

# LAB VII. BIPOLAR JUNCTION TRANSISTOR CHARACTERISTICS

## 1. OBJECTIVE

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

## 2. OVERVIEW

You need to first identify the physical structure and orientation of BJT based on visual observation. Then, you will use the LabView program **BJT\_ivcurve.vi** to measure the  $I_C - V_{CE}$  characteristics of the BJT in forward active mode. You need to determine base-to-collector DC current gain ( $h_{FE}$ ), Early voltage ( $V_A$ ) and common-emitter breakdown voltage ( $BV_{CE0}$ ).

Information essential to your understanding of this lab:

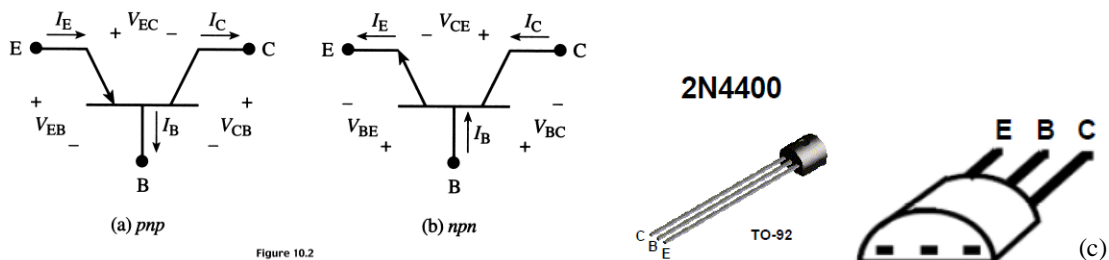
1. Theoretical background of the BJT (Streetman 7.1, 7.2, 7.4, 7.5, 7.7.2, 7.7.3)

Materials necessary for this Experiment:

1. Standard testing station
2. One BJT (Part: 2N4400)
3. 1k $\Omega$  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 are emitter (E), collector (C) and base (B). Figure 1 shows the transistor symbol for the npn transistor, pnp transistor and a schematic of TO-92 package transistor, with the pin connections identified for the BJT 2N4400. 2N4400 is a general purpose NPN amplifier transistor.

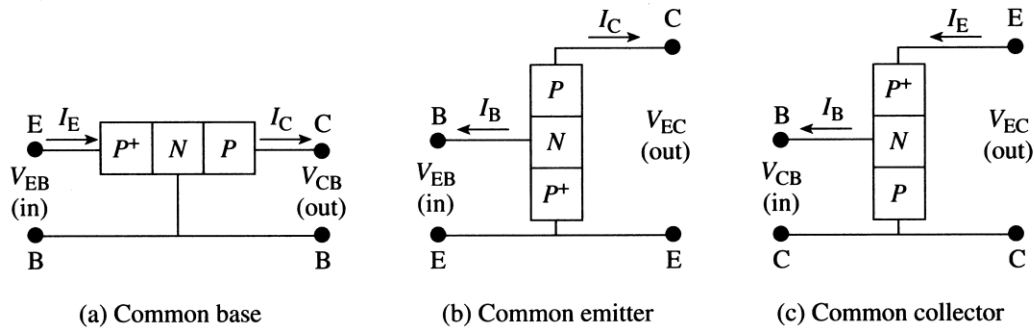


**Figure 1.** (a) NPN transistor symbol, (b) PNP transistor symbol and (c) TO-92 package 2N4400 BJT pin configuration.

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 transistors is the dc current gain,  $\beta$  (or  $h_{FE}$ ), which is the ratio of collector current to base current:  $I_C = \beta I_B$ . 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.

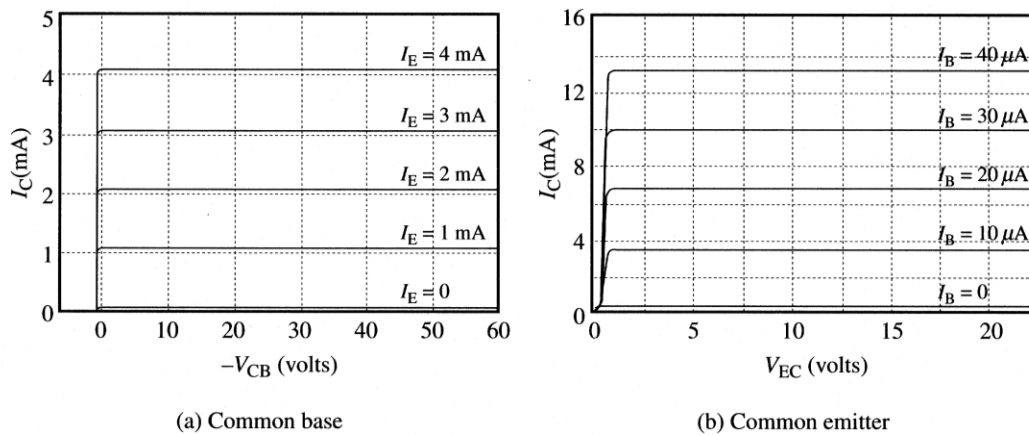
Several BJT bias configurations are possible, three of which are shown in Fig. 2. The circuit in Fig. 2a is called a common-base configuration which is typically used as a current buffer. In this configuration, the emitter of the BJT serves as the input, the collector is the output, and the base is common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

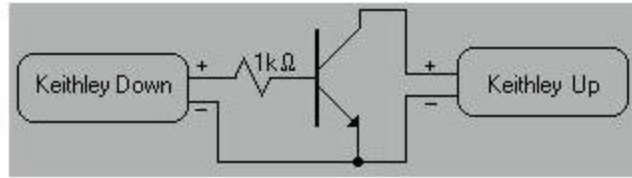
## 4. PRE-LAB REPORT

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\_ivcurve.vi**, to obtain  $I_C$ - $V_{CE}$  characteristic curves using the following setting.

