2024102014 Assignment - 2 AEC

1)

(1.1) given npn BJT

$I_B = 14.46 \mu A$

$I_E = 1.46 mA$

$V_{BE} = 0.7V$

as $V_{BE} = 0.7$ BJT is in forward active or saturation mode then,

$$I_E = I_B + I_C$$

$$1.46mA = 14.46\mu A + I_C$$

$$I_C \approx 1.445 mA$$

$$\beta = \frac{I_C}{I_B}, \quad \alpha = \frac{I_C}{I_E}$$

$$\beta = \frac{1.445 \times 10^{-3}}{14.46 \times 10^{-6}} = 99.99 \approx 100$$

$$\beta = 99.993 = 100$$

$$\alpha = \frac{1.445mA}{1.46mA} = 0.99 \approx 1$$

$$\alpha = 0.99 \approx 1$$

$$I_S(e^{V_{BE}/V_T} - 1) = I_C$$

$V_{BE} = 0.7V$, $V_T = 26mV$ at room Temp

$$I_S = \frac{1.445 \times 10^{-5}}{(e^{0.7/0.026} - 1)} = 96 \times 10^{-6} \times 10^{-8} \times 10^{-3} = 9.6 \times 10^{-16} A$$

(1.2)

$I_S = 10^{-16} A$, $\beta = 100$

$I_C = 1mA$

$I_C = I_S\left(e^{V_{BE}/V_T} - 1\right)$

$10^{13} = e^{V_{BE}/V_T}$ $\quad V_T = 26mV = 0.026V$

$V_{BE} = 0.77V$

$I_B = I_{SB}\left(e^{V_{BE}/V_T} - 1\right)$

$\boxed{\frac{I_S}{\beta}\left(\cancel{e^{V_{BE}/V_T} - 1}\right)} = I_{SB}\left(\cancel{e^{V_{BE}/V_T} - 1}\right)$

I_C $\Rightarrow$ $I_{SB} = \frac{I_S}{\beta} = 10^{-18} = \frac{10^{-16}}{100} = 10^{-18} A$

$\Rightarrow I_{SE} = \frac{I_S}{\alpha} = \left(\frac{\beta+1}{\beta}\right) I_S = 1.01 \times 10^{-16} A$

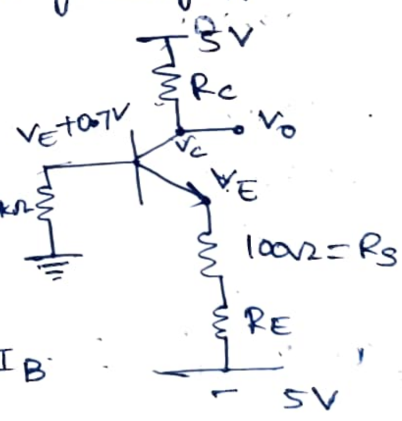
(1.3) Given,

$\beta = 100$, $V_A = \infty$ (neglecting early effect)

$I_{CQ} = 0.25 mA$ $\quad V_{CEQ} = 3V$

R_C and R_E ?

By DC analysis



$\frac{V_E + 0.7}{50k\Omega} = I_B$

$I_E = \frac{V_E + 5}{100 + R_E}$

$I_B = \frac{I_C}{\beta} = \frac{0-(V_E+0.7)}{50k\Omega} = \frac{0.25 \times 10^{-3}}{100}$

$-2V_E - 1.4 = 0.25$

$V_E = \frac{-1.65}{2} = -0.825 \Rightarrow V_B = -0.125$

$I_E = \left(\frac{\beta+1}{\beta}\right) I_C = \frac{101}{100} \times 0.25\,mA$

$I_E = 0.2525\,mA$

$(R_E + 100) I_E = V_E + 5$

$R_E = 16.4\,k\Omega$

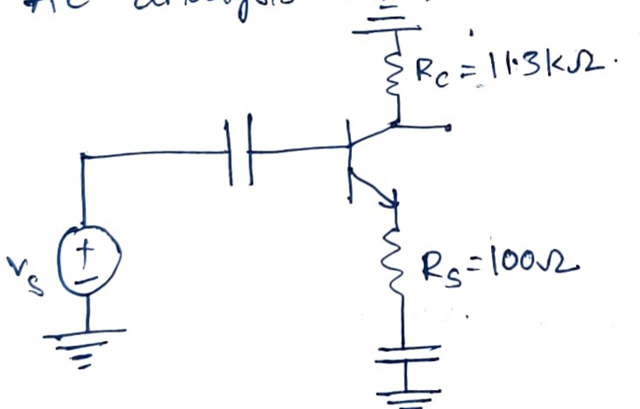
$V_{CE} = 3V \Rightarrow V_C = 3V - 0.0825V$

$V_c = 2.175$

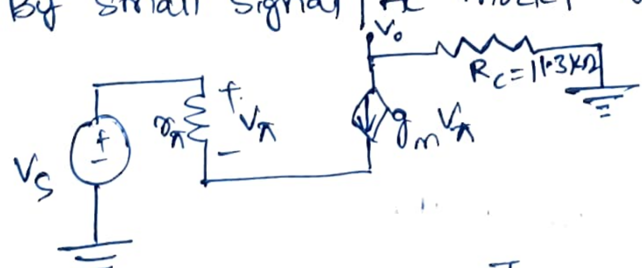
$\frac{5 - 2.175}{R_c} = I_C = 0.25\,mA$

$\boxed{R_C = 11.3\,k\Omega}$

AC analysis now,



By small signal | AC model replacement



$r_\pi = \frac{\beta}{g_m}$ $\quad g_m = \frac{I_C}{V_T}$ $\quad I_C = 0.25\,mA$

$V_o = i_c R_c$ $\quad g_m V_\pi = i_c$

$V_s = i_b r_\pi + i_e R_s$ $\quad V_e = i_e R_s$

$A_v = \frac{V_o}{V_s} = \frac{i_c R_c}{V_s} = \frac{\beta R_C}{r_\pi + (\beta+1) R_s}$

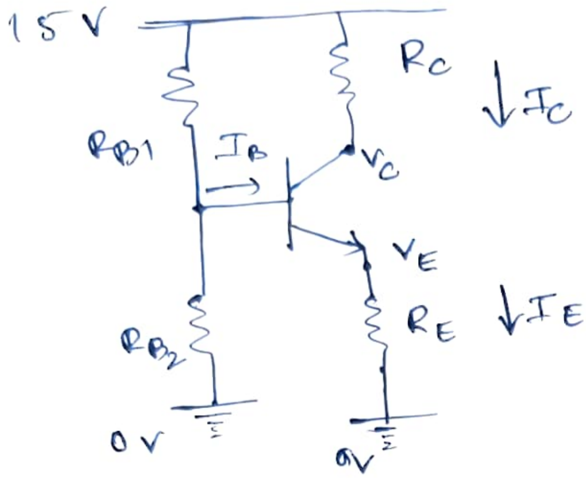
input Resistance $= \frac{\beta}{g_m} + (\beta+1) R_s = 20.4\,k\Omega$

$g_m = 9.6\,m\Omega$

$r_\pi = 10.9\,\Omega$

$\boxed{A_v = \frac{100 \times 11.3}{20.4} = 55.39}$

(2.1)



$\beta = 100$ $\quad R_{B_1} = 100k\Omega$

~~RB~~ $R_{B_2} = 50k\Omega$

$R_C = 5k\Omega$

$R_E = 3k\Omega$

$$\frac{V_{CC} R_{B_2}}{R_{B_2} + R_{B_1}} \approx V_B = \frac{15 \times 50}{150} = 5V$$

$$\boxed{V_E = 4.3V}$$

$$I_E = \frac{V_E}{R_E} = \frac{4.3V}{3k\Omega} = \boxed{1.43mA}$$

$$I_C \approx I_E \qquad \frac{15 - V_C}{R_C} = I_C$$

$$15 - V_C = 5 \times 10^3 \times 1.43 \times 10^{-3}$$

$$\boxed{V_C \approx 7.85V}$$

$$\frac{15 - V_B}{R_{B_1}} = I_B + \frac{V_B}{R_{B_2}}$$

$$\frac{15 - 3V_B}{100k\Omega} = I_B$$

$$V_E = I_E \cdot R_E$$

$$V_B - 0.7 = (\beta + 1) I_B R_E$$

$$\frac{V_B - 0.7}{(\beta+1) R_E} = \frac{15 - 3V_B}{100k\Omega} = \frac{V_B - 0.7}{303}$$

$$100V_B - 70 = 303 \times 15 - 909 V_B$$

$$1009 V_B = 303 \times 15 + 70$$

$$\boxed{V_B = 4.57V} \qquad \boxed{V_E = 3.87V}$$

$$\frac{15 - V_C}{R_C} = I_C$$

$$15 - V_C = (5k\Omega)1.29mA$$

$$\boxed{V_C = 8.55V}$$

$I_C = \beta I_B$ $\boxed{I_B = 12.9\mu A}$

$\boxed{I_E = I_B + I_C \approx 1.29mA}$

$\boxed{I_C = 1.29mA}$

2.2

$\beta \rightarrow \beta/2$

$\beta_n = 50$

$$\frac{V_B - 0.7}{(\beta_n + 1)R_E} = \frac{15 - 3V_B}{100k\Omega} = I_B$$

$$\frac{V_B - 0.7}{153k\Omega} = \frac{15 - 3V_B}{100k\Omega}$$

$100V_B - 70 = 15 \times 153 - (153)(3)V_B$

$559V_B = 2365$

$$\frac{15 - V_C}{R_C} = I_C$$

$-I_C R_C + 15 = V_C$

$V_C = 9.25$

$V_B = 4.23V$

$V_E = 3.55V$

$V_C = 9.25V$

$I_B = 23.1\mu A$

$I_C = 1.15mA$

$I_E \approx 1.15mA$

β	I_C (mA)	I_B (μA)	I_E (mA)	V_C (V)	V_B (V)	V_E (V)
100	1.29	12.9	1.29	8.55	4.57V	3.87
50	1.15	23.1	1.15	9.25	4.23V	3.55
%	10.85	79.06	10.85	8.18	7.4	8.78

(2.3) In both the cases the BJT is present in the forward active mode, we can show this through the calculations, as initially we started off with taking $V_{BE} = 0.7V$ and later arrived at the conclusion $V_{CE} > 0.2$ which proves our initial assumption that both are forward active is true.

