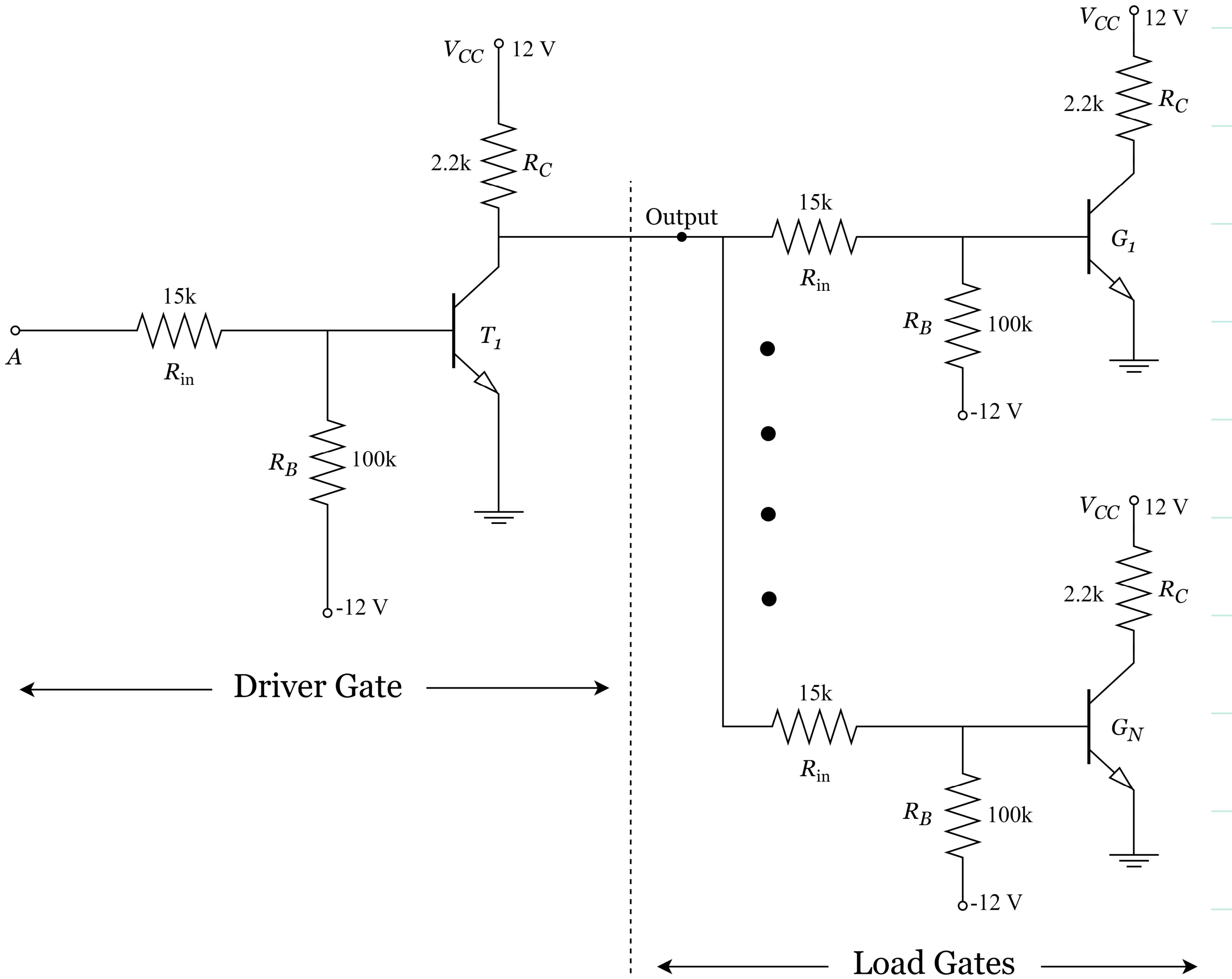
Week 2
RTL

Week 2 - RTL

Question 1

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

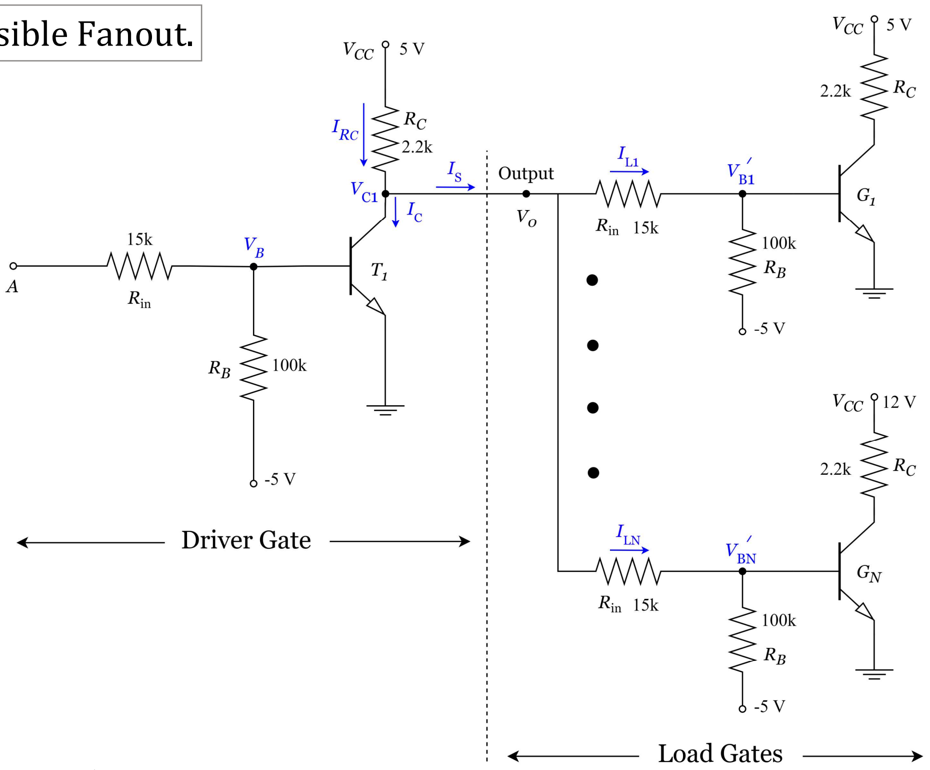
(a)	Find the Maximum possible Fanout.
(b)	Find the value of Vo if Fanout, N=2 (2 Load gates are connected) and input of Driver is Low.
(c)	If Vin = High, find the power dissipation in the Driver circuit. (assume No Loads are connected)
(d)	If Vin = High, find the power dissipation in the Driver circuit. (assume 50 Loads are connected)
(e)	If Vin = 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} = HIGH = 12 V

