EE236: Experiment No. 8
Bipolar Junction Transistor

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1 Overview of the experiment

1.1 Aim of the experiment

Aim of this experiment is to measure the forward active, reverse active parameters and DC ouput characteristics in common base (CB) and common emitter (CE) configurations. To plot the combined I_C and I_B vs V_{BE} of a BJT on a semi-log scale (Gummel plot) and β_{DC} v/s I_C characteristics for constant V_{BC}.
To calculate pi model small signal parameters (r_π, g_m and r_o) and analyse performance of BJT inverter at different frequencies.

1.2 Methods

Firstly, I wrote the netlist for BJT in CE configuration to plot I_C vs V_{CE} by varying I_B to calculate the parameters. Similarly, I did it for CB configuration to plot I_C vs V_{CB} by varying I_E to calculate the parameters. Then, I poltted the Gummel plot.
Then, I wrote the netlist of small signal model of BJT in CE configuration to calculate the small signal parameters using biasing the configuration. FInally, I simulated the switching behaviour of BJT at different frequencies in two different configurations.

2 Design

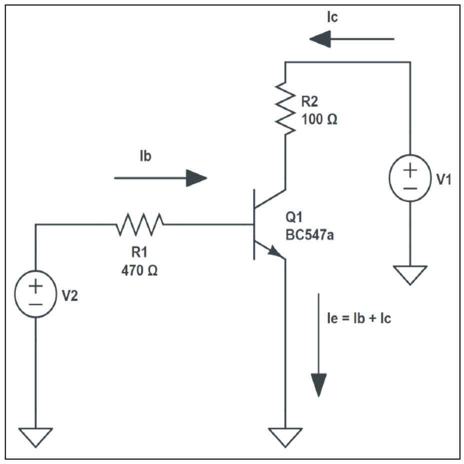


Fig. 1 : BJT in CE configuration

The circuit shown in Fig. 1 is used to plot the I_C vs V_{CE} characteristics of CE configuration. I determined the parameters α, β, Reverse β (RB) and Early Voltage (V_A) by assuming $\gamma = 1$. I_B was varied from 0A to 1mA in steps of 0.1mA.

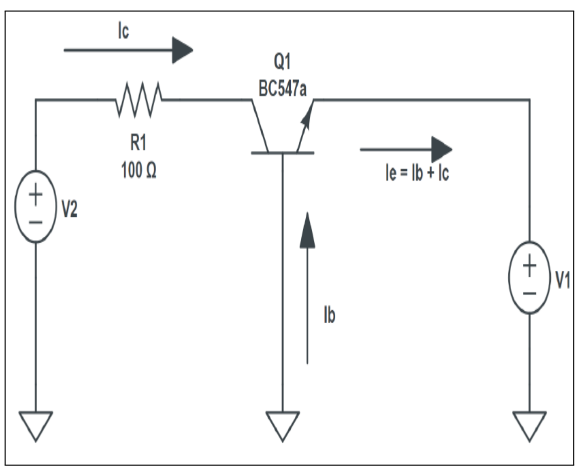


Fig. 2 : BJT in CB configuration

Fig. 2 shows the circuit used for characteristics of CB configuration similar to the previous circuit. I_E was varied from 0A to 10mA in steps of 1mA. Following are the equations used for both

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

$$\beta = \frac{I_C}{I_B}$$

Reverse β (RB) can be found by interchanging the terminals.