* as from our calculations we can say V_{BE} or Base-emitter is forward biased and collector base is reversed bias.
* due to decrease in β have in this circuit there's been a drastic change in I_B

(3.3) * below 0.24 is deep saturation $I_C \approx 0$ goes to cutoff

* forward active (0.65 – 0.71) * (0.25 – 0.26) saturation to 0.30

S.No	V_{CE}	$(I_{B_1})_1$	$(I_{B_1})_2$	$(I_{C_1})_1$	$(I_{C_2})_1$	ΔI_C	ΔI_B	β
1	100mV	50µA	60µA	5.34mA	6.21mA	0.87mA	10µA	87
2	600mV	50µA	60µA	12.95	15.29	2.34mA	10µA	234

β at saturation (100mV) 87

β at active (600mV) 234

(sat to active)

Incremental
Difference observed b/w β at different V_{CE} because collector goes into reversed bias while V_{CE} going from saturation to active mode

V_{CE}	I_C(mA)	I_B(µA)	$\beta = \frac{I_C}{I_B}$
1V	~~[illegible]~~ −178.68	0	—
1V	2.8	10	280
1V	5.5	20	275
1V	8.1	30	270
1V	10.61	40	265
1V	13.04	50	260
1V	15.39	60	256
1V	17.68	70	252
1V	19.91	80	248
1V	22.09	90	245
1V	24.2	100	242

Then $I_B \downarrow$ and there by $\uparrow \beta = \frac{I_C}{I_B \downarrow}$

Hence β increases

Yes, Early effect is observed (Base-Width modulation) causes β to increase as VCE $\uparrow$es as since higher VCE reduces the base width, so, IC increases in very small amount.

Let $I_{B_1} = 60\mu A$ at

Since slope is same

wkT, given

$$\text{slope} = I_C / (V_A + V_{CE})$$ equating slopes.

at 5V $\Rightarrow \frac{13.88}{V_A + 5V} = \frac{14.94}{V_A + 10V}$ at 10V

$$14.94 V_A - 13.88 V_A + 5 \times 14.94 = 10 \times 13.88$$

$$1.06 V_A = 64.1$$

$$V_A = 60.47 \text{ approx } (60)$$

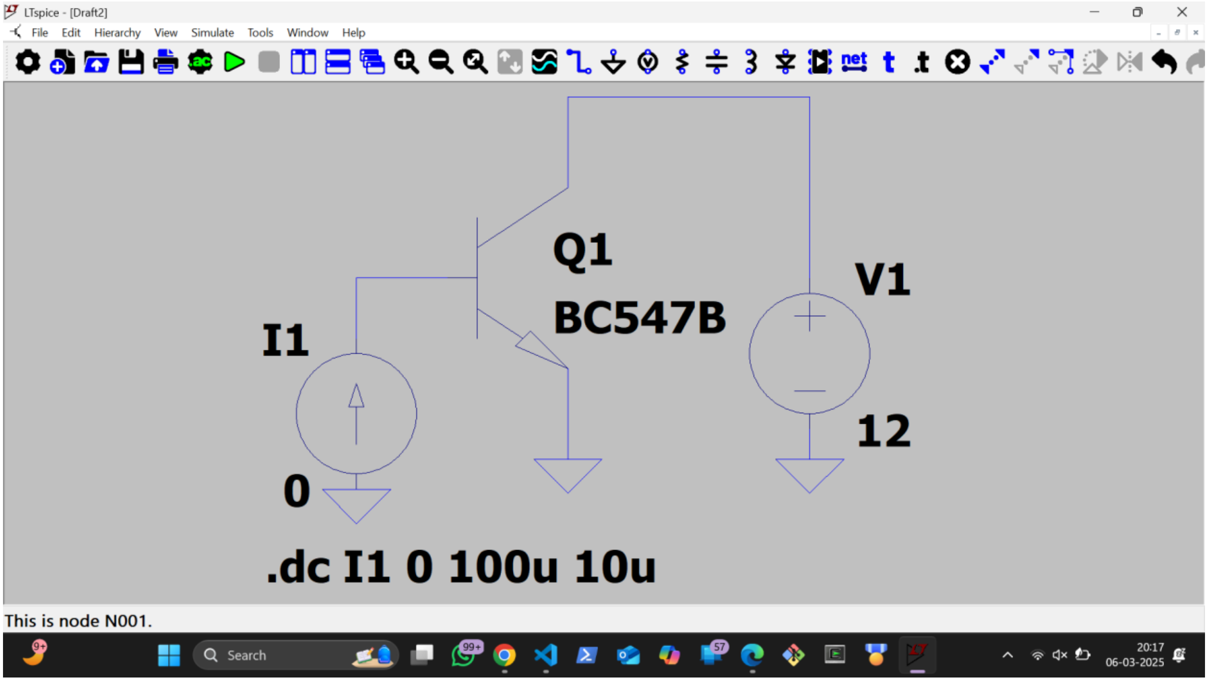
(3.2) from the graph.

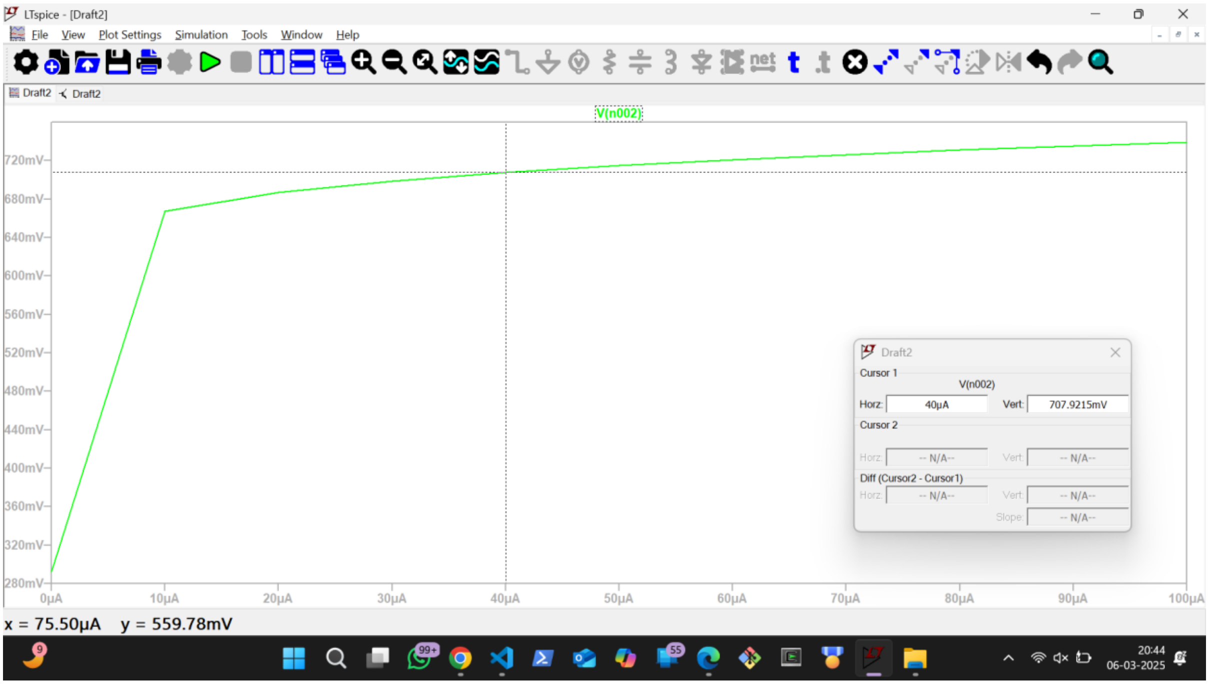
V_{BE} decreases -1.6 to -2mV per °C is almost linear.

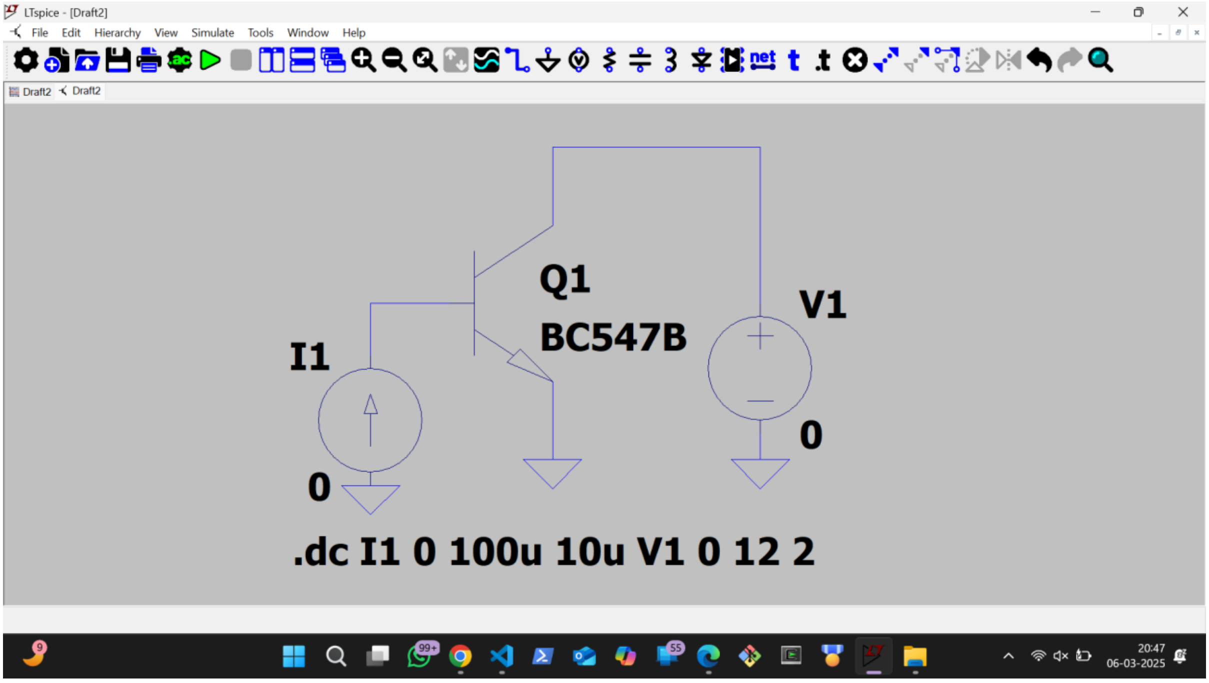
(3.1) from plot we get EBJ (Emitter base J^n) - voltage to be about 700-740 mV

from above plots for BJT in active/saturation we need to have V_{BE} greater than the EBJ voltage

