Trinity College Dublin
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The University of Dublin

3C2 DIGITAL CIRCUITS LABORATORY D1

The Bipolar Junction Transistor Inverter

Department of Electronic and Electrical Engineering

(Multisim e-Report submission)

Assignments:

A. Bipolar Junction Transistor Characteristics
B. Resistively Loaded BJT Inverter Characteristics
C. BJT Inverter Switching Performance

Submitted by:

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A. Bipolar Transistor Current - Voltage Characteristics

The given assignment starts with initialization of Multisim 14.x software. This included making of schematic entry onto the workspace and inserting all the components as mentioned in the manual.

A.1 Collector Current against Base - Emitter Voltage.

This part of experiment started with assembly of circuit as follows, the transistor was used as testing device for current-voltage relationship.

Schematic Entry:

This involved use of transistor model 2N2222A as the testing device with use of two DC Power sources as V_{BE} = 0.6 V, and V_{CE} = 6 V. And the circuit was grounded as in the schematic. All the

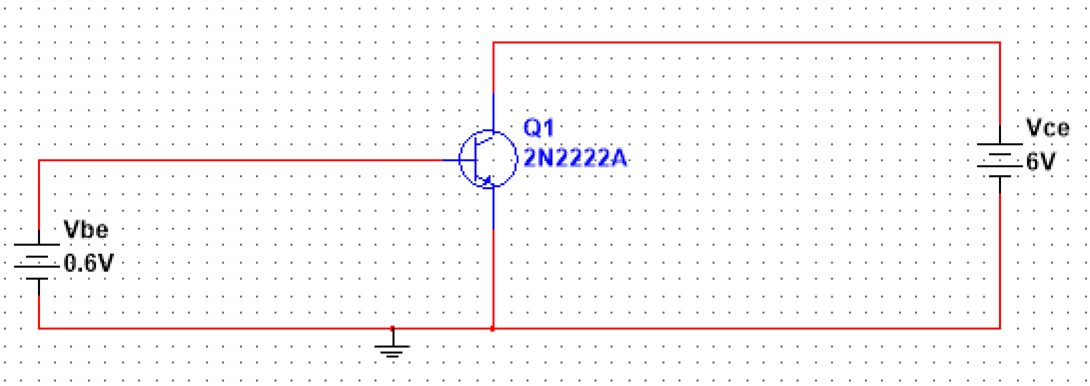


Figure A.1.1: schematic for A.1 circuit

Now, from the properties of the transistor 2N2222A, the following pre-defined parameters were noted down:

S. No	Expressions	Values
1	BF, the forward active current gain (**β_F**)	**220**
2	BR, the reverse active current gain (**β_R**)	**4**
3	TF, the forward transit time (**τ_F**)	**0.325e-9 s**
4	TR, the reverse transit time (**τ_R**)	**1e-9 s**
5	CJC, B-C zero-bias depletion capacitance (**C_{BC}**)	**9.12e-12 F**
6	CJE, B-E zero-bias depletion capacitance (**C_{BE}**)	**27e-12 F**

Table A.1.1: 2N2222A transistor parameters

After getting the data as in table above we moved onto simulation of the circuit to generate transfer characteristic curve.

Simulation Set-up:

The setup for simulation of $I_{(Vce)}$ v/s V_{BE} curve was done using DC Sweep – Simulation Analyses. The parameters set were starting from **0.2 V** and ending at **0.9 V** for V_{BE}. To normalise the direction of current across collector-emitter it was multiplied with -ve. Hence, the observations were made.

Running a Simulation:

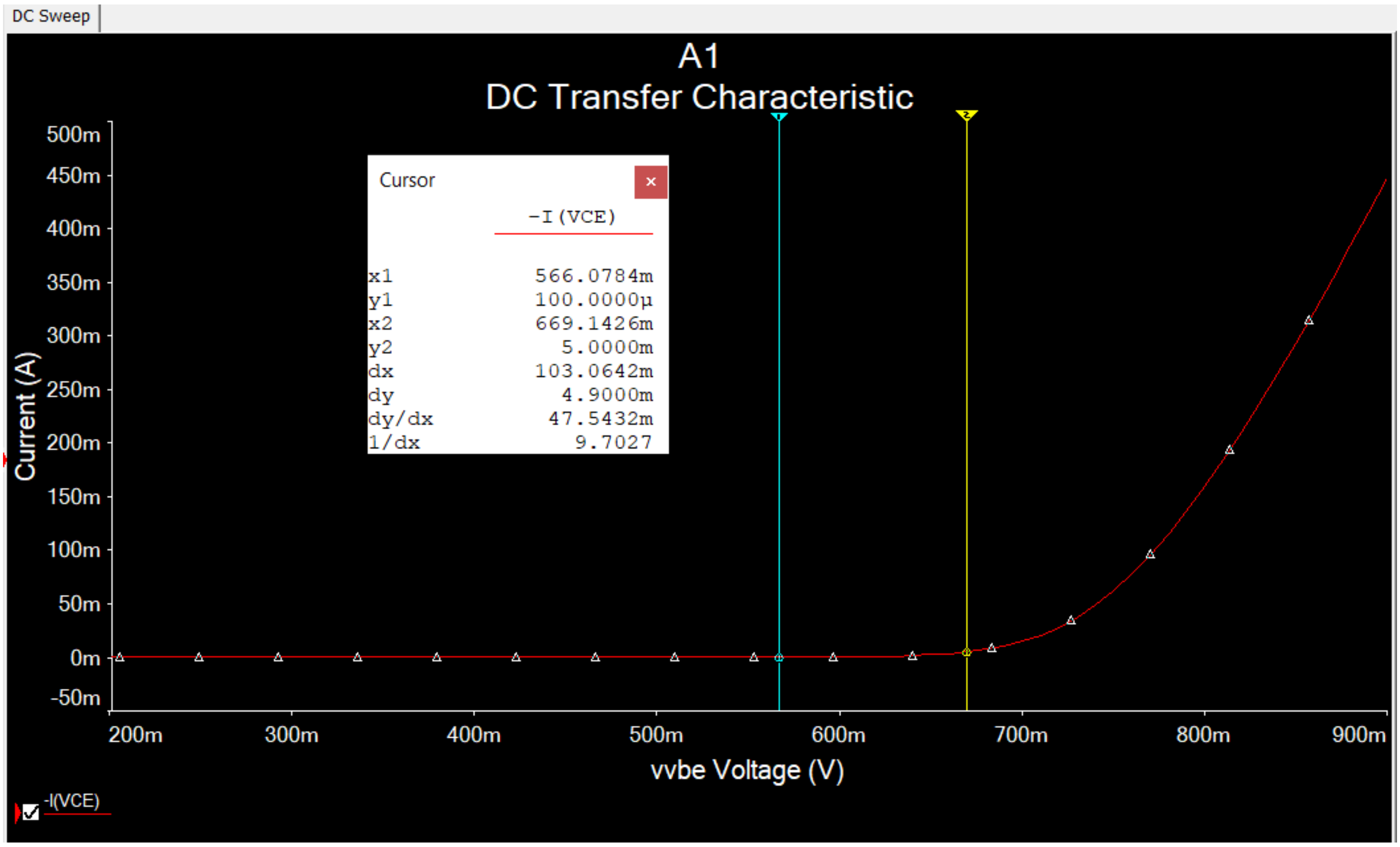


Figure A.1.2: I_C v/s V_{BE} curve for schematic

S. No.	Expression	Value
1	V_{be} CUT-IN, I_C = 100 μA	566.07 mV
2	V_{be} ON, I_C = 5 mA	669.14 mV

Table A.1.2: V_{BE} parameters obtained from curve

A.2 Collector Current vs. Collector-Emitter Voltage

Part I:

