

# Week 2

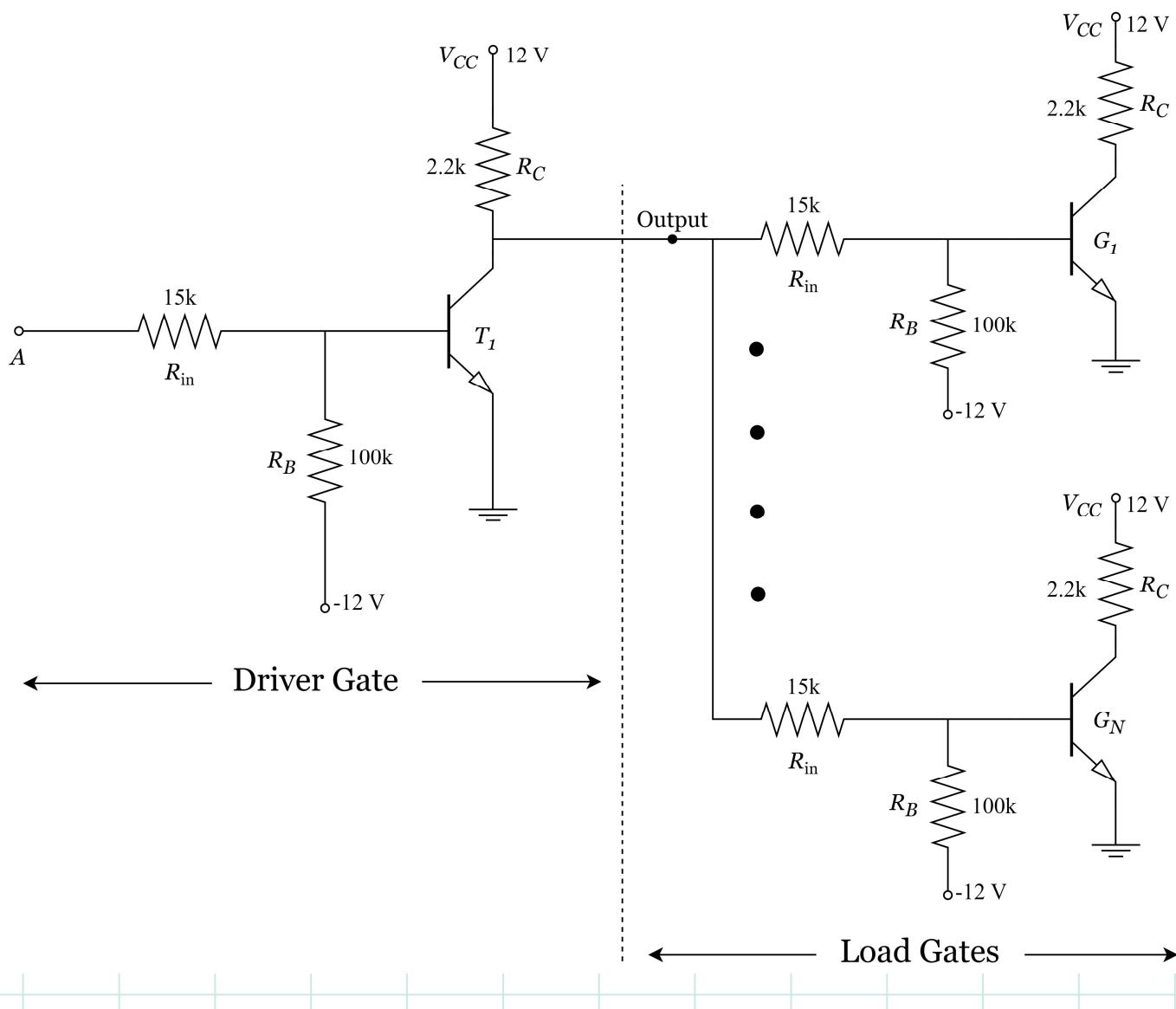
## RTL

## Week 2 - RTL

### Question 1

For the given RTL inverter circuit assume  $V_{OH} = 10\text{ V}$  and  $V_{OL} = 0.2\text{ V}$ . Also assume common emitter current gain,  $\beta_F = 30$ . Assume for saturation mode  $V_{BE} = 0.8\text{ V}$ ,  $V_{CE} = 0.2\text{ V}$  and cut in voltage for transistor  $V_\gamma = 0.5\text{ V}$ .

- (a) Find the Maximum possible Fanout.
- (b) Find the value of  $V_o$  if Fanout,  $N=2$  (2 Load gates are connected) and input of Driver is Low.
- (c) If  $V_{in} = \text{High}$ , find the power dissipation in the Driver circuit. (assume No Loads are connected)
- (d) If  $V_{in} = \text{High}$ , find the power dissipation in the Driver circuit. (assume 50 Loads are connected)
- (e) If  $V_{in} = \text{Low}$  and Fanout is 2, find the power dissipation in the Driver circuit.



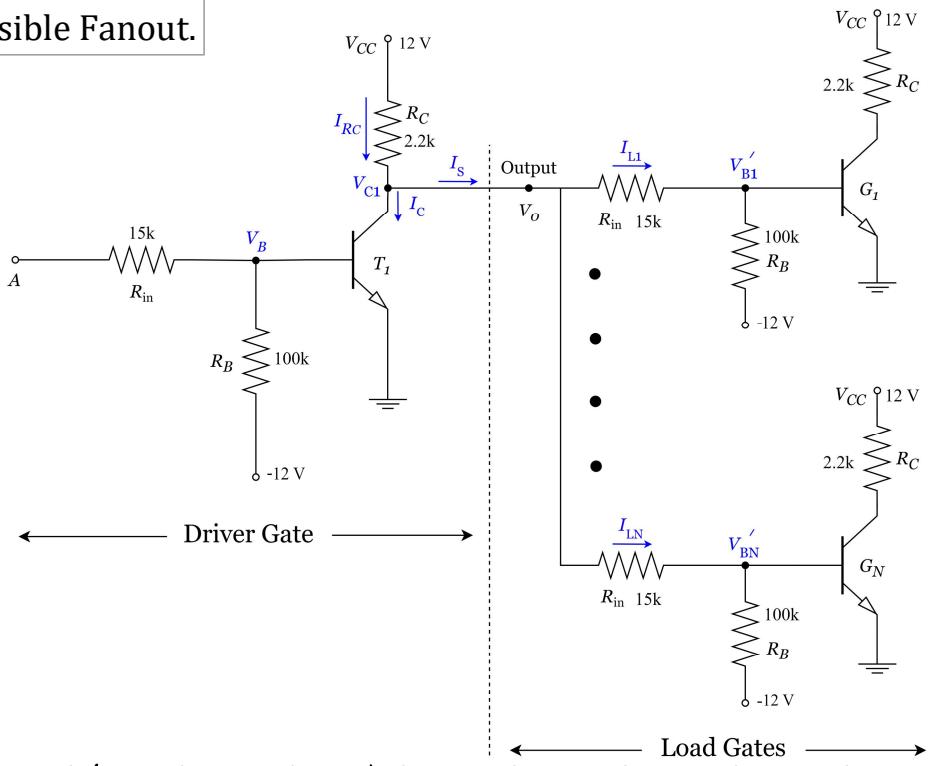
# Solution:

(a) Find the Maximum possible Fanout.

a) Case 1

$$V_{in} = \text{HIGH} = 12 \text{ V}$$

$T_1$  Saturated



$$\therefore V_{C1} = 0.2 \text{ V} = V_o$$

$$\therefore \text{Input of Load Gates } (G_1, \dots, G_N) = 0.2 \text{ V} = \text{LOW}$$

$$\text{Now, } I_{RC} = \frac{12 - V_o}{R_C} = \frac{12 - 0.2}{2.2k} = 5.3636 \text{ mA}$$

We will assume  $I_C = 0 \rightarrow$  To maximise  $I_S$

$$\therefore I_{\text{Supply}} = I_S = I_{RC} = 5.3636 \text{ mA}$$

$$\therefore \text{Individual Load current } = I_L = I_{L1} = \frac{V_o - (-12)}{(100+15)k\Omega} = \frac{12.2}{115k\Omega}$$

$$= 0.106 \text{ mA}$$

$$\therefore \text{Total Demand current} = N I_L = N(0.106) \text{ mA}$$

$$I_{\text{Supply}} = I_{\text{Demand}} \rightarrow 5.3636 = N(0.106) \rightarrow N = 50.6$$

↳ Floor  $\rightarrow N = 50$

## Case 2

$$V_{in} = LOW = 0.2 \text{ V}$$

$T_1$  in cutoff

$$\therefore V_o = HIGH$$

$\therefore V_{in}$  of Load Gates is HIGH

$\therefore G_1 \dots G_N$  in Saturation

$$\text{Now, } V_o = HIGH = V_{OH} = 10 \text{ V}$$

$$\text{As } G_1 \text{ in Saturation} \rightarrow V_{B1}' = 0.8 \text{ V}$$

$$\therefore \text{Individual Load current, } I_L = I_{L1} = \frac{V_o - V_{B1}'}{15k\Omega} = \frac{10 - 0.8}{15k\Omega}$$

$$= 0.1633 \text{ mA}$$

$$\therefore \text{Supply Current} \rightarrow I_s = \frac{12 - 10}{2.2k\Omega} = 0.909 \text{ mA}$$

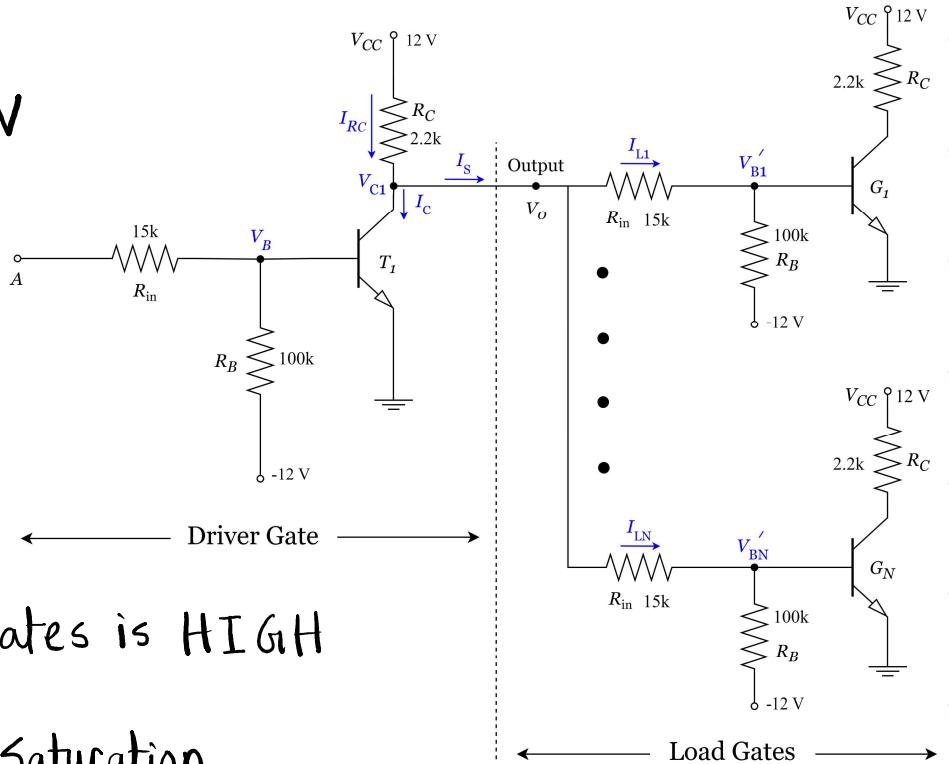
$$\therefore \text{Supply} = \text{Demand} \rightarrow I_s = N I_L$$

$$\Rightarrow 0.909 = N(0.6133) \Rightarrow N = 1.48$$

$\hookrightarrow$  Floor  
 $\downarrow$

$$N = 1$$

$$\therefore \text{Fanout} = \min(50, 1) = 1$$



- (b) Find the value of  $V_o$  if Fanout,  $N=2$  (2 Load gates are connected) and input of Driver is LOW.

b) Given, Fanout =  $N = 2$

$$V_{in} = \text{LOW} = 0.2 \text{ V}$$

$\therefore T_I$  cutoff

$V_o$  HIGH

$\therefore G_1 \dots G_N$  in Saturation

$$\text{Now, Supply} \rightarrow I_s = \frac{12 - V_o}{2.2k\Omega}$$

$$\text{Individual Load current, } I_L = I_{L1} = \frac{V_o - V_{B1}}{R_{in}} = \frac{V_o - 0.8}{15k\Omega}$$

