Experiment No.7

Characteristics of Bipolar Junction

Object

The purpose of this experiment is to determine and graph the input and output characteristics of a bipolar junction transistor (BJT) in the common emitter configuration, and to measure its h-parameters at a given DC bias point.

Required Parts and Equipment's

1. Electronic Test Board. (M90)
2. Dual DC Power Supply.
3. Digital Multi-meters.
4. NPN Transistors (BC337).
5. Resistors 33kΩ,120Ω
6. Leads and Wires.

Theory

A bipolar junction transistor (BJT) is a three-terminal device capable of amplifying a small AC signal. The three terminals are called the base, emitter, the collector. BJTs consist of a very thin base material sandwiched between two of the opposite type materials. Bipolar transistors are available in two forms, either NPN or PNP. The middle letter indicates the type of material used for the base, while the outer letters indicate the emitter and collector terminals. The emitter is heavily doped, the base is lightly doped, and the collector is intermediately doped. Fig.1 shows BJT transistor construction and symbols.

As shown in Fig.1, two P-N junctions are formed when a transistor is made, the junction between the base and emitter, and the junction between the base and collector. These two junctions form two diodes, the emitter-base diode and the collector-base diode.

There are three configurations in connecting the BJT depending on which of the three terminals is used as the common terminal. These configurations are the common emitter (CE), the common base (CB), and the common collector (CC).

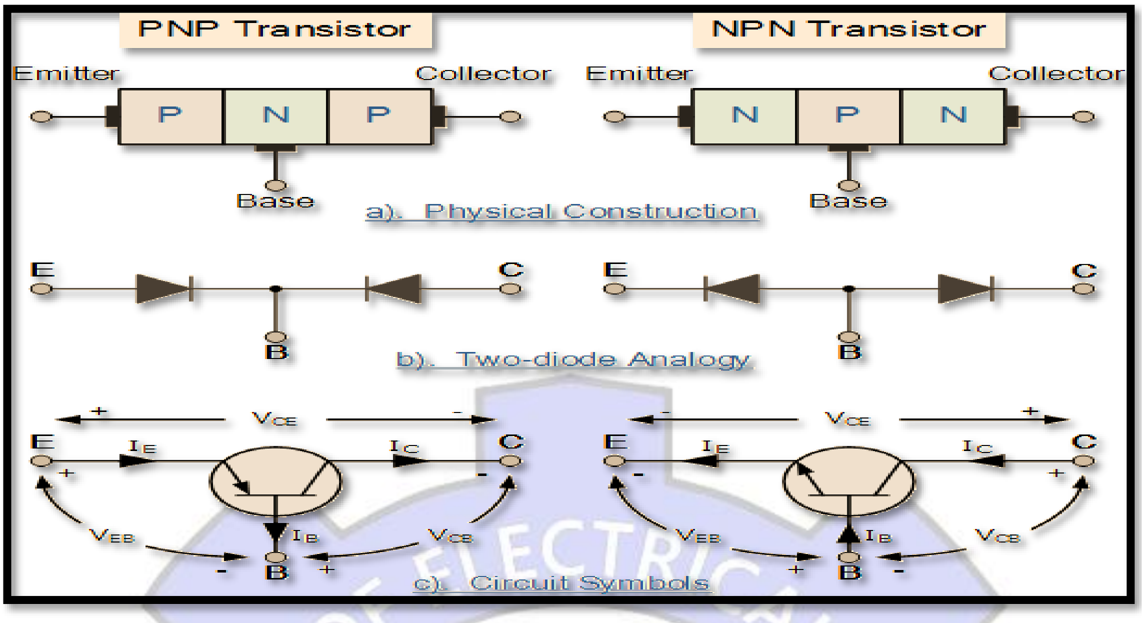

Figure 1: Types of BJT Transistors

Common emitter configuration is most effective because of its high current gain, high voltage gain and power gain. In common emitter configuration, emitter terminal is made common to both input and output circuits as shown in Fig.2. Input junction (Emitter-Base Junction) is forward biased and output junction (Collector-Base Junction) is reverse biased so that the input junction is having low resistance (since it is forward biased) and the output junction is having high resistance (since it is reverse biased).