Schematic Entry:

For this part of experiment, the DC Power to base was replaced by a DC current source as shown in the schematic diagram. The current source used was I_b = 10 μA.

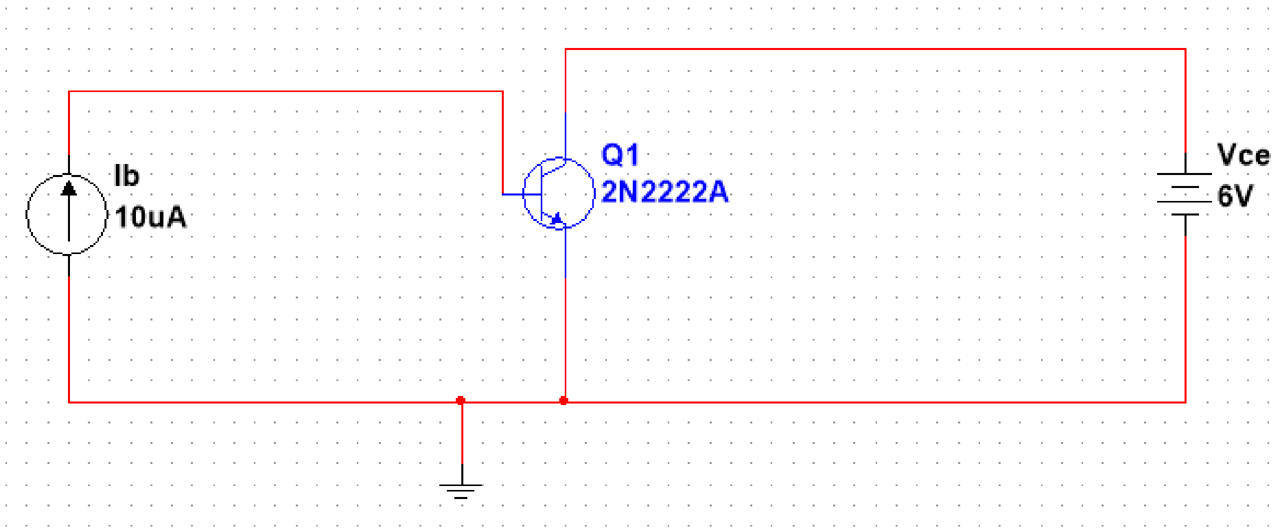


Figure A.2.1: schematic for A.2 circuit

Simulation:

The simulation using DC Sweep was done for the schematic and the curve for I_C v/s V_{CE} was generated for different values of Ib ranging from 10μA – 100 μA.