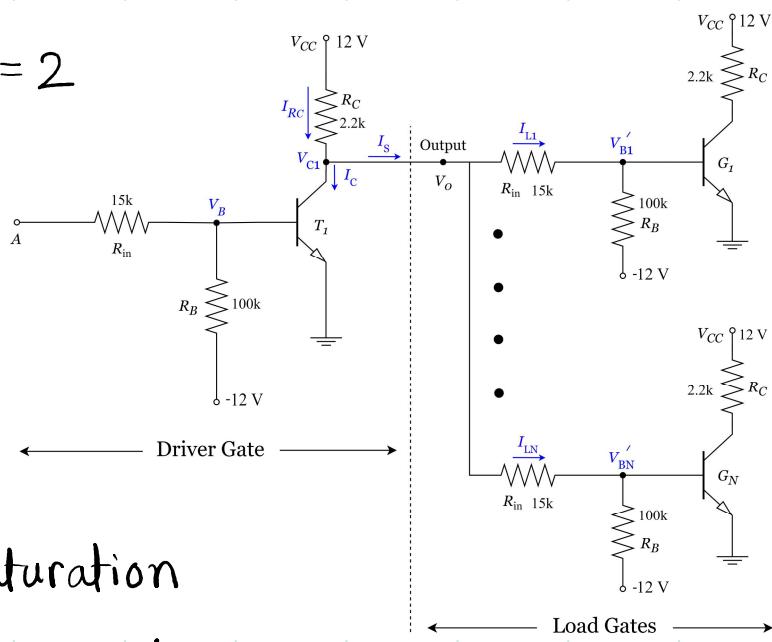
Given,  $N=2$ , Hence  $I_{L1} = I_{L2} [\because \text{Identical RTL}]$

Supply = Demand

$$I_s = N I_L$$

$$\Rightarrow \frac{12 - V_o}{2.2k} = 2 \times \frac{V_o - 0.8}{15k}$$

$$\Rightarrow V_o = 9.46 \text{ V}$$



- (c) If  $V_{in} = \text{High}$ , find the power dissipation in the Driver circuit. (assume No Loads are connected)

$$V_{in} = \text{HIGH} = 12 \text{ V}$$

$\therefore T_1$  in Saturation

$$\therefore V_B = 0.8 \text{ V}, V_C = 0.2 \text{ V}$$

Now,

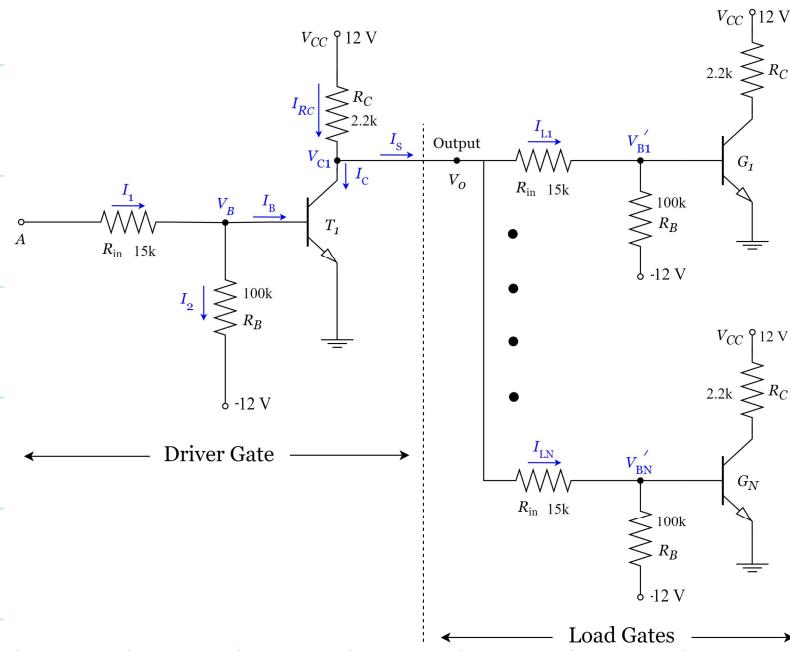
$$I_1 = \frac{12 - 0.8}{15 \text{ k}\Omega} = 0.747 \text{ mA}$$

$$I_2 = \frac{0.8 - (-12)}{100 \text{ k}\Omega} = 0.128 \text{ mA}$$

$$I_B = I_1 - I_2 = 0.619 \text{ mA}$$

$$I_S = 0 \quad [\because \text{No loads are connected}]$$

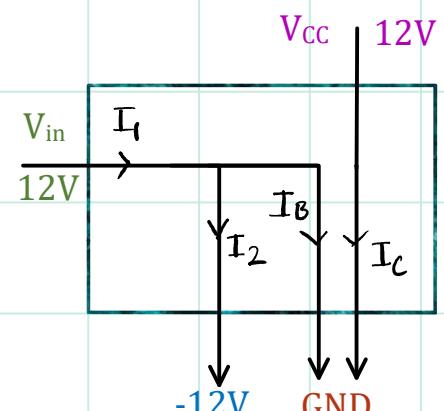
$$I_{R_C} = I_C = \frac{12 - 0.2}{2.2 \text{ k}\Omega} = 5.3636 \text{ mA}$$



$$\text{Power Dissipation} = \sum I \Delta V$$

$$= I_2 [12 - (-12)] + I_B (12 - 0) + I_C (12 - 0)$$

$$= 74.8632 \text{ mW}$$



- (d) If  $V_{in} = \text{HIGH} = 12 \text{ V}$ , find the power dissipation in the Driver circuit. (assume 50 Loads are connected)

$$V_{in} = \text{HIGH} = 12 \text{ V}$$

$\therefore T_1$  in Saturation

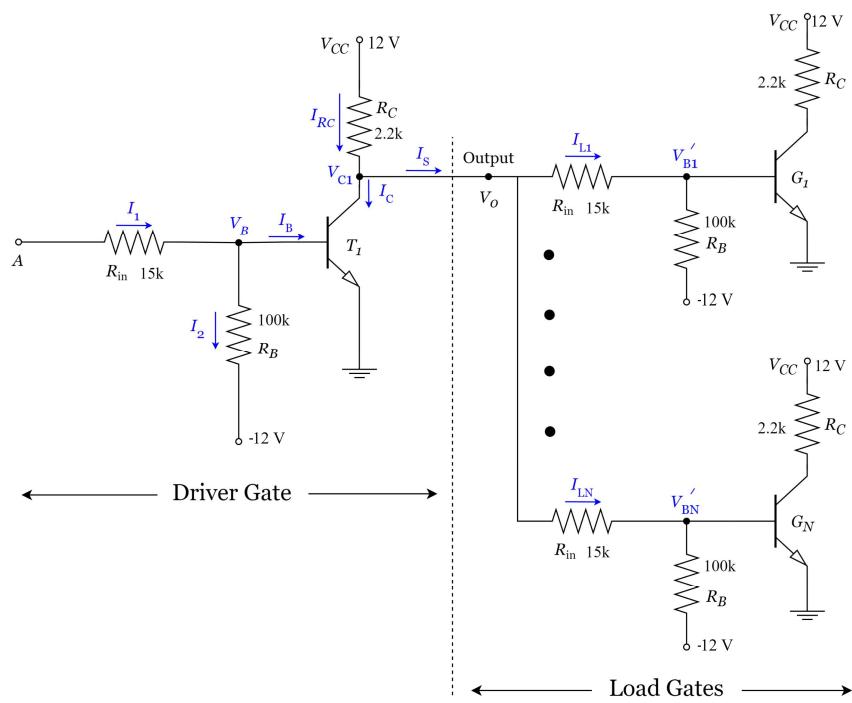
$$\therefore V_B = 0.8 \text{ V}, V_C = 0.2 \text{ V}$$