T_1 Saturated

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

$\therefore$ Input of Load Gates $(G_1, \ldots\ldots, G_N) = 0.2\,V$ = LOW

Now, $I_{RC} = \dfrac{12 - V_o}{R_C} = \dfrac{12 - 0.2}{2.2K} = 5.3636$ mA

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

$\therefore I_{supply} = I_S = I_{RC} = 5.3636$ mA

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

$= 0.106$ mA

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

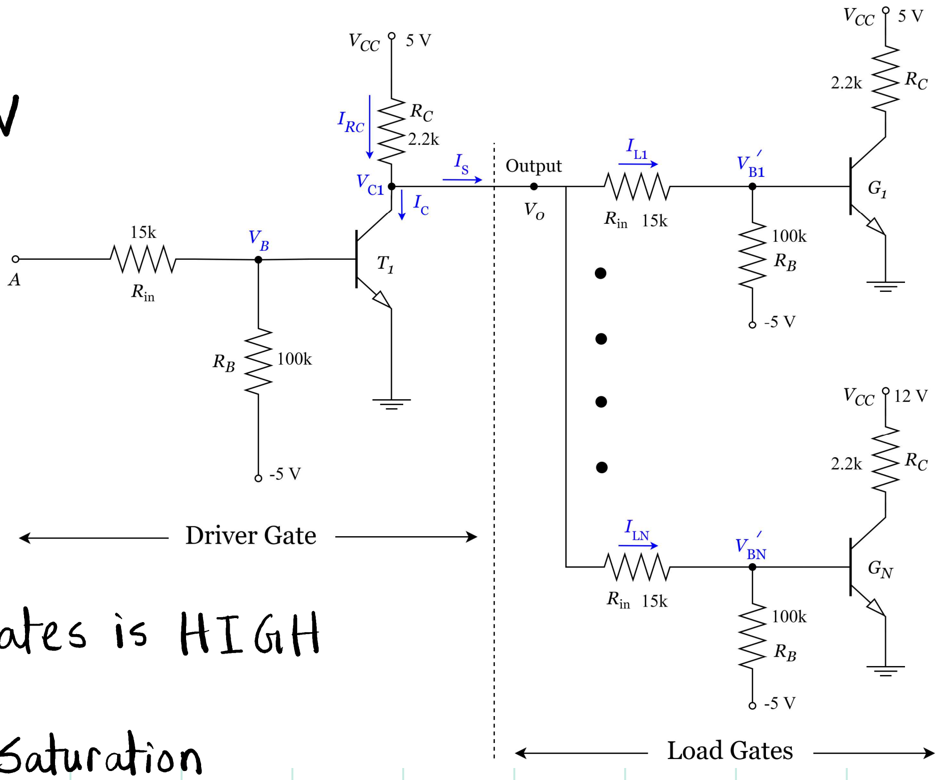
$I_{supply} = I_{Demand} \longrightarrow 5.3636 = N(0.106) \rightarrow N = 50.6$