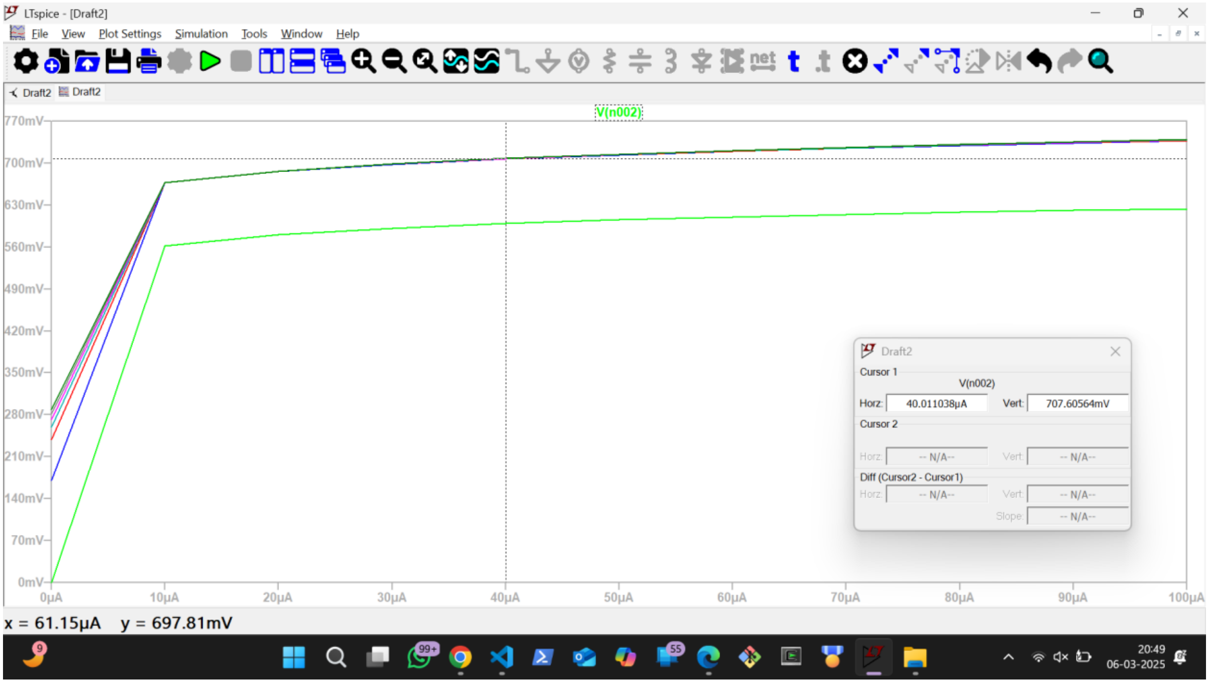
Q-3.1


LTspice - [Draft2]
File Edit Hierarchy View Simulate Tools Window Help
Q1
BC547B
V1
I1
12
0
.dc I1 0 100u 10u
This is node N001.


LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
V(n002)
720mV
680mV
640mV
600mV
560mV
520mV
480mV
440mV
400mV
360mV
320mV
280mV
0µA
10µA
20µA
30µA
40µA
50µA
60µA
70µA
80µA
90µA
100µA
Draft2
Cursor 1
V(n002)
Horz: 40µA
Vert: 707.9215mV
Cursor 2
Diff (Cursor2 - Cursor1)
x = 75.50µA y = 559.78mV

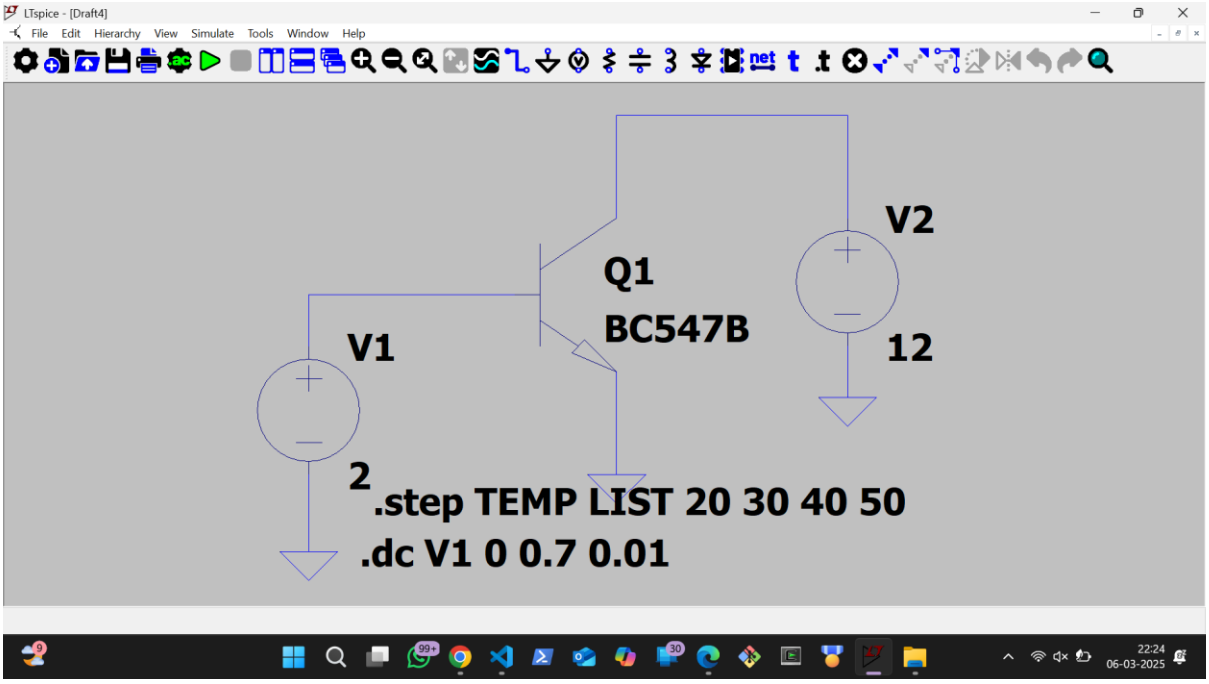


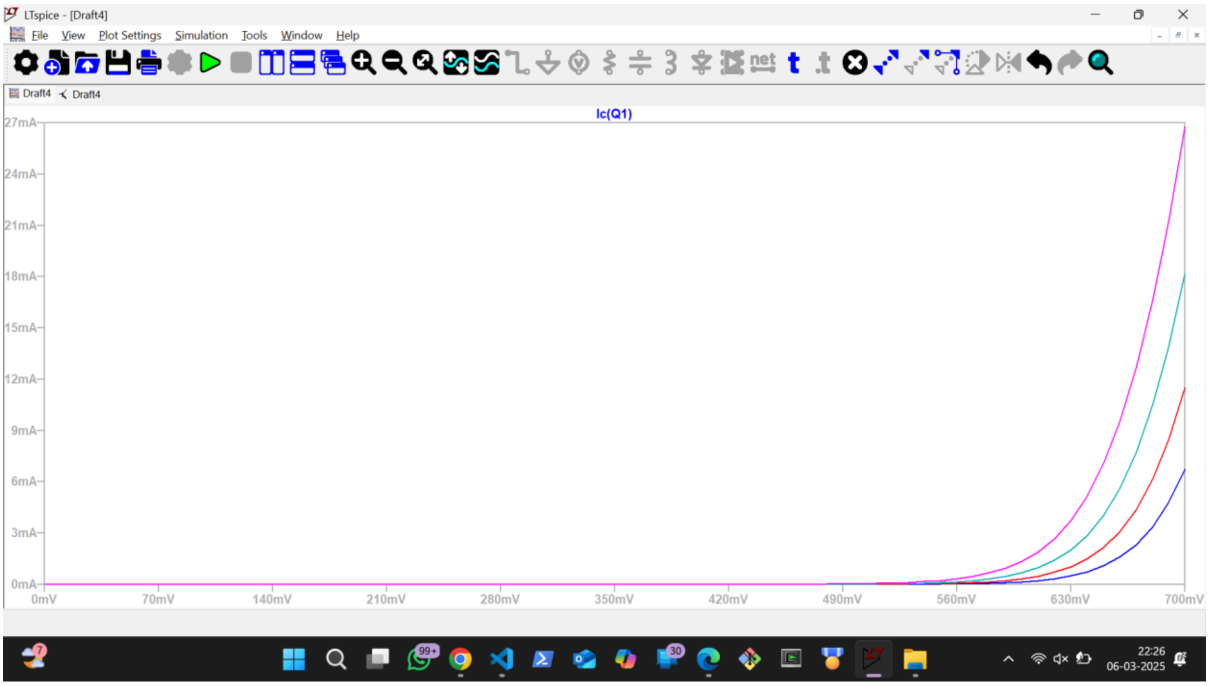
LTspice - [Draft2]
File Edit Hierarchy View Simulate Tools Window Help
Q1
BC547B
V1
I1
0
0
.dc I1 0 100u 10u V1 0 12 2
20:47
06-03-2025



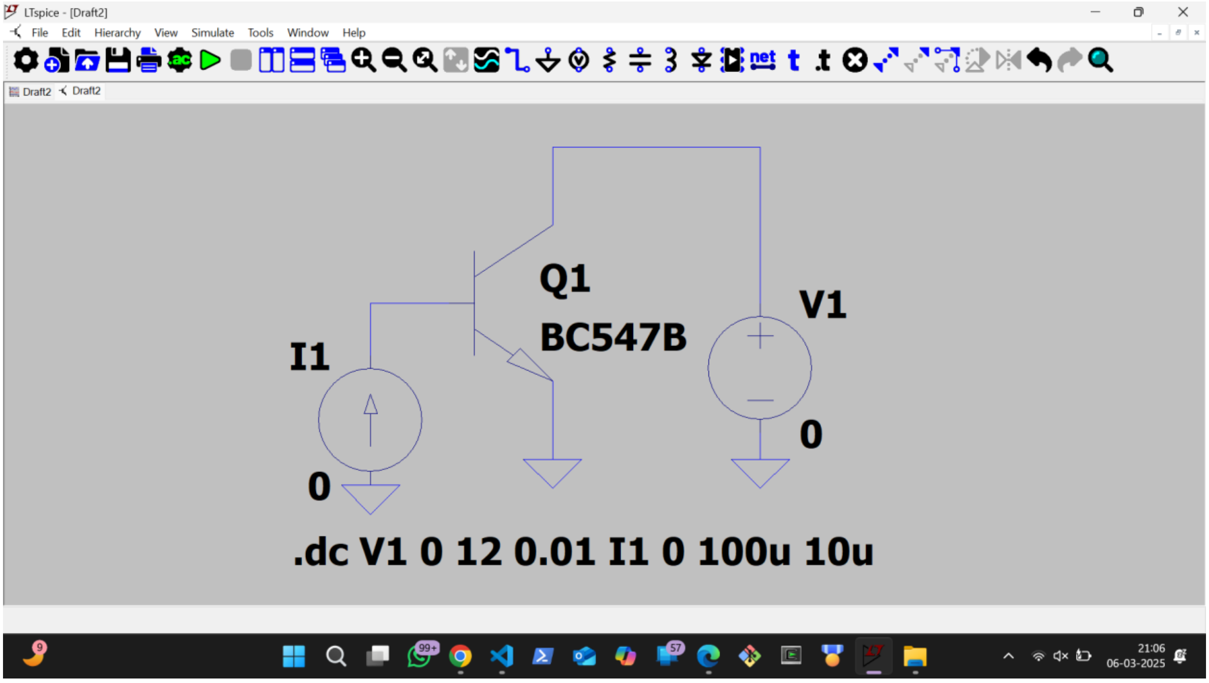
LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
V(n002)
770mV
700mV
630mV
560mV
490mV
420mV
350mV
280mV
210mV
140mV
70mV
0mV
0µA
10µA
20µA
30µA
40µA
50µA
60µA
70µA
80µA
90µA
100µA
Draft2
Cursor 1
V(n002)
Horz: 40.011038µA
Vert: 707.60564mV
Cursor 2
Diff (Cursor2 - Cursor1)
Slope:
x = 61.15µA y = 697.81mV
20:49
06-03-2025