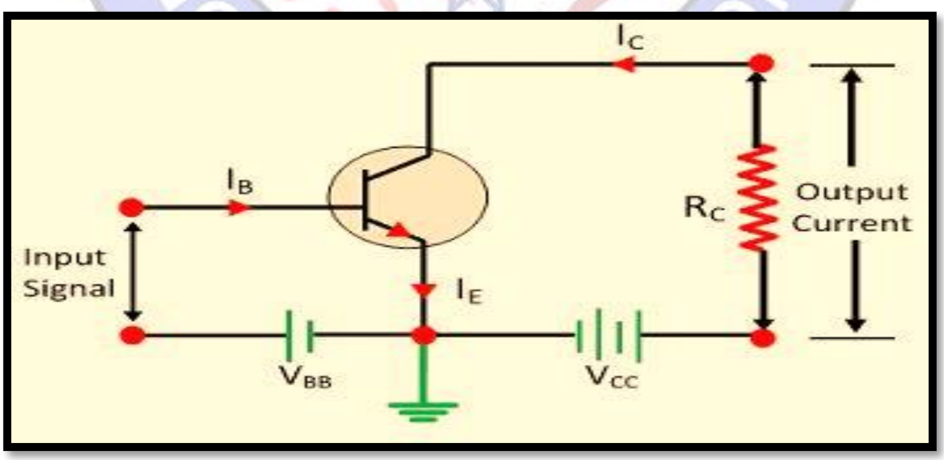

Figure 2: Common Emitter Transistor Configuration

Bipolar transistors are primarily current amplifiers. In the CE configuration, a small base current is amplified to a larger current in the collector circuit. The ratio of the DC collector current I_C to the DC base current $I_B$is called the DC beta (β_{dc}) of the transistor. Thus:

$$\boxed{\beta_{dc} = \frac{I_C}{I_B}}$$

Typical values of β_{dc} range from 20 to 250 or higher. β_{dc} is usually designated as h_{FE}in transistor datasheets. Hence:

$$\boxed{h_{FE}=\beta_{dc}}$$

Another useful parameter in bipolar transistors is the DC alpha (α_{dc}). It is defined as the ratio of the DC collector current I_C to the DC emitter current I_E. Thus:

$$\boxed{\alpha_{dc} = \frac{I_C}{I_E}}$$

Typically, values of αdc range from 0.95 to 0.99, but αdc is always less than 1.

- **Common Emitter Input and Output Characteristics**

Two sets of characteristics are necessary to describe fully the behavior of the common emitter configuration: the input (or base) characteristics, and the output (or collector) characteristics. Input characteristics of a transistor are curves showing the variation of input (base) current IB as a function of input (base-emitter) voltage V_{BE}, when the output (collector-emitter) voltage VCE is kept constant. Fig.3 depicts the input characteristics for a typical transistor.

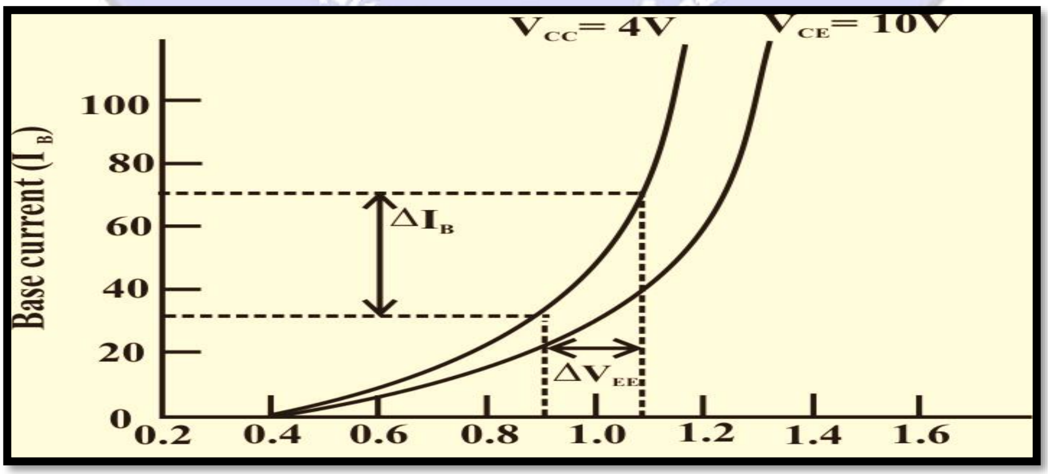

Figure 3: Typical Input Characteristics of a Silicon NPN Transistor in the Common Emitter Configuration

As shown from Fig.3, the input characteristics are similar to that of a forward-biased diode since the emitter-base junction is forward-biased. Note also the slight shift in the curves when increasing V_{CE}.

Output characteristics of a transistor are curves showing the variation of the output current I_C as a function of output voltage V_{CE}, when the input current I_B is kept constant. Fig.4 depicts the output characteristics for a typical transistor.