Now,

$$I_1 = \frac{12 - 0.8}{15 \text{ k}\Omega} = 0.747 \text{ mA}$$

$$I_2 = \frac{0.8 - (-12)}{100 \text{ k}\Omega} = 0.128 \text{ mA}$$

$$I_B = I_1 - I_2 = 0.619 \text{ mA}$$



From case(1) in Question (a)  $\rightarrow$

$$\text{Individual load current } I_{L1} = I_{L1} = \frac{V_O - (-12)}{(100+15)\text{k}} = \frac{12.2}{115\text{k}} = 0.106 \text{ mA}$$

Supply = Demand (Total load current)

$$\Rightarrow I_S = N \times I_{L1}$$

$$= 50 \times 0.106$$

$$= 5.3 \text{ mA}$$

In Driver circuit,

$$I_{RC} = \frac{12 - 0.2}{2.2\text{k}} = 5.3636 \text{ mA} \quad \text{and} \quad I_{RC} = I_c + I_S$$

$$\Rightarrow I_c = I_{RC} - I_S$$

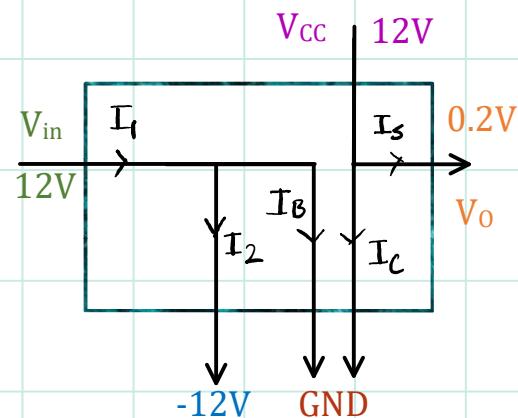
$$= 5.3636 - 5.3$$

$$= 0.0636 \text{ mA}$$

$$\text{Power Dissipation} = \sum I \Delta V$$

$$= I_2 [12 - (-12)] + I_B (12 - 0) \\ + I_S (12 - 0.2) + I_C (12 - 0)$$

$$= 58.23 \text{ mW}$$



(e) If  $V_{in}$  = Low and Fanout is 2, find the power dissipation in the Driver circuit.

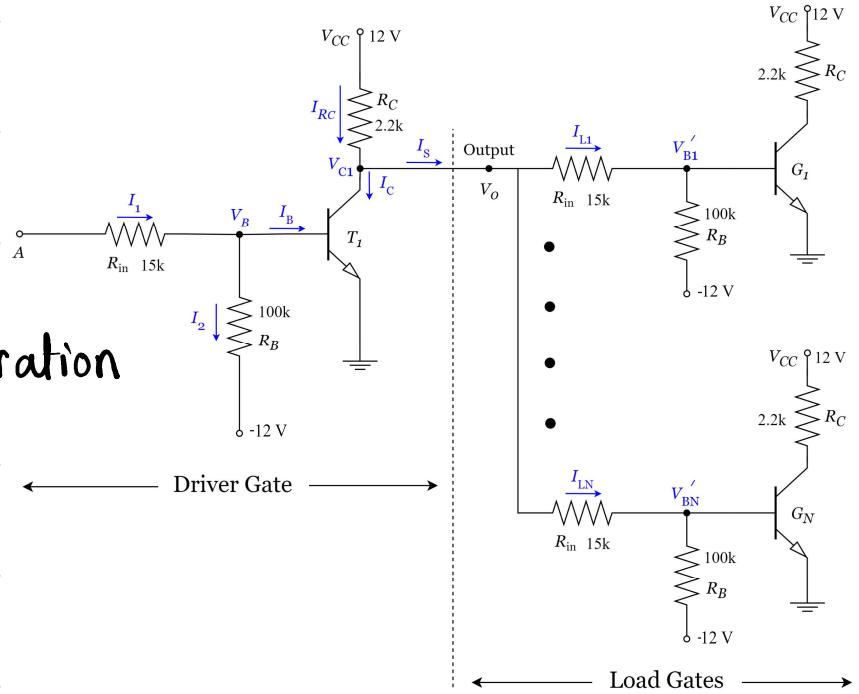
$$V_{in} = \text{Low} = 0.2 \text{ V}$$

$T_L$  in cutoff

$$\therefore V_o = \text{HIGH}$$

$\therefore G_1, \dots, G_N$  in Saturation

Given, Fanout = 2



$$\text{From (b)} \rightarrow V_o = 9.46 \text{ V}$$

In Driver Gate,  $I_B = 0$

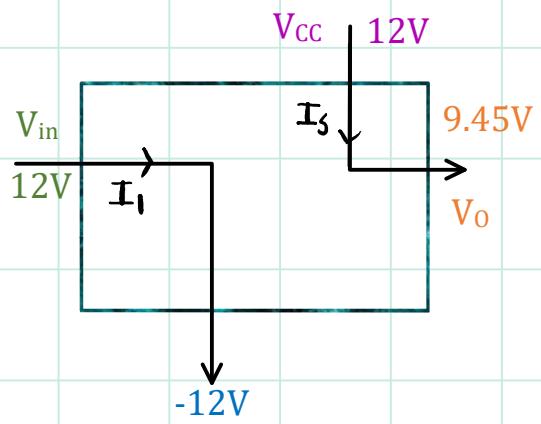
$$I_1 = I_2 = \frac{0.2 - (-12)}{115k} = 0.106 \text{ mA}$$