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

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

Store the  $I_C$ - $V_{CE}$  characteristic curves image for your lab report. Import your data into Excel spreadsheet and fill out the 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  $\mu\text{A}$  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  $\beta_F$ , the forward DC current gain. It is often simply written as  $\beta$ , 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.

$I_B [\mu\text{A}]$	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,  $h_{fe}$ . Subscripts 1 denotes  $I_B = 10 \text{ } \mu\text{A}$ , 2 denotes  $I_B = 20 \text{ } \mu\text{A}$ , 3 denotes  $I_B = 30 \text{ } \mu\text{A}$ , and so on.

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

### 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.

$I_B [\mu A]$	$V_{CE3}, V_{CE1}$		$V_{CE4}, V_{CE2}$	
	$I_C$	$h_{oe}$	$I_C$	$h_{oe}$
10				
20				
30				
40				
50				
60				

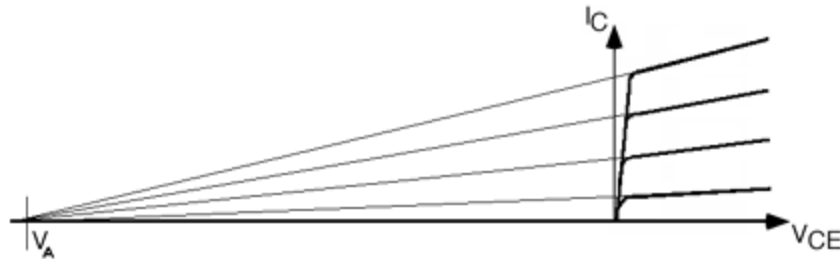
### 5.4 Early voltage ( $V_A$ )

Use the same circuit shown in Figure 4 and the same LabView program **BJT\_ivcurve.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  $20 \text{ V}$  in  $2 \text{ V}$  steps with  $0.1 \text{ A}$  compliance.

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

Store the  $I_C$ - $V_{CE}$  characteristic curves image for your lab report. Import your data into Excel spreadsheet and extrapolate your data set as shown below using lines. The Early voltage is typically in the range of  $15 \text{ V}$  to  $200 \text{ V}$ .



**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.

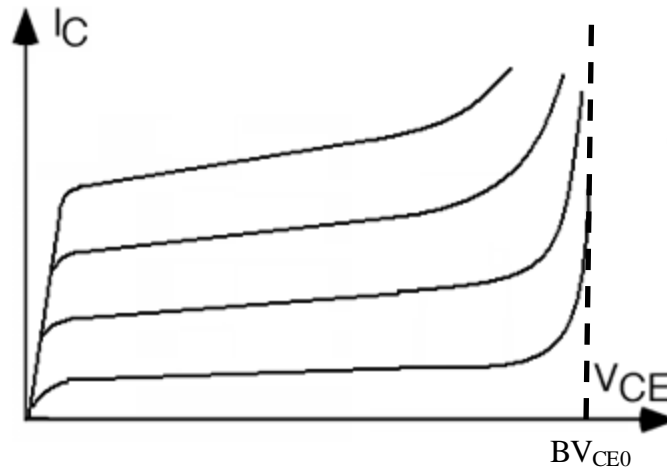
$V_{CE} = 0 \text{ V}$  to  $50 \text{ V}$  in  $2.5 \text{ V}$  steps with  $0.01 \text{ A}$  compliance.

$I_B = 0 \mu A$  to  $60 \mu A$  in  $10 \mu A$  steps with  $5 \text{ V}$  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.

$V_{CE} = 0\text{ V to }60\text{ V in }2.5\text{ V steps with }0.01\text{ A compliance.}$   
 $I_B = 0\text{ }\mu\text{A to }60\text{ }\mu\text{A in }10\text{ }\mu\text{A steps with }5\text{ V compliance.}$



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

## 6. LAB REPORT

- Write a summary of the experiment.
- DC current gain
  - Include your Table 1 data with the values you recorded in it.
  - Plot the  $I_C$ - $V_{CE}$  characteristics curves acquired by the LabView program.
  - Discuss about variations 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 about variations 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 about variations 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.
  - Read the section 7.7.2 of Streetman and Banerjee and explain why you have the Early voltage.
- Common-emitter breakdown voltage
  - Plot the  $I_C$ - $V_{CE}$  characteristics curves similar to one shown in Figure 6 using your data.
  - Determine the  $BV_{CE0}$ .
  - Read the section 7.7.3 of Streetman and Banerjee and explain what is happening in the BJT.