$\hookrightarrow$ Floor $\rightarrow N = 50$

Case 2

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

T_1 in cutoff



$\therefore V_o = HIGH$

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

$\therefore G_1 \ldots\ldots G_N$ in Saturation

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

As G_1 in Saturation $\longrightarrow$ $V'_{B1} = 0.8\ V$

$\therefore$ Individual Load current, $I_L = I_{L1} = \dfrac{V_o - V'_{B1}}{15k\Omega} = \dfrac{10 - 0.8}{15k\Omega}$

$= 0.1633\ mA$

$\therefore$ Supply Current $\longrightarrow I_S = \dfrac{12 - 10}{2.2k\Omega} = 0.909\ mA$

$\therefore$ Supply = Demand $\longrightarrow I_S = N I_L$

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

$\hookrightarrow$ Floor

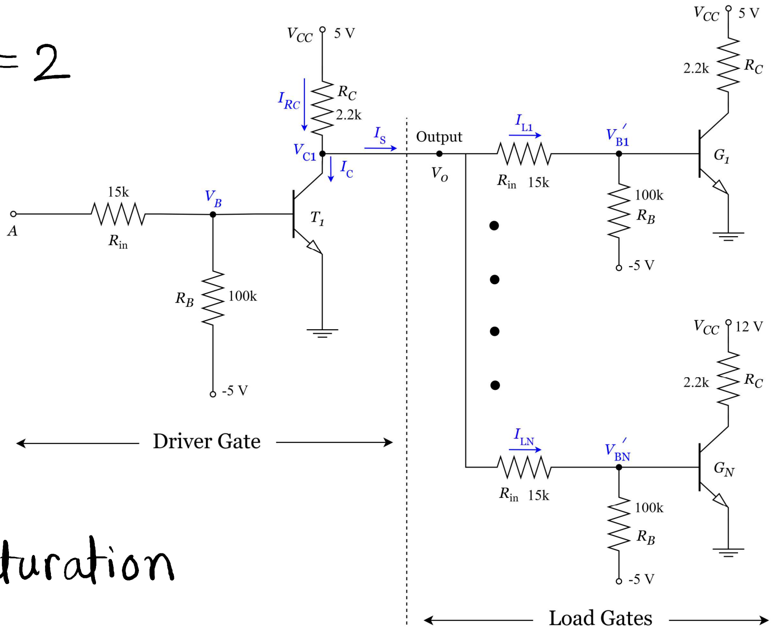
$\downarrow$

$N = 1$

$\therefore$ Fanout = Min(50, 1) = 1

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

b) Given, Fanout $= N = 2$



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

$\therefore T_1$ cutoff

V_o HIGH

$\therefore G_1 \ldots\ldots G_N$ in Saturation

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

Individual Load current, $I_L = I_{L1} = \dfrac{V_o - V'_{B1}}{R_{in}} = \dfrac{V_o - 0.8}{15\text{k}\Omega}$

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

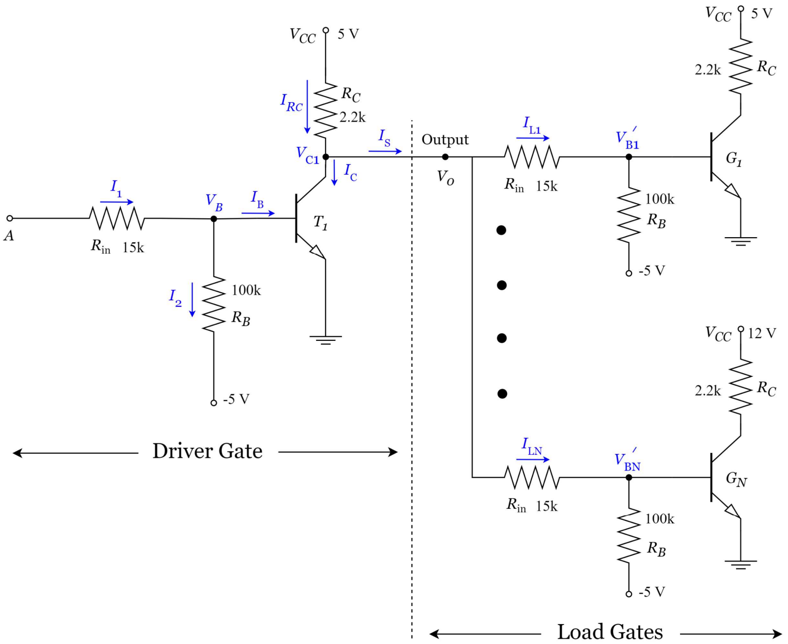
Supply = Demand

$I_S = N I_L$

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

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

(c)	If Vin = High, find the power dissipation in the Driver circuit. (assume No Loads are connected)