$$I_S = \frac{12 - 9.46}{2.2k} = 1.15 \text{ mA}$$

Power Dissipation =  $\sum I \Delta V$

$$= I_2 [12 - (-12)] + I_S (12 - 9.46)$$

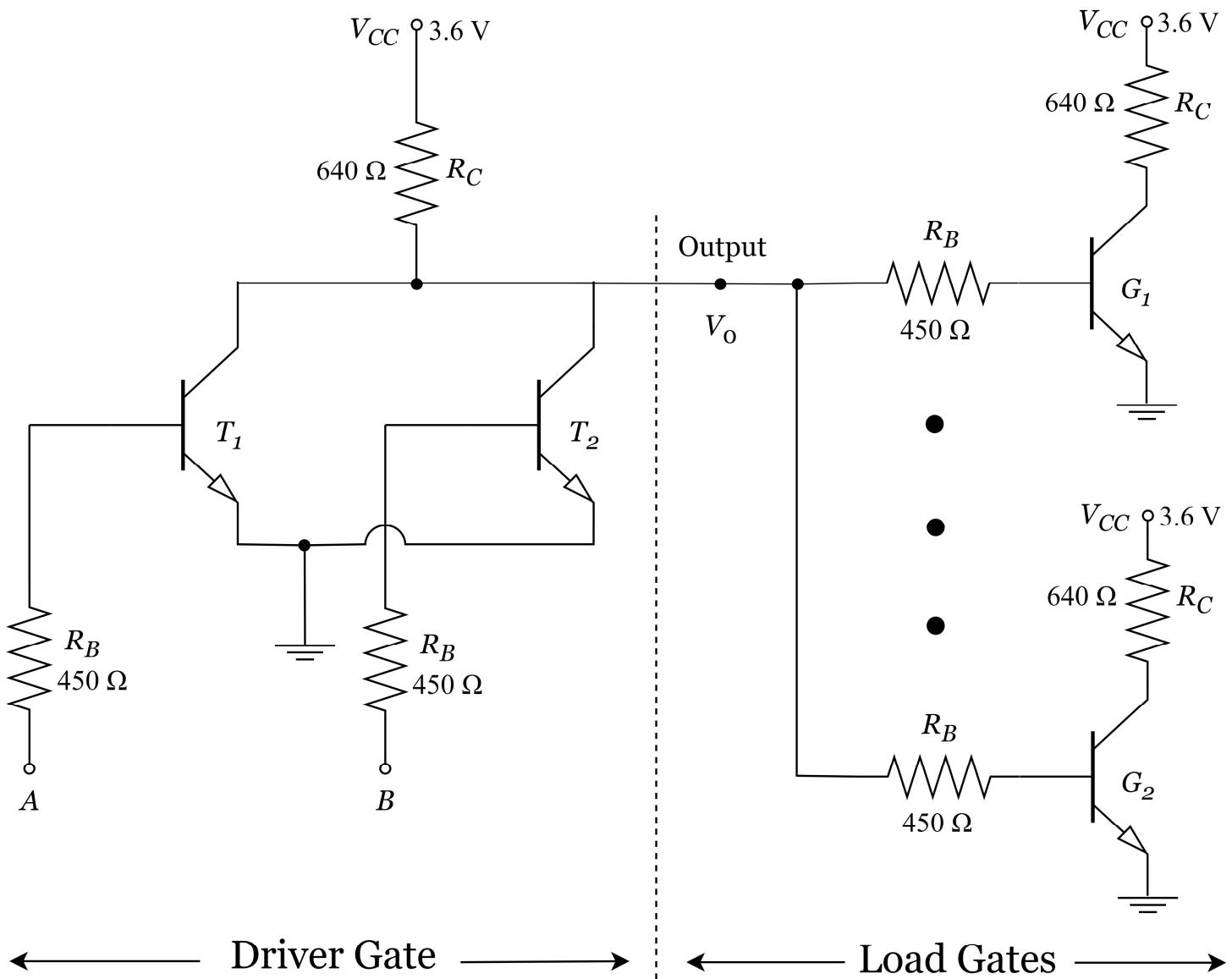
$$= 5.47 \text{ mW}$$



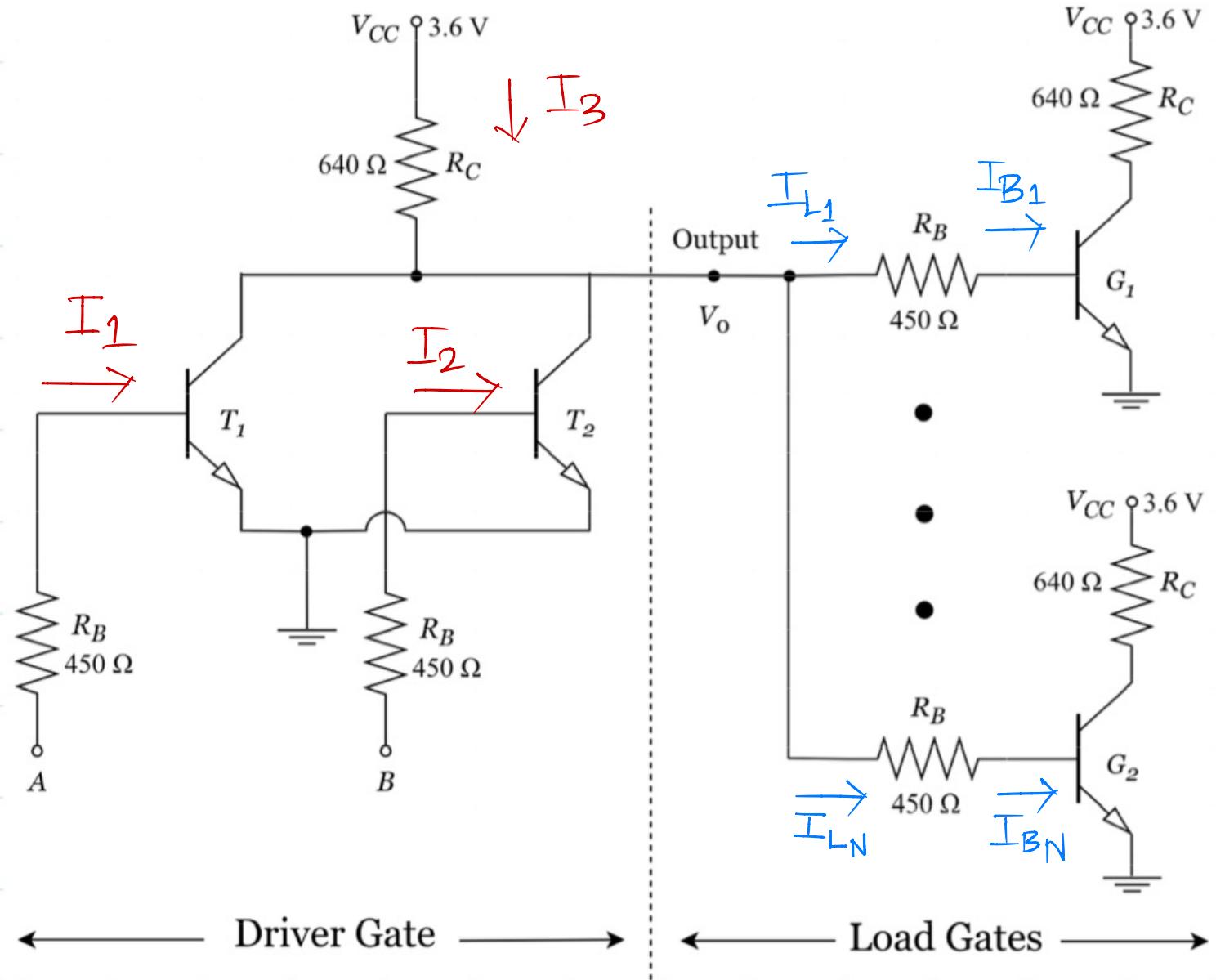
## Question 2

For the given RTL NOR circuit assume  $V_{OH} = 1.3$  V and  $V_{OL} = 0.2$  V. Also assume common emitter current gain,  $\beta_F = 30$ . Assume for saturation mode  $V_{BE} = 0.8$  V,  $V_{CE} = 0.2$  V and cut in voltage for transistor  $V_Y = 0.5$  V.

- |     |  |
|-----|--|
| (a) | Find the value of maximum fanout.  |
| (b) | Find the value of $V_O$ (output of Driver), if Fanout( $N$ ) = 5 and Inputs A, B are LOW.                            |
| (c) | Find the value of $\beta_{min}$ (for Load Gates), and Power dissipation in the Driver circuit for the conditions (b) |
| (d) | Find the Power dissipation in the Driver circuit when both inputs (A and B) are HIGH                                 |



# Circuit redrawn with appropriate labels



Solution:

- |     |                                  |
|-----|----------------------------------|
| (a) | Find the value of maximum fanout |
|-----|----------------------------------|

Case 1: A or B or Both HIGH = 3.6 V

∴  $T_1$  and  $T_2$  in saturation

$$V_{CE} = 0.2 \text{ V} \rightarrow V_o = 0.2 \text{ V}$$

∴ Input of Load Gates =  $V_o = 0.2 = \text{LOW}$

∴  $G_1, \dots, G_N$  in cutoff

∴ No current flow between Driver and Load.

$$\therefore \text{Fanout} = \infty$$

Case 2: A = B = LOW = 0.2 V

∴  $T_1$  and  $T_2$  in cutoff

$$\therefore V_o = \text{HIGH} = V_{OH} = 1.3 \text{ V}$$

∴ Load Gates are in Saturation

$$\therefore I_{\text{supply}} = I_3 = \frac{3.6 - V_{OH}}{640} = \frac{3.6 - 1.3}{640}$$

$$\therefore I_{\text{supply}} = 3.593 \text{ mA}$$

$$\text{Individual Load current, } I_L = I_{L1} = \frac{V_0 - V_{B1}}{450} = \frac{1.3 - 0.8}{450}$$

$$\therefore I_L = 1.11 \text{ mA}$$

