Lab Report: Experiment 6

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Experiment:
Plot the input and output
characteristics of CE, CB, and CC configurations
of BJT by plotting the family of curves obtained.

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1 Aim

Plot the input and output characteristics of CE, CB, and CC configiutartions of BJT by plotting the family of curves obtained.

2 Theory

2.1 Preliminaries

The BJT is a three-terminal device with currents I_E, I_B and I_C satisfying

$$I_E = I_B + I_C. \tag{1}$$

A widely used model (valid for forward- and reverse-active operation) is the Ebers–Moll model. In the forward-active regime, the collector current can be approximated by the diode-like expression

$$I_C \approx I_S \exp\left(\frac{V_{BE}}{V_T}\right) \qquad \text{(for } V_{BE} \geq 100\,\text{mV}), \tag{2}$$

where I_S is the transistor saturation current and $V_T = kT/q \approx 25.85\,\text{mV}$ at room temperature (300 K). More generally, when the transistor is biased in forward-active region with a finite collector-base reverse bias, the practical relation is

$$I_C = \beta_F I_B \approx \beta I_B \tag{3}$$

where β_F (or simply β) is the forward DC current gain. The emitter current follows from (1). In small-signal linearized analysis, the transconductance is

$$g_m = \frac{\partial I_C}{\partial V_{BE}} = \frac{I_C}{V_T}. \tag{4}$$

Two limiting operating regions are important:

- **Active region:** Base-emitter forward biased, base-collector reverse biased. Collector current is approximately controlled by V_{BE} (or I_B) and weakly depends on V_{CE} (finite output resistance).
- **Saturation region:** Both junctions forward biased. The transistor cannot sustain normal current gain and I_C falls below βI_B; the device behaves like two forward diodes and the collector voltage drops near the emitter voltage.

2.2 Common-Emitter (CE) configuration

Definitions: For CE, the *input* variables are V_{BE} (or I_B) and the *output* variables are I_C and V_{CE}. The standard plots are:

1. *Input characteristic:* I_B vs V_{BE} at several fixed values of V_{CE}.
2. *Output characteristic:* I_C vs V_{CE} for several fixed values of I_B.

Input characteristic (CE): Using the diode-like behavior of the base-emitter junction, the input curve is exponential:

$$I_B \propto I_{S,B} \exp\left(\frac{V_{BE}}{V_T}\right), \qquad \text{(approx.)} \tag{5}$$

where $I_{S,B}$ is an effective saturation parameter for the base-emitter junction that depends on geometry and doping. Thus the plot of I_B vs V_{BE} is a steeply rising exponential (on linear axes) or nearly linear on a semilog plot.

Output characteristic (CE): In forward-active region, for a given I_B the collector current is approximately constant with V_{CE}:

$$I_C \approx \beta I_B \quad \text{(flat region)}, \tag{6}$$

but with a slight slope due to the Early effect (modulation of the effective base width by V_{CE}). A common empirical model for the Early effect is

$$I_C(V_{CE}) \approx I_{C0}\left(1 + \frac{V_{CE}}{V_A}\right) \tag{7}$$

where V_A is the Early voltage (often tens to hundreds of volts). Equation (7) explains why output curves are not perfectly horizontal but have a small positive slope.

The typical regions seen on the CE output plot are:

- **Cutoff:** When V_{BE} is too small, both I_B and I_C are near zero.
- **Active:** I_C nearly constant with V_{CE} (supply-limited by I_B and β), small slope due to Early effect.
- **Saturation:** For small V_{CE} (below $V_{CE(sat)} \sim 0.1$–$0.3\,\text{V}$), I_C collapses and curves bend downward; $I_C < \beta I_B$.

2.3 Common-Base (CB) configuration

Definitions: For CB, the base is common and usually grounded; the *input* is the emitter (voltage V_{EB} or current I_E) and the *output* is the collector (I_C vs V_{CB}). The CB configuration emphasizes current gain $\alpha = I_C/I_E$ rather than β.

Input characteristic (CB): The emitter-base junction behaves like a forward diode so the emitter current depends exponentially on V_{EB}:

$$I_E \propto I_{S,E} \exp\left(\frac{V_{EB}}{V_T}\right) \tag{8}$$

As in CE, at large currents series resistance and high-level injection produce deviations.

