Experiment 9
Bipolar Junction Transistor Characteristics

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1.0 Objective

In this lab, you will determine the I_C - V_{CE} characteristics of a BJT in several regions of operation. The large signal parameters will be determined experimentally. You will then derive the large signal model for the BJT in each region of operation. The key concepts introduced in this laboratory are:

- The 4 regions of operations of the BJT
- Determination of the region of operation based on the voltages V_{BE} and V_{CE}
- Determination of large signal parameters such as β and V_A.

2.0 Prelab

- H & S Chapters 7.1 - 7.4
- Write down the complete Ebers-Moll Equations
- Write down the simplified equations appropriate for the forward active and reverse active regions. From these equations, derive the Ebers-Moll large-signal model for each region of operation.

3.0 Procedure

Shown below is the complete Ebers-Moll model for the bipolar junction transistor. You will find all the parameters for this model in this experiment. You might find it useful to tabulate your data into a table such as Table1.

FIGURE 1. Ebers-Moll Model for the npn Bipolar Junction Transistor

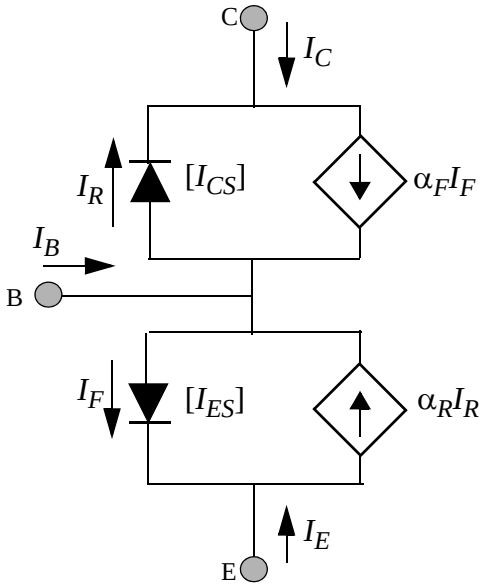


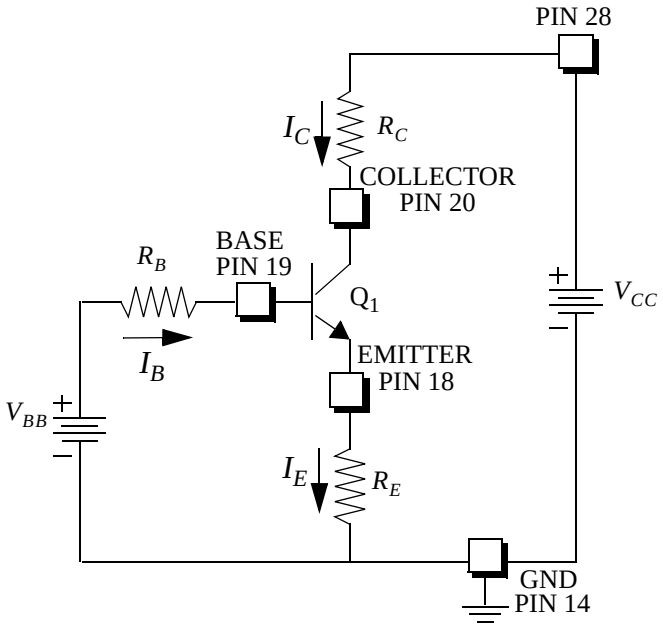
Table 1: Regions of Operations and Measurements

	Forward Active	Saturation	Cutoff	Reverse Active
V_{BE}				
V_{BC}				
I_B				
I_C				
β		NA	NA	
α		NA	NA	
I_{ES} or I_{CS}		NA	NA	

3.1 Circuit Measurements

1. Connect the M3500 (NPN1)on Lab Chip 2 as shown in Fig. 2. Let R_C =5kΩ, R_B = 1 MΩ, and R_E = 100 Ω. Let V_{CC} = 5V.

FIGURE 2. BJT Test Circuit



2. Increase V_{BB} until I_C = 0.5mA. Measure V_{BE} and V_{BC}. What region of operation is the transistor operating in? Measure I_B, the base current and compare that to the collector current. What is β? Once β is found, you can calculate α.

Lab Tip

It is often more convenient and sometimes, more accurate to measure the current by measuring the voltage across the resistor through which the current flows, using Ohm's Law.