$$V_A = \frac{I_1 V_2 - I_2 V_1}{I_1 - I_2}$$

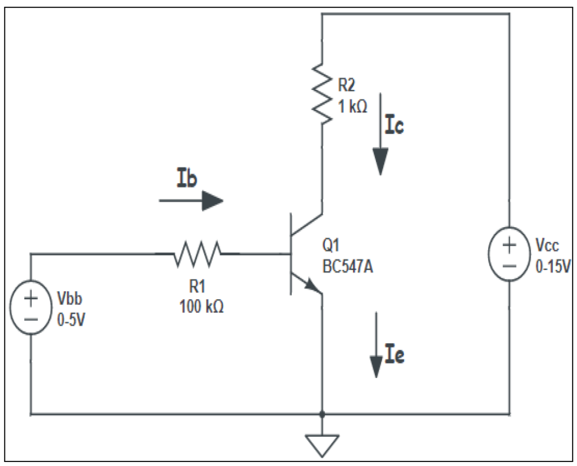


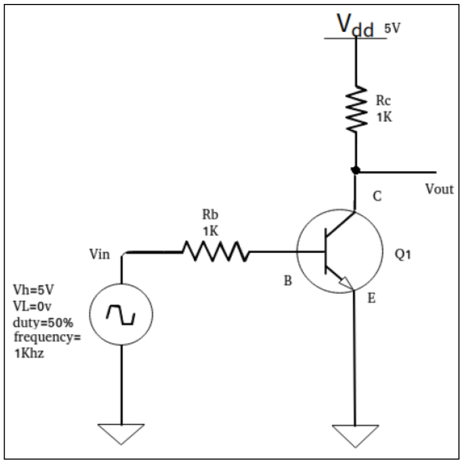
Fig. 3 : BJT Small Signal Parameters

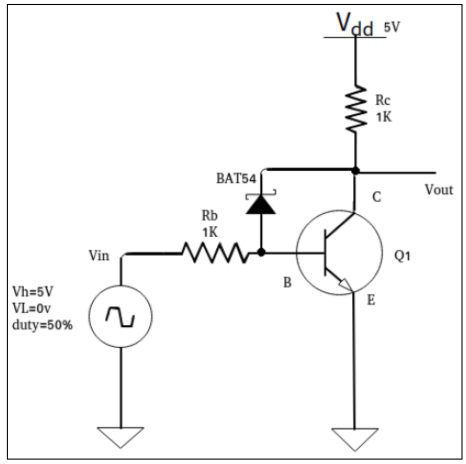
The circuit shown in Fig. 3 is used to find the small signal parameters of BJT. V_{CC} was set to 9.5V and V_{BB} was chosen as 2.985V.

$$g_m = \frac{I_C}{V_t}$$

$$r_\pi = \frac{\beta}{g_m}$$

$$r_o = \frac{V_A}{I_C}$$





BJT switching circuit

Fig. 4 : without schottky diode   Fig. 5 : with schottky diode

Fig. 4 and Fig. 5 show the switching behaviour of BJT with and without schottky diode. Input was a pulse of 5V amplitude and 1kHz frequency which was later changed to 100kHz and 1MHz. The plots were obtained and turnoff time was found. Turnoff time is the sum of storage time, the delay between input zero and output at 90% max value, and rise time, the delay between 10% max output to 90% max output.

3 Simulation results

3.1 Code snippets

3.1.1 BJT in CE configuration :

```
Mayur Ware | 19D070070
*EE236 | Lab 8
*BJT in CE Configuration
.include BC547.txt ;Including BJT model file
*Netlist
Q1 C B E bc547a ;Defining the BJT Model Collector, Base, Emitter
R1 1 B1 470
R2 2 C1 100
V1 2 GND dc 0
V2 1 GND dc 0
Vc C1 C dc 0
```

```
Vb B1 B dc 0
Ve E GND dc 0
*DC Analysis
.dc V1 0 10 0.1 V2 0.7 1.17 0.047
.control
run
set color0 = white
set color1 = black
set color2 = blue
set xbrushwidth = 2
let V = V(C) - V(E)
plot I(Vc) vs V
plot I(Vc)/I(Ve) ;Base Transport Factor
plot I(Vc)/I(Vb) ;Beta
plot I(Ve)/I(Vb) ;Reverse Beta
.endc
.end
```

3.1.2 BJT in CB configuration :

```
Mayur Ware | 19D070070
*EE236 | Lab 8
*BJT in CB Configuration
.include BC547.txt ;Including BJT model file
*Netlist
Q1 C B E bc547a ;Defining the BJT Model Collector, Base, Emitter
R1 1 C1 100
Ie E E1 dc 1m
V1 E1 GND dc 0
V2 1 GND dc 0
Vc C1 C dc 0
Vb B GND dc 0
*DC Analysis
.dc V2 -2 10 0.1 Ie 0m 10m 1m
.control
run
set color0 = white
set color1 = black
set color2 = blue
```

```
set xbrushwidth = 2
let V = V(C) - V(B)
plot I(Vc) vs V
plot I(Vc)/I(V1) ;Base Transport Factor
plot I(Vc)/I(Vb) ;Beta
plot I(V1)/I(Vb) ;Reverse Beta
.endc
.end
```