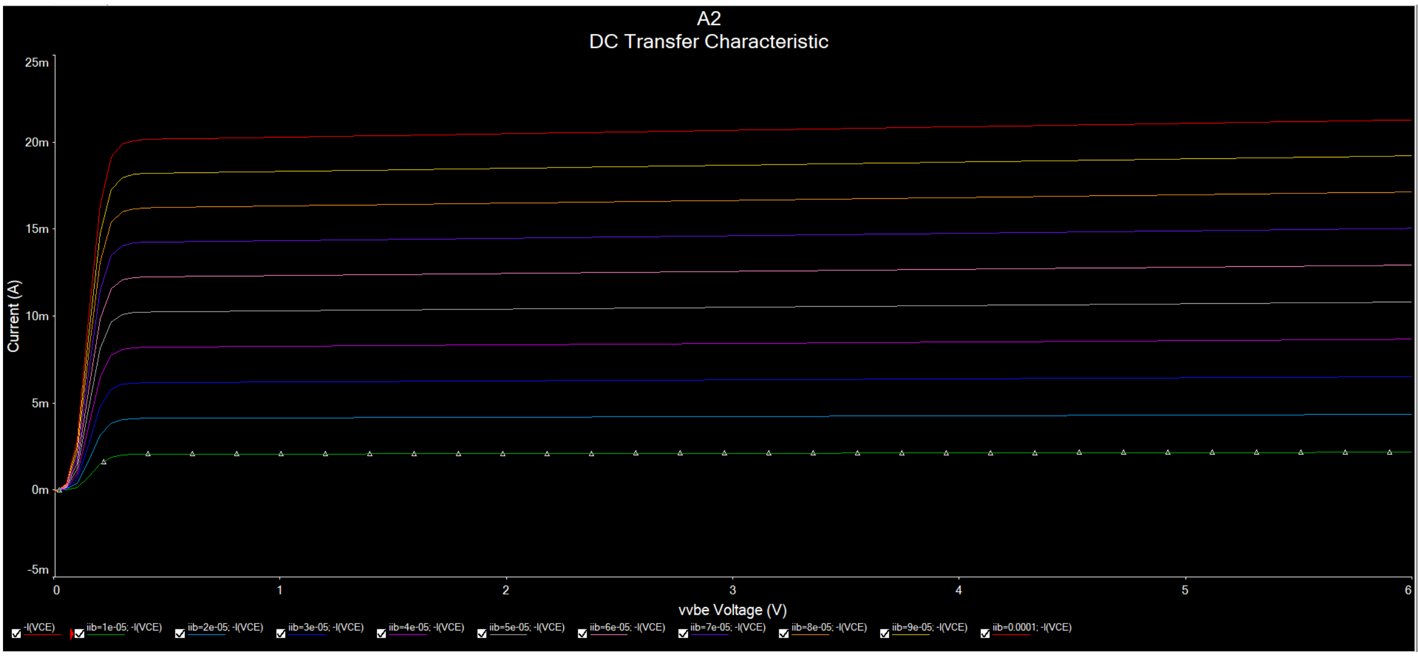


Figure A.2.2: I_C v/s V_{CE} characteristic curve plot for different I_C

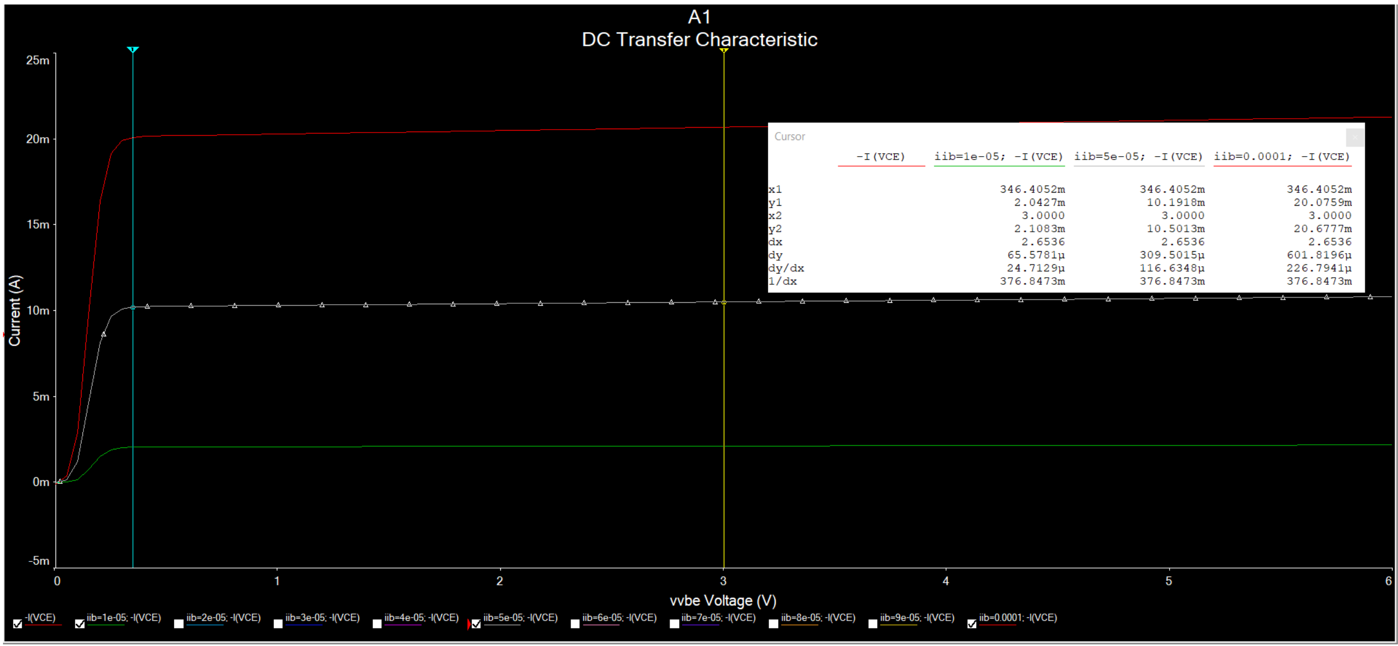


Figure A.2.3: Cursor plot for required data points

The plot is reduced to 3 curves only i.e. 10 μA, 50 μA, and 100 μA. Depicting data points for the record required as in the following table.

Theoretical β_F of 2N2222A = 220

S. No.	Expression	Values	
1.	β_F @ I_B = 10 μA, Vce = 3V	$\boldsymbol{I_c}$ = 2.1083 mA	β_F = 210.83
2.	β_F @ I_B = 100 μA, Vce = 3V	$\boldsymbol{I_c}$ = 20.677 mA	β_F = 206.77
3.	$V_{ce\ sat}$ @ I_B = 50 μA	346.40 mV	

Table A.2.1: Observed values for expressions from the plot

Comment: β_F of the transistor when compared practical and theoretical value we can observe that as the base current increases it loses its character from theoretical value. Therefore, this transistor model tends to work better at low base current.

Part II:

Schematic Entry:

For this part of experiment, the DC Power to base was replaced by a DC current source (revised from A.1) as shown in the schematic diagram. The current source used was I_b = 10 μA. But now, the transistor is also replace from 2N2222A to 2N3904 from the library. Again, the schematic is projected as follows:

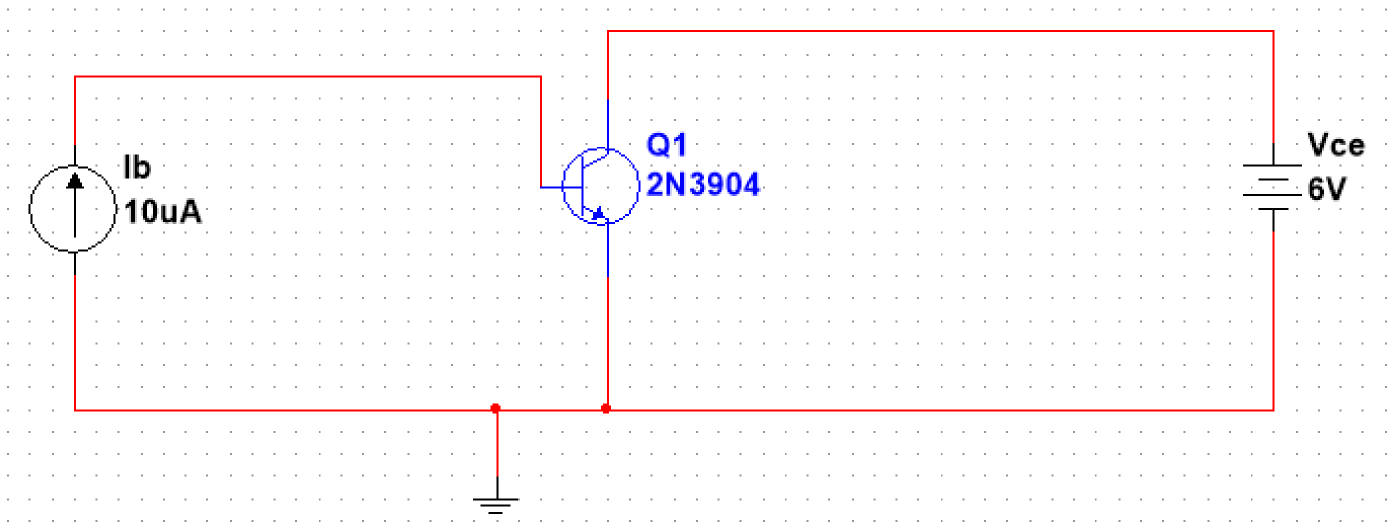


Figure A.2.4: Schematic for A.2 with 2N3904 transistor

Simulation:

The simulation using DC Sweep was done for the schematic and the curve for I_C v/s V_{CE} was generated for different values of Ib ranging from 10μA – 100 μA.