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

$\therefore T_1$ in Saturation

$\therefore V_B = 0.8\ V,\ V_C = 0.2\ V$

Now,

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

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

$$I_B = I_1 - I_2 = 0.619\ mA$$

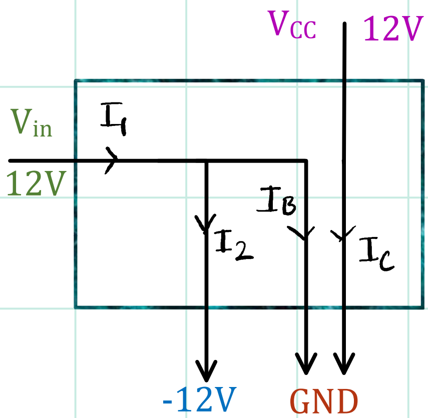
$$I_S = 0\ \left[\because \text{No loads are connected}\right]$$

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

Power Dissipation $= \sum I \Delta V$

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

$= 74.8632\ mW$

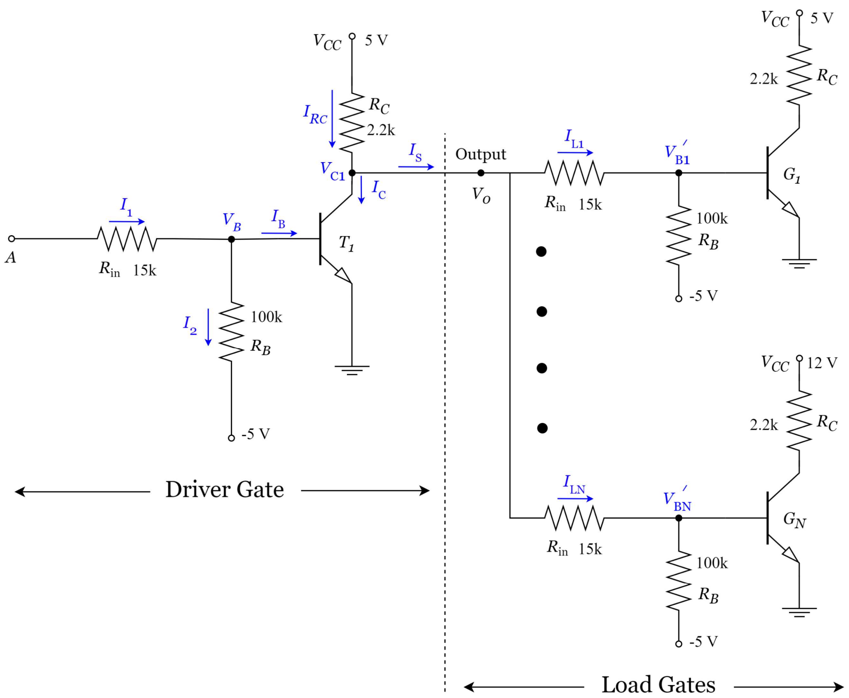


(d)	If Vin = High, find the power dissipation in the Driver circuit. (assume 50 Loads are connected)

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

$\therefore T_1$ in Saturation

$\therefore V_B = 0.8\ V,\ V_c = 0.2\ V$



Now,

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

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

$$I_B = I_1 - I_2 = 0.619\ mA$$

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

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

Supply = Demand (Total load current)

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

$$= 50 \times 0.106$$

$$= 5.3\ mA$$

In Driver circuit,

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

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

$= 5.3636 - 5.3$

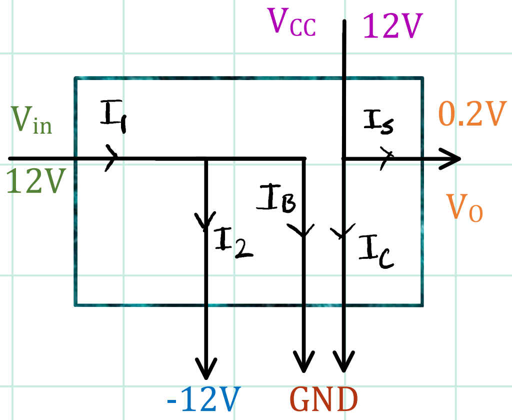
$= 0.0636 \text{ mA}$

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 Vin = Low and Fanout is 2, find the power dissipation in the Driver circuit.

