

LAB VIII. BIPOLAR JUNCTION TRANSISTOR CHARACTERISTICS

1. OBJECTIVE

In this lab, you will study the *DC* characteristics of a Bipolar Junction Transistor (BJT).

2. OVERVIEW

In this lab, you will inspect the external physical structure, labeling, and pin-out of BJT 2N4400. Next, you will use a LabVIEW program to measure the $I_C - V_{CE}$ characteristics of the BJT in forward-active mode. After that, you will determine the base-to-collector DC current gain (h_{FE}), the Early voltage (V_A) and common-emitter breakdown voltage (BV_{CE0}).

Information essential to your understanding of this lab:

1. Theoretical background of the BJT (Read Streetman 7.1, 7.2, 7.4, 7.5, 7.7.2, 7.7.3)

Materials necessary for this Experiment:

1. Standard testing station
2. One BJT (Part: 2N4400)
3. 1k Ω resistor

3. BACKGROUND INFORMATION

Bipolar junction transistors (BJTs) are three terminal devices that make up one of the fundamental building blocks of the silicon transistor technology. Three terminals emitter (E), collector (C) and base (B) are shown in Figure 1 for the pnp transistor, npn transistor and a schematic of TO-92 package transistor, with the pin connections identified for the BJT 2N4400. **The 2N4400 is a general purpose NPN amplifier transistor.**

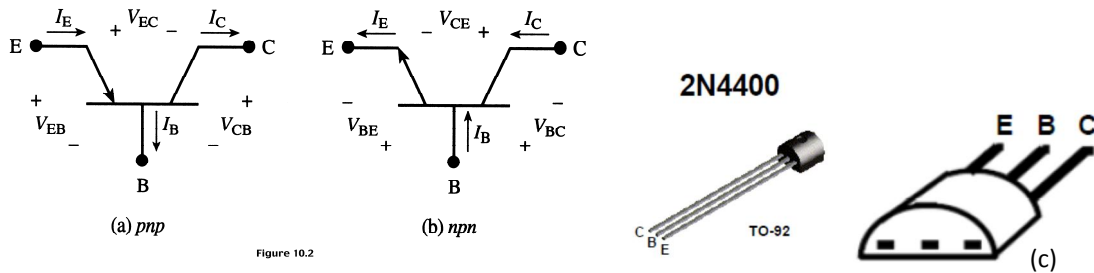


Figure 1. (a) NPN transistor symbol, (b) PNP transistor symbol and (c) TO-92 package 2N4400 BJT pin configuration.

BJTs are used to amplify current, using a small base current to control a large current between the collector and the emitter. This amplification is so important that one of the most noted parameters of these transistors is the dc current gain β (or h_{FE}), which is the ratio of collector current to base current: $I_C = \beta \cdot I_B$. In designing an amplifier circuit using BJTs, there are several important and sometimes conflicting factors to be considered in the selection of the DC bias point. These include gain, linearity, and dynamic range.

Several BJT bias configurations are possible, three of which are shown in Fig. 2. The circuit in Fig. 2a is called a common-base configuration which is typically used as a current buffer. In this configuration, the emitter of the BJT serves as the input, the collector is the output, and the base is common to both input and output. The circuit in Fig. 2b is called common-emitter configuration which is typically used as an amplifier. In this circuit, the base of the BJT serves as the input, the collector is the output, and the emitter is common to both input and output. The circuit in Fig. 2c is called common-collector configuration which is typically used as a voltage buffer. In this circuit, the base of the BJT serves as the input, the emitter is the output, and the collector is common to both input and output.

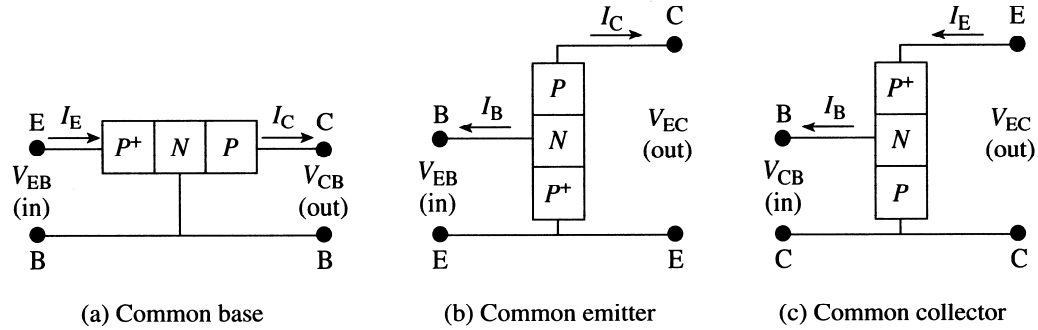


Figure 2. (a) Common base, (b) Common emitter and (c) Common collector configuration of BJT.