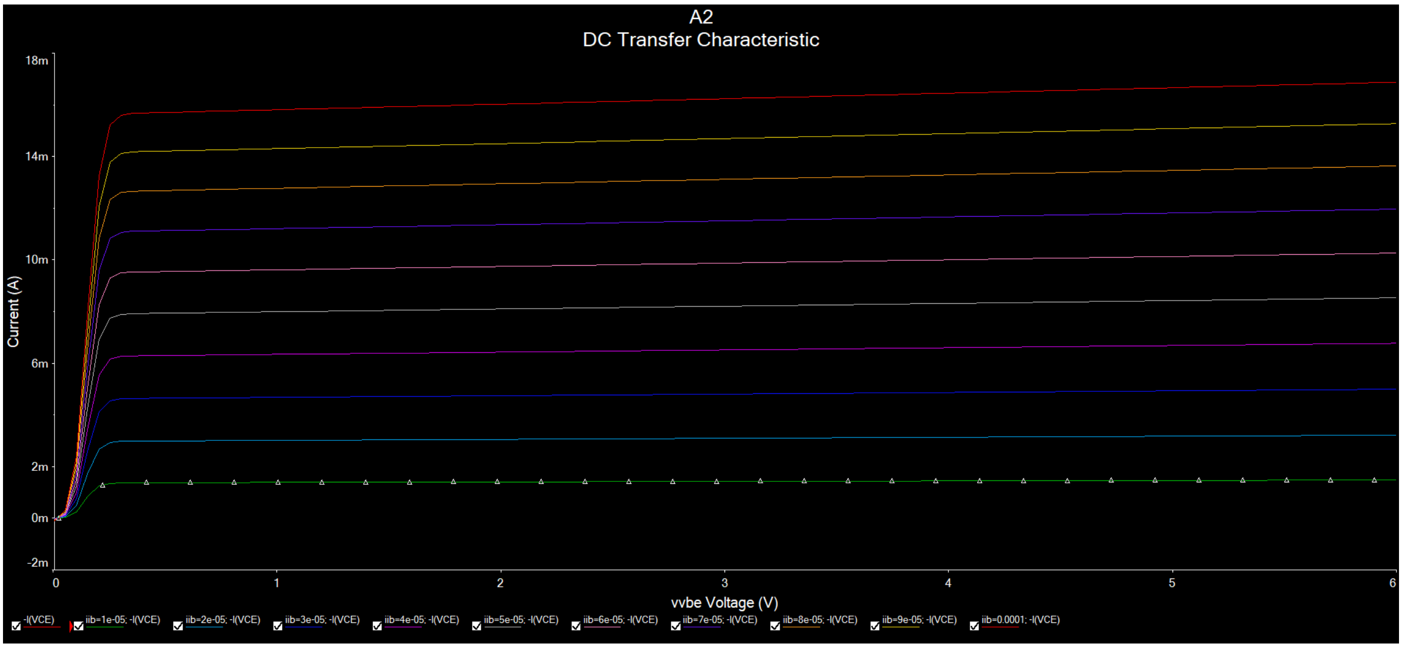


Figure A.2.5: I_C v/s V_{CE} characteristic curve plot for different I_C (2N3904)

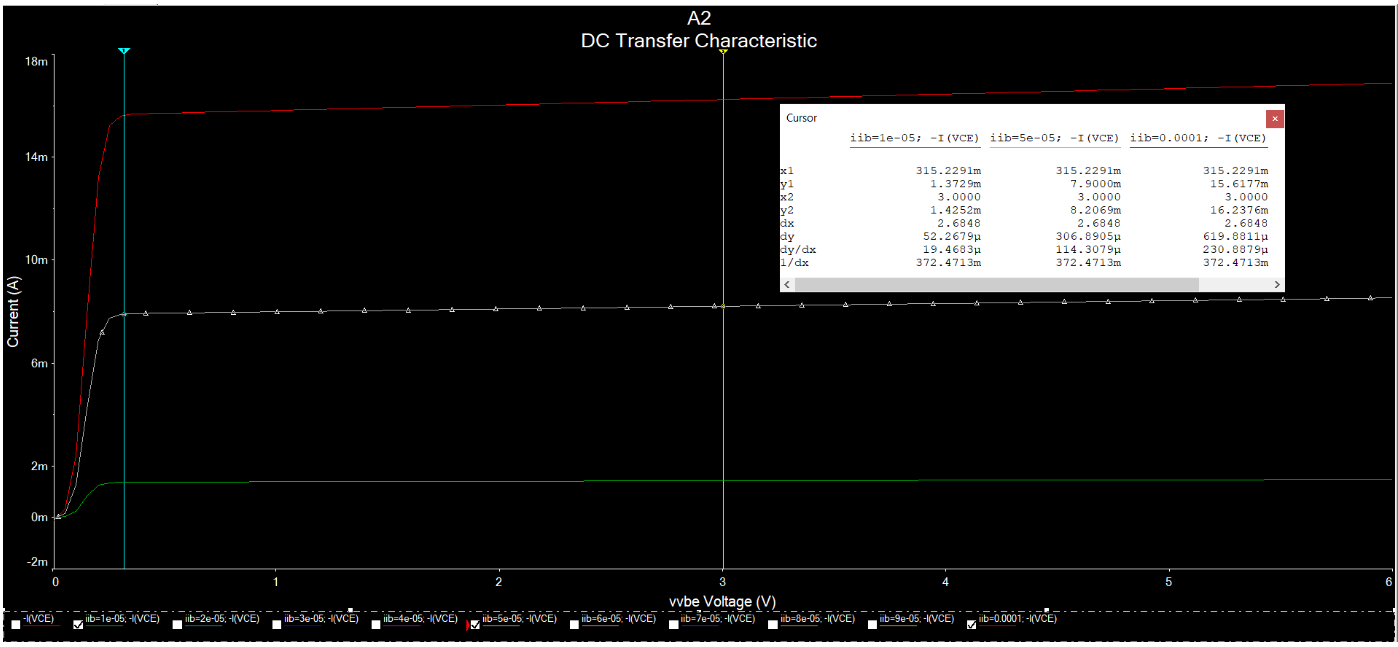


Figure A.2.6: Cursor plot for required data points (2N3904)

The plot is reduced to 3 curves only i.e. 10 μA, 50 μA, and 100 μA. Depicting data points for the record required as in the following table.

Theoretical β_F of 2N3904 = 416.4

S. No.	Expression	Values	
1.	β_F @ I_B = 10 μA, Vce = 3V	$\boldsymbol{I_c}$ = 1.425 mA	β_F = 142.52
2.	β_F @ I_B = 100 μA, Vce = 3V	$\boldsymbol{I_c}$ = 16.237 mA	β_F = 162.37
3.	$V_{ce\ sat}$ @ I_B = 50 μA	315.22 mV	

<u>Comment</u>:

β_F of the transistor when compared practical and theoretical value we can observe that as the base current increases it gains its character to that of theoretical value. Therefore, this transistor model tends to work better at high base current. Also, this transistor shows a huge difference between practical and theoretical forward beta value. The reason is mentioned above.

B. Resistively Loaded BJT Inverter - Transfer Characteristic

For this part of experiment, a new project was created with schematic and explanation as below.