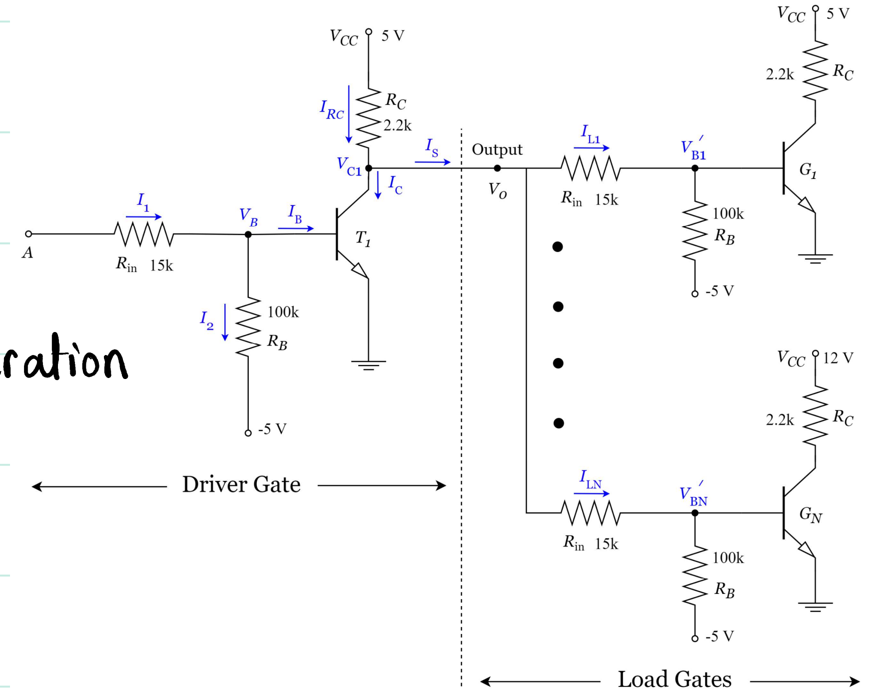
$V_{in} = LOW = 0.2\ V$

T_1 in cutoff

$\therefore V_o = HIGH$

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

Given, Fanout = 2



From (b) $\rightarrow V_o = 9.46\ V$

In Driver Gate, $I_B = 0$

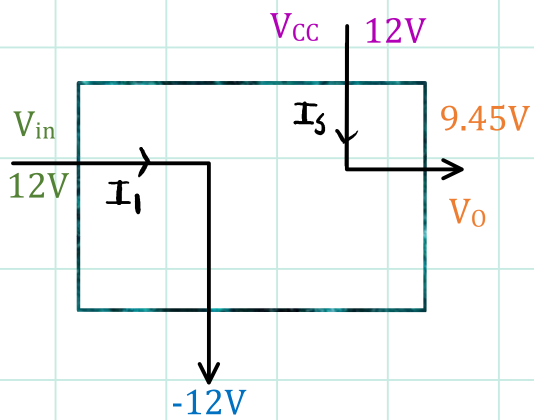
$$I_1 = I_2 = \frac{0.2 - (-12)}{115k} = 0.106\ mA$$