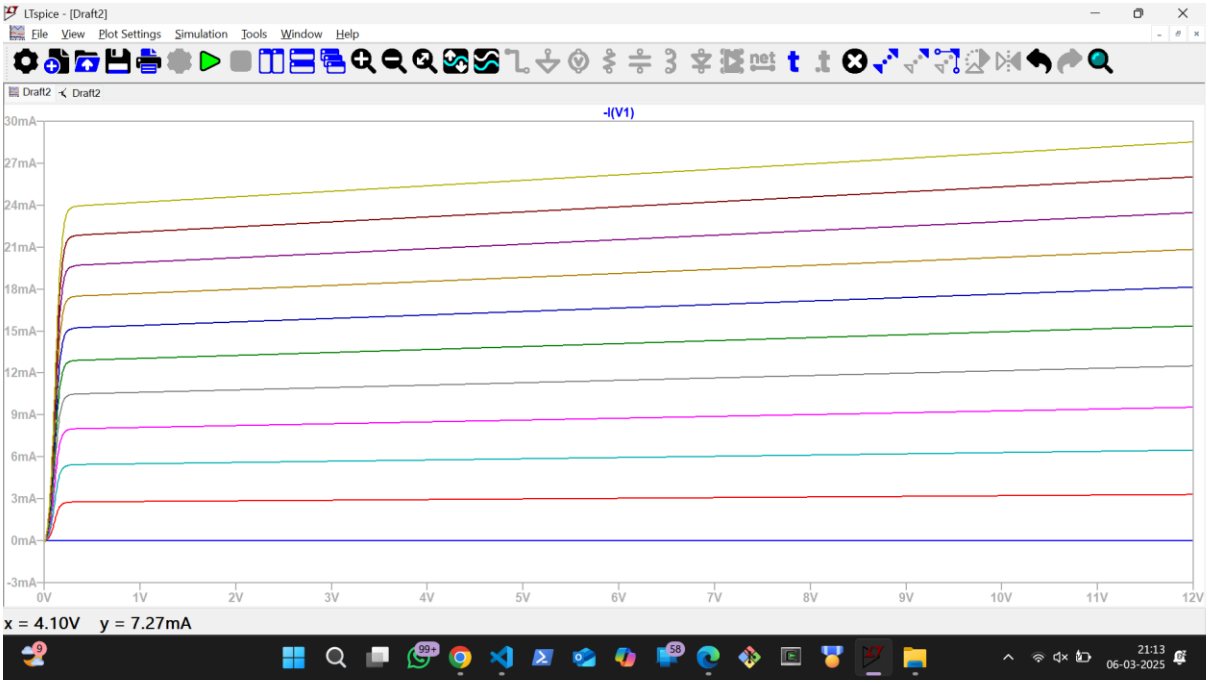
Q-3.2


LTspice - [Draft4]
File Edit Hierarchy View Simulate Tools Window Help
V2
Q1
BC547B
V1
12
2
.step TEMP LIST 20 30 40 50
.dc V1 0 0.7 0.01
22:24
06-03-2025


LTspice - [Draft4]
File View Plot Settings Simulation Tools Window Help
Draft4
Draft4
Ic(Q1)
27mA
24mA
21mA
18mA
15mA
12mA
9mA
6mA
3mA
0mA
0mV
70mV
140mV
210mV
280mV
350mV
420mV
490mV
560mV
630mV
700mV
22:26
06-03-2025

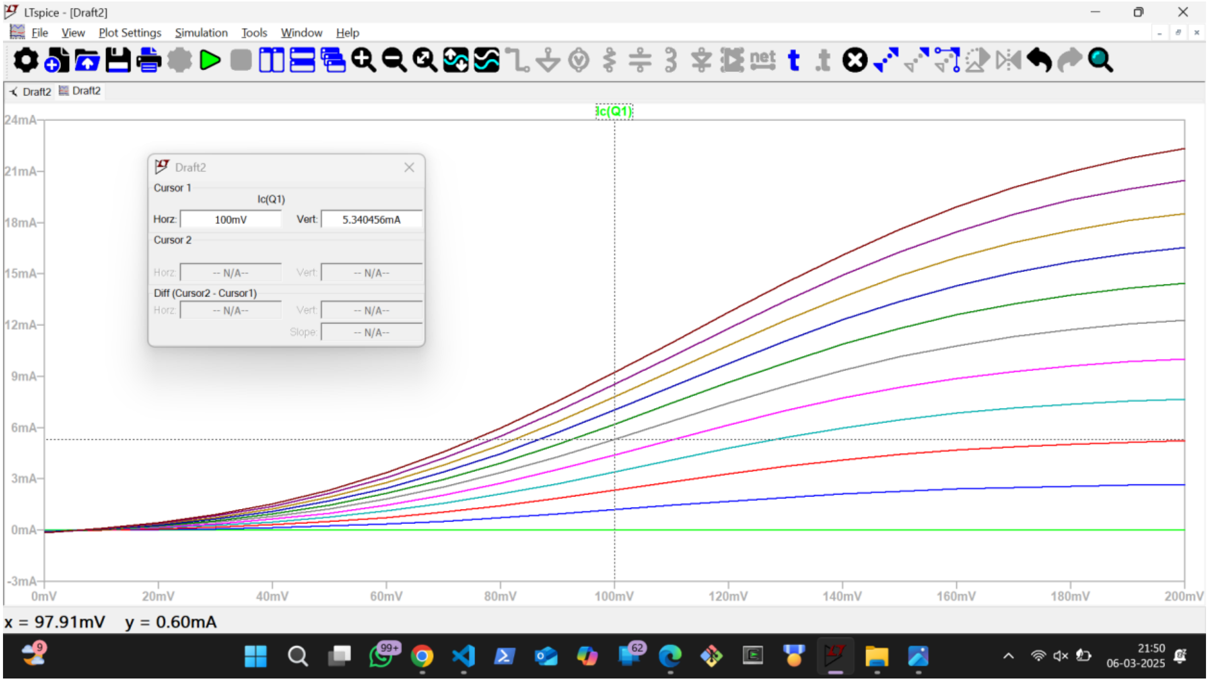
Q-3.3

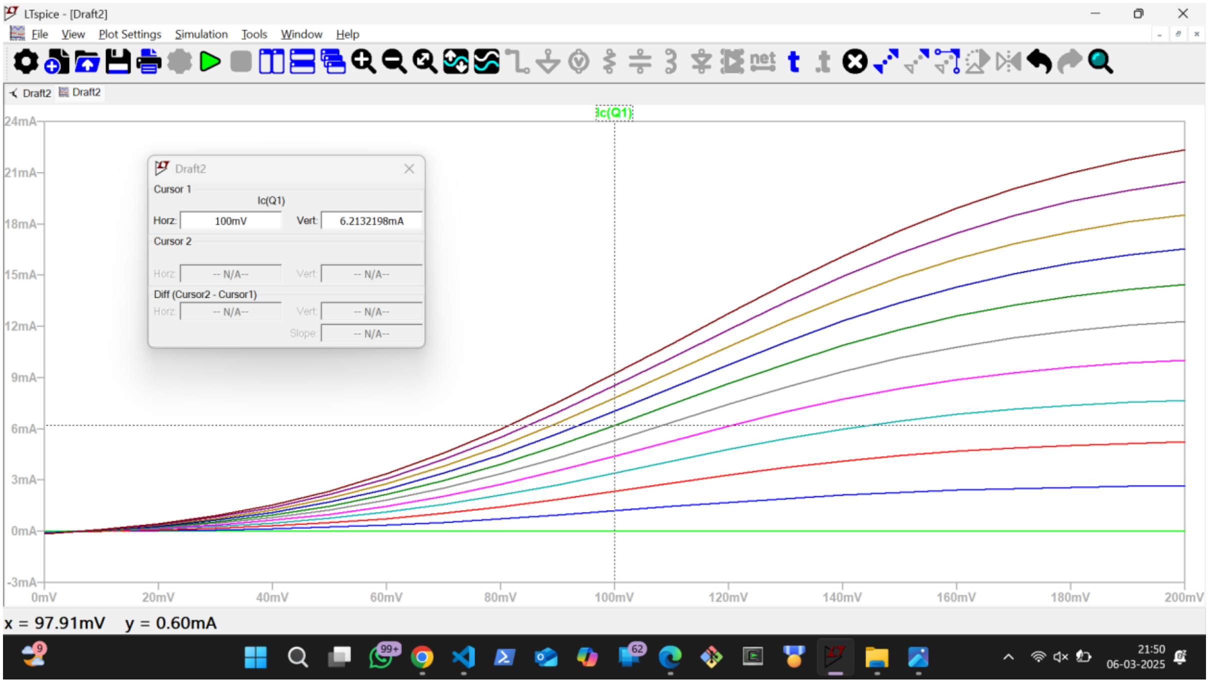

LTspice - [Draft2]
File Edit Hierarchy View Simulate Tools Window Help
Draft2
Q1
BC547B
V1
I1
0
0
0
.dc V1 0 12 0.01 I1 0 100u 10u
21:06
06-03-2025


LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Draft2
-I(V1)
30mA
27mA
24mA
21mA
18mA
15mA
12mA
9mA
6mA
3mA
0mA
-3mA
0V
1V
2V
3V
4V
5V
6V
7V
8V
9V
10V
11V
12V
x = 4.10V y = 7.27mA
21:13
06-03-2025