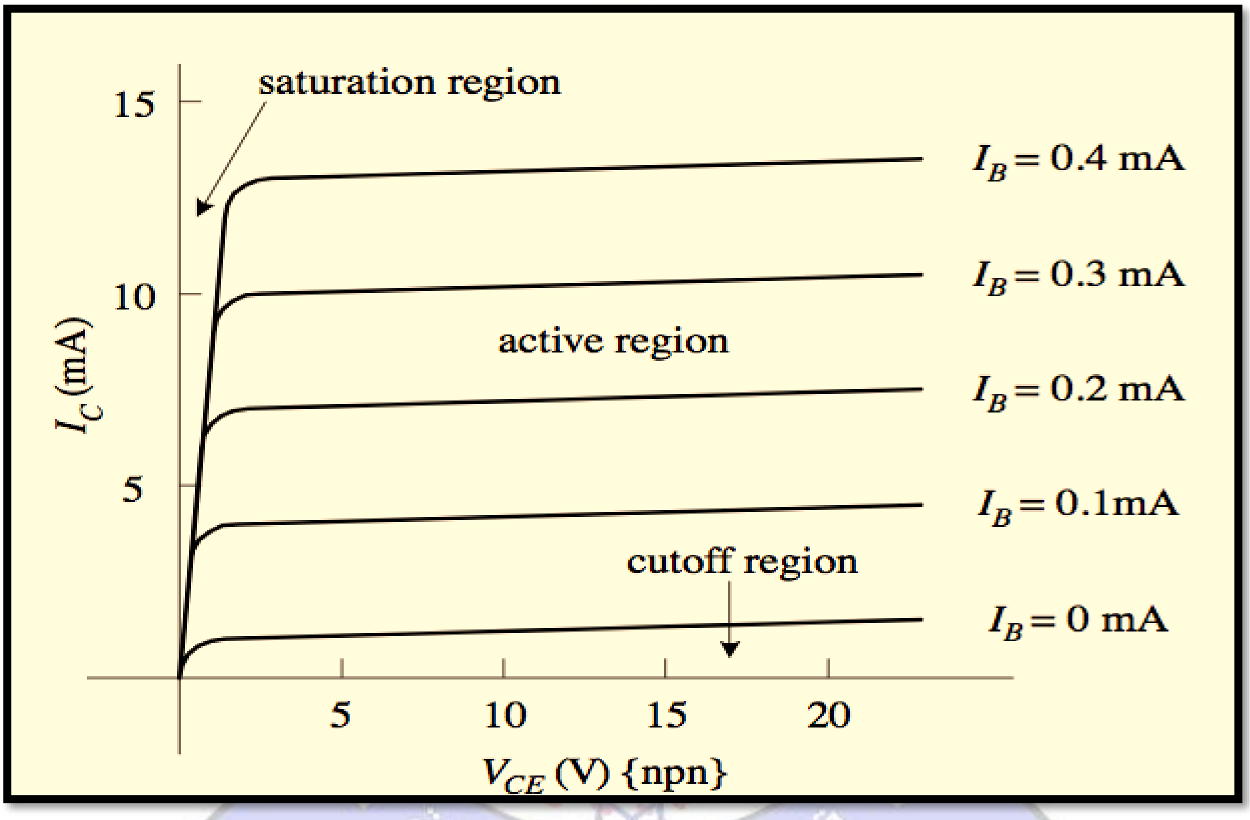

Figure 4: Typical Output Characteristics of a Silicon NPN Transistor in the Common Emitter Configuration

As shown from Fig.4, for very small values of V_{CE} the collector-base junction is forward biased and the transistor is in the saturation region. In this portion of the curves, I_C is increased linearly with V_{CE}. As V_{CE} increases, the collector-base junction becomes reverse-biased and the transistor goes into the active region. In this portion of the curves, I_C remains essentially constant (for a given value of I_B) as V_{CE} continues to increase. Actually, I_C increases very slightly as V_{CE} increases due to widening of the collector-base depletion region. For this portion of the characteristic curves, the value of I_C is only determined by the expression:

$$\boxed{I_C = \beta_{dc} I_B}$$

Fig.5 shows a common emitter circuit that can be used to generate the input and output characteristic curves. The purpose of RB in this circuit is to limit the base current to a safe level.

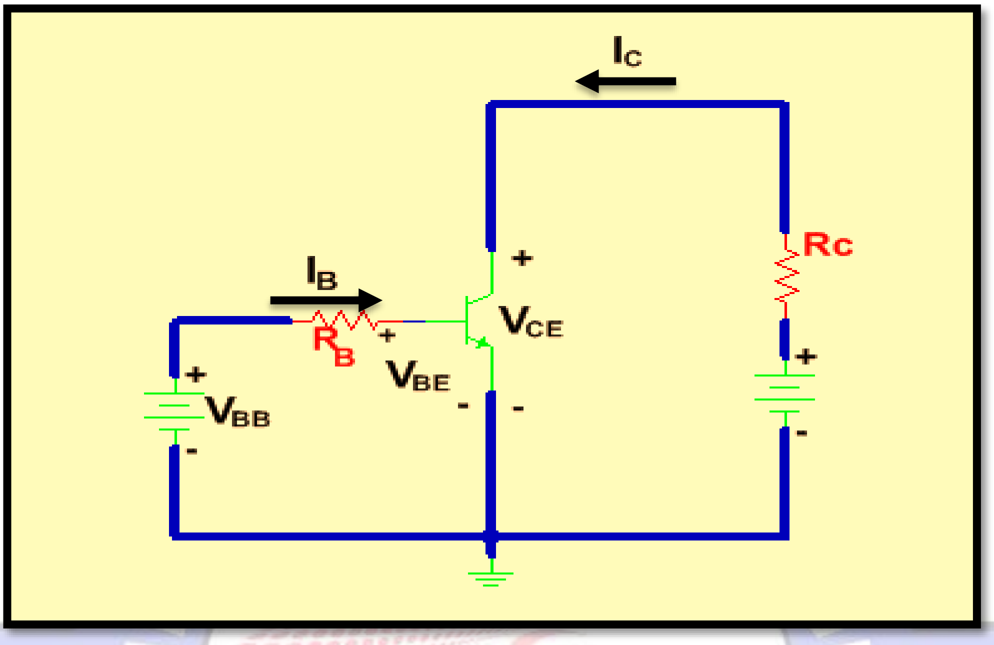

Figure 5: Test Circuit used to generate the Common Emitter Input and Output Characteristics