The DC characteristics of BJTs can be presented in a variety of ways. The most useful and the one which contains the most information is the output characteristic, I_C versus V_{CB} and I_C versus V_{CE} shown in Fig. 3.

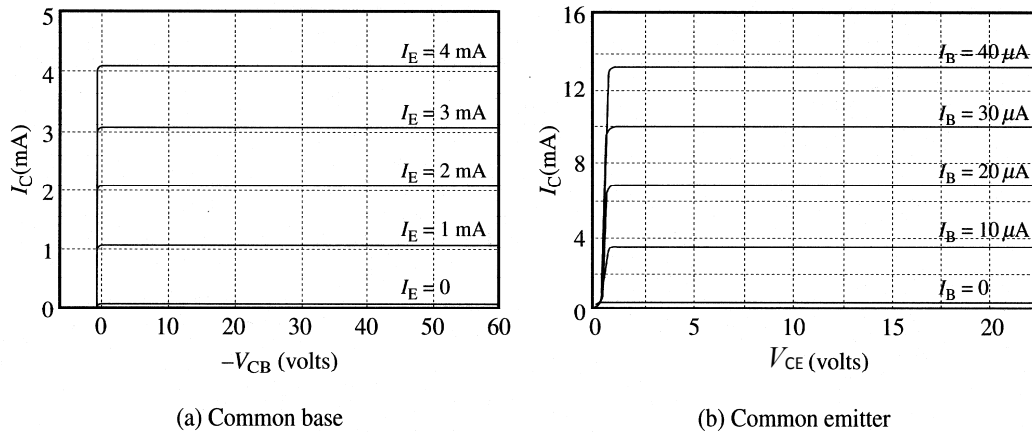


Figure 3. Typical I-V characteristics of BJT for (a) common base and (b) common emitter configuration.

4. PREPARATION

1. Study the Figure 7-12 in Streetman and describe the $I_C - V_{CE}$ characteristics of typical BJT in your own words.
2. Outline 7.7.2 in Streetman and explain what the Early voltage is.
3. Outline 7.7.3 in Streetman and explain what BV_{CE0} is.

5. PROCEDURE

5.1 DC Current Gain (h_{FE})

Identify the leads of the BJT 2N4400 using Figure 1 and construct a circuit shown in Figure 4.

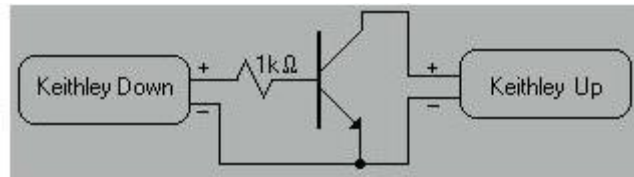


Figure 4. A circuit for obtaining the I_C - V_{CE} characteristics.

The lower Keithley is used to supply V_{BE} and the upper Keithley is used to supply V_{CE} . Use the LabVIEW program, **BJT_IV_Curve.vi**, to obtain I_C - V_{CE} characteristic curves using the following setting. You may use setup mode (see top right area of the vi's GUI) to check whether your setup is valid. Use the following information to setup your Keithleys:

$$V_{CE} = 0 \text{ V to } 4 \text{ V in } 0.1 \text{ V steps with } 0.1 \text{ A compliance.}$$

$$I_B = 10 \text{ } \mu\text{A to } 60 \text{ } \mu\text{A in } 10 \text{ } \mu\text{A steps with } 25 \text{ V compliance.}$$

After verifying the setup, run the vi, compare your plots with that of Figure 3, and if acceptable store the I_C - V_{CE} characteristic data and curves image for your lab report. Be sure to understand how the curves are generated. Open your data set and use the figure below to understand the formatting to extract I_B , I_C and V_{CE} .

