KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS
DEPARTMENT OF ELECTRICAL ENGINEERING
Electronic Circuits I - EE203

Experiment # 5

Bipolar Junction Transistor Characteristics

OBJECTIVE

The purpose of this experiment is to

- Measure and Graph the collector characteristis curves for a BJT.
- Use the Characteristics curves to determine the β_{DC} of the transistor at a given point.
- Study data sheet of BJT

COMPONENTS REQUIRED

- Transistor 2N3904
- Resistors 33KΩ, 100Ω

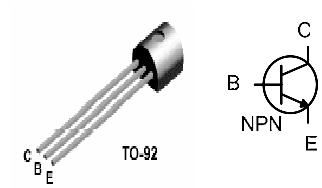


Figure 1 2N3904 Pin configuration

PRELAB

Refer to the specifications for the 2N3904 and find the following information:

a. transistor type
b. maximum power it can dissipate at 25^0C
c. maximum collector current rating
d. maximum collector to emitter voltage rating
e. operating temperature range
f. minimum and maximum h_{FE}
g. the emitter to base breakdown voltage
h. h_{FE} @ I_C = 10 mA

SUMMARY OF THEORY

A Bipolar junction transistor (BJT) is a three terminal device capable of amplifying an *ac* signal (see Figure 1). The three terminals are called base (B), emitter(E), collector(C), and come in two flavours NPN (On a NPN transistor arrow is not pointed IN (See Figure 1)) and PNP. The middle letter indicate the type of material used for the base, while outer letters indicate the emitter and collector material. The sandwiched materials produce two *pn* junctions. These two junctions form two diodes-the emitter-base diode and base-collector diode.

BJTs are current amplifiers. A small base current is amplfied to a larger current in the collector-emitter circuit. Consider first the NPN transistor shown at the top. If the base is at higher ($\approx$0.6 volt) potential than the emitter then a current i_B will flow into the base. The current into the collector is β times larger than the base current. The quantity β (usually called h_{FE} in transistor data sheets) is a characteristic of the individual transistor and is typically in the range from 100-500 for the types of transistors we will be using. The transistor can be thought of as a current amplifier device -- the current at the output (collector or emitter) is β times large than the current at the input (base). Another useful characteristic is the dc alpha.

For a transistor to amplify, power is required from dc sources. The dc voltages required for proper opertaion are referred to as bias voltages. The purpose of bias is to establish and maintain the requied operating conditions despite variations between transistors or changes in the circuit parameters. For normal operation, the base-emitter junction is forward-biased and base-collector junction reverse-biased. Since the base emitter junction is forward-biased, it has characteristics of a forward-biased diode.

PSPICE

A. BJT I_C – V_{CE} characteristic curves

Use Schematics to connect the circuit shown in Figure 2. Select *Analysis* → *Setup* → *DC Sweep*. Select V_{CE} from 0 to 8V. The Sweep type is linear. Set *Nested Sweep* for I_B from 0.1mA to 0.5mA. Mark X in the *Enable Nested Sweep*. Generate three curves for I_B = 0.1mA, 0.3mA and 0.5mA.

Determine α and β from the curves for the following values of I_B and V_{CE} :I_B = 0.1mA, 0.3mA and 0.5mA at V_{CE} = 1V and V_{CE} = 2.5V. Compare with experimental result.

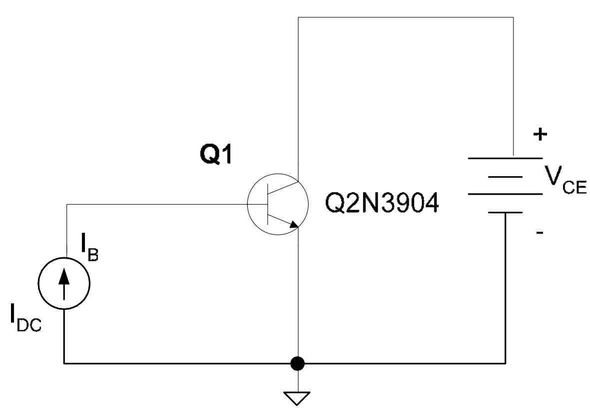


Figure 2

B. DC Current Gain β versus collector current I_C and I_B

Use the same circuit shown in Figure 2. Set V_{CE} = 5V. Select *Analysis* → *Setup* → *DC Sweep*. Sweep for I_B from 100µA to 1mA in *DECADES* with 20 points per decade. Run the simulation. Plot the trace IC(Q1)/IB(Q1) versus IB. Also plot IC(Q1)/IB(Q1) versus IC.