Output characteristic (CB): The CB output plot shows I_C vs V_{CB} for fixed I_E. In the active region I_C is nearly constant with V_{CB} (for sufficiently large reverse bias) and equal to αI_E:

$$I_C \approx \alpha I_E\,. \tag{9}$$

The slope with respect to V_{CB} is typically even smaller than in CE (since the collector current is directly controlled by emitter injection and the device exhibits a large intrinsic output resistance in this topology).

2.4 Common-Collector (CC) configuration (Emitter-follower)

Definitions: In CC the collector is common (usually tied to supply); the *input* is the base (voltage V_B or base current I_B) and the *output* is the emitter (voltage V_E or current I_E).

Input characteristic (CC): Because the base-emitter junction still behaves like a diode, the input current I_B depends exponentially on V_{BE} (or $V_B - V_E$). However, when plotting V_E vs I_B or V_B vs I_B, the presence of feedback (emitter follows base minus V$_{BE}$)*changestheapparentslope.*

Output characteristic (CC): A typical plot is emitter voltage V_E versus collector-emitter voltage or versus load conditions. For moderate load changes the emitter tracks the base minus the diode drop:

$$V_E \approx V_B - V_{BE} \approx V_B - 0.7\,\text{V} \quad \text{(approx. for silicon).} \tag{10}$$

If the base is driven by a source, the emitter output moves nearly one-for-one with the base (unity voltage gain less the diode drop), which explains the name emitter-follower. In terms of currents,

$$I_E = (\beta + 1)I_B \quad \Rightarrow \quad I_E/I_B = \beta + 1. \tag{11}$$

Thus a plot of I_E vs I_B is approximately linear with slope $\beta + 1$.

2.5 BJT DC parameters

Parameters involved in BJT calculations,

$$\beta = \frac{I_C}{I_B} \quad \text{(current gain)} \tag{12}$$

$$\alpha = \frac{I_C}{I_E} \quad \text{(current transfer ratio)} \tag{13}$$

$$\tag{14}$$

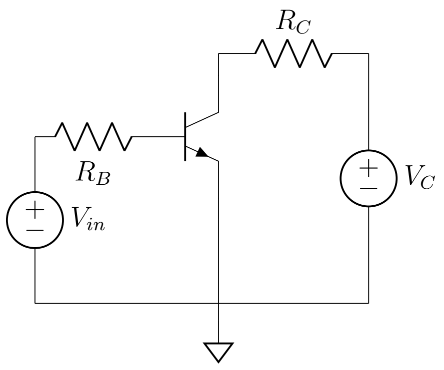
where $V_T = \dfrac{k_B T}{q} = 0.025875V$ at $T = 300K$

3 Experimental Setup

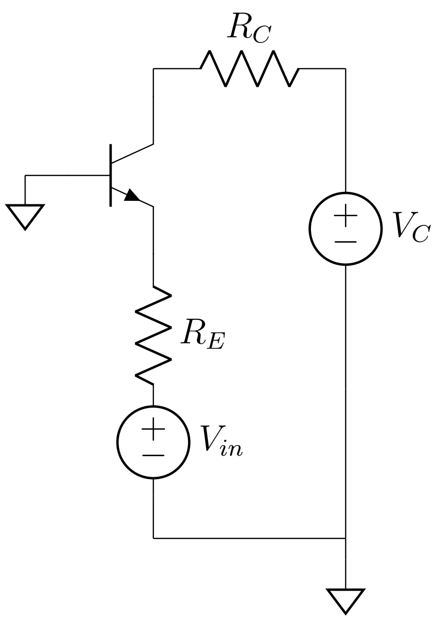
3.1 Circuit

BJT available in the lab was model BC547 (npn), and values of resistance R used are 150Ω everywhere.

