac{1.012\text{ mA}}{205.7\text{ µA}} = 4.921$.

	Active Mode	**Saturation Mode**
V_C	5.06 V	1.918 V
V_B	-3.0 mV	2.546 V
V_E	-0.661 V	1.873 V
V_{BE}	0.658 V	0.673 V
V_{CE}	5.721 V	0.045 V
I_C	1.00638 mA	1.01215 mA
I_B	5.12 µA	205.68 µA
I_E	1.0115 mA	1.21783 mA

Table 2: Measurement results.

Calculated Resistor	**Equivalent Resistor**	**Measured Resistor**	
10 kΩ	10 kΩ	9.877 kΩ	R_C
14.371 kΩ	14.347 kΩ	14.176 kΩ	R_E
	15 kΩ	14.82 kΩ	
	330 kΩ	325.38 kΩ	
96.028 kΩ	96.2 kΩ	95.542 kΩ	R_1
	47 kΩ	46.689 kΩ	
	47 kΩ	46.679 kΩ	
	2.2 kΩ	2.173 kΩ	
100 kΩ	100 kΩ	98.75 kΩ	R_2

Table 3: Active Mode Resistors.

Calculated Resistor	**Equivalent Resistor**	**Measured Resistor**	
13 kΩ	13.043 kΩ	12.925 kΩ	R_C
	15 kΩ	14.86 kΩ	
	100 kΩ	99.35 kΩ	
14 kΩ	14.042 kΩ	13.855 kΩ	R_E
	15 kΩ	14.82 kΩ	
	220 kΩ	217.68 kΩ	
96.028 kΩ	96.2 kΩ	95.542 kΩ	R_1
	47 kΩ	46.689 kΩ	
	47 kΩ	46.679 kΩ	
	2.2 kΩ	2.173 kΩ	
100 kΩ	100 kΩ	98.75 kΩ	R_2

Table 4: Active Mode Resistors.