$$\text{Total Demand} = N I_L$$

$$\text{Total Supply} = \text{Total Demand}$$

$$\Rightarrow I_{\text{Supply}} = I_{\text{Demand}}$$

$$\Rightarrow 3.593 = N \times 1.11$$

$$\Rightarrow N = 3.23 \rightarrow \text{Floor} \rightarrow N = 3$$

$$\therefore \text{Maximum Fanout} = \text{Min}(\infty, 3) = 3$$

(b) Find the value of  $V_o$  (output of Driver), if Fanout( $N$ ) = 5 and Inputs A, B are LOW.

$$A = B = \text{LOW} = 0.2 \text{ V}$$

$\therefore T_1$  and  $T_2$  are in cutoff

$\therefore V_o = \text{HIGH} \rightarrow \text{Load Gate inputs}$

$\therefore$  Load Gates are in Saturation

$$\therefore I_{\text{Supply}} = I_3 = \frac{3.6 - V_o}{640}$$

$$\text{Individual Load current, } I_L = I_{L1} = \frac{V_o - V_{B1}'}{450} = \frac{V_o - 0.8}{450}$$

$$\text{Total Demand} = N I_L$$

$$\text{Total Supply} = \text{Total Demand}$$

$$\therefore I_{\text{Supply}} = I_{\text{Demand}} \rightarrow I_3 = N I_L$$

$$\Rightarrow \frac{3.6 - V_o}{640} = 5 \times \frac{V_o - 0.8}{450}$$

$$\Rightarrow V_o = 1.145 \text{ V}$$

- (c) Find the value of  $\beta_{\min}$  (for Load Gates), and Power dissipation in the Driver circuit for the conditions (b)

From (b)  $\rightarrow V_o = 1.145 \text{ V}$

$$(i) \text{ Now, } \beta_{\min} = \frac{I_c}{I_B} \quad [:\text{ when in saturation}]$$

Here, Load Gates are in Saturation

For Load Gate G<sub>1</sub>  $\rightarrow$

$$V_{B1}' = 0.8 \text{ V} \quad \text{and} \quad V_{C1}' = 0.2 \text{ V}$$

$$\therefore I_B = I_{L1} = \frac{V_o - V_{B1}'}{R_B} = \frac{1.145 - 0.8}{450}$$

$$\therefore I_B = 0.767 \text{ mA}$$

$$I_c = I_{c1}' = \frac{3.6 - V_{C1}'}{640} = \frac{3.6 - 0.2}{640}$$

$$\therefore I_c = 5.3125 \text{ mA}$$

$$\therefore \beta_{\min} = \frac{I_c}{I_B} = \frac{5.3125}{0.767} = 6.9263$$

(ii) In Driver circuit,

$T_1$  and  $T_2$  are in cutoff

∴ The only current that will flow is from  $V_{CC}$  to  $V_O$

From (b)  $\rightarrow V_0 = 1.145 \text{ V}$ .

