# Experiment Report:
# Bipolar Junction Transistor Static Characteristics

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## Abstract

An NPN transistor is connected in a circuit for common emitter configuration. The input, output and transfer characteristics of the transistor is measured by varying the currents $I_C$, $I_B$ and the potential differences $V_{CE}$ and $V_{EB}$ accordingly. For the input characteristics, the input current $I_B$ had an overshoot at a particular voltage $V_{EB}$ which increased when $V_{CE}$ was increased. In the output characteristics, the output current $I_C$ showed a saturation after some $V_{CE}$ for a constant $I_B$. The saturation current $I_C$ increased proportionally with the input current $I_B$.

## 1 Objective

- To study the input and output characteristics of a transistor in Common Emitter mode and determine transistor parameters.

## 2 Theory and Working Formula

A bipolar junction, also known as a bipolar junction transistor (BJT), is a three-terminal semiconductor device that consists of two PN junctions. The three terminals are known as emittor (E), base (B) and collector (C). A BJT can be either NPN or PNP. An NPN transistor has two N-type materials on both sides of a P-type material while a PNP transistor has two P-type materials on either side of an N-type material. The working principle of the two transistors is the same but differs in the biasing of the base current and the polarity of the power supply (see figure 2). In most cases, the emitter-base junction is forward-biased whereas the collector-base junction is reverse-biased in a circuit.

A transistor can be configured in three different ways in a circuit: common emitter (CE), common base (CB) and common collector (CC). In common base (CB), the base of the transistor is connected to both the input and the output signal (preferably the ground), whereas in the common emitter (CE) and common collector (CC), the emitter and collector are connected to the common ground, respectively.

This experiment primarily studies the input, output and transfer characteristics of an NPN transistor in common emitter configuration. The circuit diagram for the experiment is given in figure 1.

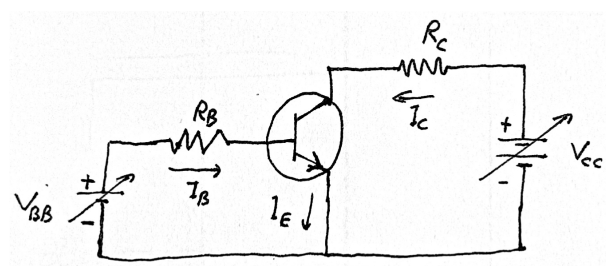



Figure 1: Circuit diagram for the experiment (common emitter configuration)

The input characteristics of the transistor is the variation of $I_B$ as the $V_{CE}$ (potential across the collector and emitter) is kept constant while varying $I_C$. The input dynamic resistance $r_\mathrm{i}$ is given by:

$$r_\mathrm{i} = \frac{\Delta V_{BE}}{\Delta I_B} \quad (V_{CE} \text{ is constant}) \tag{1}$$

The output characteristics is the variation of $I_E$ while $I_B$ is kept constant and $V_{CE}$ is varying. The output dynamic resistance $r_o$ is given by:

$$r_\mathrm{o} = \frac{\Delta V_{CE}}{\Delta I_C} \quad (I_B \text{ is constant}) \tag{2}$$

The transfer characteristics is the variation of $I_C$ (output

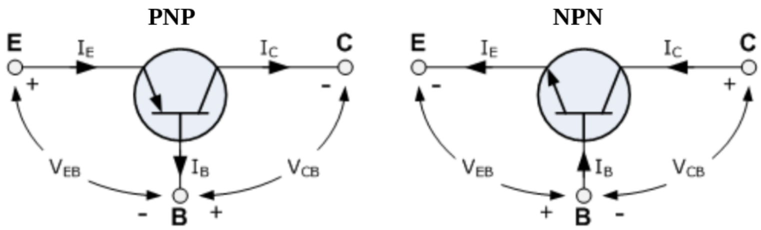



Figure 2: A schematic of an NPN bipolar junction transistor (left) and a PNP bipolar junction transistor (right)

current) with $I_B$ (input current) for a constant $V_{CE}$ when the transistor is active. The current amplication factor $\beta_{\text{dc}}$ (for DC supply) and $\beta_{\text{ac}}$ (for AC supply) is defined as follows:

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad (V_{CE} \text{ is constant}) \tag{3}$$

The value of $\beta$ is usually very large, which means that a small input current $I_B$ controls a large output current $I_C$. Since $I_B$ and $I_C$ vary proportionally, $\beta_{\text{ac}} \approx \beta_{\text{dc}}$.