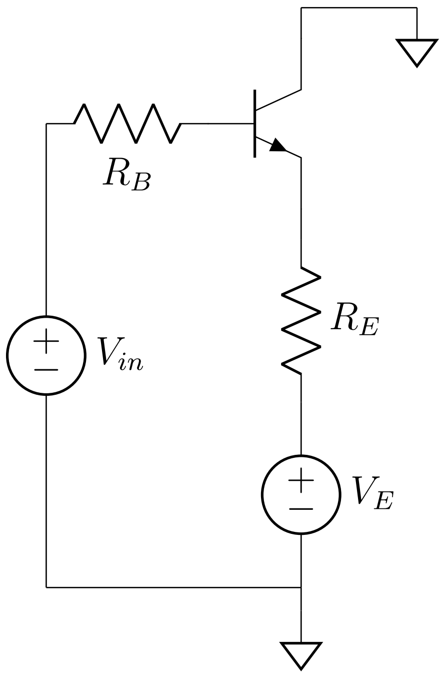
1. Common Emitter



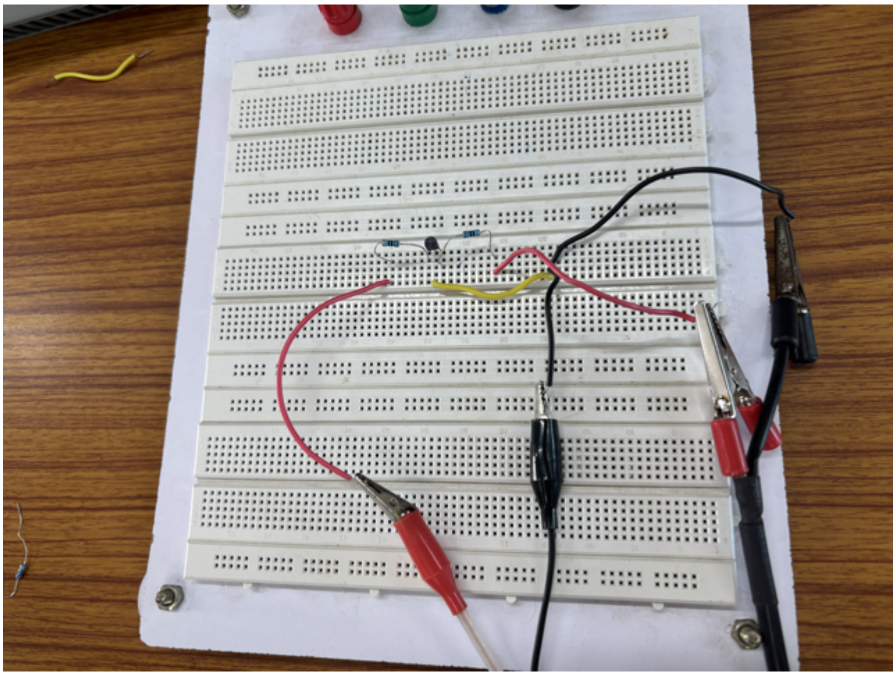
2. Common Base

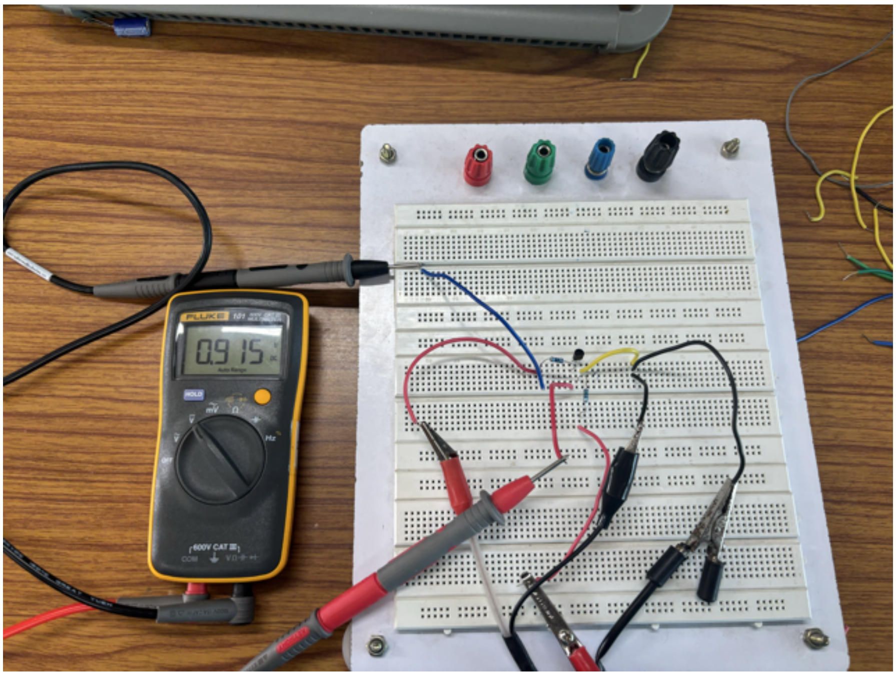


3. Common Collector



Circuit pictures,



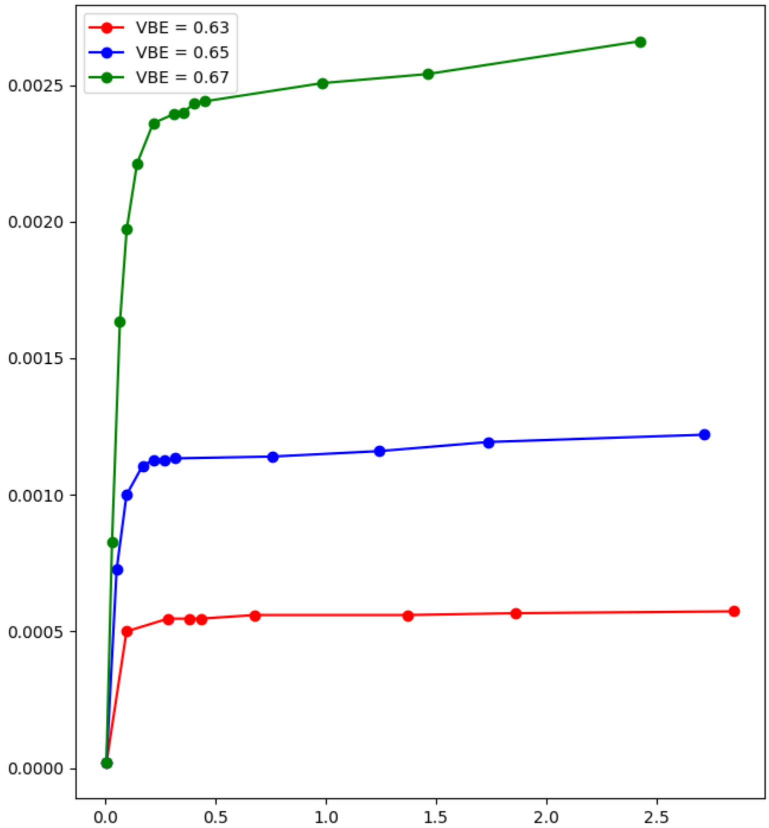


4 Procedure

4.1 Common Emitter Configuration

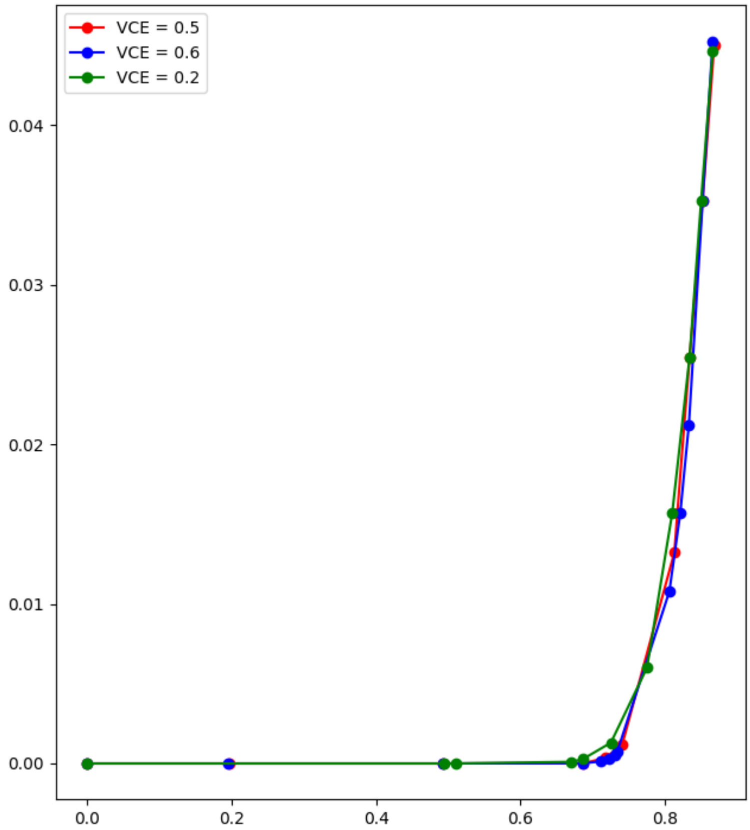
4.1.1 Output Characteristics

1. Connect the circuit as shown in the figure.
2. Keep V_{BE} constant and vary V_{CE} using a multimeter and taking appropriate step size.
3. Repeat the above step for different values of V_{BE} $(0.63, 0.65, 0.67)$ to obtain a family of curves.
