EE 236: Experiment No. 6
Study of NMOS and CMOS Characteristics

Vinamra Baghel, 190010070

April 11, 2022

1 Overview of the experiment

1.1 Aim of the experiment

The following were the aims of the experiment:

- To measure the forward active and reverse active parameters in common base and common emitter configurations.
- To plot the output DC characteristics in CB and CE configurations.
- To plot the combined I_C and I_B vs V_{BE} of a BJT on a semi-log scale (also called Gummel plot).
- To plot the β_{DC} vs I_C characteristics for constant V_{BC}.
- To calculate pi model small signal parameters.
- To analyse performance of BJT inverter at different frequencies.

1.2 Methods

The method overview includes constructing circuit netlists according to the given circuits, simulating them using *dc*, *op*, or *tran* analyses and calculating required parameters for all parts. The first experiment's first part required us to plot $I_C - V_{CE}$ characteristics in CE configuration, and calculate α, β, reverse β, and early voltage (V_A). The first experiment's second part required us to plot $I_C - V_{CB}$ characteristics in CB configuration, and calculate α, β, and reverse β. The second experiment required us to plot a Gummel plot and β_{DC} vs I_C. The third experiment required us to find pi model small signal parameters. The fourth experiment required us to analyse BJT switching behaviour at different frequencies.

2 Design

2.1 Experiment 1 - BJT Parameters

2.1.1 CE Configuration

The netlist according to the following circuit diagram was made which included an bc547 BJT transistor, resistors, and voltage sources.

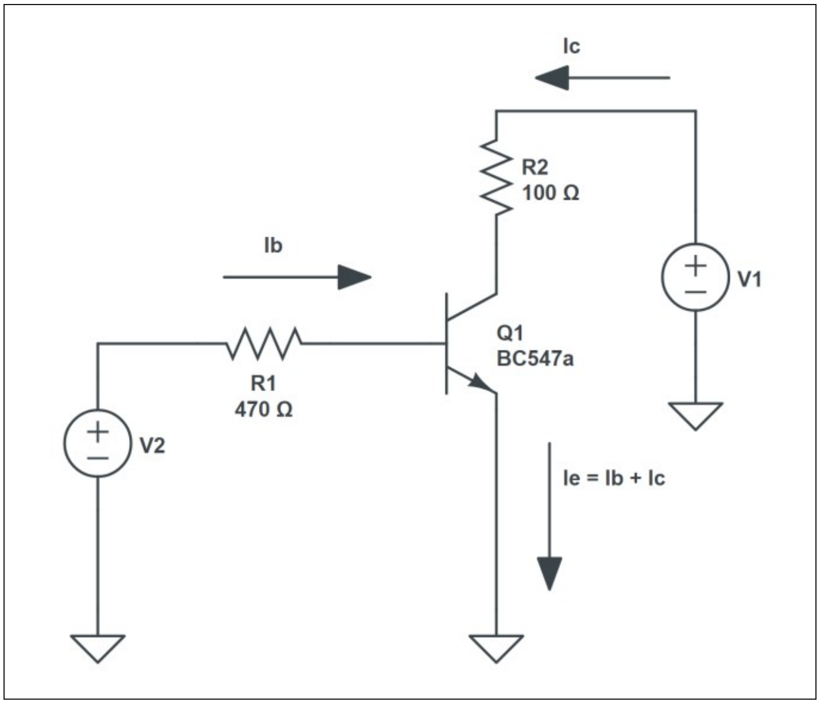


Figure 1: The I-V Characterization Circuit for CE Configuration

DC analysis was performed by varying V_1 from 0 to 20V in steps of 0.1V and I_B from 0 to 1mA in steps of 0.1mA using a current source to obtain the I-V characteristic plots.

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

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

Reverse beta was found using the same formula for I_B and V_1 terminals reversed.

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

2.1.2 CB Configuration

The netlist according to the following circuit diagram was made which included an bc547 BJT transistor, resistors, and voltage sources.

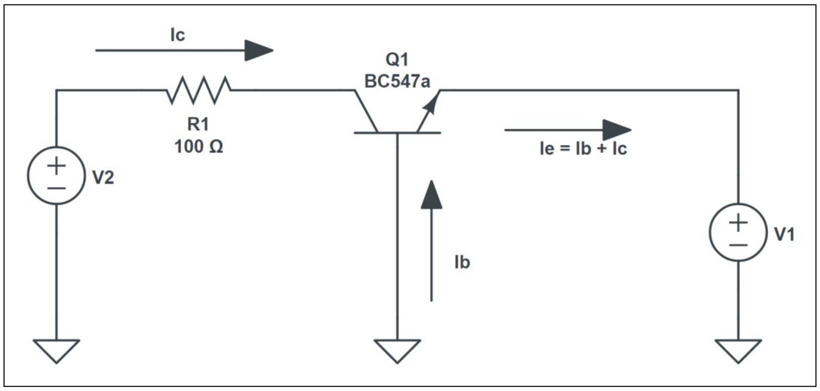


Figure 2: The I-V Characterization Circuit for CB Configuration

DC analysis was performed by varying V_2 from -5 to 15V in steps of 0.1V and I_E from 0 to 10mA in steps of 1mA to obtain the I-V characteristic plots. The parameters were calculated using the methods mentioned above.