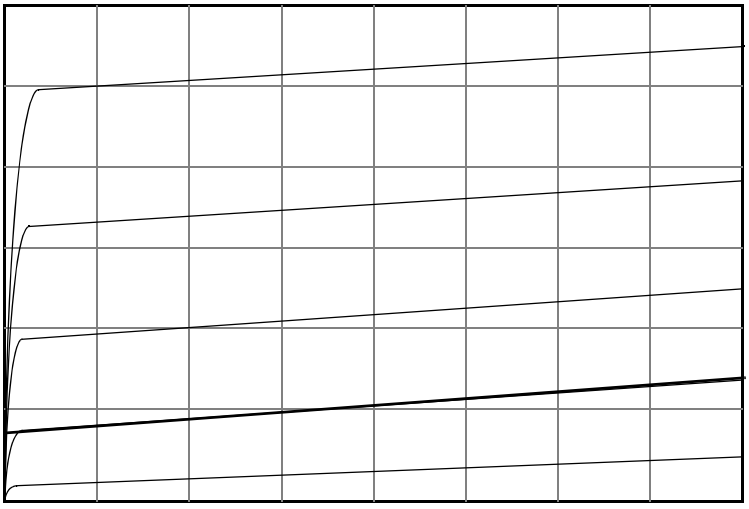
3. Draw the simplified Ebers-Moll model for the BJT in this region of operation and find its parameters.
4. While keeping the voltage V_{BB} constant at 4V, vary V_{CC} from 0V to 6V. This should take the transistor through 2 regions of operation. Note the base current I_B. Make a careful plot of I_C vs. V_{CE} and the noise in the I_C measurement. You will need to take many points at low V_{CE} due to the steep slope of the curve. Note V_{BE} , V_{BC}, and I_B at saturation. Draw the simplified Ebers-Moll model for the BJT in the saturation region. From this plot, find the early voltage V_A. Does the Ebers-Moll model predict the correct behavior?
5. Change V_{BB} to -3V (V_{CC} remains at 5 V) How much collector current flows? Does it agree with the Ebers-Moll model? What region of operation is this? What is V_{BE} and V_{BC}? Draw the simplified Ebers-Moll model for the BJT in this region of operation.

6. Interchange the collector and the emitter and let V_{BB} be 4V. Measure V_{BE} and V_{BC}. What region of operation is the transistor operating in? Measure I_B, the base current and compare that to the collector current. What is β? Draw the simplified Ebers-Moll model for the BJT in this region and find its parameters

3.2 HP-4155 Measurements

1. Load the program **PBJT6** into the HP-4155
2. Place the Lab Chip 2 into the test fixture and connect with the SMUs.
3. At the **Source Setup Screen**, change the *start value* of the base current to be the base current you found in procedure 3.1.4. Strictly speaking, the base current is not a constant in procedure 3.14.
4. Run the test program and note the curves traced out by the 4155.
5. Using the marker and cursor, find the Early voltage, V_A for the curve corresponding to the base current you observed in procedure 3.1.4.

FIGURE 3. Sample I_C - V_{CE} characteristics for a bipolar junction transistor. (extrapolated line in dark)



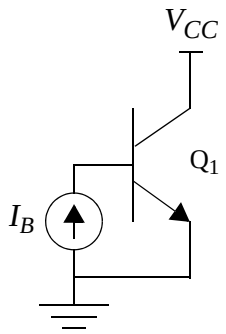
6. You can find β by comparing the collector current with its corresponding base current. Find the value of β for the base current you found in procedure 3.1.4. How do they compare?
7. Get a hardcopy of the I_C - V_{CE} curve.
8. Interchange the connection for the collector and emitter and repeat the experiment. Find β_R and V_{AR}. *Note*: you will need to change the scaling manually to see the curves.
9. Get a hardcopy of the I_C - V_{CE} curve.

10. Make hardcopies of both measurements. How do they compare?

3.3 Diode Characteristics of BJT

1. Load the default diode program for HP-4155.
2. Connect the base and the emitter od Lab Chip 2 to the appropriate SMUs as described by the **SOURCE SETUP SCREEN**.
3. The program will plot the current as a function of the base-emitter voltage on a log scale. Using the equation for a forward biased diode, determine I_{ES}.
4. Interchange the connections and repeat the experiment to find I_{CS}.
5. Get a hardcopy

FIGURE 4. BJT circuit for SPICE simulation



4.0 Optional Experiment

4.1 Circuit Simulation

Perform a SPICE analysis using the parameters you found. The circuit is shown above. You will need to perform a nested sweep. V_{CC} will vary from 0 to 5 V and I_B will vary with the initial base current from procedure 3.1.4 in steps of 10 μA. Plot I_C vs. V_{CE}. Fill in the parameters for the M3500 in the data sheet in the Appendix.

Using the program PBJT and PDIODE, modify them to find the parameters for the pnp transistor M3511 (PNP)on Lab Chip 1 (collector = pin 27, base = pin 26, emitter = pin 25).

5.0 Appendix

FIGURE 5. Data Sheet for M3500 and M3511