Schematic Entry:

The schematic was made using the same transistor model used before 2N2222A. DC Power of **5V** was used as **Vce**. **Base Resistance** was taken as **20 kΩ** and **Collector Resistance** as **1 kΩ**. But now input base source is a Pulse Voltage with parameters as mentioned in the schematic.

Part I:

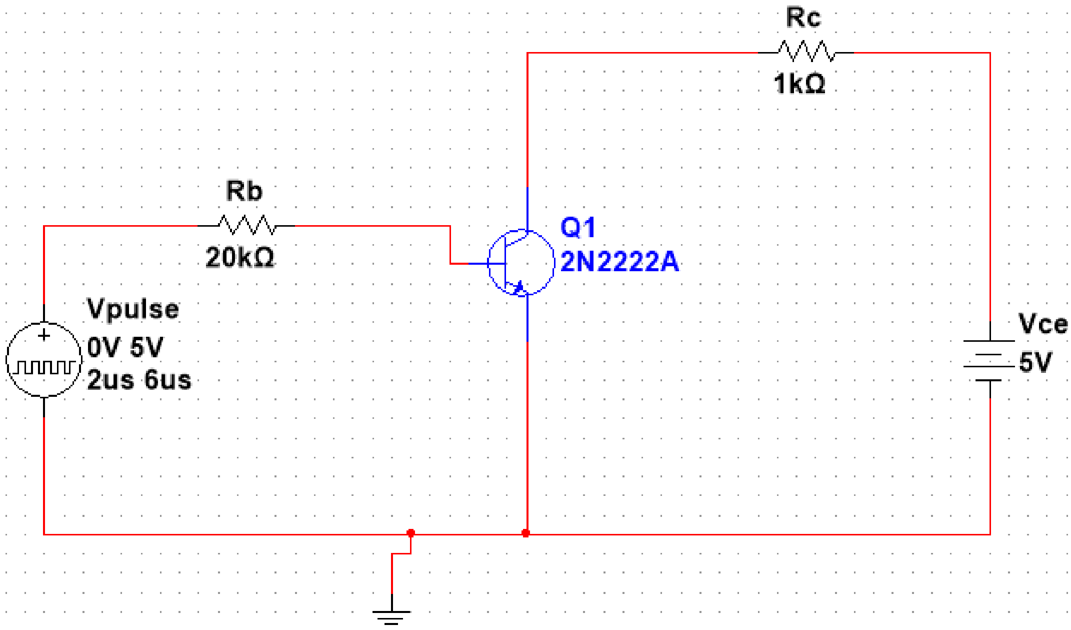


Figure B.1.1: Schematic for B circuit

Simulation:

The pulse voltage parameters from the manual were used and hence a DC Sweep analysis was done on the range given 0V-5V. The plot V_o v/s V_i is simulated as follows:

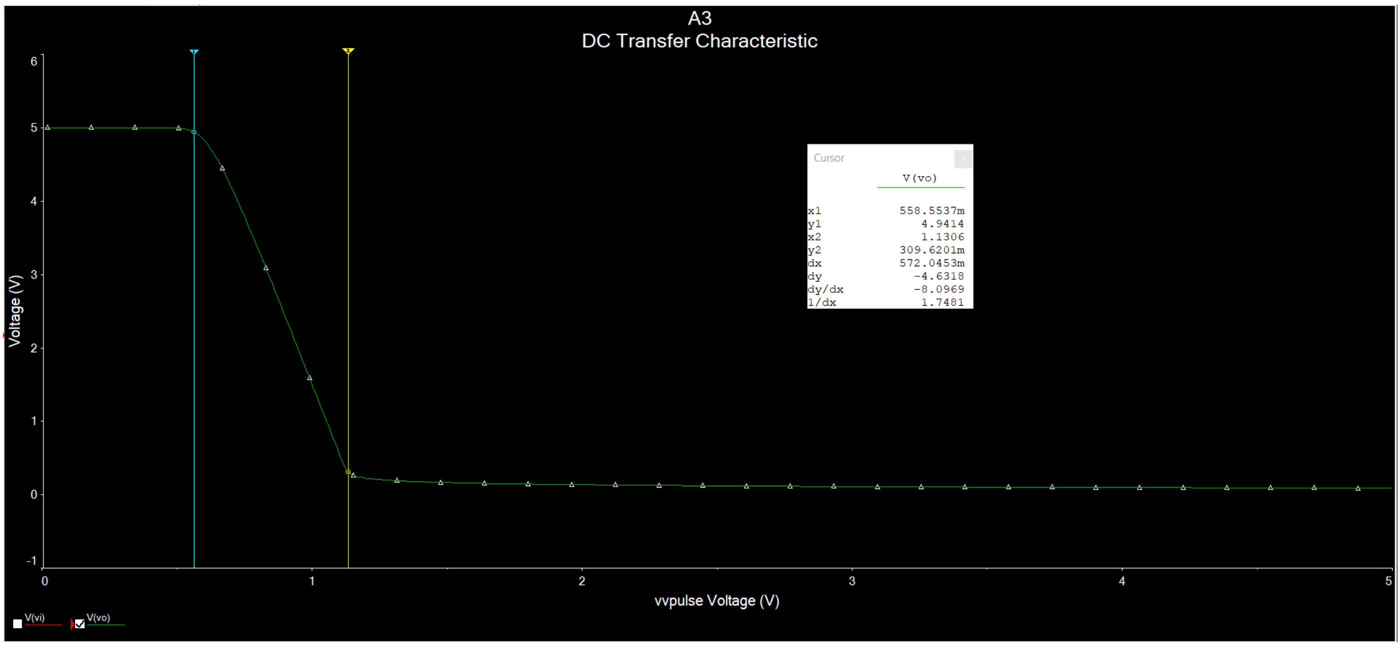


Figure B.1.2: V_O v/s V_i plot for the schematic

For the required data needed the two cursors plotted in the simulations give the values for following table. The following data is from the practical demonstration of the circuit.