2.2 Experiment 2 - Gummel Plot

The simple circuit was used:

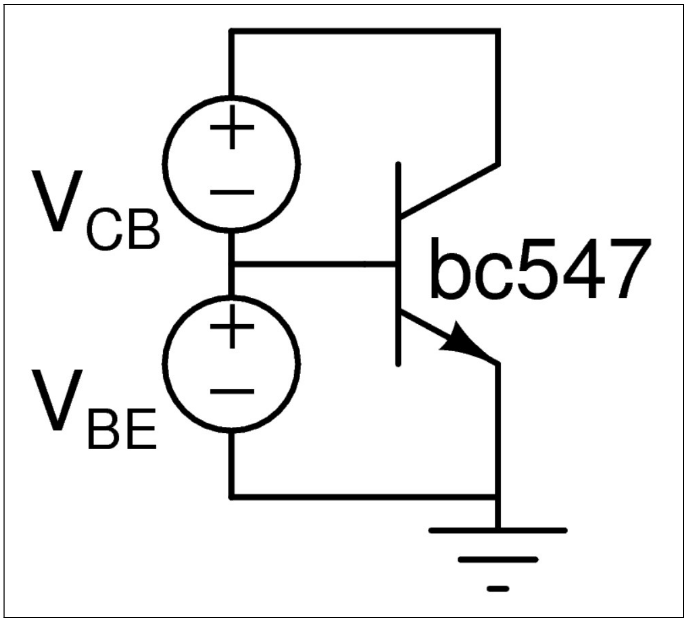


Figure 3: Gummel Plot Circuit

The mentioned plots were made.

2.3 Experiment 3 - Small Signal Parameters

The following netlist was made:

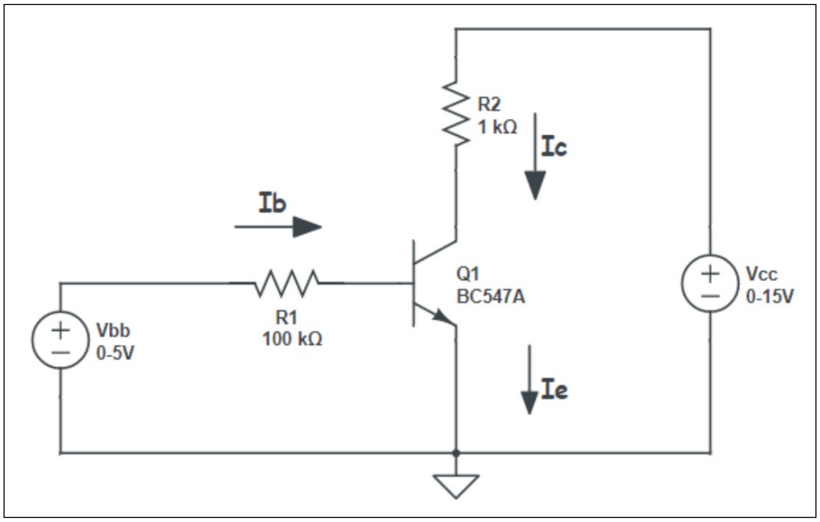


Figure 4: Small Signal Parameters

I_C was fixed at 4.5mA and V_{CC} was taken as 9.5V. Accordingly, V_{BB} was chosen to be 2.843V using β from the previous parts. *.op* was used for simulation.

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

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

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

2.4 Experiment 4 - Switching Behaviour

The following netlist was made:

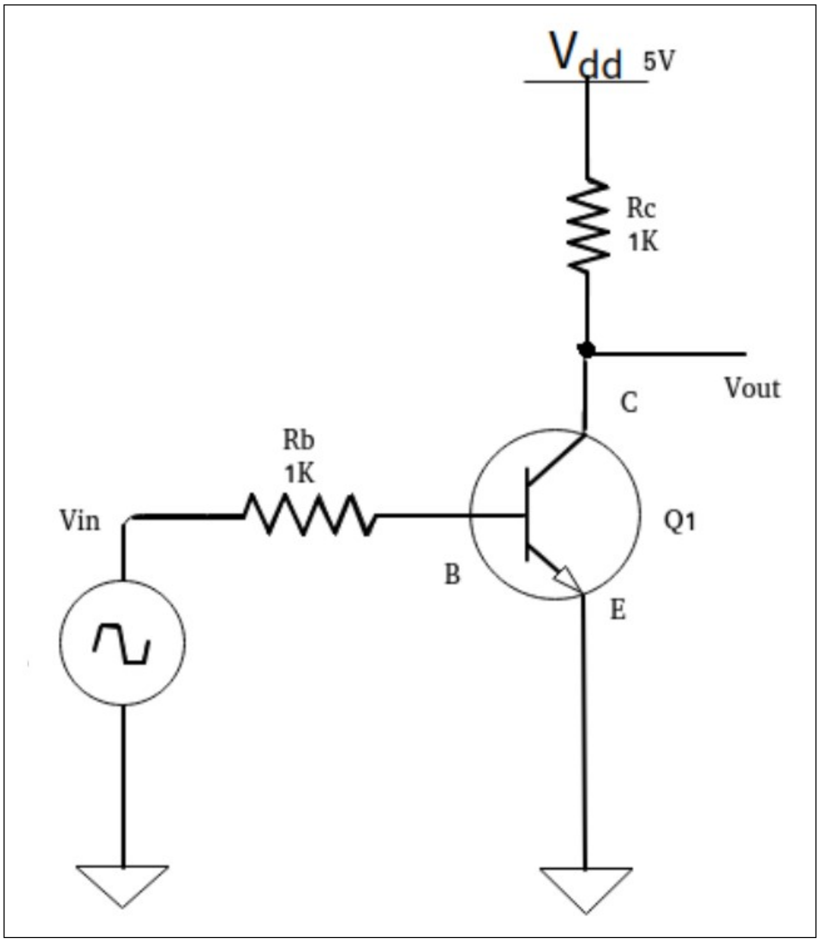


Figure 5: BJT Switching Circuit

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. Tran analysis was done till 2.5 times pules width.
The bc547 was then replaced with 2N3904 for 100kHz frequency.
A schottky diode was then added to the bc547 circuit as shown:

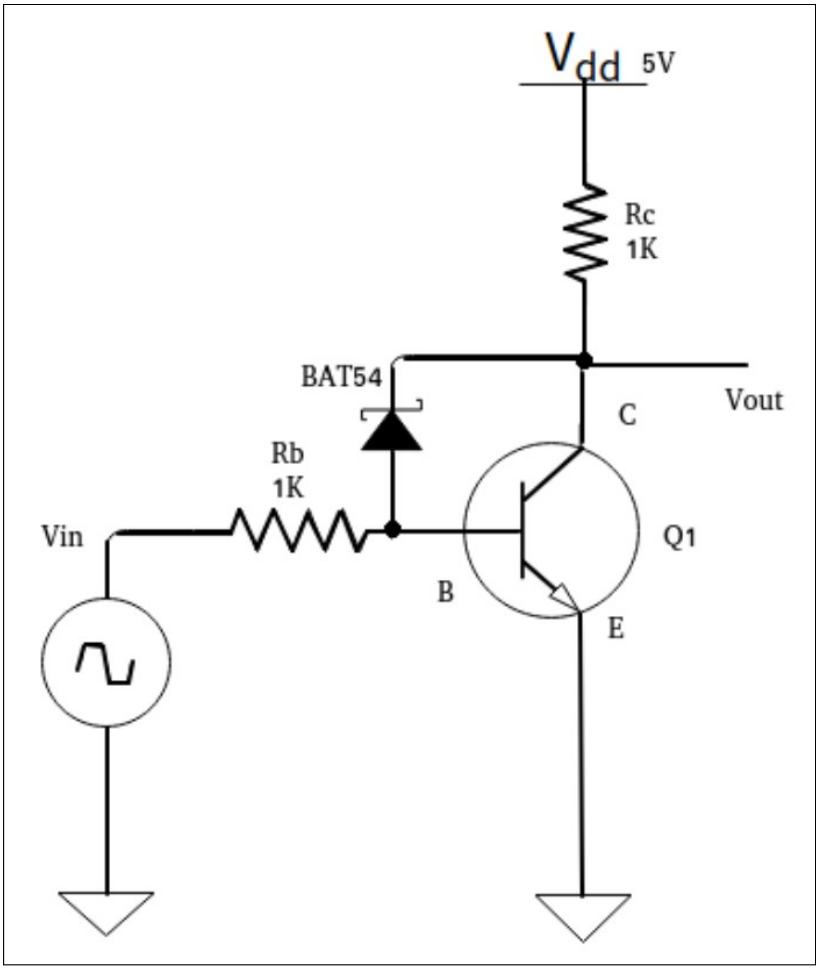


Figure 6: BJT Switching Circuit with Schottky Diode

3 Simulation results

3.1 Code snippets

3.1.1 Experiment 1 - BJT Parameters

CE Configuration

```
Vinamra Baghel 190010070 BJT Parameters in CE configuration
.include BC547.txt

*Netlist
Q1 c b e bc547a
r1 2 bb 470
r2 1 c 100
Ve e gnd 0
V1 1 gnd 12
V2 2 gnd 1
Ib bb b 0

*Analysis
.dc V1 0 20 0.1 Ib 0 1m 0.1m

.control
run
let Vc1 = V(c)[0, 200]
let Vc2 = V(c)[201, 401]
let Vc3 = V(c)[402, 602]
let Vc4 = V(c)[603, 803]
let Vc5 = V(c)[804, 1004]
let Vc6 = V(c)[1005, 1205]
let Vc7 = V(c)[1206, 1406]
let Vc8 = V(c)[1407, 1607]
let Vc9 = V(c)[1608, 1808]
let Vc10 = V(c)[1809, 2009]
let Vc11 = V(c)[2010, 2210]
let Ic1 = -I(V1)[0, 200]
let Ic2 = -I(V1)[201, 401]
let Ic3 = -I(V1)[402, 602]
let Ic4 = -I(V1)[603, 803]
let Ic5 = -I(V1)[804, 1004]
let Ic6 = -I(V1)[1005, 1205]
let Ic7 = -I(V1)[1206, 1406]
let Ic8 = -I(V1)[1407, 1607]
let Ic9 = -I(V1)[1608, 1808]
let Ic10 = -I(V1)[1809, 2009]
let Ic11 = -I(V1)[2010, 2210]

plot Ic1 vs Vc1 Ic2 vs Vc2 Ic3 vs Vc3 Ic4 vs Vc4 Ic5 vs Vc5 Ic6 vs
   Vc6 Ic7 vs Vc7 Ic8 vs Vc8 Ic9 vs Vc9 Ic10 vs Vc10 Ic11 vs Vc11

```

```
let alpha = -I(V1)[401]/I(Ve)[401]
let beta = I(V1)[401]/I(V2)[401]
let va1 = (Vc2[200]*Ic2[195] - Vc2[195]*Ic2[200])/(Ic2[195]-Ic2
   [200])
let va2 = (Vc11[200]*Ic11[195] - Vc11[195]*Ic11[200])/(Ic11[195]-
   Ic11[200])
print alpha beta
print va1
print va2
.endc
.end
```

CB Configuration

```
Vinamra Baghel 190010070 BJT Parameters in CB configuration
.include BC547.txt

*Netlist
Q1 c b e bc547a
r1 2 c 100
Vbd b gnd 0
V1 1 gnd -1
V2 2 gnd 12
Ie e 1 0

*Analysis
.dc V2 -5 15 0.1 Ie 0 10m 1m

.control
run
let Vc1 = V(c)[0, 200]
let Vc2 = V(c)[201, 401]
let Vc3 = V(c)[402, 602]
let Vc4 = V(c)[603, 803]
let Vc5 = V(c)[804, 1004]
let Vc6 = V(c)[1005, 1205]
let Vc7 = V(c)[1206, 1406]
let Vc8 = V(c)[1407, 1607]
let Vc9 = V(c)[1608, 1808]
let Vc10 = V(c)[1809, 2009]
let Vc11 = V(c)[2010, 2210]
let Ic1 = -I(V2)[0, 200]
let Ic2 = -I(V2)[201, 401]
let Ic3 = -I(V2)[402, 602]
let Ic4 = -I(V2)[603, 803]
let Ic5 = -I(V2)[804, 1004]
let Ic6 = -I(V2)[1005, 1205]
let Ic7 = -I(V2)[1206, 1406]
let Ic8 = -I(V2)[1407, 1607]
let Ic9 = -I(V2)[1608, 1808]
```

```
let Ic10 = -I(V2)[1809, 2009]
let Ic11 = -I(V2)[2010, 2210]

plot Ic1 vs Vc1 Ic2 vs Vc2 Ic3 vs Vc3 Ic4 vs Vc4 Ic5 vs Vc5 Ic6 vs
   Vc6 Ic7 vs Vc7 Ic8 vs Vc8 Ic9 vs Vc9 Ic10 vs Vc10 Ic11 vs Vc11

let beta = I(V2)[401]/I(Vbd)[401]
let alpha = beta/(1+beta)
print alpha beta
.endc
.end
```

3.1.2 Experiment 2 - Gummel Plot

```
Vinamra Baghel 190010070 BJT Gummel Plot
.include BC547.txt

*Netlist
Q1 c b gnd bc547a
Vcb c bb 5
Vbd b bb 0
Vbe bb gnd 0

*Analysis
.dc Vbe 0.3 1.2 0.01

.control
run
plot ylog (-I(Vcb)), (-I(Vbd)) vs V(b)-V(e)
let beta = I(Vcb)/I(Vbd)
let Ic = -1*I(Vcb)
plot beta vs Ic
.endc
.end
```

3.1.3 Experiment 3 - Small Signal Parameters

```
Vinamra Baghel 190010070 BJT Small Signal Parameters
.include BC547.txt

*Netlist
Q1 c b e bc547a
r1 1 bb 100k
r2 2 cc 1k
Vc c 3 0
Vb b 1 0
Ve e gnd 0
Vbb bb gnd 2.843
Vcc cc gnd 9.5
Ic 2 3 4.5m
```

```

*Analysis
.op

.control
run
let gm = -I(Vc)/26m
let beta = I(Vc)/I(Vb)
let rpi = -beta/gm
let ro = -73/I(Vc)
print gm beta rpi ro
.endc
.end
```