# 3 Materials Required

(i) Bipolar junction NPN transistor (CL100 or equivalent), (ii) resistors (1kΩ, 100kΩ), (iii) breadboard, (iv) connecting wires, (v) multimeters (three quantity), (vi) DC power supply.

# 4 Observations

Transistor code: CDIL CL100S, Transistor type: NPN, Transistor Configuration: Common emitter (CE)
$R_B = 100.4\text{k}\Omega$, $R_C = 0.974\text{k}\Omega$

Table 1: Input Characteristics

| Sl | $V_{CE} = 0.061$V | | | $V_{CE} = 2.018$V | | |
|---|---|---|---|---|---|---|
| No. | $V_{EB}$ | $V_{R_B}$ | $I_B$ | $V_{EB}$ | $V_{R_B}$ | $I_B$ |
| 1 | 0.006V | 0.1mV | 0.0$\mu$A | 0.006V | 0.1mV | 0.0$\mu$A |
| 2 | 0.054V | 0.5mV | 0.0$\mu$A | 0.046V | 0.5mV | 0.0$\mu$A |
| 3 | 0.106V | 1.0mV | 0.01$\mu$A | 0.109V | 1.0mV | 0.01$\mu$A |
| 4 | 0.152V | 1.4mV | 0.01$\mu$A | 0.173V | 1.6mV | 0.02$\mu$A |
| 5 | 0.206V | 1.9mV | 0.02$\mu$A | 0.218V | 2.0mV | 0.02$\mu$A |
| 6 | 0.259V | 2.4mV | 0.02$\mu$A | 0.254V | 2.3mV | 0.02$\mu$A |
| 7 | 0.319V | 3.0mV | 0.03$\mu$A | 0.318V | 2.9mV | 0.03$\mu$A |
| 8 | 0.351V | 3.6mV | 0.04$\mu$A | 0.362V | 3.4mV | 0.03$\mu$A |
| 9 | 0.406V | 7.1mV | 0.07$\mu$A | 0.406V | 4.2mV | 0.04$\mu$A |
| 10 | 0.454V | 22.6mV | 0.23$\mu$A | 0.453V | 7.1mV | 0.07$\mu$A |
| 11 | 0.512V | 162.6mV | 1.62$\mu$A | 0.495V | 20.5mV | 0.2$\mu$A |
| 12 | 0.557V | 0.823V | 8.2$\mu$A | 0.537V | 80.7mV | 0.8$\mu$A |
| 13 | 0.575V | 1.626V | 16.2$\mu$A | 0.544V | 106.2mV | 1.06$\mu$A |
| 14 | 0.582V | 2.018V | 20.1$\mu$A | 0.563V | 209.6mV | 2.09$\mu$A |
| 15 | 0.585V | 2.226V | 22.17$\mu$A | 0.603V | 0.981V | 9.77$\mu$A |
| 16 | 0.609V | 4.979V | 49.59$\mu$A | 0.636V | 3.644V | 36.29$\mu$A |
| 17 | 0.618V | 6.58V | 65.54$\mu$A | 0.644V | 5.257V | 52.36$\mu$A |
| 18 | 0.623V | 7.83V | 77.99$\mu$A | 0.648V | 6.360V | 63.35$\mu$A |
| 19 | 0.625V | 8.57V | 85.36$\mu$A | 0.650V | 6.920V | 68.92$\mu$A |
| 20 | 0.633V | 10.92V | 108.76$\mu$A | – | – | – |
| 21 | 0.668V | 31.70V | 315.74$\mu$A | – | – | – |