3.1.3 Gummel Plot :

```
Mayur Ware | 19D070070
*EE236 | Lab 8
*Gummel Plot
.include BC547.txt ;Including BJT model file
*Netlist
Q1 C B GND bc547a ;Defining the BJT Model Collector, Base, Emitter
Vin In 0 5
V1 1 In 5
Rc 2 1 100
Rb 3 In 470
Vc 2 C 0
Vb 3 B 0
*DC Analysis
.dc Vin 0.2 1.2 10m
.control
run
set color0 = white
set color1 = black
set color2 = blue
set xbrushwidth = 2
plot log(i(Vc)) vs V(3) log(abs(i(Vb))) vs V(3)
let beta = log(i(Vc)) - log(abs(i(Vb)))
plot beta vs i(Vc)
.endc
.end
```

3.1.4 BJT switching behaviour without schottky diode :

```
Mayur Ware | 19D070070
```

```
*EE236 | Lab 8
*Switching Behavior
.include BC547.txt ;Including BJT model file
.include 2N3904.txt
*Netlist
*Q1 C B GND bc547a ;Defining the BJT Model Collector, Base, Emitter
Q1 C B GND 2n3904c
Vin In 0 PULSE(0 5 0 0 0 5u 10u)
Rb In B 1k
Rc 2 C 1k
V_dd 2 0 5
*Transient Analysis
.tran 1u 5u
.control
run
set color0 = white
set color1 = black
set color2 = blue
set xbrushwidth = 2
plot V(C) V(In)
.endc
.end
```

3.1.5 BJT switching behaviour with schottky diode :

```
Mayur Ware | 19D070070
*EE236 | Lab 8
*Switching Behavior using Schottky
.include BC547.txt ;Including BJT model file
.include BAT54.txt ;Including Schottky model file
*Netlist
Q1 C B GND bc547a ;Defining the BJT Model Collector, Base, Emitter
X1 B C BAT54
Vin In 0 PULSE(0 5 0 0 0 5u 10u)
Rb In B 1k
Rc 2 C 1k
V_dd 2 0 5
*Transient Analysis
.tran 0.01u 0.04m
.control
```

```
run
set color0 = white
set color1 = black
set color2 = blue
set xbrushwidth = 2
plot V(C) V(In)
.endc
.end
```

3.2 Simulation results

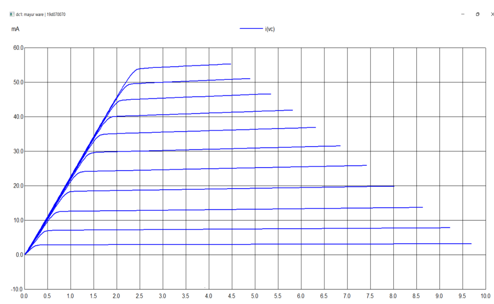
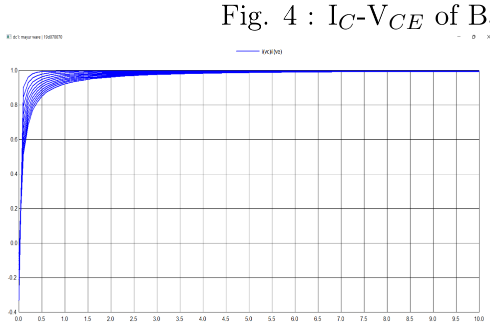
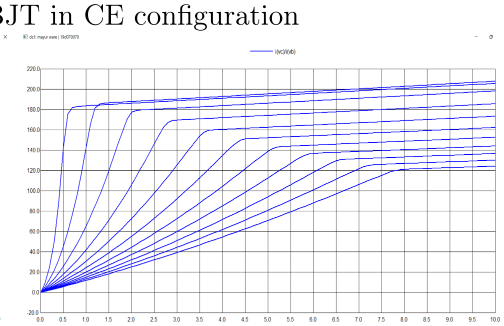