3.1.4 Experiment 4 - Switching Behaviour

```
Vinamra Baghel 190010070 BJT Switching behaviour
.include BC547.txt
.include BAT54.txt
.include 2N3904.txt

*Netlist
Q1 out b gnd bc547a
*X1 b out BAT54
rc dd out 1k
rb in b 1k
Vin in gnd pulse(0 5 0 0 0 0.5m 1m)
Vdd dd gnd 5

*Analysis
.tran 0.01u 2.5m

.control
run
let Vmin = minimum(V(out))
plot V(out) V(in)
meas tran fall trig v(out) val=1.1*Vmin rise=2 targ v(out) val=4.5
   rise=2
meas tran strg when v(out)=4.5 rise=1
let turnoff = fall + strg - 0.5m
print turnoff
.endc
.end
```

3.2 Simulation results

3.2.1 Experiment 1 - BJT Parameters

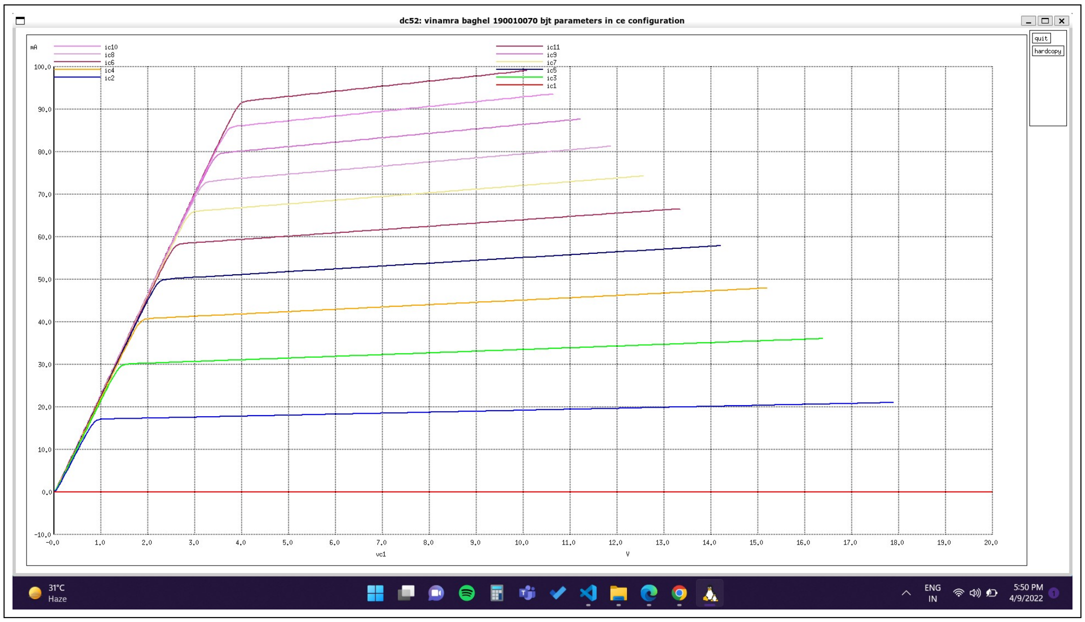


Figure 7: $I_C - V_{CE}$ Characteristics in CE Configuration

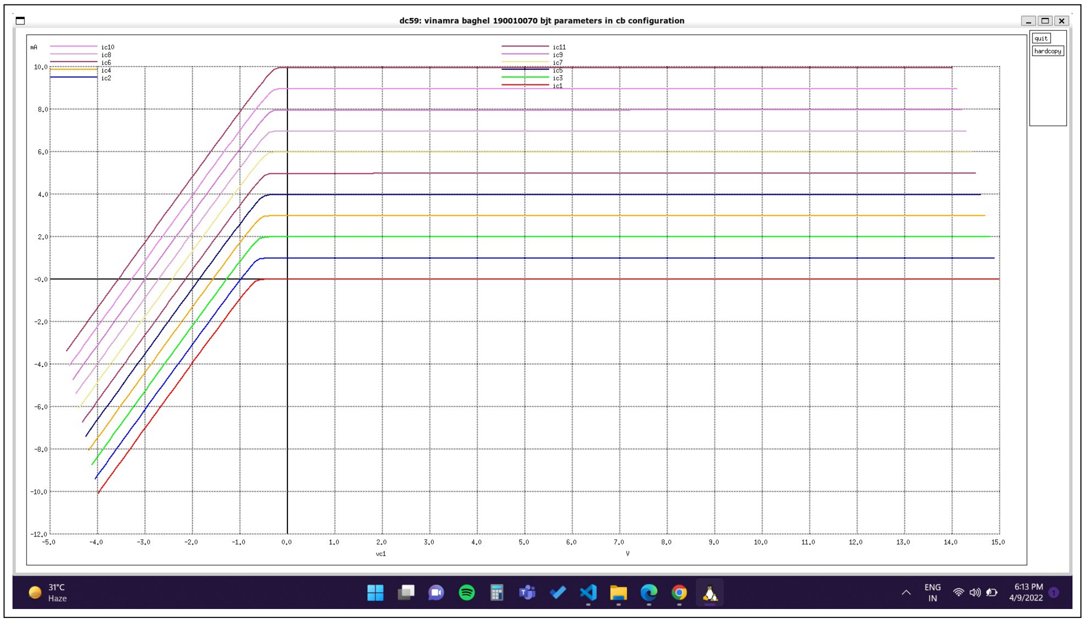


Figure 8: $I_C - V_{CB}$ Characteristics in CB Configuration