- **Transistor h-parameters**

In order to analyze transistor amplifier operation, an AC small signal model for the BJT is required. The most widely used equivalent circuit model to describe the transistor behavior at low and mid-band frequencies is the h-parameter model. For the common emitter configuration, when the transistor is considered as a linear two port network, the input small signal AC voltage (v_{be}) and the output small signal AC current (i_c) can be expressed in terms of the input current (i_b) and output voltage (v_{ce}) by the following equations:

$$\boxed{\begin{aligned} v_{be} &= h_{ie}.i_b + h_{re}.v_{ce} \\ i_c &= h_{fe}.i_b + h_{oe}.v_{ce} \end{aligned}}$$

The common emitter hybrid parameters in equation 4 are defined as:

h_{ie}= input resistance =$\frac{v_{be}}{i_b}\Big|_{v_{ce=0}}$

h_{re}= reverse transfer voltage ratio =$\frac{v_{be}}{v_{ce}} \Big|_{i_{b=0}}$

h_{fe}= forward transfer current ratio =$\frac{i_c}{i_b} \Big|_{v_{ce=0}}$

h_{oe}= output conductance = $\frac{i_c}{v_{ce}} \Big|_{i_{b=0}}$

The unit of h_{ie} is the Ohm, and that of h_{oe} is the Siemens, while hfe and hre are unit-less. This versatility in the units is the reason behind the name of the hybrid parameters.

Fig.6 shows the small-signal AC equivalent circuit of the transistor in the common emitter configuration.

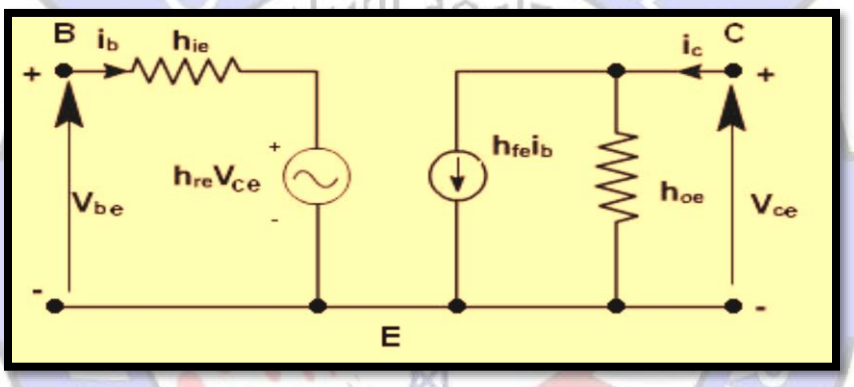

Figure 6: Common Emitter Transistor Hybrid Equivalent Circuit Model

The h-parameters of the transistor can be determined graphically from its input and output characteristics. The parameters h_{ie} and hre are determined from the input (or base) characteristics, while the parameters h_{fe} and h_{oe} are obtained from the output (or collector) characteristics.

Fig.7 presents the method of finding the input resistance h_{ie} graphically at the specified Q-point of the transistor. It should be noted that h-parameters depend on the specific operating point (Q-Point) of the transistor. As observed from the figure, h_{ie} is determined from the equation:

$$\boxed{h_{ie} = \frac{\Delta V_{BE}}{\Delta I_B} \Big|_{V_{CE=const.}}}$$

The small increments ΔI_B and ΔV_{BE} should be taken around the Q-point as depicted in Fig.7.

The parameter h_{re} can also be obtained from the input characteristics as shown in Fig.8. In this case:

$$\boxed{h_{re} = \frac{\Delta V_{BE}}{\Delta V_{CE}} \Big|_{I_{B=const.}}}$$

The base current I_B should be taken as the Q-point operating value I_{BQ}. The parameter h_{re} is very low and can be ignored in most practical cases.