4. Since we can't directly measure current with a multimeter measure potential across the R_C (since this is just a scaled version of I_C).
5. Plot the family of I_C vs V_{CE} curves.



4.1.2 Input Characteristics

1. Connect the circuit as shown in the figure.
2. Keep V_{CE} constant and vary V_{BE} using a multimeter and taking appropriate step size.
3. Repeat the above step for different values of V_{CE} $(0.2, 0.5, 0.6)$ to obtain a family of curves.
4. Since we can't directly measure current with a multimeter measure potential across the R_B (since this is just a scaled version of I_B).
5. Plot the family of I_B vs V_{BE} curves.

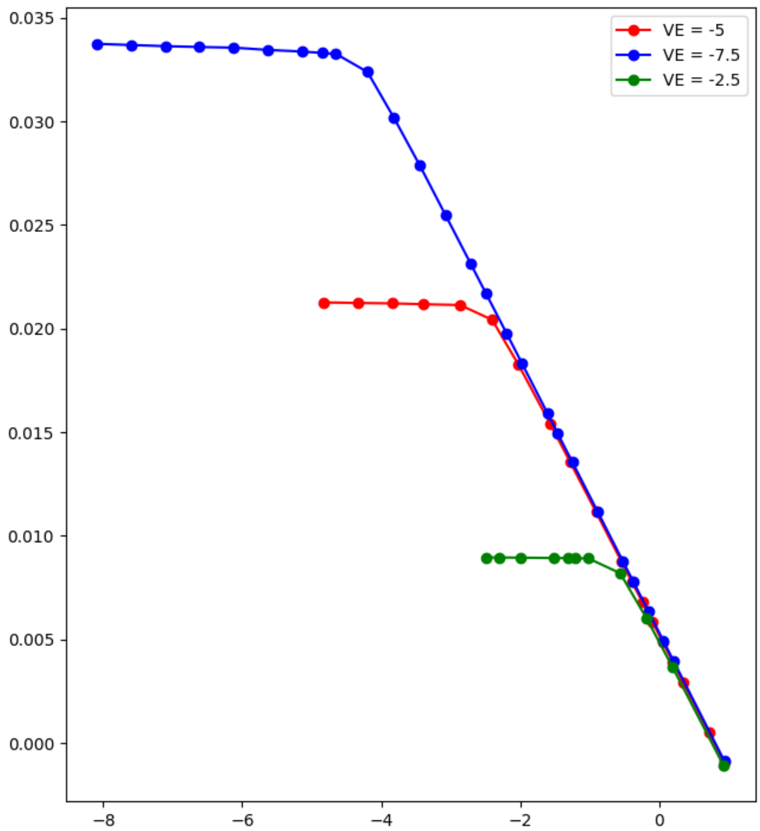


4.2 Common-Base Configuration

4.2.1 Output Characteristics

1. Connect the circuit as shown in the figure.
2. Keep V_{BE} constant and vary V_{CB} using a multimeter and taking appropriate step size.
3. Repeat the above step for different values of V_{BE} $(-2.5, -5, -7.5)$ to obtain a family of curves.
4. Since we can't directly measure current with a multimeter measure potential across the R_C (since this is just a scaled version of I_C).