Find, from second plot, the maximum DC current gain. Find the corresponding I_B and I_C. Determine α at calculated I_C.

C. β versus Temperature

Circuit for this analysis is shown in Figure 2. Consider V_{CE} = 5V.You can generate β versus I_C curves at different temperatures. This is a typical curve found in most data sheets for BJTs.

Select *Analysis* → *Setup* → *DC Sweep*. Sweep for I_B from 100µA to 1mA in *DECADES* with 20 points per decade. Click on the *Nested Sweep* button and set values -25, 25,125 Celsius. Mark 'X' in the *Enable Nested Sweep* box. Run the simulation. Generate a plot of β versus I_C.

At what I_C the β is maximum?

Note: If you find difficulty in identifying the curves, you should run each case separately and verify the identity of each curve. Put label on the plot to identify each curve.

ATTACH ALL NECESSARY PRINT OUT OF YOUR PROBE WITH COMMENTS.

DATA SHEET FOR TRANSISTOR

A partial data sheet for the 2N3903 and 2N3904 *npn* transistors is shown in Figure 4. Notice that the maximum collector-emitter voltage (V_{CEO}) is 40V. The CEO subscript indicates that the voltage is measured from collector (C) to emitter(E) with the base open (O). In the text we use $V_{CE(max)}$ for clarity. Also notice that the maximum collector current is 200mA. The collector-emitter saturation voltage, $V_{CE(sat)}$ is 0.2 V maximum for $I_{C(sat)}$=10 mA and increases with the current.

The β_{DC} (DC current gain) is specified for several values of I_C and it is worth discussing.

About β_{DC}

The β_{DC} is an important bipolar transistor parameter that we need to examine. β_{DC} varies with both collector current and temperature. Keeping the junction temperature constant and increase in I_C causes β_{DC} to increase to a maximum. A further increase in I_C beyond this point causes β_{DC} to decrease. If I_C is held constant and the temperature is varied, β_{DC} changes directly with the temperature. If the temperature goes up, β_{DC} goes up and vice versa.

2N3904

SMALL SIGNAL TRANSISTORS (NPN)

MAXIMUM RATINGS AND ELECTRICAL CHARACTERISTICS

Ratings at 25°C ambient temperature unless otherwise specified

	SYMBOL	VALUE	UNIT
Collector-Base Voltage	V_{CBO}	60	V
Collector-Emitter Voltage	V_{CEO}	40	V
Emitter-Base Voltage	V_{EBO}	6.0	V
Collector Current	I_C	200	mA
Power Dissipation at T_A = 25°C at T_C = 25°C	P_{tot}	625 1.5	mW W
Thermal Resistance Junction to Ambient Air	$R_{\theta JA}$	250(1)	°C/W
Junction Temperature	T_j	150	°C
Storage Temperature Range	T_S	– 65 to +150	°C

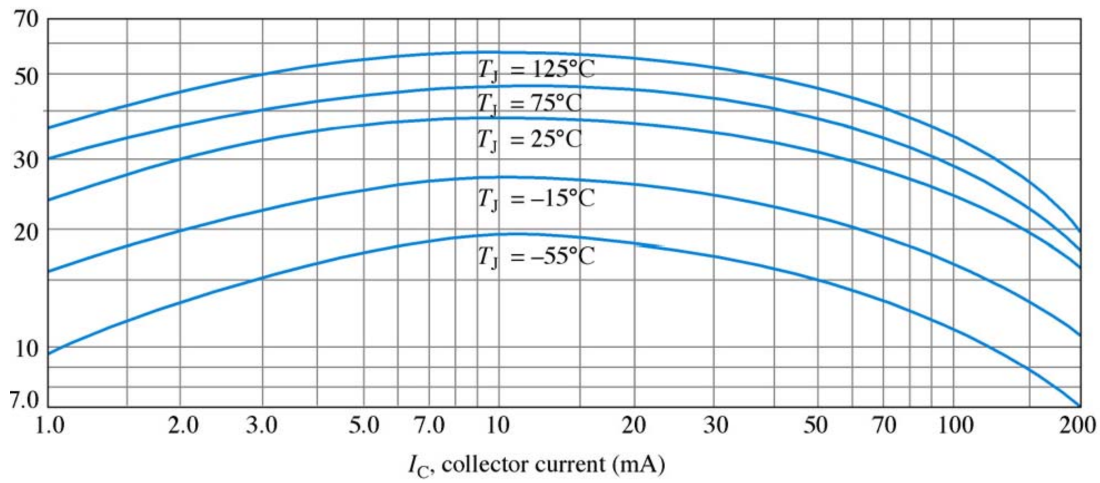
NOTES:
(1) Valid provided that leads are kept at ambient temperature.