BJT IV Curve						
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	V_{CE}			I_B		
V_{ce}	$I_c = 1.0000$	$I_c = 2.0000$	$I_c = 3.0000$	$I_c = 4.0000$	$I_c = 5.0000$	$I_c = 6.000000E-5$
0	-2.09E-05	-2.26E-05	-3.46E-05	-4.70E-05	-5.93E-05	-7.12E-05
0.1	0.000322	0.000761	0.001234	0.001728	0.002237	0.002754
0.2	0.000526	0.001274	0.002084	0.002941	0.003831	0.004744
0.3	0.000551	0.001309	0.002147	0.003034	0.003956	0.004905
0.4	0.000553	0.001314	0.002155	0.003046	0.003972	0.004927
0.5	0.000555	0.001317	0.00216	0.003053	0.003983	0.00494
0.6	0.000556	0.00132	0.002165	0.00306	0.003991	0.004949
0.7	0.000557	0.001323	0.002169	0.003065	0.003998	0.00496
0.8	0.000558	0.001325	0.002173	0.003072	0.004005	0.004969

Next, import your data into an Excel spreadsheet and generate Table 1 below (write I_C in mA) using the measured data and calculate h_{FE} . Note that I_C is likely in the mA range while I_B is in the μA range. The common-emitter DC gain (base-to-collector current gain, h_{FE}) is calculated by $h_{FE} = I_C/I_B$ with V_{CE} at a constant voltage. h_{FE} is also called β_F , the forward DC current gain. It is often simply written as β , and is usually in the range of 10 to 500 (most often near 100). h_{FE} is affected by temperature and current.

Table 1. I_C - V_{CE} characteristic of the BJT 2N4400.

$I_B [\mu A]$	10		20		30		40		50		60	
V_{CE}	I_C	h_{FE}	I_C	h_{FE}	I_C	h_{FE}	I_C	h_{FE}	I_C	h_{FE}	I_C	h_{FE}
1 V												
2 V												
3 V												
4 V												

5.2 Small-Signal Current Gain (h_{fe})

Now, using the same set of data that you got for the DC current gain measurement, estimate the small-signal current gain h_{fe} and fill out the Table 2 below. The small-signal current gain is calculated by $h_{fe} = \Delta I_C / \Delta I_B$ with the V_{CE} at a constant voltage.

Table 2. Small-signal current gain, h_{fe} .

V_{CE}	$h_{fe} (I_{B2}, I_{B1})$	$h_{fe} (I_{B3}, I_{B2})$	$h_{fe} (I_{B4}, I_{B3})$	$h_{fe} (I_{B5}, I_{B4})$	$h_{fe} (I_{B6}, I_{B5})$	$h_{fe} (I_{B5}, I_{B2})$
1 V						
2 V						
3 V						
4 V						

NOTE: (Subscripts 1 denotes $I_B = 10 \mu A$, 2 denotes $I_B = 20 \mu A$, 3 denotes $I_B = 30 \mu A$, and so on.)

5.3 Output Conductance (h_{oe})

Again, using the same set of data, estimate the output conductance h_{oe} and fill out the Table 3 below. The output conductance is calculated by $h_{oe} = \Delta I_C / \Delta V_{CE}$ with the I_B at a constant current.

Table 3. Output conductance, h_{oe} . Subscripts denote V_{CE} values.

	V_{CE3}, V_{CE1}			V_{CE4}, V_{CE2}		
$I_B [\mu A]$	I_{C3}	I_{C1}	h_{oe}	I_{C4}	I_{C2}	h_{oe}
10						
20						
30						
40						
50						
60						

5.4 Early Voltage (V_A)

Use the same circuit shown in Figure 4 and the same LabVIEW program **BJT_IV_Curves.vi**. Again, the lower Keithley is used to supply V_{BE} and the upper Keithley is used to supply V_{CE} . Set up the following to obtain the I_C - V_{CE} characteristic curves.

$V_{CE} = 0 \text{ V}$ to 20 V in 2 V steps with 0.1 A compliance.

$I_B = 10 \mu A$ to $60 \mu A$ in $10 \mu A$ steps with 25 V compliance.

Store the I_C - V_{CE} characteristic data AND curve image for your lab report. Import your data into Excel spreadsheet and extrapolate (you may estimate using draw tools or trendlines) your data set as shown below to estimate the Early voltage. The Early voltage is typically in the range of 15 V to 200 V .