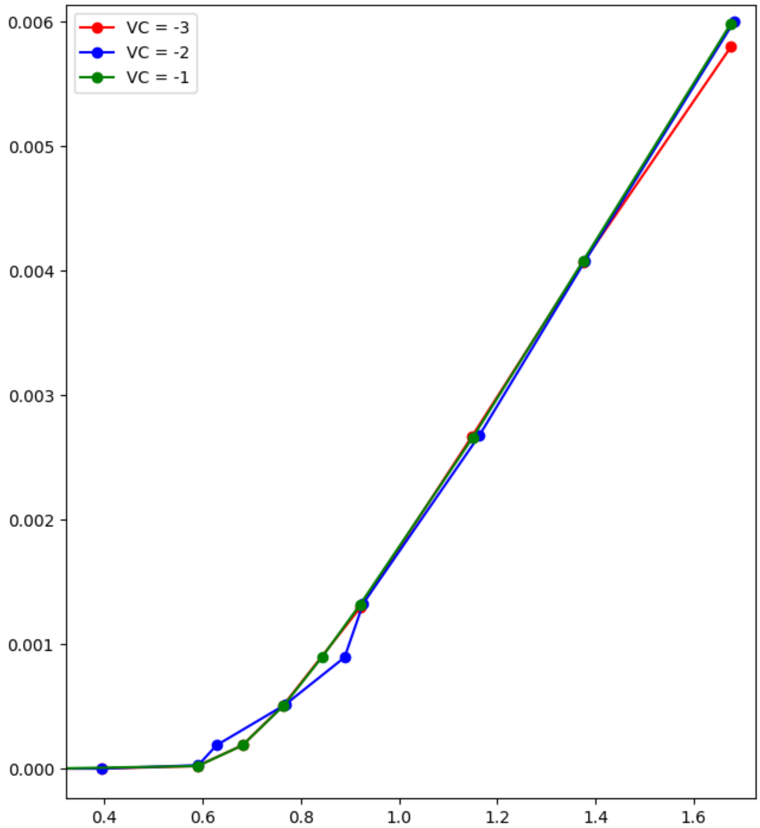
5. Plot the family of I_C vs V_{CB} curves.



4.2.2 Input Characteristics

1. Connect the circuit as shown in the figure.
2. Keep V_{CB} constant and vary V_{BE} using a multimeter and taking appropriate step size.
3. Repeat the above step for different values of V_{CB} $(-1, -2, -3)$ to obtain a family of curves.
4. Since we can't directly measure current with a multimeter measure potential across the R_E (since this is just a scaled version of I_E).