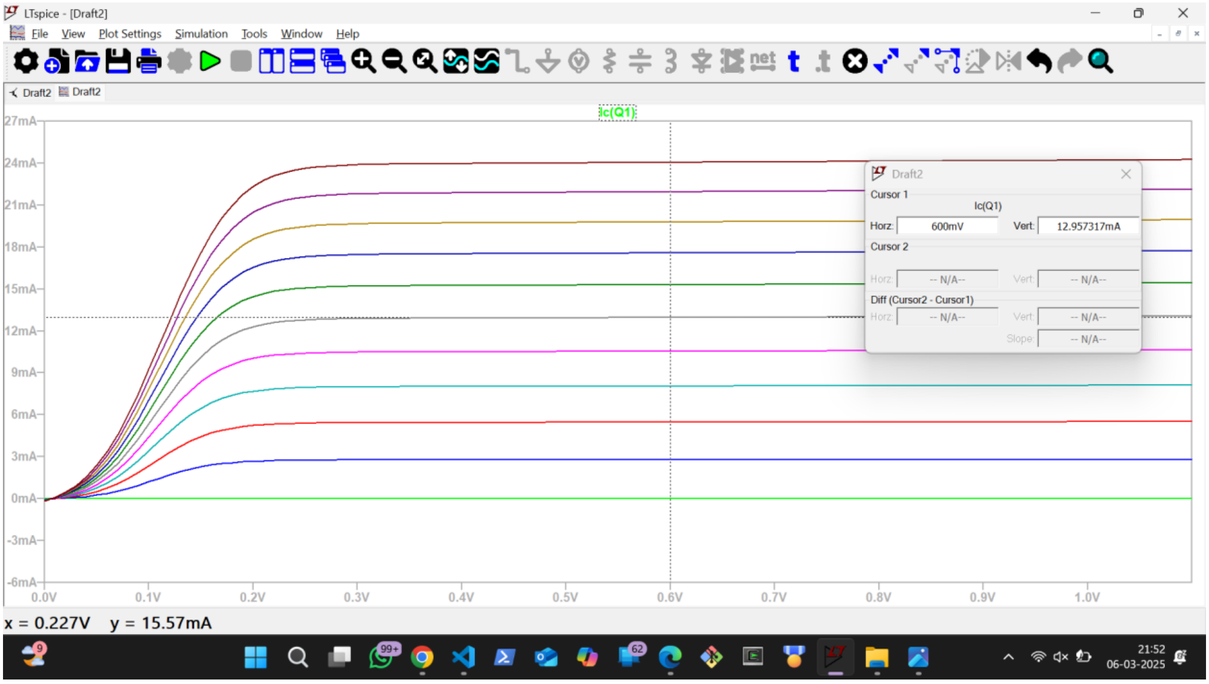
Calculation of beta(β) by change in currents of Ic and Ib at 50uA and 60uA

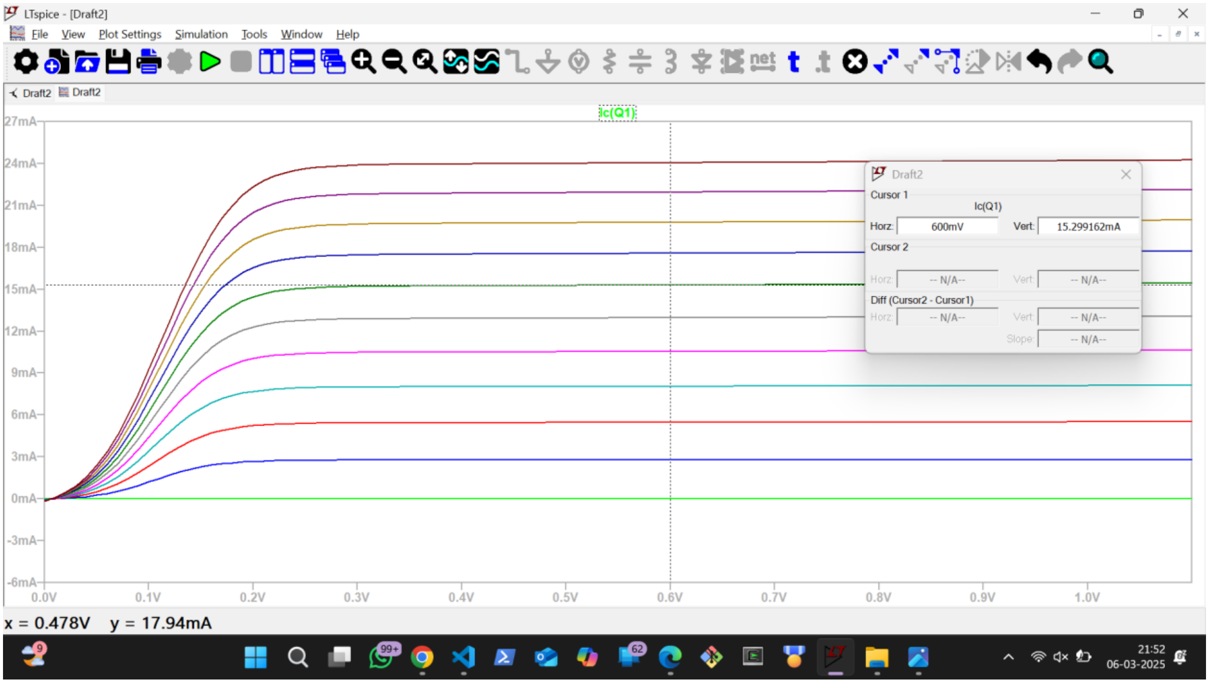
At 100mV



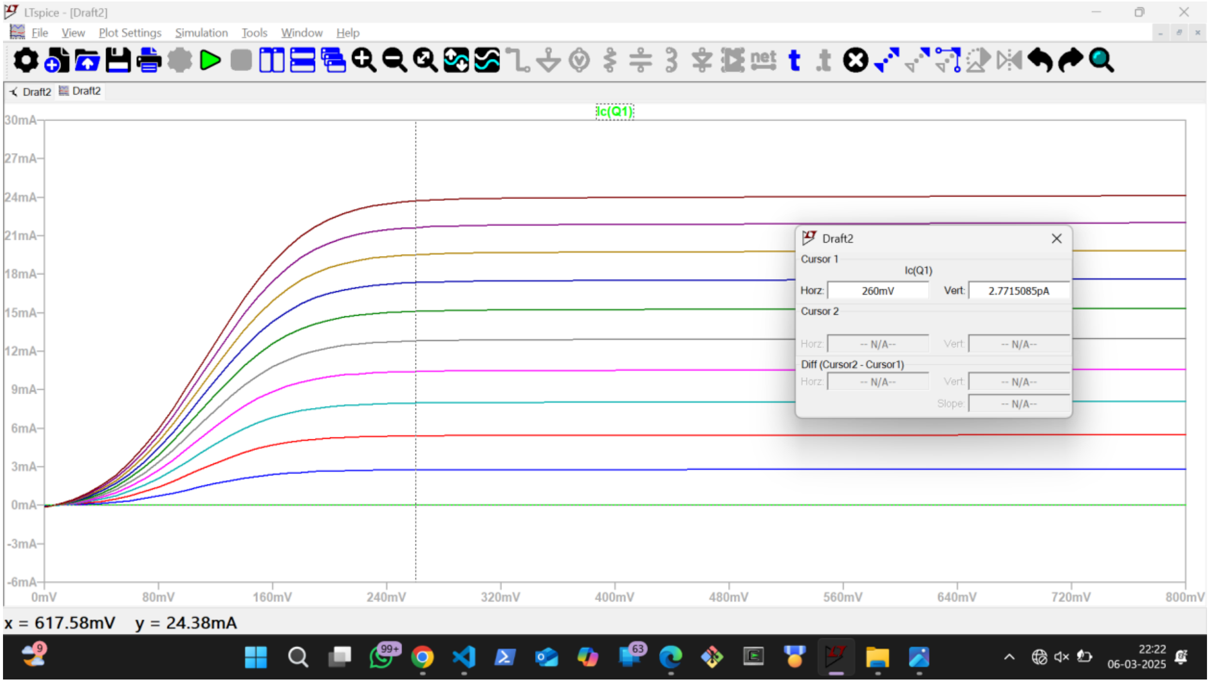


At 600mV


LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Ic(Q1)
Draft2
Cursor 1
Ic(Q1)
Horz: 600mV Vert: 12.957317mA
Cursor 2
Diff (Cursor2 - Cursor1)
x = 0.227V y = 15.57mA
21:52
06-03-2025


LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Ic(Q1)
Draft2
Cursor 1
Ic(Q1)
Horz: 600mV Vert: 15.299162mA
Cursor 2
Diff (Cursor2 - Cursor1)
x = 0.478V y = 17.94mA
21:52
06-03-2025