Collector-Base Breakdown Voltage at I_C = 10 μA, I_E = 0	$V_{(BR)CBO}$	60	–	V
Collector-Emitter Breakdown Voltage at I_C = 1 mA, I_B = 0	$V_{(BR)CEO}$	40	–	V
Emitter-Base Breakdown Voltage at I_E = 10 μA, I_C = 0	$V_{(BR)EBO}$	6	–	V
Collector Saturation Voltage at I_C = 10 mA, I_B = 1 mA at I_C = 50 mA, I_B = 5 mA	 V_{CEsat} V_{CEsat}	 – –	 0.2 0.3	 V V
Base Saturation Voltage at I_C = 10 mA, I_B = 1 mA at I_C = 50 mA, I_B = 5 mA	 V_{BEsat} V_{BEsat}	 – –	 0.85 0.95	 V V
Collector-Emitter Cutoff Current V_{EB} = 3 V, V_{CE} = 30 V	I_{CEV}	–	50	nA
Emitter-Base Cutoff Current V_{EB} = 3 V, V_{CE} = 30 V	I_{EBV}	–	50	nA
DC Current Gain at V_{CE} = 1 V, I_C = 0.1 mA at V_{CE} = 1 V, I_C = 1 mA at V_{CE} = 1 V, I_C = 10 mA at V_{CE} = 1 V, I_C = 50 mA at V_{CE} = 1 V, I_C = 100 mA	 h_{FE} h_{FE} h_{FE} h_{FE} h_{FE}	 40 70 100 60 30	 – – 300 – –	 – – – – –

Figure 4 Partial transistor data sheet

Figure below shows the variation of β_{DC} with $\boldsymbol{I_C}$ and junction temperature (T_j) for a typical transistor.

A transistor data sheet usually specifies β_{DC} (h_{FE}) at specific $\boldsymbol{I_C}$ values. Even at fixed values of $\boldsymbol{I_C}$ and temperature, β_{DC} varies from device to device for a given transistor due to inconsistencies in the manufacturing process that are unavoidable. The β_{DC} specified at a certain values of $\boldsymbol{I_C}$ is usually the minimum value, $\beta_{DC(min)}$, although the maximum and typical values are also sometimes specified.



Maximum Transistor Ratings

A transistor like any other electronic device has limitations on its operation. These limitations are stated in the form of maximum ratings and are normally specified on the manufacturer's data sheet as shown in Figure 4. Typical maximum ratings are given for collector-to-base voltage, collector-to-emitter voltage, collector current and power dissipation. The product of V_{CE} and $\boldsymbol{I_C}$ must not exceed the maximum power dissipation ($P_{tot(max)}$). Both V_{CE} and $\boldsymbol{I_C}$ cannot be maximum at the same time. $P_{tot(max)}$ is usually specified at 25^0C. For Higher temperature, $P_{tot(max)}$ is less. Data sheets often give derating factors for determining $P_{tot(max)}$ at any temperature above 25^0C. For example, a derating factor of $2mW/^0C$ indicates that the maximum power dissipation is reduced 2 mW for each centigrade degree increase in temperature

DEMO: Transistor curve Tracer

Your instructor will introduce you to the different functions of the transistor curve tracer for testing transistor's characteristics. Instructors display both I_C-V_{BE} and I_C-V_{CE}.