Table 2: Output Characteristics

| Sl. | $V_{R_B} = 0$V | | | $V_{R_B} = 1$V | | | $V_{R_B} = 2$V | | | $V_{R_B} = 3$V | | | $V_{R_B} = 4$V | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | $V_{CE}$ (V) | $V_{R_C}$ | $I_C$ | $V_{CE}$ (V) | $V_{R_C}$ | $I_C$ | $V_{CE}$ (V) | $V_{R_C}$ | $I_C$ | $V_{CE}$ (V) | $V_{R_C}$ | $I_C$ | $V_{CE}$ (V) | $V_{R_C}$ | $I_C$ |
| 1 | 0.010 | 0.0mV | 0.0$\mu$A | 0.006 | 0.0mV | 0.0$\mu$A | 0.007 | 0.0mV | 0.0$\mu$A | 0.006 | 0.0mV | 0.0$\mu$A | 0.006 | 0.3mV | 0.3$\mu$A |
| 2 | 0.032 | 0.0mV | 0.0$\mu$A | 0.029 | 45.1mV | 46.3$\mu$A | 0.010 | 10.5mV | 10.8$\mu$A | 0.016 | 52mV | 53.4$\mu$A | 0.017 | 86.6mV | 88.9$\mu$A |
| 3 | 0.979 | 0.0mV | 0.0$\mu$A | 0.058 | 184.8mV | 0.190mA | 0.022 | 60.4mV | 62.0$\mu$A | 0.025 | 116mV | 0.119mA | 0.024 | 159.9mV | 0.164mA |
| 4 | 1.652 | 0.1mV | 0.1$\mu$A | 0.073 | 310.2mV | 0.318mA | 0.034 | 130.0mV | 0.134mA | 0.029 | 162mV | 0.166mA | 0.031 | 250.5mV | 0.257mA |
| 5 | 1.880 | 0.1mV | 0.1$\mu$A | 0.090 | 0.520V | 0.534mA | 0.043 | 216.2mV | 0.222mA | 0.037 | 246mV | 0.252mA | 0.039 | 385.2mV | 0.395mA |
| 6 | 2.755 | 0.2mV | 0.2$\mu$A | 0.129 | 1.021V | 1.04mA | 0.052 | 307.2mV | 0.315mA | 0.044 | 344mV | 0.353mA | 0.043 | 0.462V | 0.474mA |
| 7 | 3.197 | 0.2mV | 0.2$\mu$A | 0.222 | 1.369V | 1.40mA | 0.060 | 429.8mV | 0.441mA | 0.050 | 457mV | 0.470mA | 0.052 | 0.691V | 0.709mA |
| 8 | 4.157 | 0.3mV | 0.3$\mu$A | 0.285 | 1.414V | 1.45mA | 0.067 | 0.541V | 0.555mA | 0.056 | 0.590V | 0.606mA | 0.057 | 0.840V | 0.862mA |
| 9 | 5.494 | 0.4mV | 0.4$\mu$A | 0.340 | 1.420V | 1.46mA | 0.072 | 0.655V | 0.672mA | 0.067 | 0.850V | 0.872mA | 0.064 | 1.105V | 1.13mA |
| 10 | 6.04 | 0.5mV | 0.5$\mu$A | 0.437 | 1.430V | 1.46mA | 0.081 | 0.846V | 0.868mA | 0.074 | 1.076V | 1.10mA | 0.072 | 1.362V | 1.40mA |
| 11 | 7.06 | 0.6mV | 0.6$\mu$A | 0.532 | 1.426V | 1.46mA | 0.090 | 1.068V | 1.10mA | 0.082 | 1.361V | 1.40mA | 0.077 | 1.611V | 1.65mA |
| 12 | 8.34 | 0.7mV | 0.7$\mu$A | 0.611 | 1.432V | 1.47mA | 0.097 | 1.258V | 1.29mA | 0.088 | 1.558V | 1.60mA | 0.083 | 1.897V | 1.94mA |
| 13 | 9.86 | 0.9mV | 0.9$\mu$A | 0.775 | 1.433V | 1.47mA | 0.103 | 1.422V | 1.46mA | 0.094 | 1.792V | 1.84mA | 0.100 | 2.737V | 2.81mA |
| 14 | 10.97 | 1.0mV | 1.0$\mu$A | 0.881 | 1.434V | 1.47mA | 0.111 | 1.650V | 1.69mA | 0.097 | 1.927V | 1.98mA | 0.121 | 3.764V | 3.86mA |
| 15 | 11.19 | 1.0mV | 1.0$\mu$A | 1.038 | 1.436V | 1.47mA | 0.118 | 1.820V | 1.86mA | 0.11 | 2.399V | 2.46mA | 0.140 | 4.530V | 4.65mA |