Saturation and Active mode mark

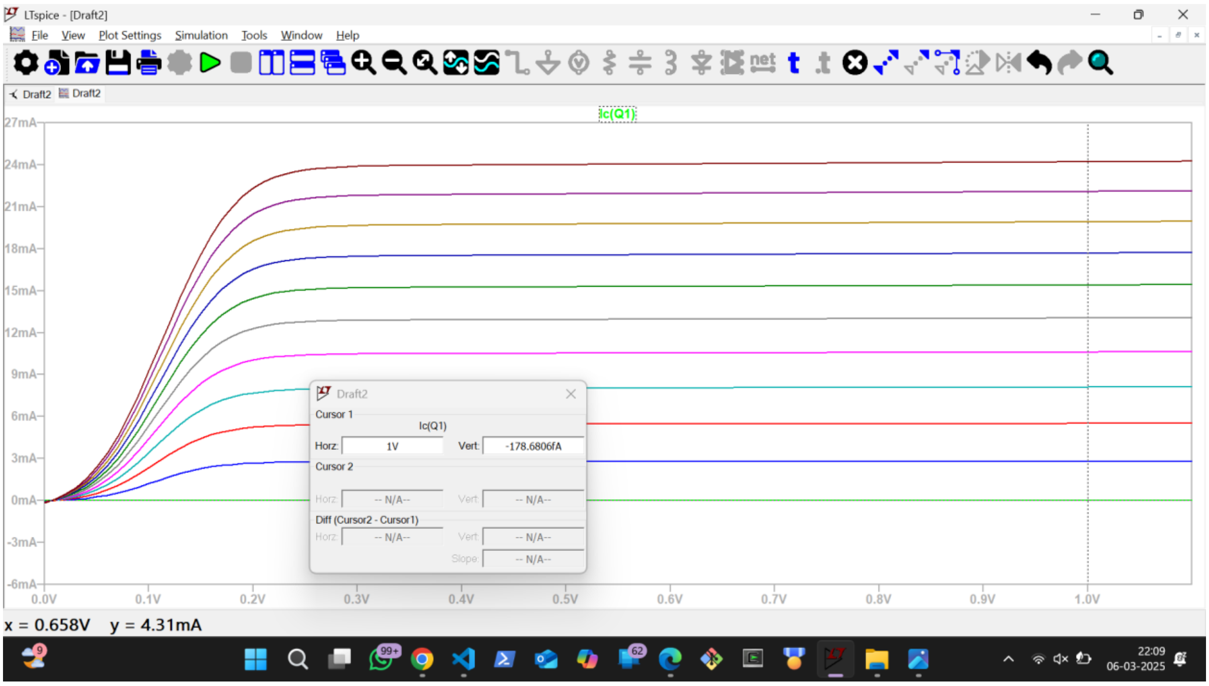


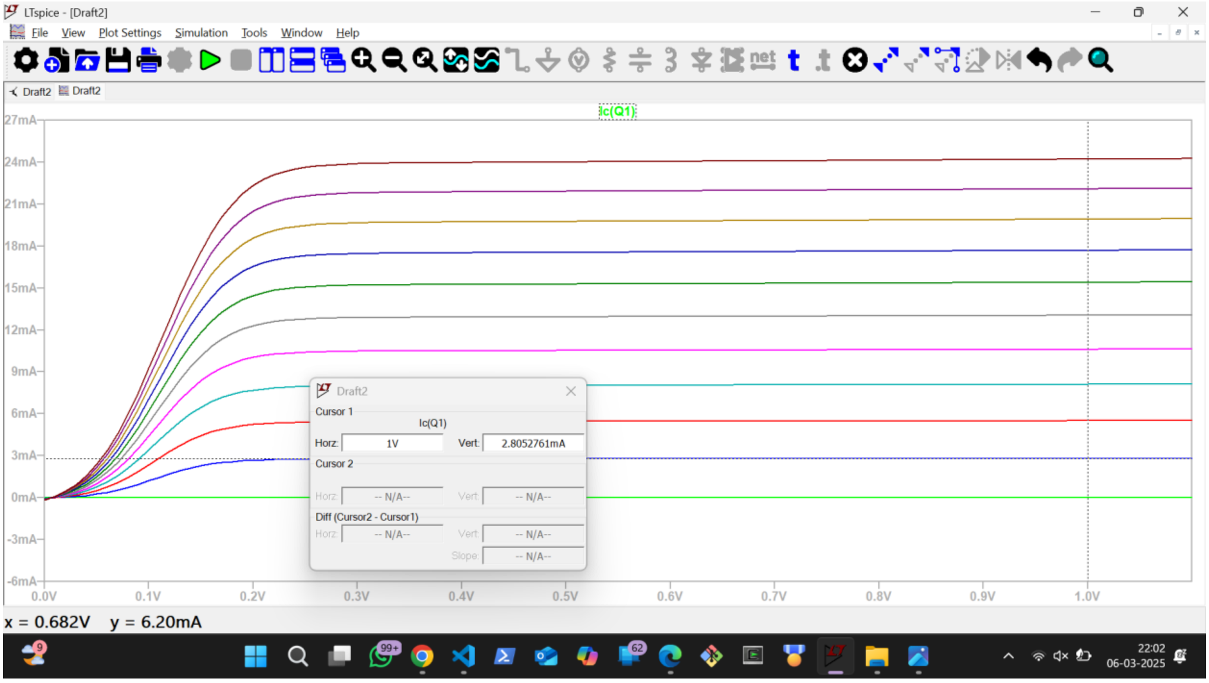
220mV-260mV-300mV saturation

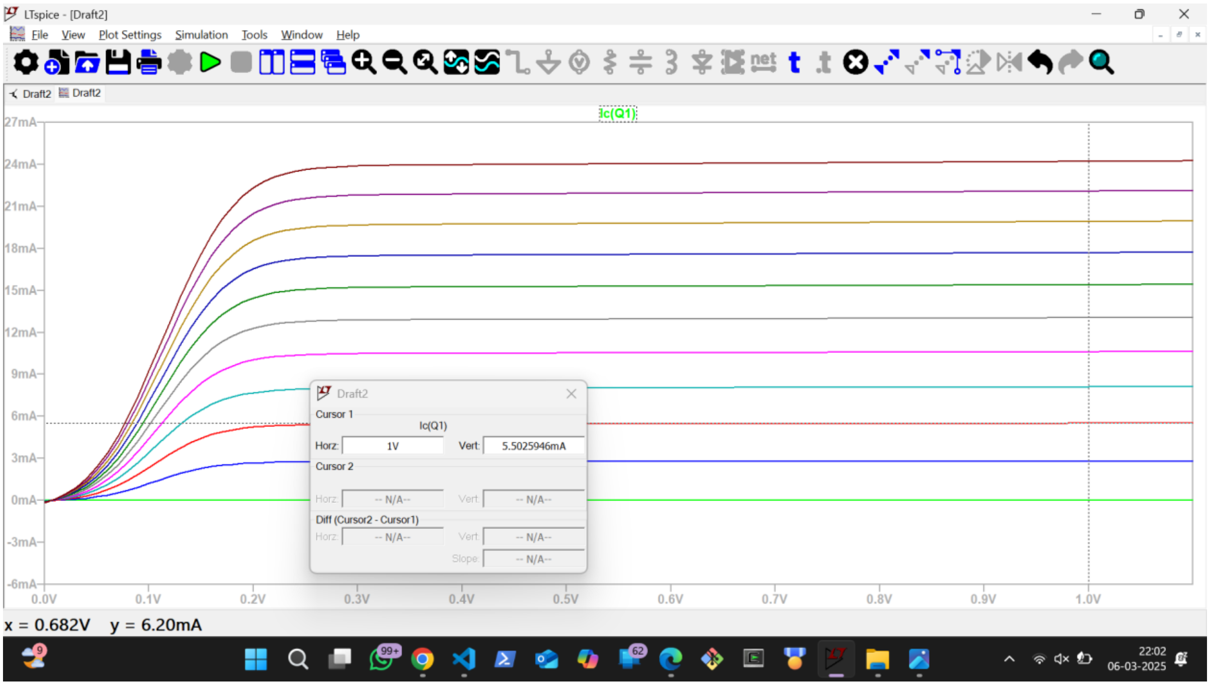
Above it is active mode

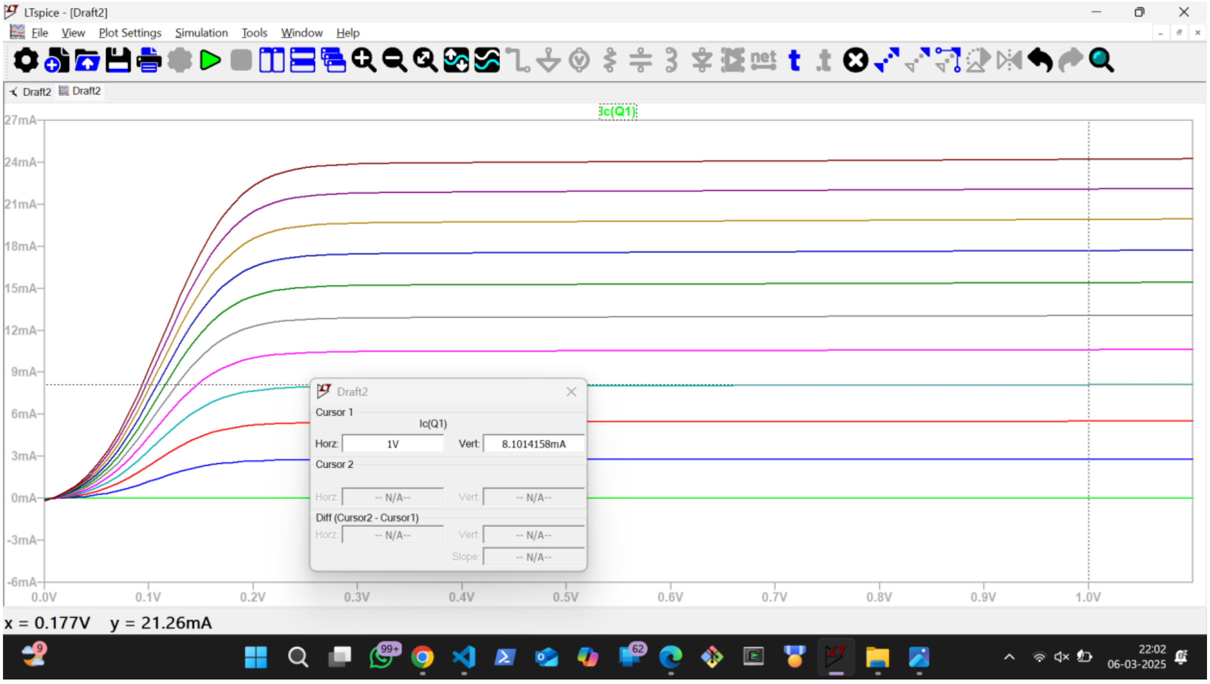
Below it is Ic~0 and cutoff mode

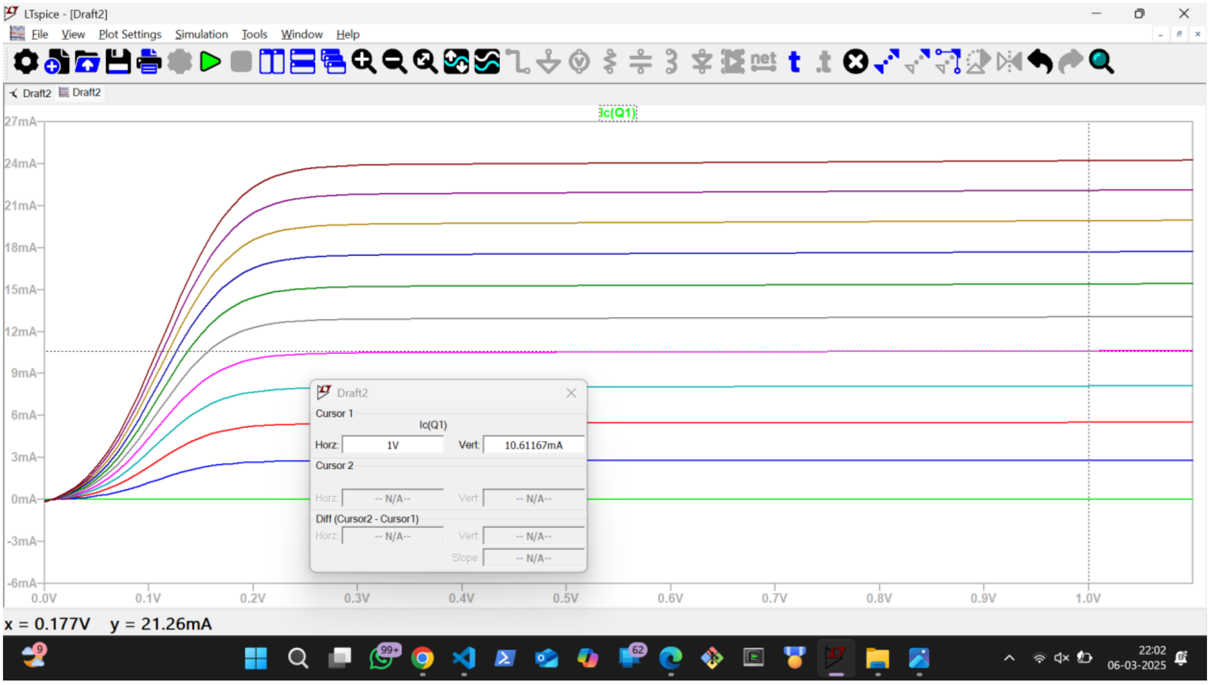
Tabulating β at 1V by Ic and Ib

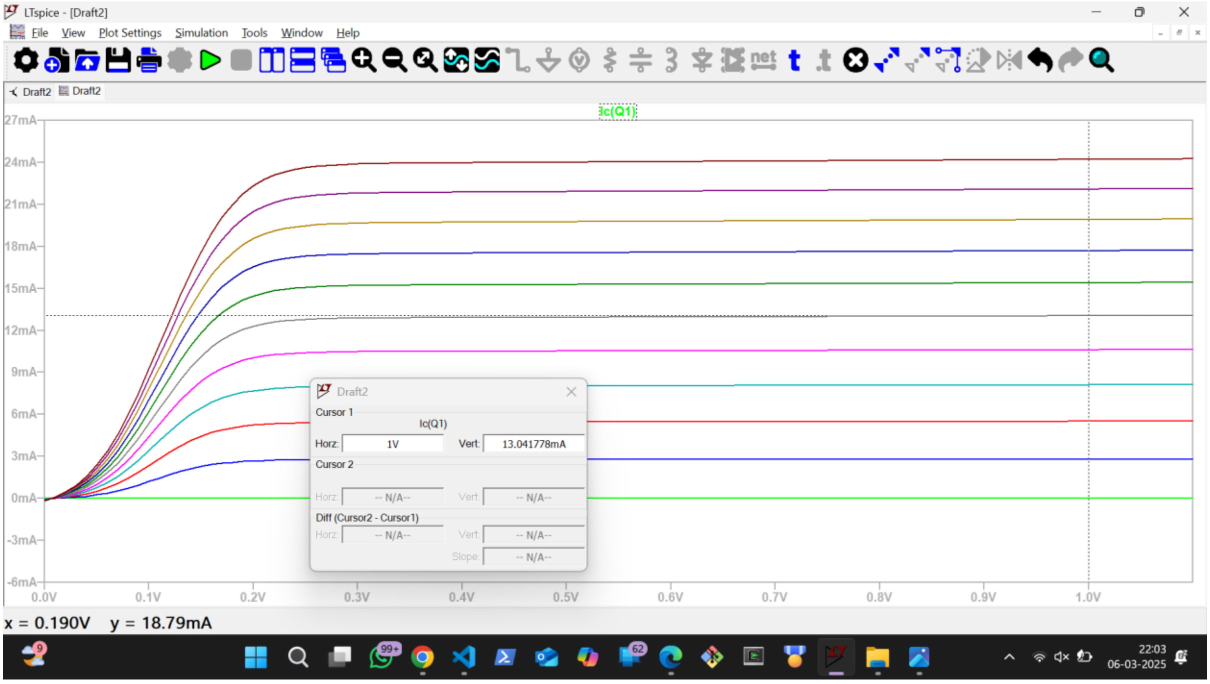


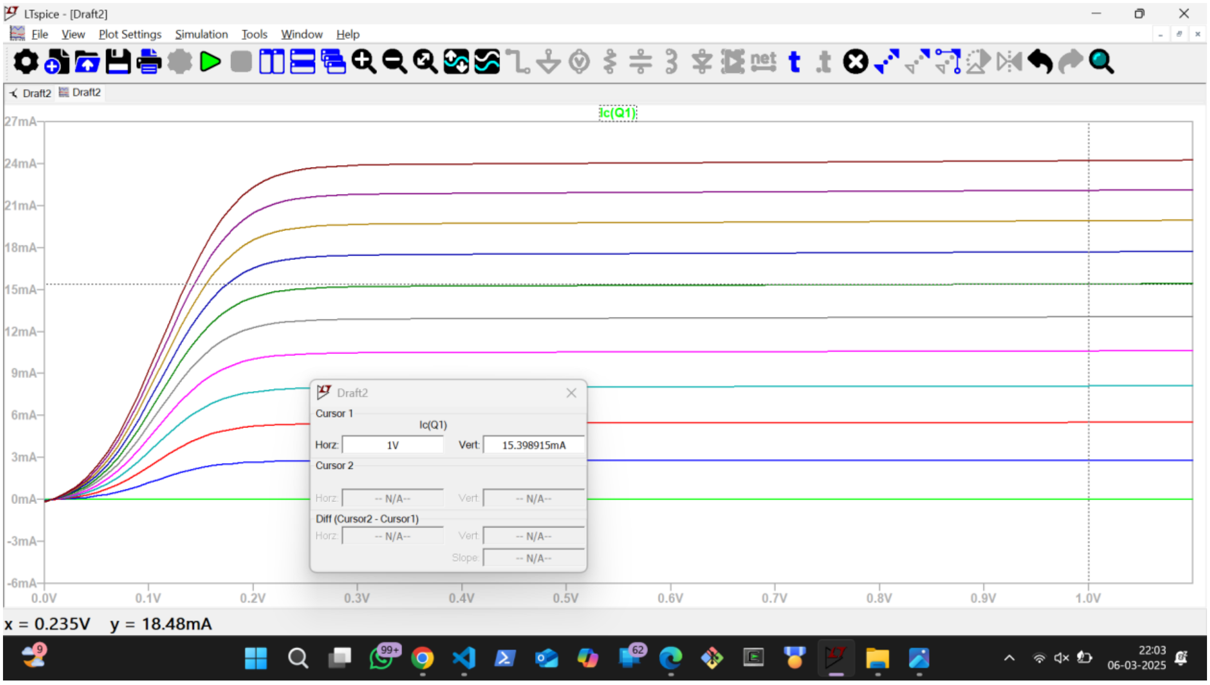

LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Draft2 Draft2
Ic(Q1)
27mA
24mA
21mA
18mA
15mA
12mA
9mA
6mA
3mA
0mA
-3mA
-6mA
0.0V
0.1V