5. Plot the family of I_E vs V_{BE} curves.



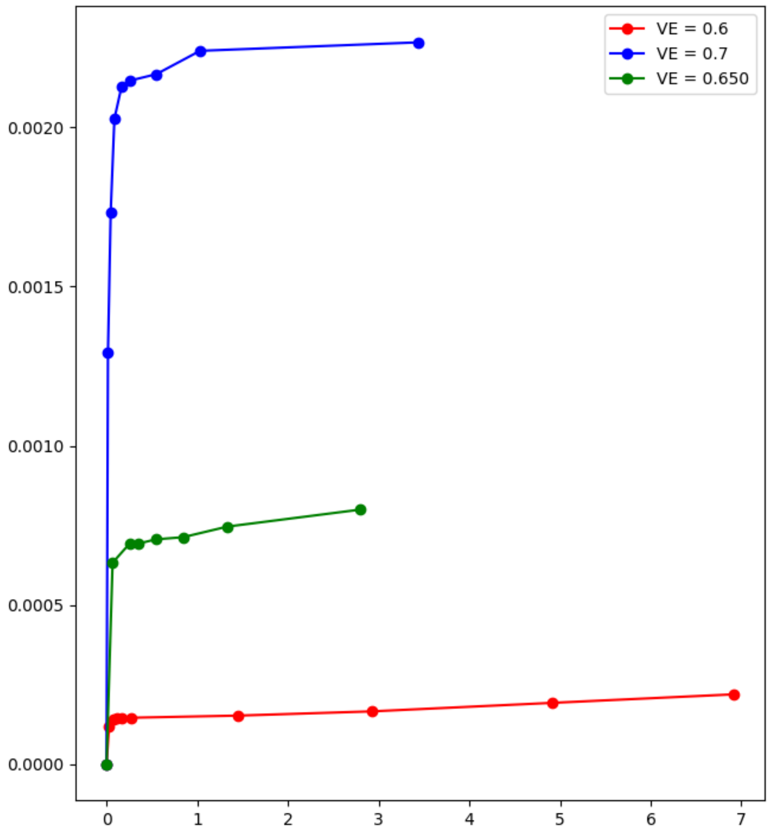
4.3 Common-Collector Configuration

4.3.1 Output Characteristics

1. Connect the circuit as shown in the figure.
2. Keep V_{CB} constant and vary V_{CE} using a multimeter and taking appropriate step size.
3. Repeat the above step for different values of V_{CB} $(0.6, 0.65, 0.7)$ to obtain a family of curves.

4. Since we can't directly measure current with a multimeter measure potential across the R_E (since this is just a scaled version of I_E).

5. Plot the family of I_E vs V_{CE} curves.



4.3.2 Input Characteristics

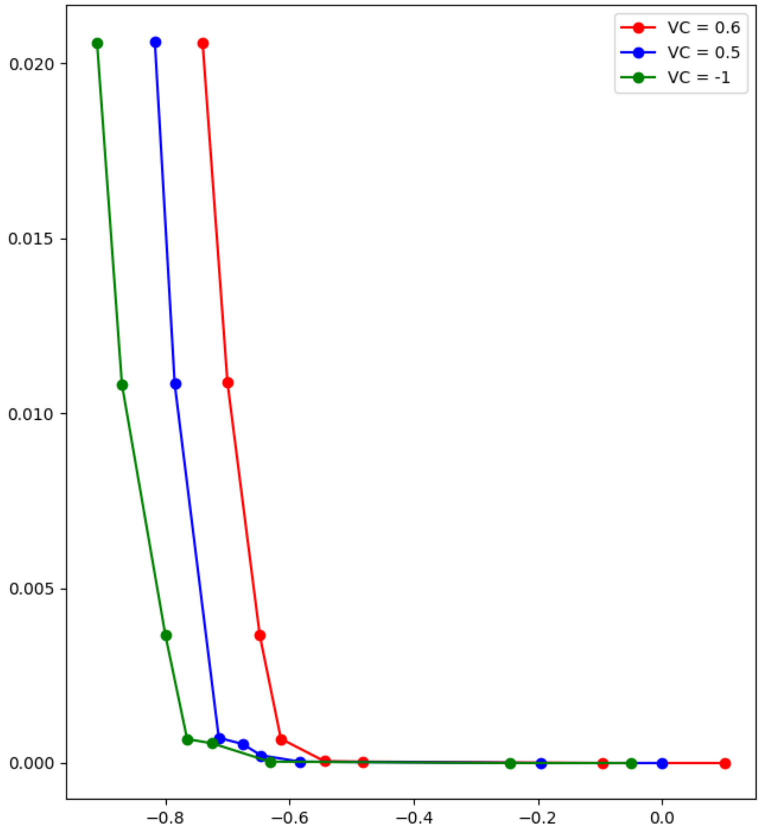
1. Connect the circuit as shown in the figure.

2. Keep V_{CE} constant and vary V_{CB} using a multimeter and taking appropriate step size.

3. Repeat the above step for different values of V_{CE} $(0.6, 0.5, 1)$ to obtain a family of curves.

4. Since we can't directly measure current with a multimeter measure potential across the R_B (since this is just a scaled version of I_B).

5. Plot the family of I_B vs V_{CB} curves.



5 Analysis

5.1 Input Characteristics

All 3 configurations (CE, CB, CC) show exponential input characteristic, following Schottky's diode equation. This makes sense as an npn BJT is a diode which has 3 doped regions (n, p, followed by n). Hence we can expect a similar graph.