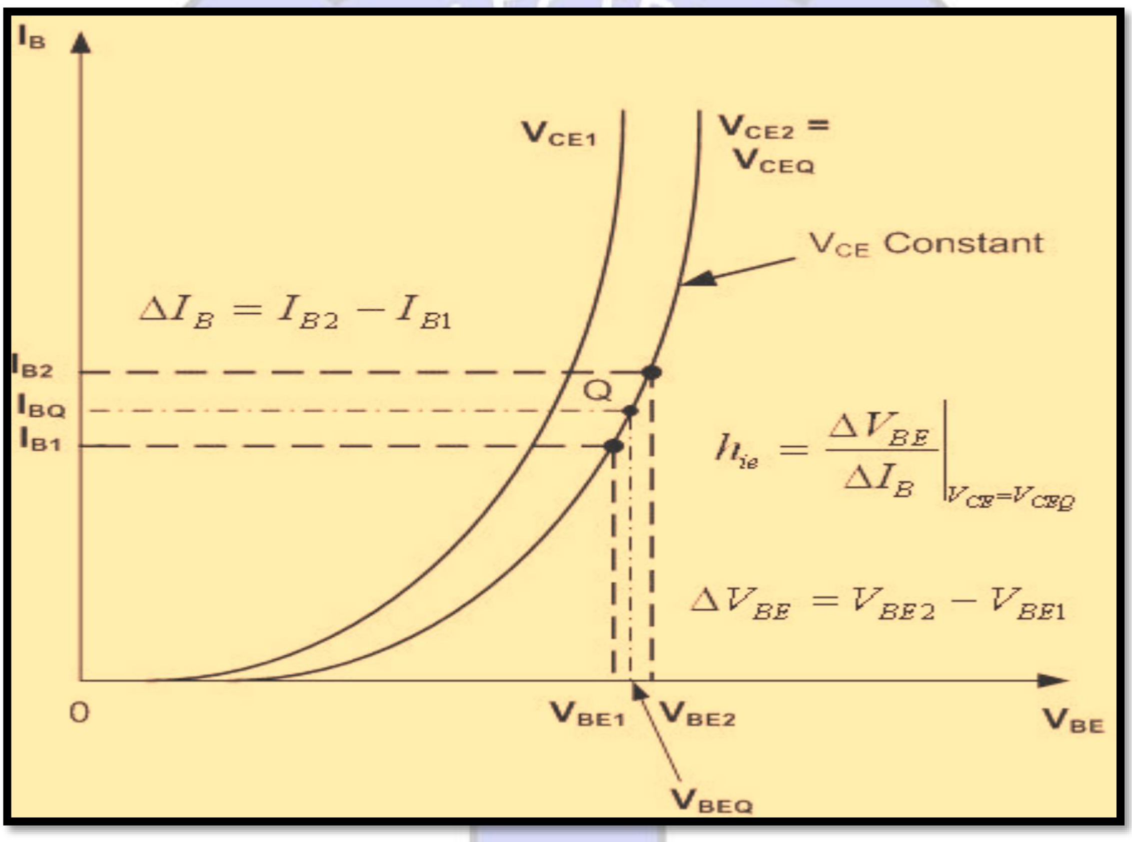

Figure 7: Graphical Determination of h_{ie} from the Input Characteristics

The small signal current gain h_{fe} can be determined from the output characteristics of the transistor as shown in Fig.9. As shown from this figure, h_{fe} can be found from:

$$\boxed{h_{fe} = \frac{\Delta I_C}{\Delta I_B} \Big|_{V_{CE=const.}}}$$

Actually, h_{fe} represents the AC beta of the transistor:

$$h_{fe} = \beta_{ac}$$

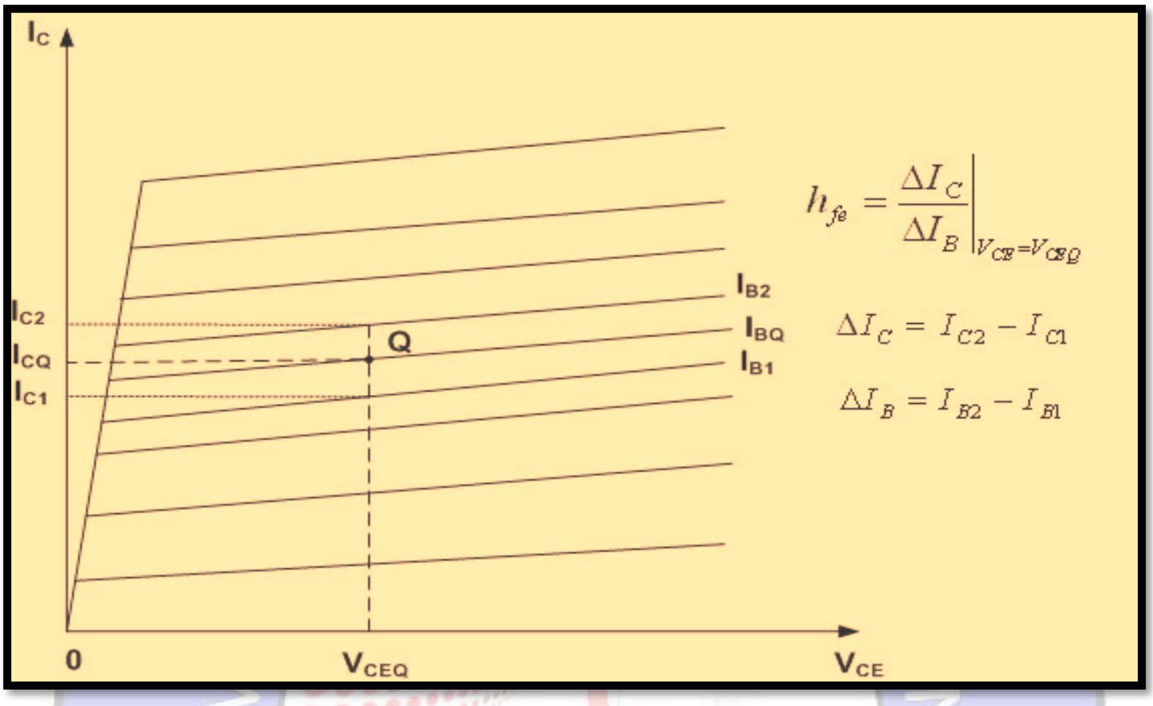

Figure 9: Graphical Determination of h_{fe} from the Output Characteristics

If I_C is plotted against I_B for a given V_{CE}, then an approximate linear relation can be obtained in the active region of the transistor as shown in Fig.10.