| 16 | 12.09 | 1.1mV | 1.1$\mu$A | 1.427 | 1.436V | 1.47mA | 0.133 | 2.139V | 2.20mA | 0.12 | 2.814V | 2.88mA | 0.162 | 5.130V | 5.26mA |
| 17 | 12.96 | 1.2mV | 1.2$\mu$A | 1.997 | 1.438V | 1.48mA | 0.144 | 2.342V | 2.40mA | 0.13 | 3.135V | 3.22mA | 0.190 | 5.500V | 5.64mA |
| 18 | 13.52 | 1.2mV | 1.2$\mu$A | 2.172 | 1.440V | 1.48mA | 0.163 | 2.584V | 2.65mA | 0.146 | 3.542V | 3.64mA | 0.239 | 5.680V | 5.83mA |
| 19 | 14.56 | 1.4mV | 1.4$\mu$A | 3.136 | 1.444V | 1.48mA | 0.176 | 2.678V | 2.74mA | 0.171 | 3.980V | 4.08mA | 0.335 | 5.740V | 5.89mA |
| 20 | 15.11 | 1.4mV | 1.4$\mu$A | 4.770 | 1.449V | 1.48mA | 0.216 | 2.798V | 2.87mA | 0.209 | 4.217V | 4.32mA | 0.648 | 5.760V | 5.91mA |
| 21 | 15.89 | 1.5mV | 1.5$\mu$A | 5.880 | 1.454V | 1.49mA | 0.330 | 2.856V | 2.93mA | 0.38 | 4.308V | 4.42mA | 0.556 | 5.760V | 5.91mA |
| 22 | 17.07 | 1.6mV | 1.6$\mu$A | 8.21 | 1.462V | 1.50mA | 0.450 | 2.870V | 2.94mA | 0.502 | 4.319V | 4.43mA | 0.672 | 5.760V | 5.91mA |
| 23 | 18.95 | 1.8mV | 1.8$\mu$A | 9.34 | 1.464V | 1.50mA | 0.562 | 2.873V | 2.94mA | 0.721 | 4.330V | 4.44mA | 0.808 | 5.770V | 5.92mA |
| 24 | 19.61 | 1.8mV | 1.8$\mu$A | 11.00 | 1.468V | 1.50mA | 0.800 | 2.875V | 2.95mA | 1.125 | 4.338V | 4.45mA | 1.066 | 5.780V | 5.93mA |
| 25 | 20.62 | 1.9mV | 2.0$\mu$A | 12.07 | 1.472V | 1.51mA | 1.019 | 2.879V | 2.96mA | 1.746 | 4.351V | 4.46mA | 1.445 | 5.790V | 5.94mA |
| 26 | 21.51 | 2.0mV | 2.1$\mu$A | 13.36 | 1.478V | 1.52mA | 1.289 | 2.883V | 2.96mA | 2.173 | 4.361V | 4.48mA | 1.833 | 5.800V | 5.95mA |
| 27 | 22.71 | 2.2mV | 2.3$\mu$A | 15.62 | 1.486V | 1.52mA | 1.607 | 2.888V | 2.96mA | 2.482 | 4.371V | 4.48mA | 2.686 | 5.820V | 5.98mA |
| 28 | 23.71 | 2.2mV | 2.3$\mu$A | 18.98 | 1.496V | 1.54mA | 1.930 | 2.892V | 2.96mA | 3.228 | 4.385V | 4.50mA | 2.994 | 5.830V | 5.98mA |
| 29 | 25.34 | 2.4mV | 2.5$\mu$A | 20.86 | 1.505V | 1.54mA | 2.891 | 2.901V | 2.98mA | 6.58 | 4.440V | 4.56mA | 3.170 | 5.860V | 6.02mA |
| 30 | 27.14 | 2.6mV | 2.7$\mu$A | 24.79 | 1.521V | 1.56mA | 3.704 | 2.911V | 2.98mA | 7.35 | 4.460V | 4.58mA | 3.640 | 5.880V | 6.04mA |
| 31 | – | – | – | 28.50 | 1.531V | 1.57mA | 4.691 | 2.921V | 3.00mA | 10.64 | 4.520V | 4.64mA | 4.169 | 5.900V | 6.06mA |
| 32 | – | – | – | – | – | – | 7.16 | 2.953V | 3.03mA | 13.28 | 4.570V | 4.69mA | 4.452 | 5.900V | 6.06mA |
| 33 | – | – | – | – | – | – | – | – | – | – | – | – | 9.72 | 6.100V | 6.26mA |
| 34 | – | – | – | – | – | – | – | – | – | – | – | – | 12.30 | 6.170V | 6.33mA |