Power Dissipation =  $\sum I \Delta V$

The diagram shows a common-emitter circuit with a DC power source  $V_{CC} = 3.6 \text{ V}$  at the top. The output voltage  $V_o$  is indicated at the bottom. A current  $I_3$  flows through the base-emitter junction. The calculated output voltage is  $1.145 \text{ V}$ .

$$= I_3(V_{CC} - V_o)$$

$$= \frac{3.6 - 1.145}{640} \times (3.6 - 1.145)$$

$$= 9.417 \text{ mW}$$

(d) Find the Power dissipation in the Driver circuit when both inputs (A and B) are HIGH

$$V_A = V_B = \text{HIGH} = 3.6 \text{ V}$$

$\therefore T_1$  and  $T_2$  are in Saturation

$$V_{BE} = 0.8 \text{ V} \rightarrow V_{B1} = V_{B2} = 0.8 \text{ V}$$

$$V_{CE} = 0.2 \text{ V} \rightarrow V_{C1} = V_{C2} = V_0 = \text{LOW}$$

$\therefore G_1, \dots, G_N$  in cutoff

$\therefore$  No current flow between Driver and Load.

$$\text{Now, } I_{B1} = \frac{3.6 - V_{B1}}{450} = \frac{3.6 - 0.8}{450} = 6.22 \text{ mA}$$

$$I_{B2} = \frac{3.6 - V_{B2}}{450} = \frac{3.6 - 0.8}{450} = 6.22 \text{ mA}$$

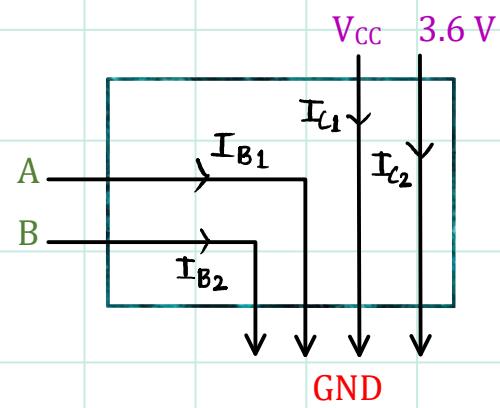
$$\text{Now, } I_3 = \frac{3.6 - 0.2}{640} = 5.31 \text{ mA}$$