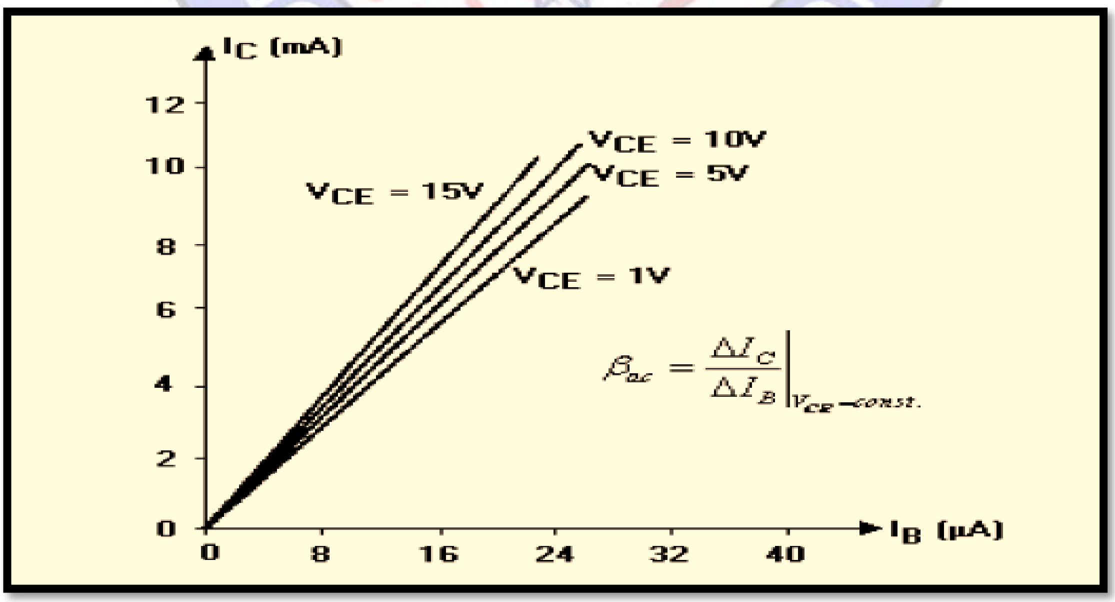

Figure 10: I_C versus I_B for a Typical Transistor in the Active Region

The output conductance h_{oe} can also be gotten from the output characteristics of the transistor at a specific Q-point as shown in Fig.11. In this case:

$$h_{oe} = \frac{\Delta I_C}{\Delta V_{CE}} \Big|_{I_{B=const.}}$$

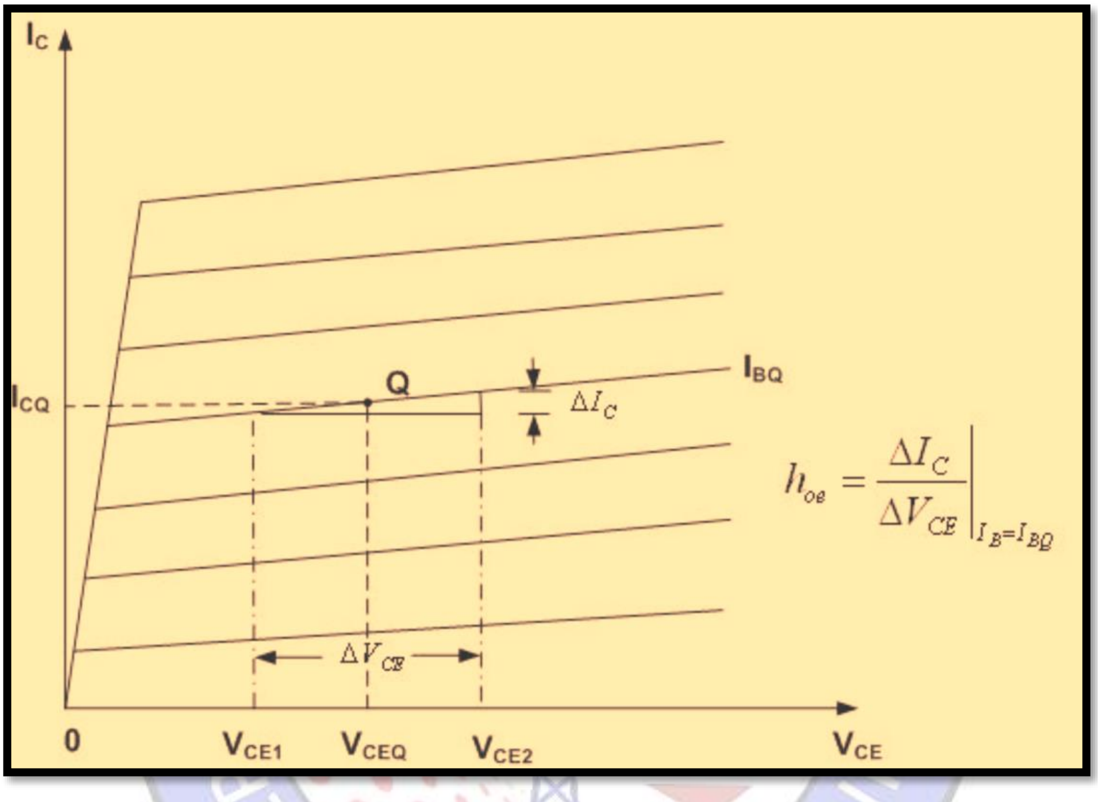

Figure 11: Graphical Determination of hoe from the Output Characteristics

Procedure

1. Connect the common emitter test circuit shown in Fig.12. Try to identify the leads of the BC337 transistor correctly. It is built in a M90 package as depicted in Fig.12.
2. Set $V_{CE} = 0V$, and increase the base current I_B in several steps from 0 to 100µA by varying the DC supply voltage V_{BB}, and record V_{BE} in each step as shown in Table-1.
3. Reduce V_{BB} to 0V and set $V_{CE} = 5V$ by adjusting the DC power supply V_{CC}. Increase I_B from 0 to 100µA (by slowly increasing V_{BB}) in several steps and record V_{BE}. V_{CE} should be kept constant at 5V in each step by adjusting V_{CC}.

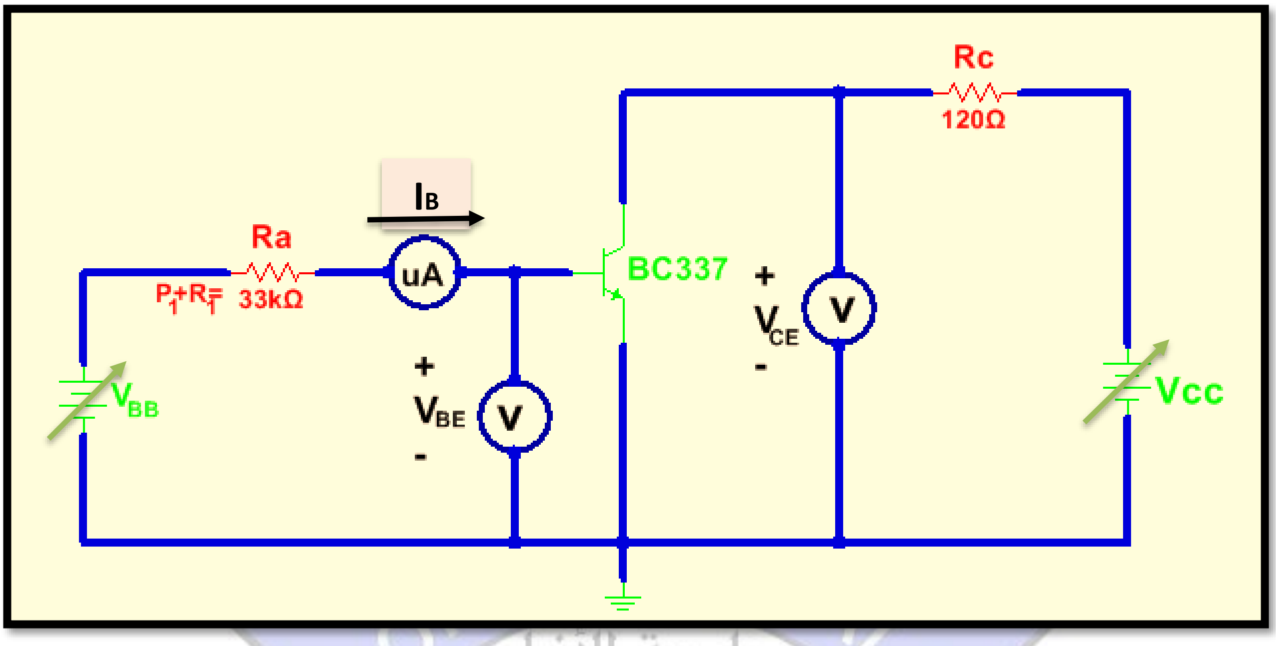

Figure 12: Transistor Test Circuit Used to obtain the Input Characteristics

V_{CE} = 0V		V_{CE} = 5V	
I_B(µA)	V_{BE}(V)	I_B(µA)	V_{BE}(V)
0		0	
10		10	
20		20	
30		30	
40		40	
50		50	
60		60	
70		70	
80		80	
90		90	
100		100	