S. No	Expression	Values
1.	$\mathbf{V_{OH}}$	4.94V
2.	$\mathbf{V_{iL\ MAX}}$	558.55 mV
3.	$\mathbf{V_{OL}}$	309.62 mV
4.	$\mathbf{V_{iH\ MIN}}$	1.1306 V

Table B.1.1: Expression values from practical experiment

The theoretical values for the given circuit and its comparison is as follows:

V_{OH} = V_{CC} = 5.00 V

$V_{iL\ MAX}$ = $V_{BE\ CUT\text{-}IN}$ = 566.07 mV

V_{OL} = $V_{CE\ SAT}$ = 346.40 mV

$V_{iH\ MIN}$ = $V_{BE\ ON} + \frac{R_b}{\beta_F R_C}[V_{CC} - V_{CE\ SAT}] = 669.14\ mV + \frac{20000}{220*1000}[5\ V - 346.40\ mV]$ = 1.092 V

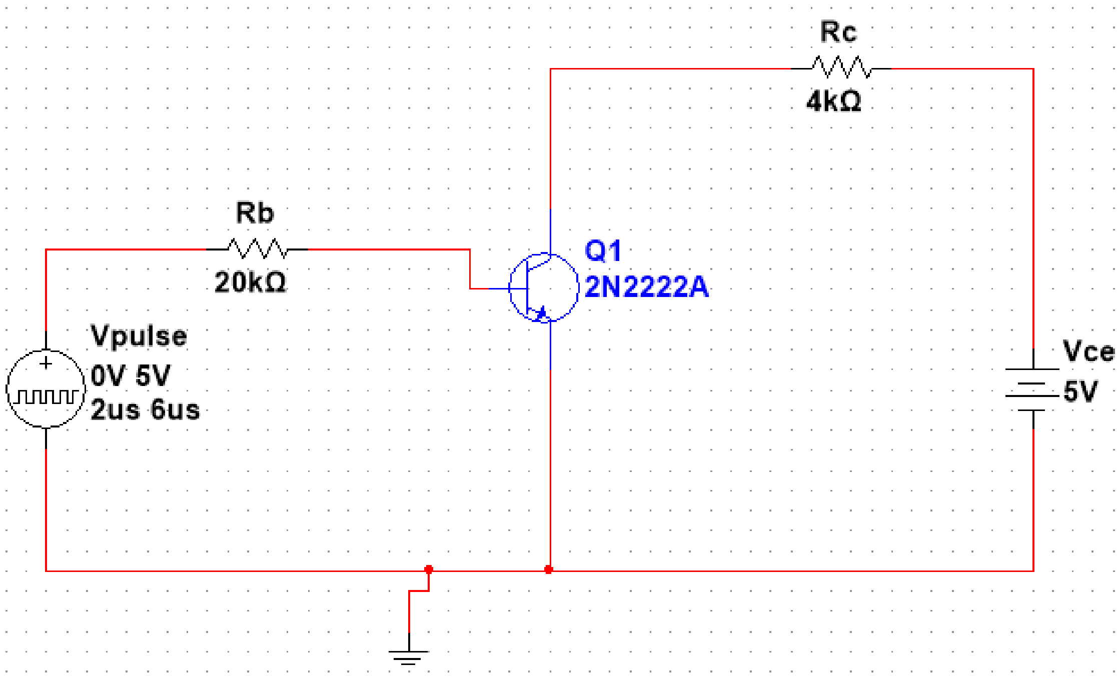
<u>Comment:</u>

- Comparing to practical value the difference might be caused due to internal transistor values.
- Only slight difference is noticeable for most of the expressions except V_{OL} which due to no sharp edge accurate point of interest couldn't be figured out.

Part II:

Schematic Entry:

In this part, the **Collector Resistance** is replaced by **4 kΩ** resistor.



B.2.1: Modified schematic from B.1 circuit

Simulation:

The pulse voltage parameters from the manual were used and hence a DC Sweep analysis was done on the range given 0V-5V. The plot $\mathbf{V_o}$ **v/s** $\mathbf{V_i}$ is simulated as follows:

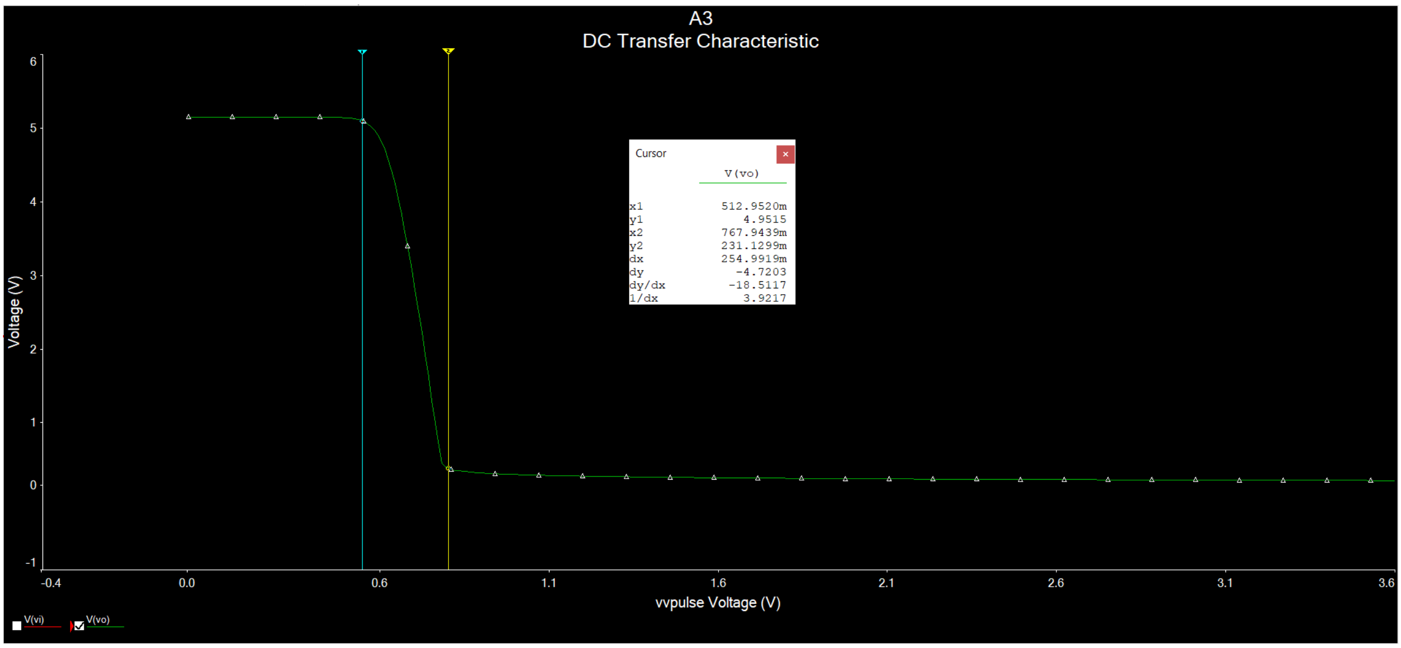


Figure B.2.2: V_O v/s V_i plot for the schematic

For the required data needed the two cursors plotted in the simulations give the values for following table. The following data is from the practical demonstration of the circuit.

S. No.	Expression	Values
1.	$\mathbf{V_{OH}}$	4.95 V
2.	$\mathbf{V_{iL\ MAX}}$	512.95 mV
3.	$\mathbf{V_{OL}}$	231.12 mV
4.	$\mathbf{V_{iH\ MIN}}$	767.94 mV

Table B.2.1: Expression values from practical experiment

Comment:

The observed change in V_I is noticeable as with collector load resistance is increased to 4k, which makes the slope more steep. The expected slope i.e. -1 couldn't be achieved in practical example. As a result nearest possible values were taken into account.