Fig. 4 : I_C-V_{CE} of BJT in CE configuration





BJT in CE configuration

Fig. 5 : α-V_{CE} Fig. 6 : β-V_{CE}

Fig. 4, Fig. 5 and Fig. 6 show the overall characteristics of BJT in CE configuration. α approaches to 1 with increase in V_{CE}. Whereas, β first linearly increases upto a point and then gets almost constant. Slopes of these curves determine threshold voltage (V_A).
$\alpha = 0.9952$, $\beta = 208.45$, RB $= 0.4992$ and $V_A =$ -71.15V.

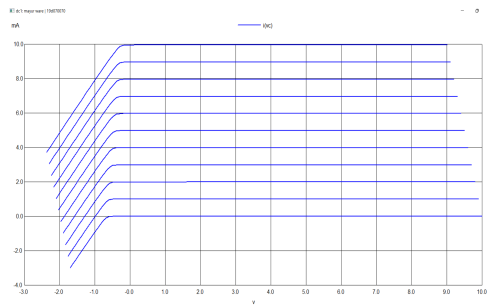
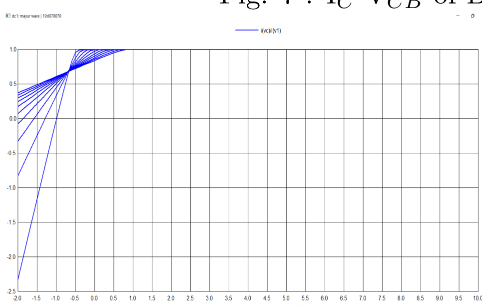
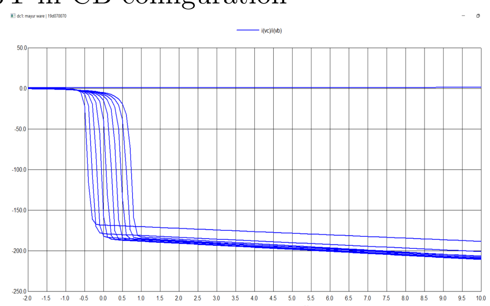


Fig. 7 : I_C-V_{CB} of BJT in CB configuration





BJT in CB configuration

Fig. 8 : α-V_{CB} Fig. 9 : β-V_{CB}

Fig. 7, Fig. 8 and Fig. 9 show the overall characteristics of BJT in CB configuration. α approaches to 1 with increase in V_{CB}. Whereas, β first decreases upto a point and then gets almost constant.
$\alpha = 0.9949$, $\beta = 197.82$, RB $= 1.031$.

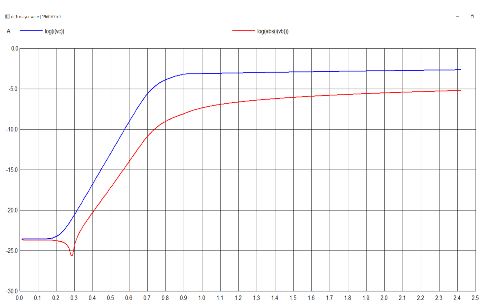


Fig. 10 : Gummel Plot

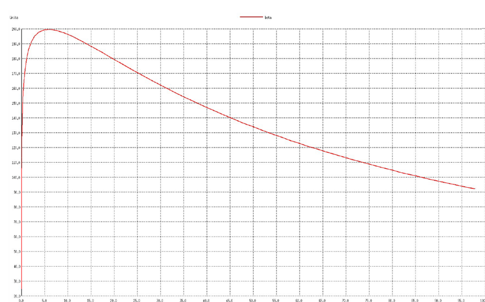


Fig. 11 : β_{DC}-IC

Fig. 10 and Fig. 11 show the gummel plot and beta-Ic plots respectively.