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

Power Dissipation $= \Sigma I \Delta V$

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

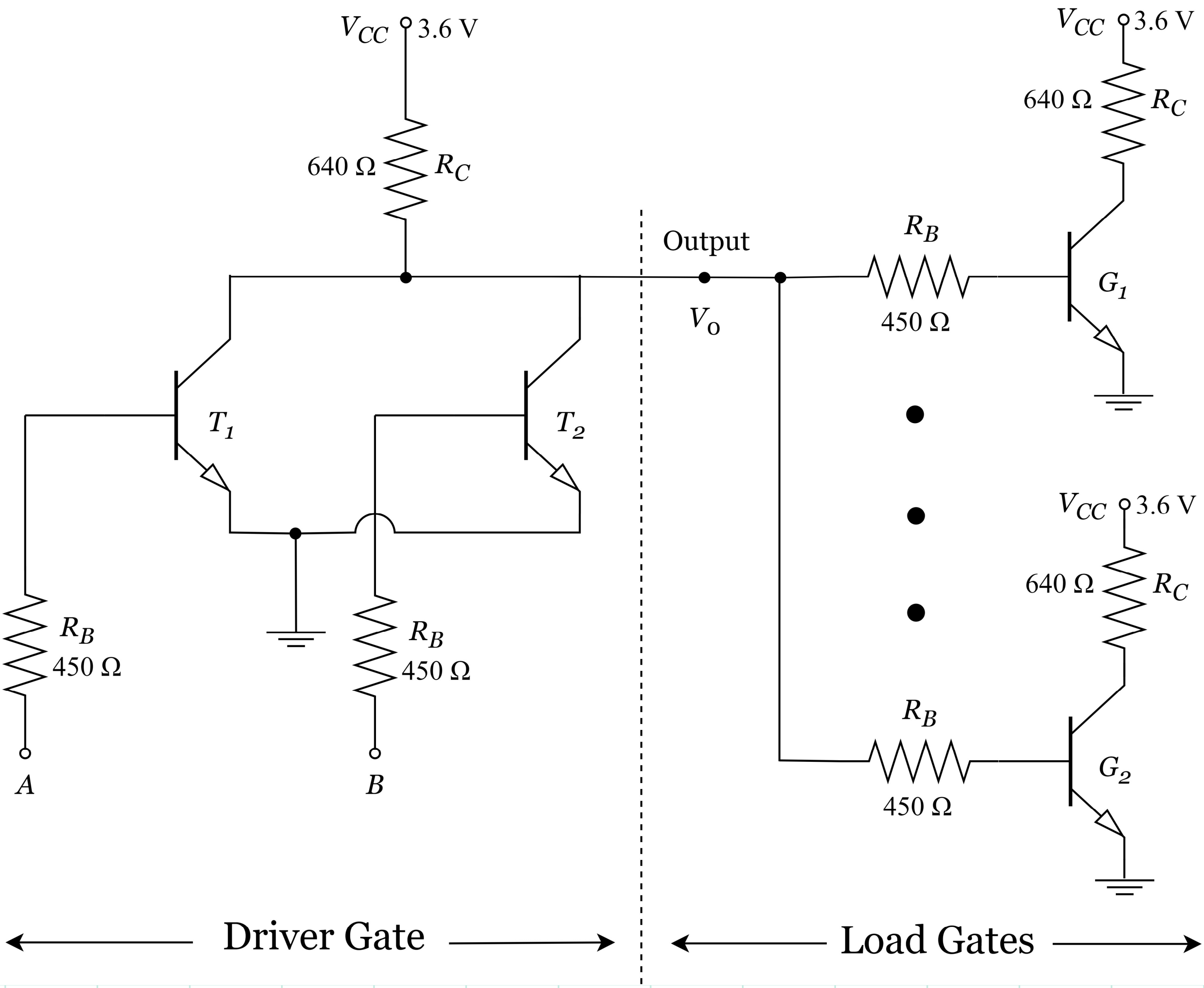
$= 5.47\ mW$



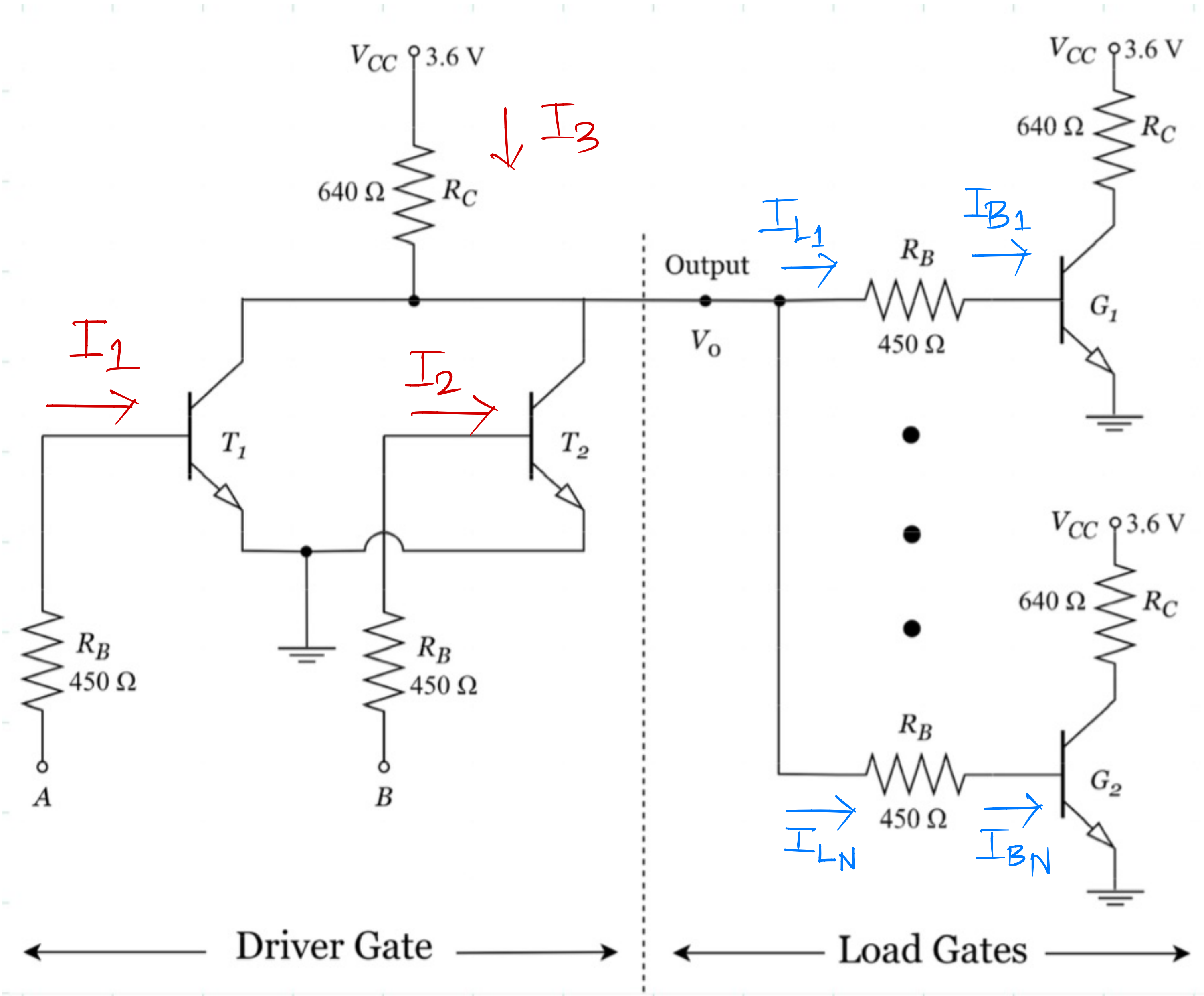
Question 2

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 $V_\gamma = 0.5$ 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 β_{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 $= 3.6\ V$

$\therefore T_1$ and T_2 in Saturation

$V_{CE} = 0.2\ V \longrightarrow V_o = 0.2\ V$

$\therefore$ Input of Load Gates $= V_o = 0.2 =$ LOW

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

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

$\therefore$ Fanout $= \infty$

Case 2: $A = B =$ LOW $= 0.2\ V$

$\therefore T_1$ and T_2 in cutoff

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

$\therefore$ Load Gates are in Saturation

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

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

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

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

Total Demand $= N I_L$

Total Supply $=$ Total Demand

$\Rightarrow I_{supply} = I_{Demand}$

$\Rightarrow 3.593 = N \times 1.11$

$\Rightarrow N = 3.23 \rightarrow$ Floor $\rightarrow N = 3$