C. BJT Inverter - Switching Characteristics

This continues from schematic used in previous part B. Now, the transient curve is observed, and the time parameters observed are stated in the table.

Part I

The circuit parameters used are **R_b =20 kΩ, Rc =1 kΩ**

Simulation:

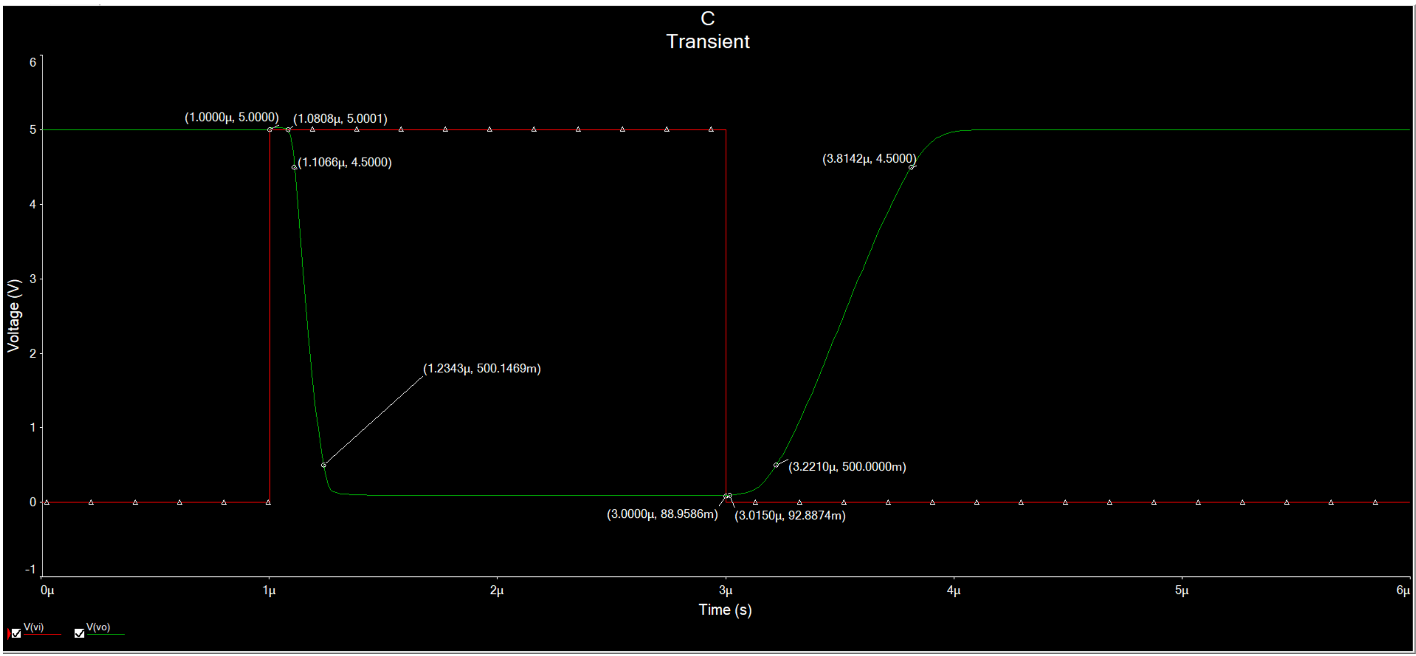


Figure C.1.1: Transient plot for given parameters

S. No.	Expression	Calculations	Values
1.	t_d	1.808-1.000	0.0808 µs
2.	t_f	1.2343-1.1066	0.1277 µs
3.	t_s	3.0150-3.000	0.0150 µs
4.	t_r	3.8142-3.2210	0.5914 µs

Table C.1.1: Transient plot for given parameters

Calculations:

$I_{BF} = \frac{V_i - V_{BE\,ON}}{R_b} = \frac{1.125\,V - 669.14\text{ mV}}{20000} = 0.02279\text{ mA}$

$I_{BR} = \frac{-V_{BE\,ON}}{R_b} = 0.03345\text{ mA}$

$I_{C\,MAX} = \frac{V_{cc} - V_{CE\,SAT}}{R_c} = \frac{5\text{V} - 346.04\text{mV}}{1000} = 4.653\text{ mA}$

$\tau_S = \frac{(1+\beta_R)\beta_F\tau_F + \beta_R\beta_F\tau_R}{1+\beta_F+\beta_R} = \frac{5*220*0.325*10^{-9} + 4*220*100*10^{-9}}{1+220+4} = 0.3927\text{ ms}$

$t_d = R_b(C_{je} + C_{jc}) \ln \frac{V_{cc}}{V_{cc} - V_{BE\,cut-in}} = 20000 * (27 + 9.12) * 10^{-12} * \ln \frac{5V}{5V - 566.07} = 0.08678\ \mu s$

$t_f = 0.8\beta_F(\tau_F + R_c C_{jc}) \ln \frac{\beta_F I_{BF}}{\beta_F I_{BF} - I_{C\,MAX}}$

$= 0.8 * 220 * (0.325 + 1000 * 9.12) \ln \frac{220*0.02279}{220*0.02279 - 4.653}$

$= 0.00437\ \mu s$

$t_s = \tau_S \ln \frac{I_{BF} - I_{BR}}{\frac{I_{CMAX}}{\beta_F} - I_{BR}} = 0.3927 * \ln \frac{0.02279 - 0.03345}{0.02115 - 0.03345} = 0.0000562\ \mu s$

$t_R = 0.8\beta_F(\tau_F + R_c C_{jc}) \ln \frac{\frac{I_{CMAX}}{\beta_F} - I_{BR}}{-I_{BR}} = 0.22771\ \mu s$

Comment:

The difference between practical and theoretical value due to approximation of points we chose on the slope. The difference is not huge if seen on large unit but due to inaccuracy in practical values observed caused this shift from expected values.