Small Signal Paramters of BJT:
v(c) = 5.004189e+00
i($\mathbf{v}_{cc}$) = -4.49581e-03
i(v_{cc})/i(v_{bb}) = 1.974125e+02 **Beta**
gm = -1.72916e-01
(i(v_{cc})/i(v_{bb}))/gm = -1.14167e+03 $\mathbf{r}_{pi}$
$\mathbf{r}_o$ = V_A/Ic = 15829.58843

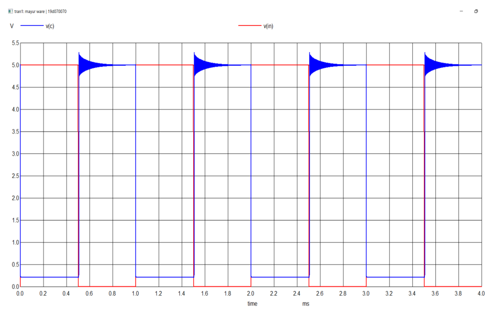


Fig. 12 : BC547 at f=1kHz

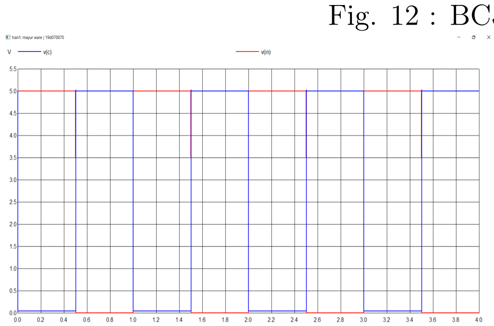


Fig. 13 : BC547 at f=100kHz

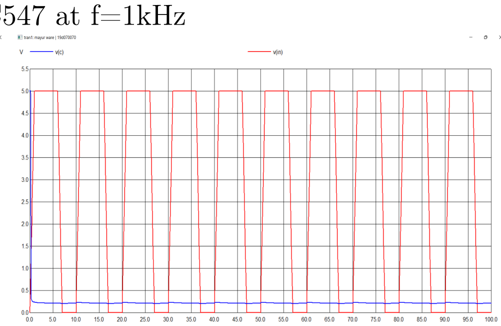
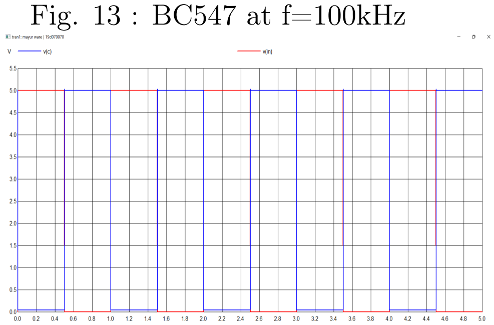
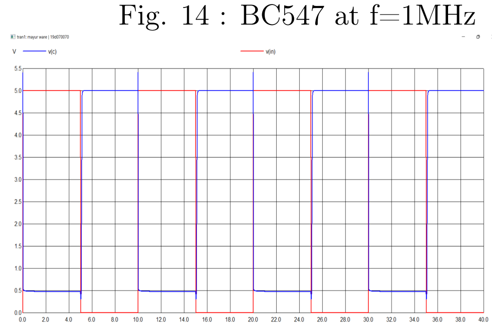


Fig. 14 : BC547 at f=1MHz





BJT in CB configuration

Fig. 15 : 2N3904 at f=100 kHz

Fig. 16 : BC547 at f=1kHz with schottky diode

Fig. 12, Fig. 13, Fig. 14, Fig. 15 and Fig. 16 depict the switching behaviour

of two different types of BJTs BC547 and 2N3904 at different frequencies. Also, BC547 with schottky diode configuration. Table below tabulates the data of turnoff times.
Turnoff times in μ sec.

Frequency	BC547	2N3904	BC547 with Schottky
1kHz	5.24	-	-
100kHz	4.68	0.36	0.09
1MHz	-	-	-

We can conclude that 2N3904 is faster than BC547. Also, schottky diode configuration is faster than the normal configuration.

4 Experimental results

This section is not applicable for this experiment.

5 Experiment completion status

I have completed all sections as well as exercises in this lab.

6 Questions for reflection

This section is not applicable for this experiment.

■