Table-1: Recorded Data for the Transistor Input Characteristics

4. Connect the circuit shown in Fig.13 to obtain the output characteristics of the transistor.

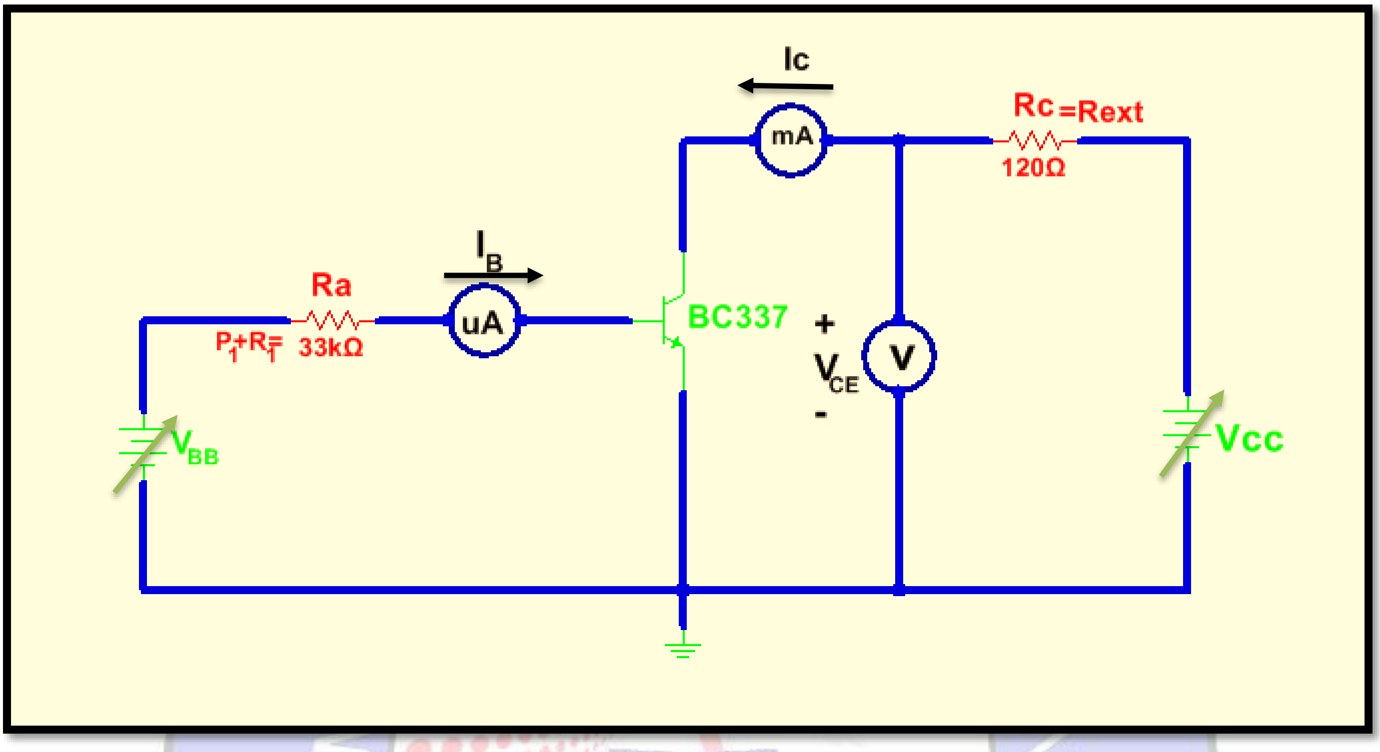

Figure 13: Transistor Test Circuit Used to obtain the Output Characteristics

5. Start with both power supplies set to 0V. Slowly increase V_{BB} until $I_B = 20\mu A$. Now slowly increase V_{CC} in several steps and record V_{CE} and I_C in each step as shown in Table-2.
6. Repeat step 5 for base current values of 40μA, and 60μA respectively. Record data as illustrated in Table-2.

$I_B(\mu A) = 20$		$I_B(\mu A) = 40$		$I_B(\mu A) = 60$	
V_{CE}(V)	I_C (mA)	V_{CE}(V)	I_C (mA)	V_{CE}(V)	I_C (mA)
0		0		0	
0.1		0.1		0.1	
0.2		0.2		0.2	
0.4		0.4		0.4	
0.6		0.6		0.6	

0.8		0.8		0.8	
1		1		1	
3		3		3	
5		5		5	
8		8		8	
10		10		10	

Table-2: Recorded Data for the Transistor Output Characteristics

Discussion

1. From the obtained data in Table-1, plot the input characteristic curves of the transistor.
2. Sketch the three output characteristic curves of the transistor from the results obtained in Table-2.
3. Find the *h-parameters* of the transistor at $I_B = 40\mu A$ and $V_{CE} = 5V$ from the plotted input and output characteristics.
4. Use the plotted characteristic curves to determine the DC current gain β_{dc} for the transistor at $V_{CE} = 3.0V$ and base current of 20µA, 40µA, and 60µA respectively. Repeat for $V_{CE} = 5.0V$. Tabulate your results as illustrated in Table-3 below.
5. Does the experimental data indicate that β_{dc} is constant at all points? Does this have any effect on the linearity of the transistor? What effect would a higher β_{dc} have on the characteristic curves you measured?
6. What is the maximum power dissipated in the transistor for the data taken in the experiment?
7. Show that the DC alpha of the transistor is given by: 1+

   $$\alpha_{dc} = \frac{\beta_{dc}}{\beta_{dc} + 1}$$

   Compute α_{dc} for your transistor at $V_{CE} = 5.0V$ and $I_B = 40\mu A$.

8. What value of V_{CE} would you expect if the base terminal of the transistor is opened? Explain your answer.