3.2.2 Experiment 2 - Gummel Plot

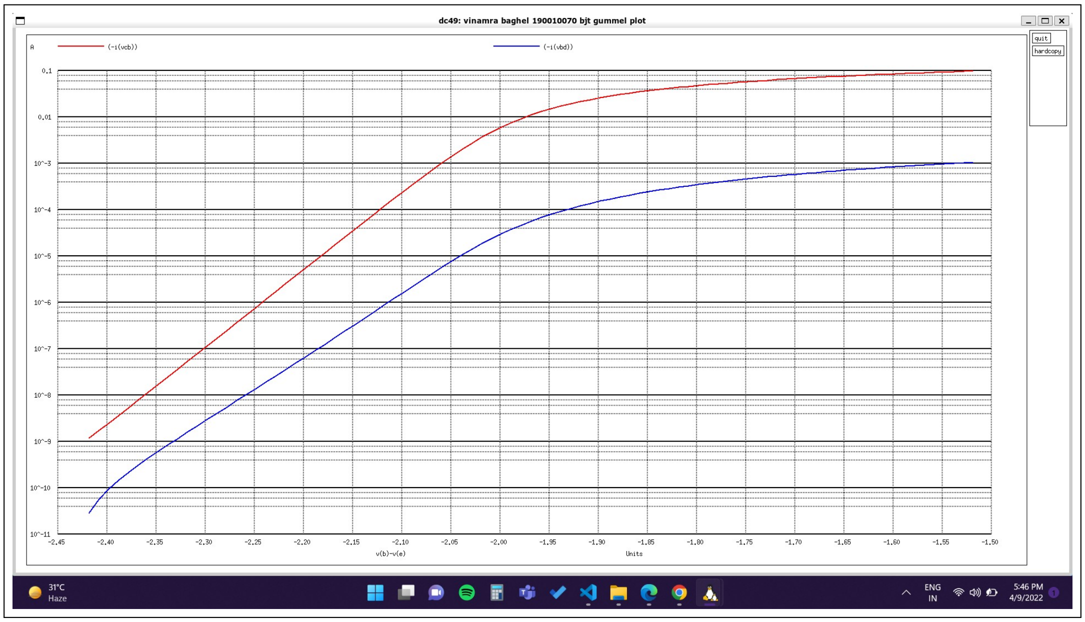


Figure 9: Gummel Plot

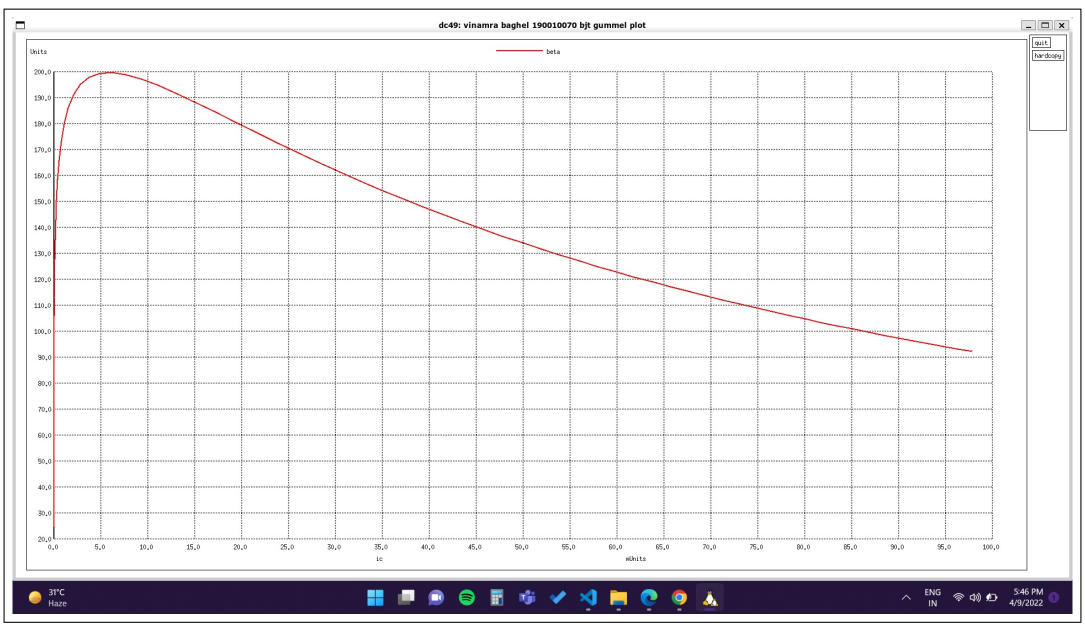


Figure 10: β_{DC} vs I_C

3.2.3 Experiment 3 - Small Signal Parameters

No plots.

3.2.4 Experiment 4 - Switching Behaviour

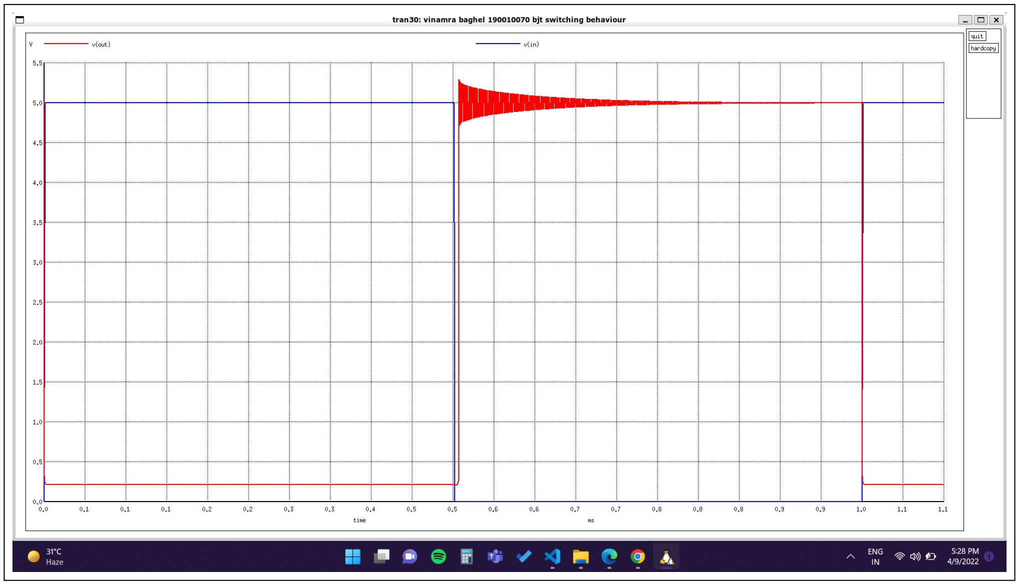
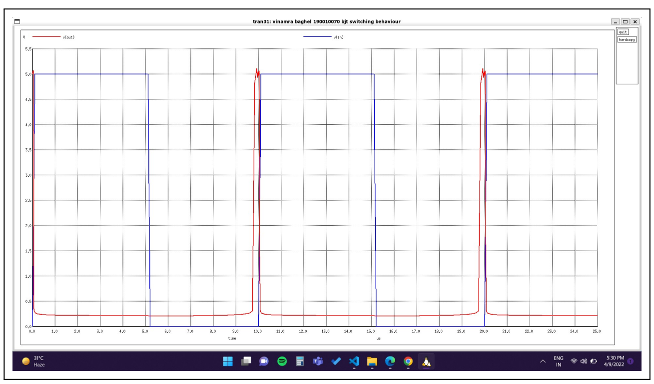
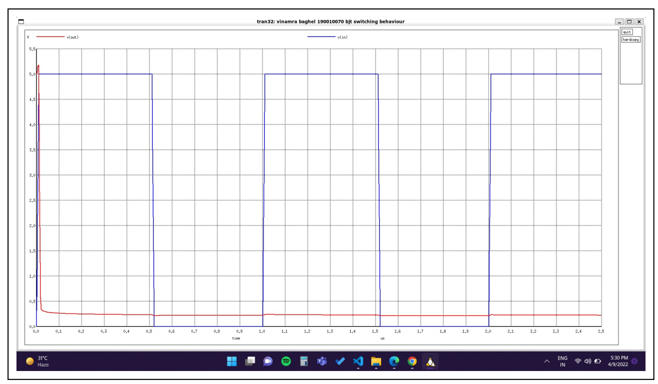