5.2 Output Characteristics

All 3 configurations (CE, CB, CC) show similar graphs. The graphs have 3 regions,

- Cutoff Region: Output current ≈ 0
- Active Region: There is a linear relation between input and output.
- Saturation REgion: Output current goes into saturation i.e. remains constant.

Depending on configuration, output or input term varies but overall graph remains the same.

6 Determination of DC current gain β in BJT configurations

This section explains how to determine the DC current gain (commonly written β or h_{FE}) of a bipolar junction transistor (BJT) in the three standard configurations: common-emitter (CE), common-base (CB) and common-collector (CC, emitter-follower). For each configuration we give the measurement procedure, the equations used to compute β (or α where appropriate), and a worked numerical example using the CE value $\beta_{CE} = 284.405046343$.

6.1 General definitions

- Collector current: I_C.
- Base current: I_B.
- Emitter current: I_E (note $I_E = I_C + I_B$ exactly).
- DC current gain (common-emitter definition):

$$\beta_{DC} \equiv \beta = \frac{I_C}{I_B}. \tag{15}$$

- Forward current gain (common-base):

$$\alpha = \frac{I_C}{I_E}, \qquad \text{with} \quad \beta = \frac{\alpha}{1-\alpha}, \quad \alpha = \frac{\beta}{\beta+1}. \tag{16}$$

6.2 Common-Emitter (CE)

Measurement procedure

1. Bias the transistor so it is in forward-active region.
2. Hold V_{CE} constant and sweep the base current I_B across a suitable range (e.g. $10\,\mu$A to $100\,\mu$A in equal steps) using a current source or a series resistor and precise voltage reference.
3. For each value of I_B measure the resulting collector current I_C and record the pair (I_B, I_C).

Data analysis If the transistor remains in the linear forward-active region, the relation

$$I_C \approx \beta\, I_B \tag{17}$$

holds. We can extract β from experimental data by computing $\beta_i = I_{C,i}/I_{B,i}$ $\beta_i = I_{C,i}/I_{B,i}$ for each recorded point.

Worked numerical example Based on the different points recorded, the calculated value of β comes out to be:

$$\beta_{CE} = 284.405046343,$$

6.3 Common-Base (CB)

Measurement procedure

1. Bias the collector-base junction in reverse (choose V_{CB} such that the device is in the active region; typical experimental values: $V_{CB} = 5$–$10\,$V).
2. Sweep the emitter current I_E (or vary emitter voltage while measuring I_E and I_C). For each I_E record I_C.

Data analysis Compute the forward current gain

$$\alpha = \frac{I_C}{I_E}. \tag{18}$$

Convert α to β when required via

$$\beta = \frac{\alpha}{1-\alpha}. \tag{19}$$

Thus, a CB measurement yielding $\alpha \approx 0.99650$ corresponds to $\beta \approx 284.405$ and this matches the value obtained in the other configuration. This matches the α value obtained by calculating $\frac{\alpha}{1-\alpha}$

6.4 Common-Collector (CC)

Measurement procedure

1. Keep the collector at a fixed voltage (connected to the supply so transistor is not saturating) and sweep I_B (or the base voltage), measure the emitter current I_E (and optionally I_C).

Data analysis In the emitter-follower configuration the emitter current is related to the base current by

$$I_E = (\beta + 1)I_B. \tag{20}$$

Hence one can compute

$$\beta = \frac{I_E}{I_B} - 1. \tag{21}$$

7 Conclusion

The experimental analysis successfully demonstrated the input and output characteristics of BJT in CE, CB, and CC configurations. Each configuration exhibits distinct properties making them suitable for specific applications. The CE configuration provides high gain, CB offers good high-frequency response, and CC serves as an effective buffer. The measured results closely match theoretical predictions, validating the understanding of BJT behavior in different configurations.

Data points and codes used can be found at, https://github.com/ArjunPavanje/EE2301/tree/main/Experiment_6/codes
Circuit pictures can be found at, https://github.com/ArjunPavanje/EE2301/tree/main/Experiment_6/circuit_figs