$\therefore$ 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.

$A = B = LOW = 0.2\,V$

$\therefore$ T_1 and T_2 are in cutoff

$\therefore$ V_0 = HIGH $\longrightarrow$ Load Gate inputs

$\therefore$ Load Gates are in Saturation

$$\therefore I_{supply} = I_3 = \frac{3.6 - V_0}{640}$$

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

Total Demand $= N I_L$

Total Supply = Total Demand

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

$$\Rightarrow \frac{3.6 - V_0}{640} = 5 \times \frac{V_0 - 0.8}{450}$$

$$\Rightarrow V_0 = 1.145\ V$$

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

From (b) → $V_0 = 1.145\ V$

(i) Now, $\beta_{min} = \frac{I_C}{I_B}$ [∵ when in saturation]

Here, Load Gates are in saturation

For Load Gate G_1 →

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

$$\therefore I_B = I_{L1} = \frac{V_0 - V_{B1}'}{R_B} = \frac{1.145 - 0.8}{450}$$

$$\therefore I_B = 0.767\ mA$$

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

$$\therefore I_C = 5.3125\ mA$$

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

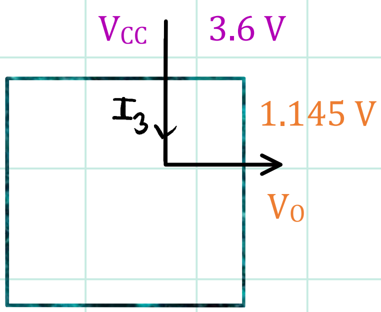
(ii) In Driver circuit,

T_1 and T_2 are in cutoff

$\therefore$ The only current that will flow is from V_{cc} to V_o

From (b) $\rightarrow$ $V_o = 1.145$ V.