0.2V
0.3V
0.4V
0.5V
0.6V
0.7V
0.8V
0.9V
1.0V
Draft2
Cursor 1
Ic(Q1)
Horz: 1V
Vert: 2.8052761mA
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Slope: -- N/A--
x = 0.682V y = 6.20mA
22:02
06-03-2025

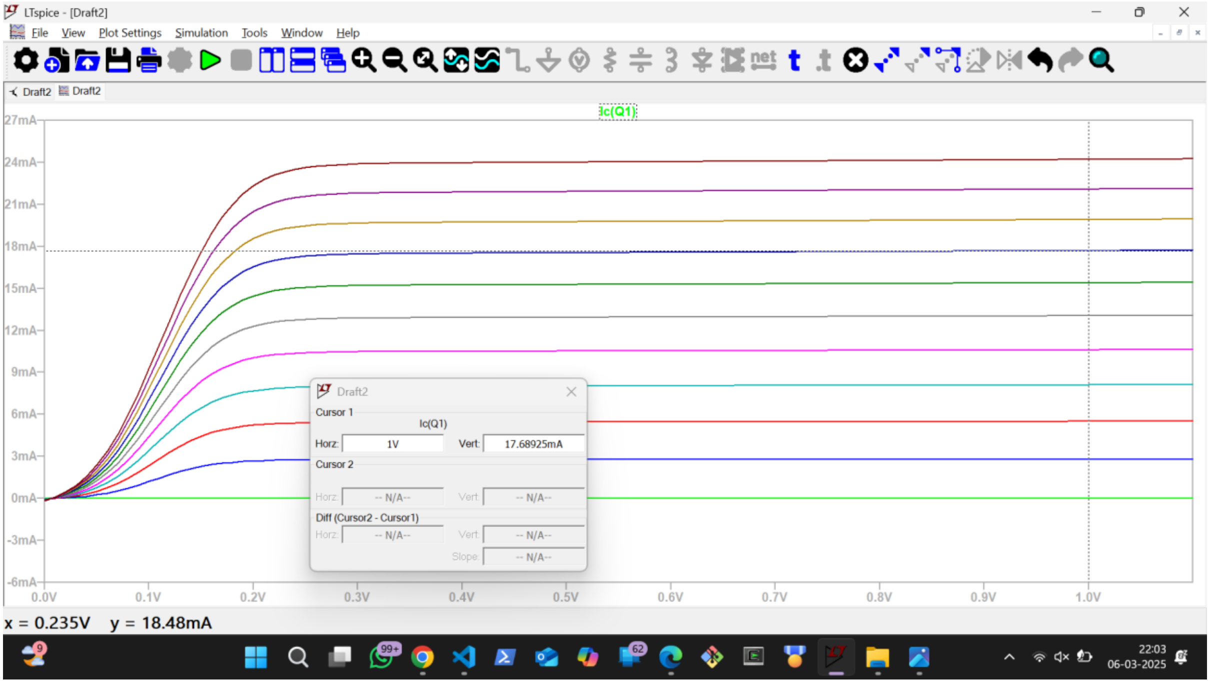

LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Draft2 Draft2
Ic(Q1)
27mA
24mA
21mA
18mA
15mA
12mA
9mA
6mA
3mA
0mA
-3mA
-6mA
0.0V
0.1V
0.2V
0.3V
0.4V
0.5V
0.6V
0.7V
0.8V
0.9V
1.0V
Draft2
Cursor 1
Ic(Q1)
Horz: 1V
Vert: 5.5025946mA
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Slope: -- N/A--
x = 0.682V y = 6.20mA
22:02
06-03-2025