Table 3: Transfer Characteristics for $V_{CE} \approx 1.8V$

| Sl. No. | $V_{R_B}$ (in V) | $I_B$ (in $\mu$A) | $I_C$ (in mA) |
|---|---|---|---|
| 1 | 0.0 | 0.00 | 0.00 |
| 2 | 1.0 | 9.96 | 1.48 |
| 3 | 2.0 | 19.92 | 2.96 |
| 4 | 3.0 | 29.88 | 4.46 |
| 5 | 4.0 | 39.84 | 5.95 |

# 5 Results

The values of the current $I_B$ in table 1 are calculated from the $V_{R_B}$ column and the measured resistance $R_B$ upto the correct significant figures. Similarly, for table 2, $I_C$ is determined from the respective $V_{R_C}$ and the measured resistance $R_C$. Instead of an ammeter, a voltmeter is used to measure the voltage drop across the resistors $R_C$ and $R_B$ to obtain the currents $I_C$ and $I_B$ respectively. Similarly in table 3, the $I_B$ is calculated from $V_{R_B}$ and the resistance $R_B$. The graph plots of the data in tables 1, 2 and 3 are given in figure 3.

To obtain the input dynamic resistance of the transistor, the data points with $V_{EB} \leq 0.62$ were excluded for $V_{CE} = 0.061V$ and $V_{CE} = 2.018V$. Then, individually for each $V_{CE}$, linear fit was performed to obtain the slope of the $V_{EB}$ v/s $I_B$ plot which corresponds with the input dynamic resistance $r_{\mathrm{i}}$ for that $V_{CE}$. The results for $r_{\mathrm{i}}$ are as follows:

Table 4: Input dynamic resistance $r_{\mathrm{i}}$ obtained for two different $V_{CE}$

| $V_{CE}$ (in V) | $r_{\mathrm{i}}$ (in $\Omega$) |
|---|---|
| 0.061 | $1.8 \pm 0.1$ |
| 2.018 | $4.3 \pm 0.2$ |

For the output dynamic resistance of the transistor, the data for $V_{CE} \leq 0.5V$ in table 2 were excluded and a linear fit was performed for each $I_B$ current for the $I_C$ v/s $V_{CE}$ plot (see figure 3). The slope of the line of best-fit is $r_{\mathrm{o}}$ for the given $I_B$ current. The values of $r_{\mathrm{o}}$ obtained are as follows:

Table 5: Output dynamic resistance $r_{\mathrm{o}}$ obtained for different input currents $I_B$

| $I_B$ (in $\mu$A) | $r_{\mathrm{o}}$ (in k$\Omega$) |
|---|---|
| 0.00 | $9735.5 \pm 86.5$ |
| 9.96 | $273.0 \pm 4.1$ |
| 19.92 | $81.6 \pm 1.5$ |
| 29.88 | $50.8 \pm 0.8$ |
| 39.84 | $26.9 \pm 0.5$ |

To determine the current amplification factor $\beta_{\mathrm{dc}}$, a linear fit was perform on the data of table 3, where the slope of the $I_C$ v/s $I_B$ graph is $\beta_{\mathrm{ac}}$ obtained as:

$$\beta_{\mathrm{ac}} = 149.4 \pm 0.2$$

# 6 Discussion

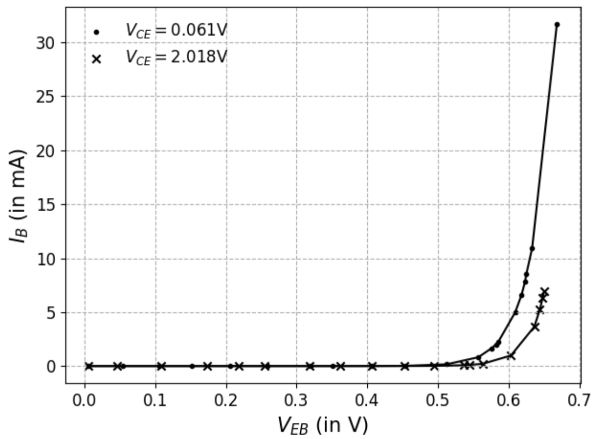
The graph plots of the input, output and transfer characteristics are given in figure 3. The input characteristics show a large increase in the $I_B$ after a threshold $V_{EB}$ voltage. Also, this threshold $V_{EB}$ seems to increase with the $V_{CE}$ by comparing the plots for $V_{CE} = 0.061V$ and $V_{CE} = 2.018V$. This may intuitively make sense as $I_C + I_B = I_E$ and an increase in $V_{CE}$ facilitates an increase in $I_C$ which may compensate for the shift of the graph.

In the plot of the output characteristics, the output current $I_C$ reaches a saturation after some $V_{CE}$ which is consistent with the theory. Also, this saturation current of $I_C$ increases with the increase in the input current $I_B$ which shows the application of an NPN transistor a device to 'scale-up' or 'scale-down' the amplitude of a given signal. Also, this current amplification can be more clearly studied from the plot for transfer characteristics (see figure 3) which shows a linear relationship between the input current $I_B$ and the output current $I_C$. This result is also consistent with the theory.

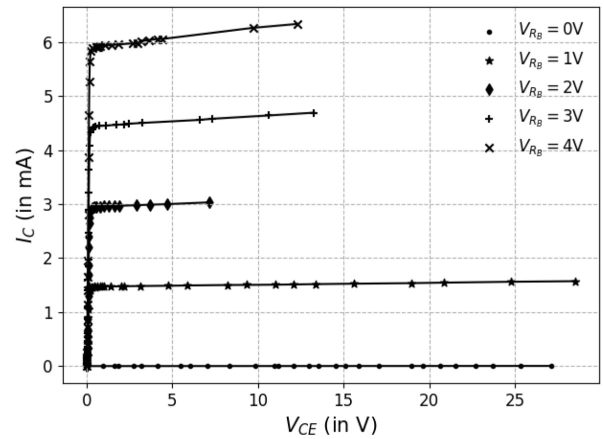
It can be observed from table 5 that the output dynamic resistance of the transistor decreases with the increase in the input base current $I_B$. Also, the value of the current amplification factor $\beta_{\mathrm{ac}}$ is a very large value which indicates that a very small input base current (a few $\mu$A) can control the flow of a large current (in mA) $I_C$ which is consistent with the theory.

# 7 Conclusion

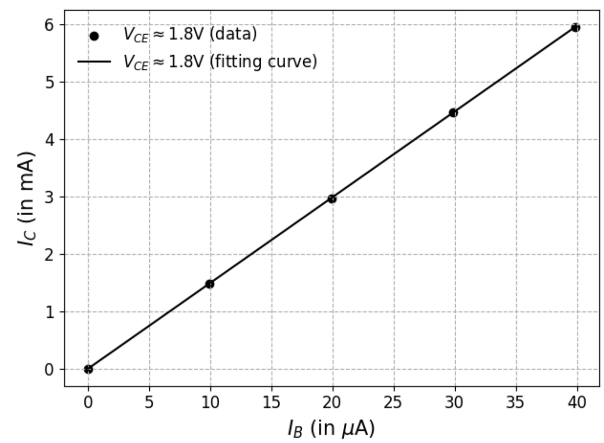
The input and output characteristics of the NPN transistor in common emitter configuration has been studied successfully and the values of its input dynamic resistance, output dynamic resistance and the current amplification factor are obtained.




(a) Input characteristics




(b) Output characteristics




(c) Transfer characteristics

Figure 3: Plots of the experiment from the observation tables 1, 2 and 3.

# 8 Precautions

1. Ensure that the three terminals of the NPN transistor are correctly identified and connected in the circuit.
2. The ground of the two voltage sources must be shorted in the circuit.