Experiment 7: Bipolar Junction Transistor and Heterojunction Bipolar Transistor

Department of Electrical Engineering
Indian Institute of Technology, Bombay

EE236: Experiment 7

Background Information

The Bipolar Junction Transistor (BJT) is a three-terminal, two-junction device widely used in high-frequency applications such as RF circuits. The terminals are:

- Base (B)
- Collector (C)
- Emitter (E)

A BJT allows a small current injected at the base to control a much larger current flowing between the emitter and collector terminals, making it suitable for amplification and switching.

DC Parameters of BJT

Key Definitions

1. **Base Transport Factor (α_T)**:
$$\alpha_T = \frac{I_C}{I_E}$$
2. **Emitter Efficiency (γ)**:
$$\gamma = \frac{I_{E,n}}{I_E}$$
3. **Common Emitter Current Gain (β)**:
$$\beta = \frac{I_C}{I_B}$$

Components Necessary

- BC547 BJT
- MT3S1 HBT
- Resistors: 1kΩ, 470Ω, 15kΩ, 18kΩ, 10kΩ, 1.2kΩ, 250Ω
- Potentiometer: 1kΩ
- Capacitor: $4.7\mu F$
- Breadboard, Multimeters, and Connecting Wires

Part I: BJT Parameters in Common Base Configuration

1. Setup and Measurements

In this part, we analyze the output characteristics of a BC547 BJT in the Common Base (CB) configuration by varying the emitter current (I_E) and measuring the collector current (I_C) for different collector-base voltages (V_{CB}).

Circuit Configuration

1. Connect the BC547 BJT in the Common Base configuration.
2. Emitter connected to ground through a variable resistor to control I_E.
3. Collector connected to a DC power supply with a variable V_{CB}.
4. Ensure the collector-base junction is reverse-biased.

Data Collection

Assuming the following data was collected during measurements:

I_E (mA)	V_{CB} (V)	I_C (mA)
3	4	2.4
6	4	5.8
9	4	8.2

Table 1: Measured Data for BJT in Common Base Configuration

2. Calculating α and β

Step 1: Calculate α

Using the formula:

$$\alpha = \frac{I_C}{I_E}$$

Calculating for different I_E:

- For $I_E = 3\,\text{mA}$:

$$\alpha = \frac{2.4\,\text{mA}}{3\,\text{mA}} = 0.8$$

- For $I_E = 6\,\text{mA}$:

$$\alpha = \frac{5.8\,\text{mA}}{6\,\text{mA}} \approx 0.9667$$

- For $I_E = 9\,\text{mA}$:

$$\alpha = \frac{8.2\,\text{mA}}{9\,\text{mA}} \approx 0.9111$$

Step 2: Calculate β

Assuming $\gamma \approx 1$, we can approximate the base current (I_B):

$$I_B = I_E - I_C$$

Calculating β:

- For $I_E = 3\,\text{mA}$:

$$I_B = 3\,\text{mA} - 2.4\,\text{mA} = 0.6\,\text{mA}$$
$$\beta = \frac{2.4\,\text{mA}}{0.6\,\text{mA}} = 4$$

- For $I_E = 6\,\text{mA}$:

$$I_B = 6\,\text{mA} - 5.8\,\text{mA} = 0.2\,\text{mA}$$
$$\beta = \frac{5.8\,\text{mA}}{0.2\,\text{mA}} = 29$$

- For $I_E = 9\,\text{mA}$:

$$I_B = 9\,\text{mA} - 8.2\,\text{mA} = 0.8\,\text{mA}$$
$$\beta = \frac{8.2\,\text{mA}}{0.8\,\text{mA}} = 10.25$$

3. Results Summary for Part I

I_E (mA)	α	β
3	0.8	4
6	0.9667	29
9	0.9111	10.25

Table 2: Summary of BJT Parameters

Observations

- α values are close to 1, indicating efficient charge carrier transport.
- β values vary, reflecting the transistor's varying amplification ability.

Part II: Frequency Response of BJT and HBT

A. Frequency Response of BJT (BC547)

1. Setup

- Connect the BC547 in a common emitter configuration.
- Set the DC operating point at $V_{CE} = 6.0V$, $I_C = 12\,\text{mA}$, and $I_B = 50\,\mu\text{A}$.
- Apply a small signal of $V_i = 500\,\text{mV}$ peak-to-peak.

2. Measure Frequency Response

Frequency Steps

$$\{1k, 5k, 10k, 50k, 100k, 150k, 200k, 250k, 300k, 350k, 400k, 450k, 500k, 550k, 600k\}$$

Example Data Collection

Assuming we collected the following data:

Frequency (kHz)	V_{out} (V)	Gain (A)
1	1.0	20
5	1.8	36
10	2.2	44
50	3.0	60
100	2.5	50
150	1.5	30
200	0.8	16
250	0.5	10
300	0.4	8
350	0.3	6
400	0.2	4
450	0.15	3
500	0.1	2
550	0.05	1
600	0.03	0.6

Table 3: BJT Frequency Response Data

B. Frequency Response of HBT (MT3S1)

1. Setup

- Connect the MT3S1 HBT in a common emitter configuration.
- Set the DC operating point at $V_{CE} = 3.5V$, $I_C = 12\,\text{mA}$, and $I_B = 50\,\mu\text{A}$.
- Apply a small signal of $V_i = 500\,\text{mV}$ peak-to-peak.

2. Measure Frequency Response

Using similar frequency steps as for the BJT, we can obtain HBT output.

Frequency (kHz)	V_{out} (V)	Gain (A)
1	1.5	30
5	2.5	50
10	3.5	70
50	4.0	80
100	3.8	76
150	3.0	60
200	2.5	50
250	2.0	40
300	1.5	30
350	1.0	20
400	0.5	10
450	0.3	6
500	0.2	4
550	0.1	2
600	0.05	1

Table 4: HBT Frequency Response Data

3. Gain vs Frequency Response Plot

4. Analysis of Results

The $-3dB$ cutoff frequencies can be identified from the plots:

- **BJT (BC547):** $f_c = 150\,\text{kHz}$
- **HBT (MT3S1):** $f_c = 400\,\text{kHz}$

5. Conclusion

The HBT shows a superior frequency response compared to the BJT, exhibiting a higher $-3dB$ cutoff frequency and a consistently higher gain across the frequency spectrum. This makes HBTs more suitable for high-frequency applications due to their improved performance characteristics.

frequency_response_plot.png

Figure 1: Gain vs Frequency Response of BJT and HBT