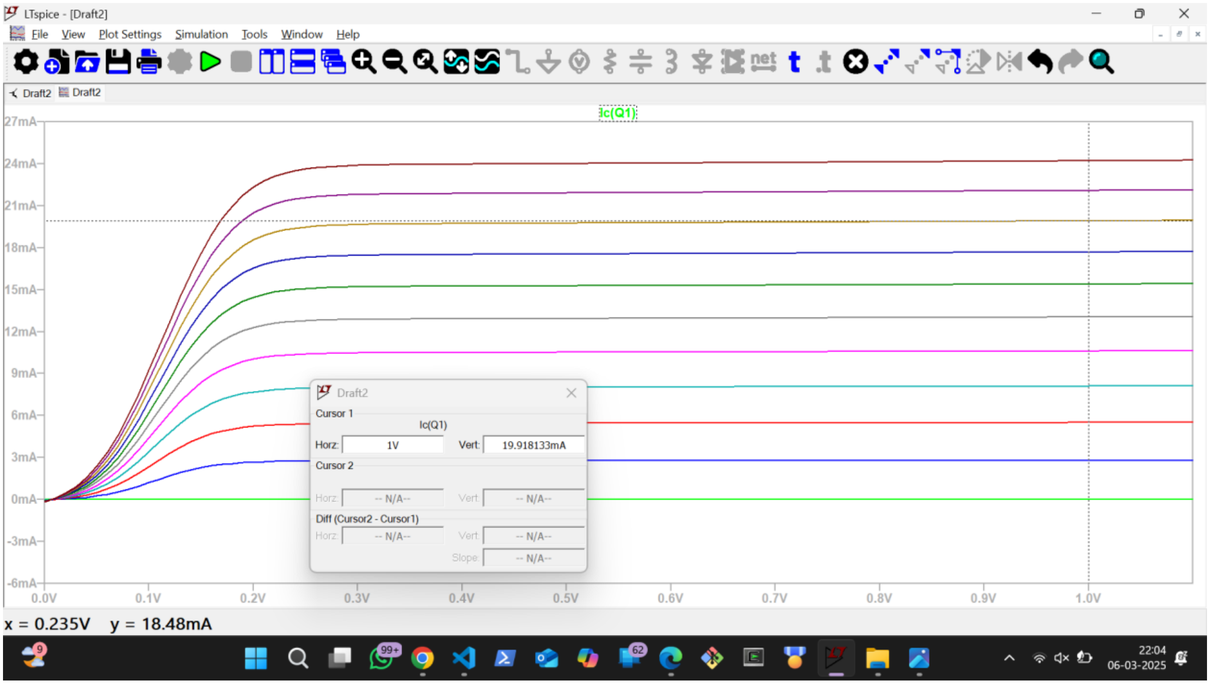

LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Ic(Q1)
Cursor 1
Ic(Q1)
Horz: 1V
Vert: 8.1014158mA
Cursor 2
Diff (Cursor2 - Cursor1)
x = 0.177V y = 21.26mA
22:02
06-03-2025

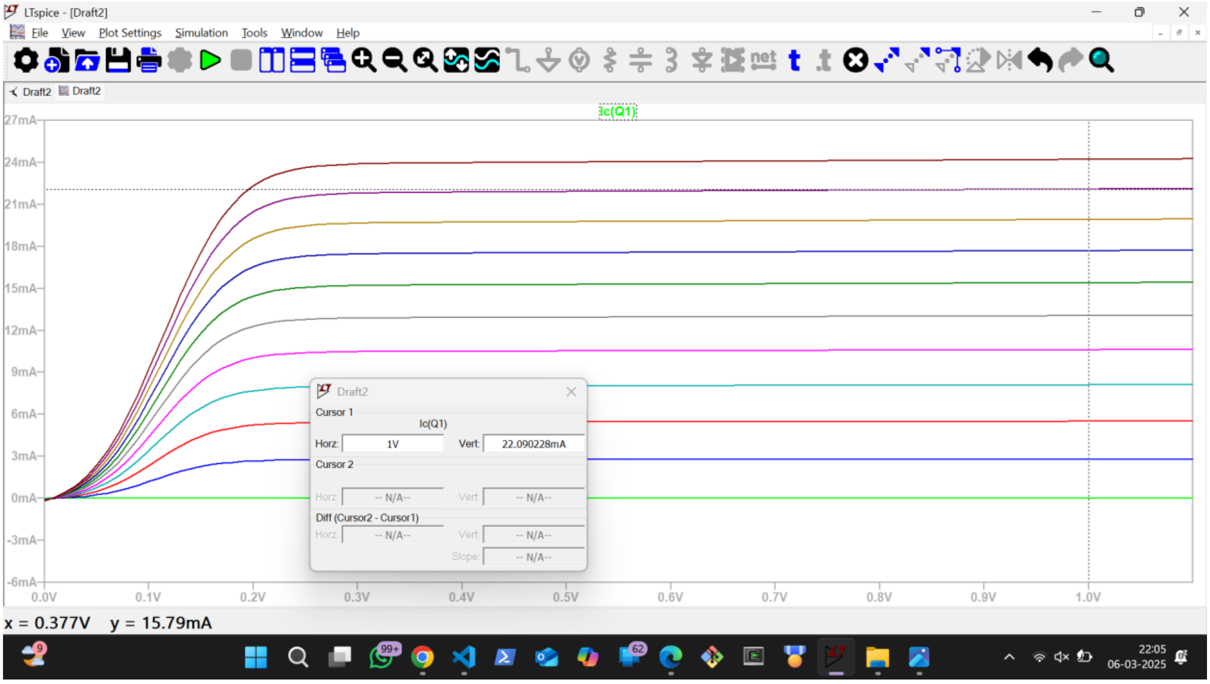

LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Ic(Q1)
Cursor 1
Ic(Q1)
Horz: 1V
Vert: 10.61167mA
Cursor 2
Diff (Cursor2 - Cursor1)
x = 0.177V y = 21.26mA
22:02
06-03-2025

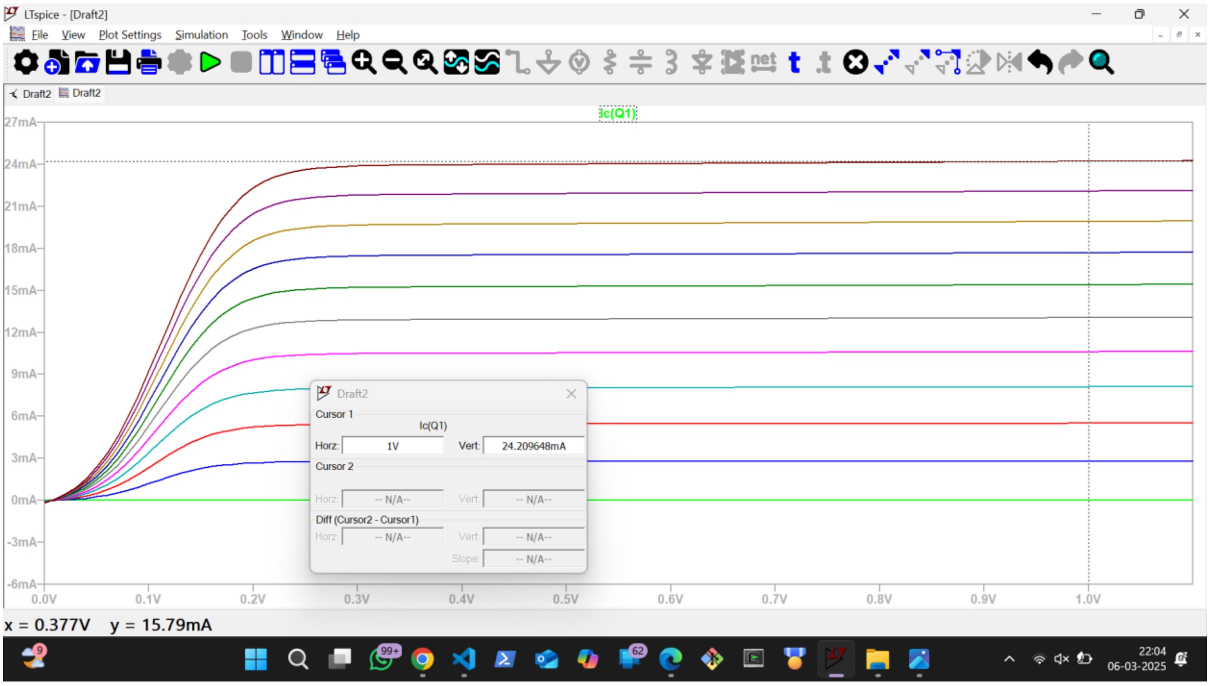

LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Draft2 Draft2
Ic(Q1)
27mA
24mA
21mA
18mA
15mA
12mA
9mA
6mA
3mA
0mA
-3mA
-6mA
0.0V 0.1V 0.2V 0.3V 0.4V 0.5V 0.6V 0.7V 0.8V 0.9V 1.0V
Draft2
Cursor 1
Ic(Q1)
Horz: 1V Vert: 13.041778mA
Cursor 2
Horz: -- N/A-- Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A-- Vert: -- N/A--
Slope: -- N/A--
x = 0.190V y = 18.79mA
22:03
06-03-2025


LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Draft2 Draft2
Ic(Q1)
27mA
24mA
21mA
18mA
15mA
12mA
9mA
6mA
3mA
0mA
-3mA
-6mA
0.0V 0.1V 0.2V 0.3V 0.4V 0.5V 0.6V 0.7V 0.8V 0.9V 1.0V
Draft2
Cursor 1
Ic(Q1)
Horz: 1V Vert: 15.398915mA
Cursor 2
Horz: -- N/A-- Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A-- Vert: -- N/A--
Slope: -- N/A--
x = 0.235V y = 18.48mA
22:03
06-03-2025


LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Ic(Q1)
27mA
24mA
21mA
18mA
15mA
12mA
9mA
6mA
3mA
0mA
-3mA
-6mA
0.0V
0.1V
0.2V
0.3V
0.4V
0.5V
0.6V
0.7V
0.8V
0.9V
1.0V
Draft2
Cursor 1
Ic(Q1)
Horz: 1V
Vert: 17.68925mA
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Slope: -- N/A--
x = 0.235V y = 18.48mA
22:03
06-03-2025


LTspice - [Draft2]
File View Plot Settings Simulation Tools Window Help
Ic(Q1)
27mA
24mA
21mA
18mA
15mA
12mA
9mA
6mA
3mA
0mA
-3mA
-6mA
0.0V
0.1V
0.2V
0.3V
0.4V
0.5V
0.6V
0.7V
0.8V
0.9V
1.0V
Draft2
Cursor 1
Ic(Q1)
Horz: 1V
Vert: 19.918133mA
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Slope: -- N/A--
x = 0.235V y = 18.48mA
22:04
06-03-2025





By these 11 values tabulated and calculated β

Early Voltage VA

VA is 60.47V