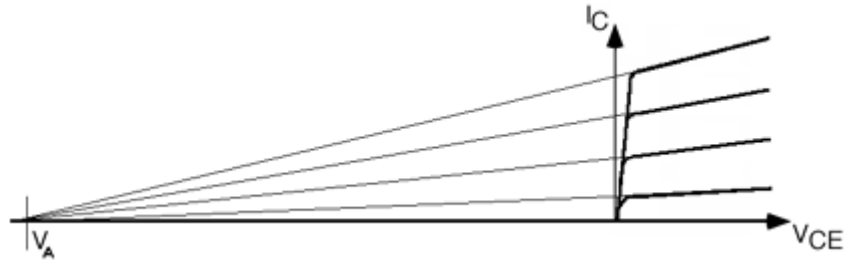


Figure 5. I_C - V_{CE} characteristics of a BJT and the Early voltage (V_A).

5.5 Common-Emitter Breakdown Voltage (BV_{CE0})

Again, use the same circuit shown in Figure 4 and the same LabVIEW program **BJT_ivcurve.vi**. Once again, the lower Keithley is used to supply V_{BE} and the upper Keithley is used to supply V_{CE} . Set up the following to obtain the I_C - V_{CE} characteristic curves.

$V_{CE} = 0\text{ V}$ to 40 V in 1 V steps with 0.1 A compliance.

$I_B = 0\text{ }\mu\text{A}$ to $60\text{ }\mu\text{A}$ in $10\text{ }\mu\text{A}$ steps with 25 V compliance.

Store the I_C - V_{CE} characteristic curves image for your lab report. Import your data into Excel spreadsheet and estimate the common-emitter breakdown voltage as shown below. **If you cannot see the breakdown behavior** with the operating conditions given above, change your V_{CE} as the following and run the LabVIEW program again.

$V_{CE} = 0\text{ V}$ to 45 V in 1 V steps with 0.1 A compliance.

$I_B = 0\text{ }\mu\text{A}$ to $60\text{ }\mu\text{A}$ in $10\text{ }\mu\text{A}$ steps with 25 V compliance.

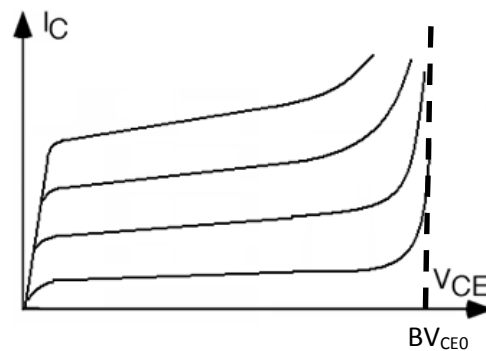


Figure 6. I_C - V_{CE} characteristics of a BJT and the common-emitter breakdown voltage (BV_{CE0}).

6. LAB REPORT

Type a lab report with a cover sheet containing your title, name, your lab partner's name, class, section number, date the lab was performed and the date the report is due. Use the following outline to draft your lab report:

- **ABSTRACT:** Briefly describe the contents of your report.
- **ANALYSIS:**
 - *DC current gain:*
 - Create a well formatted table consisting of the Table 1 data.
 - Plot the I_C - V_{CE} characteristics curves acquired by the LabVIEW program in EXCEL with proper title, labels etc.
 - Discuss trends of the DC current gain with different Values of I_B and V_{CE} .
 - *Small-Signal Current Gain:*
 - Include your Table 2 data with the values you recorded in it.
 - Plot the I_C - V_{CE} characteristics curves acquired by the LabVIEW program.
 - Discuss trends of the small-signal current gain with different values of I_B and V_{CE} .
 - *Output Conductance:*
 - Include your Table 3 data with the values you recorded in it.
 - Plot the I_C - V_{CE} characteristics curves acquired by the LabVIEW program.
 - Discuss trends of the output conductance with different values of I_B and V_{CE} .
 - *Early Voltage:*
 - Plot the I_C - V_{CE} characteristics curves with the negative branch of the x-axis extended enough to clearly show the Early voltage. LABEL and ESTIMATE the Early Voltage on your graph.
 - Read the section 7.7.2 of Streetman and Banerjee and explain why you have the Early voltage.
 - What does the Early Voltage tell you about your BJT?
 - *Common-Emitter Breakdown Voltage:*
 - Plot the I_C - V_{CE} characteristics curves similar to one shown in Figure 6 using your data.
 - Determine and LABEL the BV_{CE0} .
 - Read the section 7.7.3 of Streetman and Banerjee and explain what is happening in the BJT.
- **CONCLUSION:** Briefly condense your findings from the above analyses of your experimental data with respect to the theory of BJTs you studied from the **PREPERATION** section.
- **Attach:** Signed instructor verification form.