Part II

The circuit parameters used are **R_b =5 kΩ, Rc =1 kΩ**

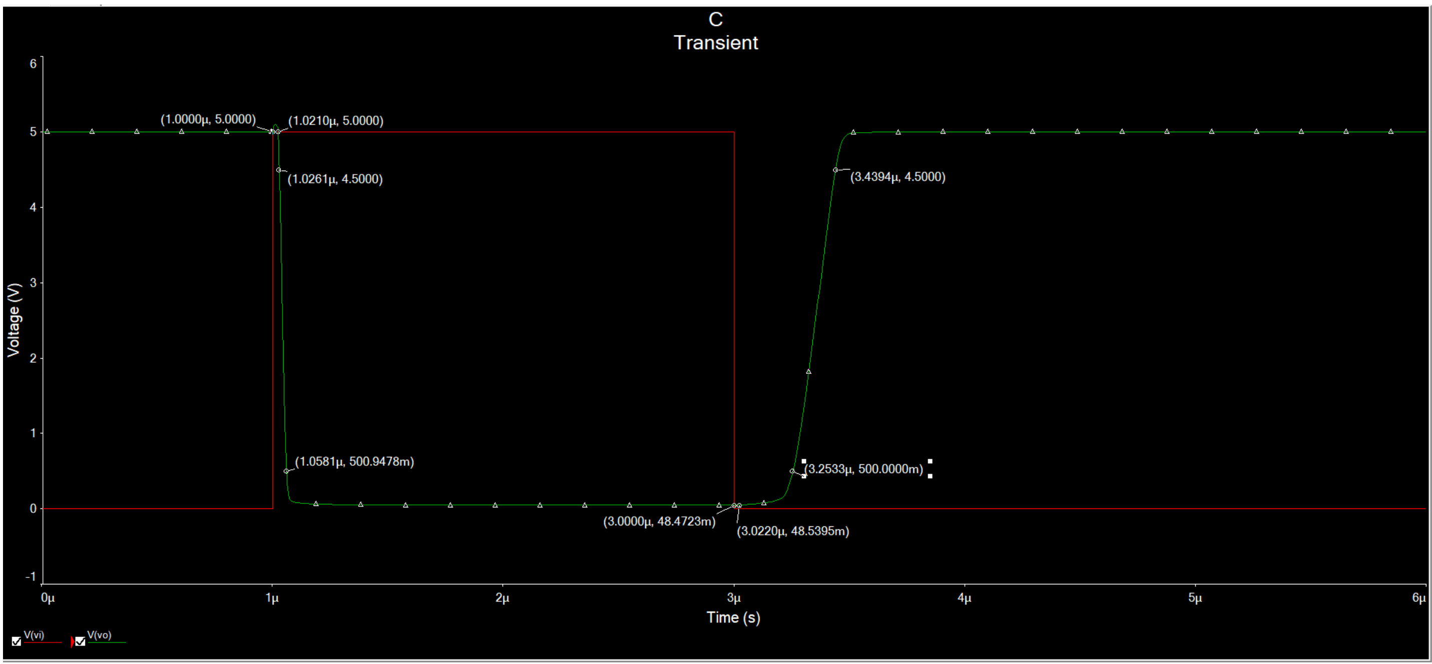


Figure C.2.1: Transient plot for given parameters

S. No.	Expression	Calculations	Values
1.	t_d	1.0210-1.000	0.021 µs
2.	t_f	1.0581-1.0261	0.032 µs
3.	t_s	3.0220-3.000	0.022 µs
4.	t_r	3.4394-3.2533	0.1861 µs

Table C.2.1: Transient plot for given parameters

Comment:

As the base load resistor is reduced to **5 kΩ**, the slope observed is more steeper. Hence, less time is taken to reach edge of saturation from $V_{BE\ cut\text{-}off}$.

Part III

The circuit parameters used are R_b =20 **kΩ**, Rc =4 **kΩ**

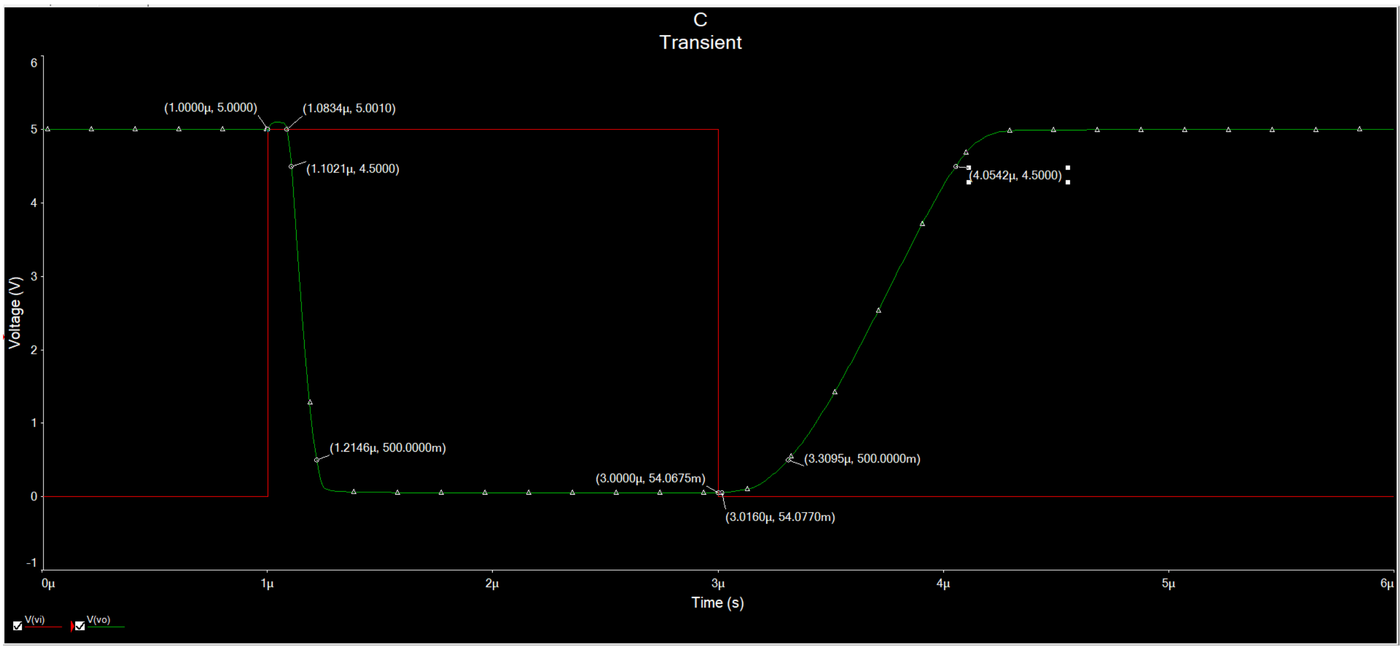


Figure C.3.1: Transient plot for given parameters

S. No.	Expression	Calculation	Values
1.	t_d	1.0834-1.000	0.0834 μs
2.	t_f	1.2146-1.1021	0.1125 μs
3.	t_s	3.0160-3.000	0.0160 μs
4.	t_r	4.0542-3.3095	0.7447 μs

Table C.3.1: Transient plot for given parameters

<u>Comment</u>**:**

As the collector load resistor is increased to **4 kΩ**, a slope observed is less steeper. Hence, more time is taken to reach edge of saturation from $V_{BE\ cut\text{-}off}$.

All these experiments are performed in an ideal condition as it based on software simulation. In real life application bigger variation could be observed.

Conclusion:

As studied in lecture, implementation in a simulating software really helped to understand the concept and working behind BJT and Inverter operation. The study of various characteristics helped in visualising the ideology of how it could be applied in practical applications.