Figure 11: bc547 with frequency 1 kHz



(a) bc547 with frequency 100 kHz



(b) bc547 with frequency 1 MHz

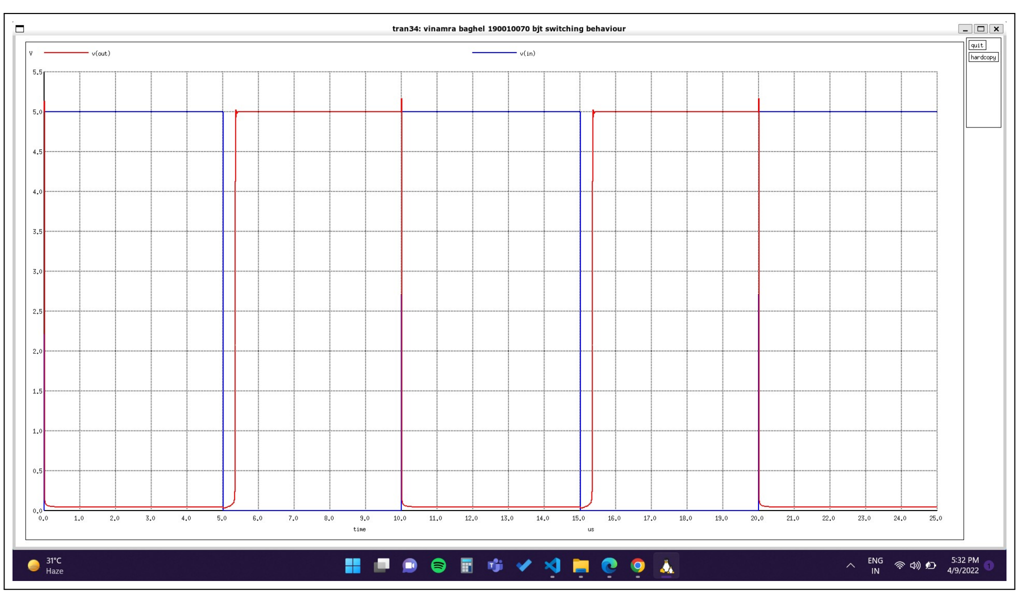


Figure 13: 2N3094 with frequency 100 kHz

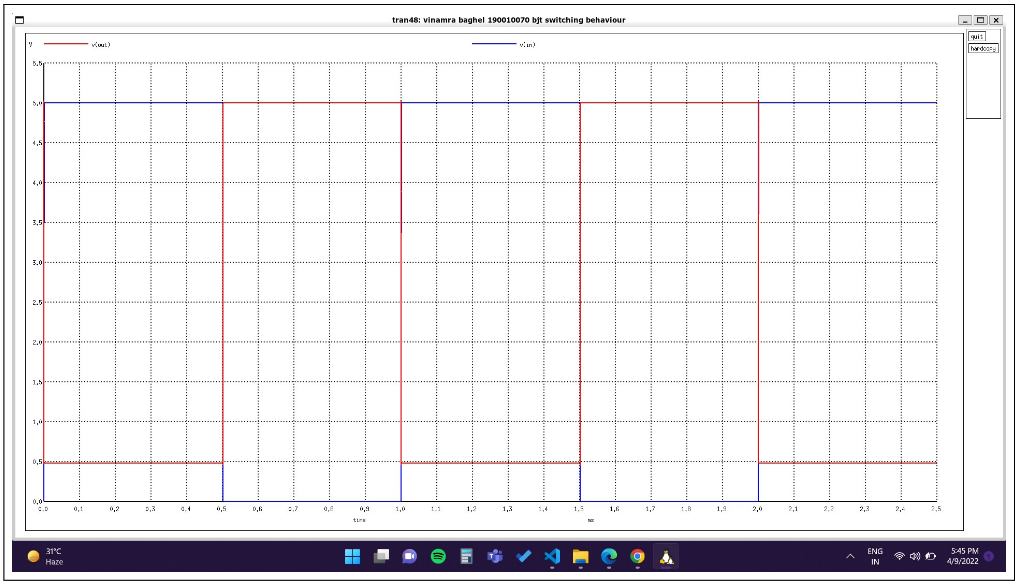


Figure 14: bc547 with frequency 1 kHz with Schottky Diode

4 Experimental results

4.1 Experiment 1 - BJT Parameters

4.1.1 CE Configuration

$$\alpha = 0.9953$$

$$\beta = 210.46$$

$$RB = 0.4999$$

$$V_A = -73V$$

4.1.2 CB Configuration

$$\alpha = 0.9950$$

$$\beta = 198.32$$

$$RB = 1.0299$$

4.2 Experiment 2 - Gummel Plot

Only plots.

4.3 Experiment 3 - Small Signal Parameters

$$g_m = 0.1731$$

$$r_\pi = 1.216\, k\Omega$$

$$r_o = 16.22\, k\Omega$$

4.4 Experiment 4 - Switching Behaviour

Turnoff times: in μs

Frequency	bc547	2N3904	bc547 with Schottky
1 kHz	5.0525	0.3755	0.1841
100 kHz	4.6790	0.3755	0.1841
1 MHz	-	0.3688	0.1759

5 Experiment completion status

I could complete all the parts of the lab. There was no hardware involvement as it was all simulation based. The results were shown to the TA and then submitted.