$$I_{C1} = I_{C2} = \frac{I_3}{2} = 2.65 \text{ mA}$$

Power Dissipation =  $\sum I \Delta V$

$$= I_{B1}(3.6 - 0) + I_{B2}(3.6 - 0) \\ + I_{C1}(3.6 - 0) + I_{C2}(3.6 - 0)$$

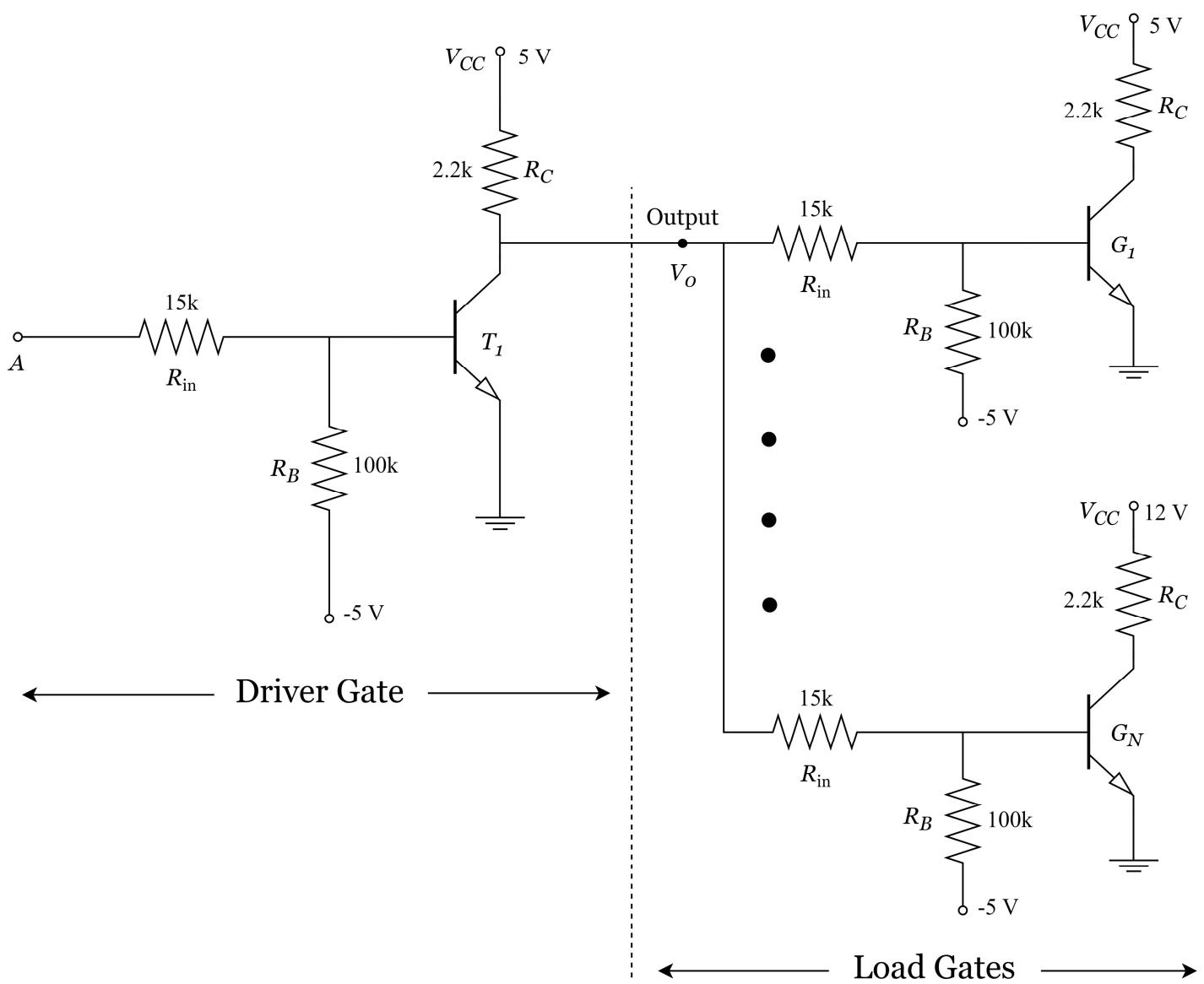
$$= 63.92 \text{ mW}$$



### Question 3

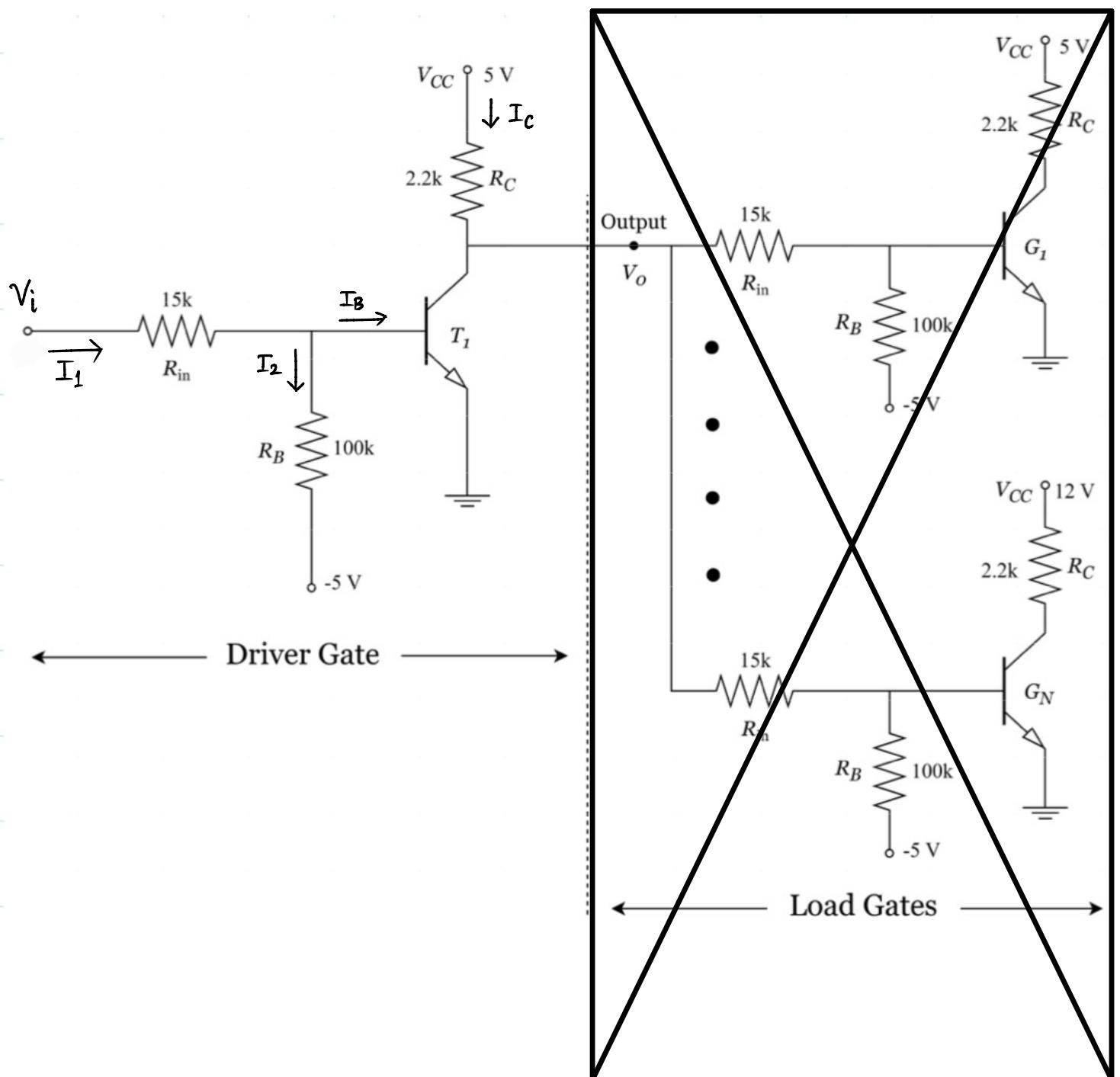
For the given RTL inverter circuit assume  $V_{OH} = 11.5$  V and  $V_{OL} = 0.2$  V. Also assume common emitter current gain,  $\beta_F = 30$ . Assume for saturation mode  $V_{BE} = 0.8$  V,  $V_{CE} = 0.2$  V and cut in voltage for transistor  $V_T = 0.5$  V.

- |     |   |
|-----|---|
| (a) | Find the value of $V_{IL}$ in V         |
| (b) | Find the value of $V_{IH}$ in V         |
| (c) | Find the value Noise margin, $V_N$ in V |



# Circuit redrawn with appropriate labels

We don't need  
load gates for this



Solution:

(a) Find the value of  $V_{IL}$  in V

$V_{IL} \rightarrow T_1$  is in between cutoff and just turning ON

$$\therefore V_{BE} = 0.5 \text{ V} \rightarrow V_B = 0.5 \text{ V} [\because V_E = 0]$$

At this point,  $I_B \approx 0 \text{ mA}$

$$\therefore I_1 = I_2$$

$$\Rightarrow \frac{V_i - 0.5}{15k} = \frac{0.5 - (-12)}{100k}$$

$$\Rightarrow \frac{V_i - 0.5}{15k} = 0.125 \text{ mA}$$

$$\Rightarrow V_i = 2.375 \text{ V} \rightarrow V_{IL}$$

(b) Find the value of  $V_{IH}$  in V

$T_1$  is in edge of Saturation (In between F.A. and saturation)

In this special case, we will use Formulas for Saturation

except  $\frac{I_c}{I_B} < \beta_F$  (we will use  $\frac{I_c}{I_B} = \beta_F$ )

$$\therefore V_{BE} = 0.8 \text{ V} \quad I_c = \beta I_B$$

$$V_{CE} = 0.2 \text{ V}$$

$$I_C = \frac{12 - 0.2}{2.2k} = 5.3636 \text{ mA}$$

$$I_B = \frac{I_C}{\beta} = \frac{5.3636}{30} = 0.1788 \text{ mA}$$

$$I_2 = \frac{0.8 - (-12)}{100k} = 0.128 \text{ mA}$$

$$I_1 = I_2 + I_B = (0.128 + 0.1788) \\ = 0.3068 \text{ mA}$$

$$I_1 = \frac{V_i - 0.8}{15k} = 0.3068 \text{ mA}$$

$$\Rightarrow V_i = 5.4081 \text{ V} \longrightarrow V_{IH}$$

(c) Find the value Noise margin,  $V_N$  in V

$$V_{NH} = V_{OH} - V_{IH} = 11.5 - 5.4081 \\ = 6.0982 \text{ V}$$

$$V_{NL} = V_{IL} - V_{OL} = 2.375 - 0.2 \\ = 2.175 \text{ V}$$

$$\text{Noise Margin} = \text{Min}(6.0982, 2.175) \\ = 2.175 \text{ V}$$