Power Dissipation $= \sum I \Delta V$



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

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

$$= 9.417 \text{ mW}$$

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

$V_A = V_B = HIGH = 3.6\ V$

$\therefore T_1$ and T_2 are in Saturation

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

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

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

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

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

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

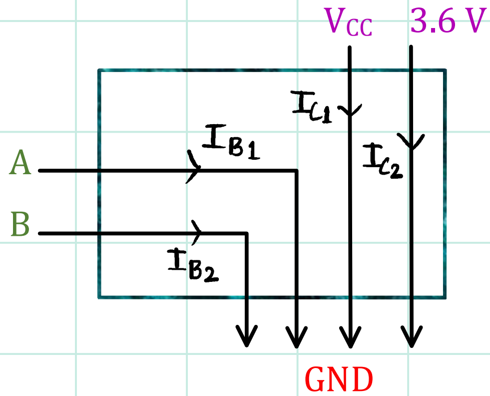
Now, $I_3 = \dfrac{3.6 - 0.2}{640} = 5.31\ mA$

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

Power Dissipation $= \Sigma I \Delta V$

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

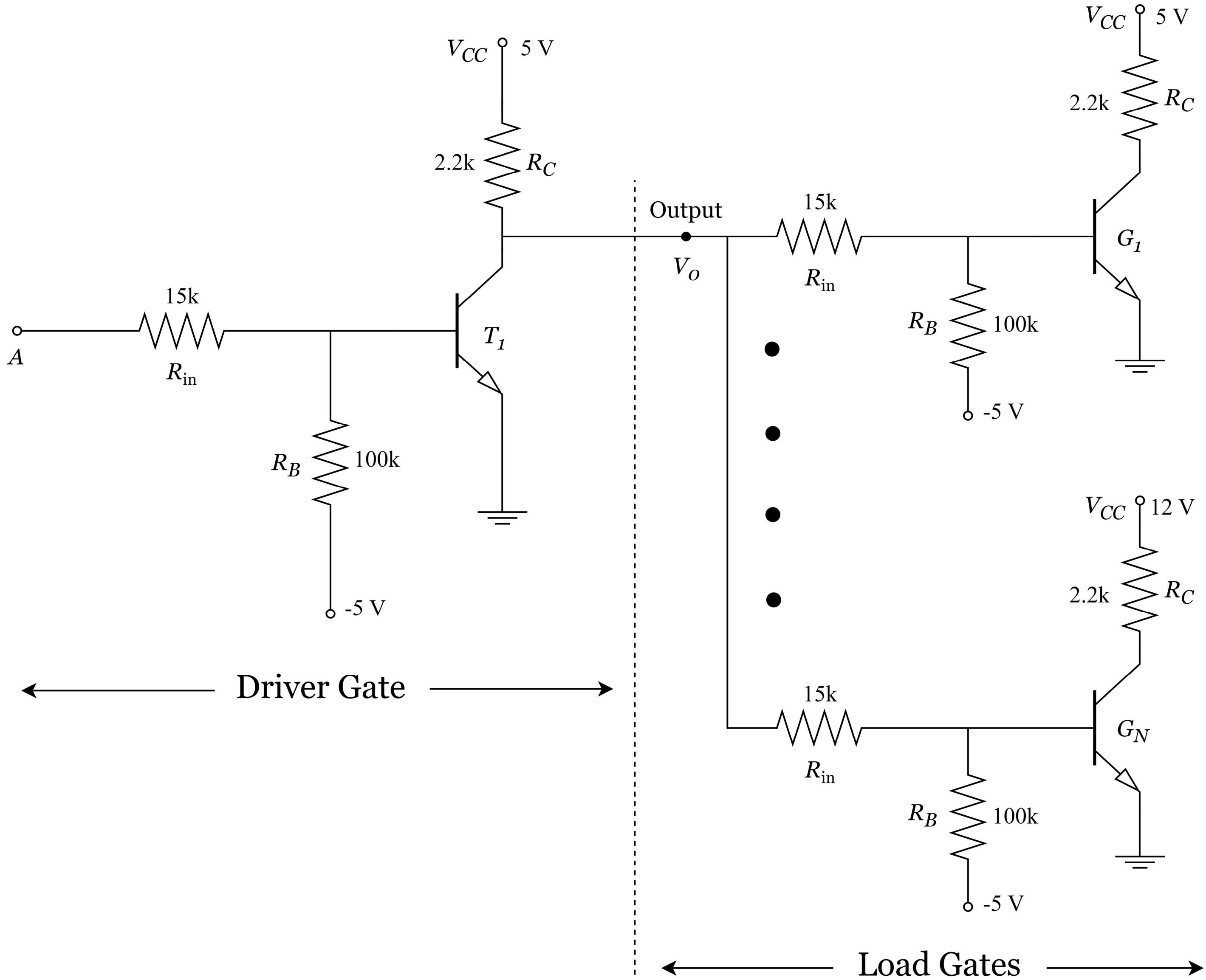
$= 63.92\ mW$



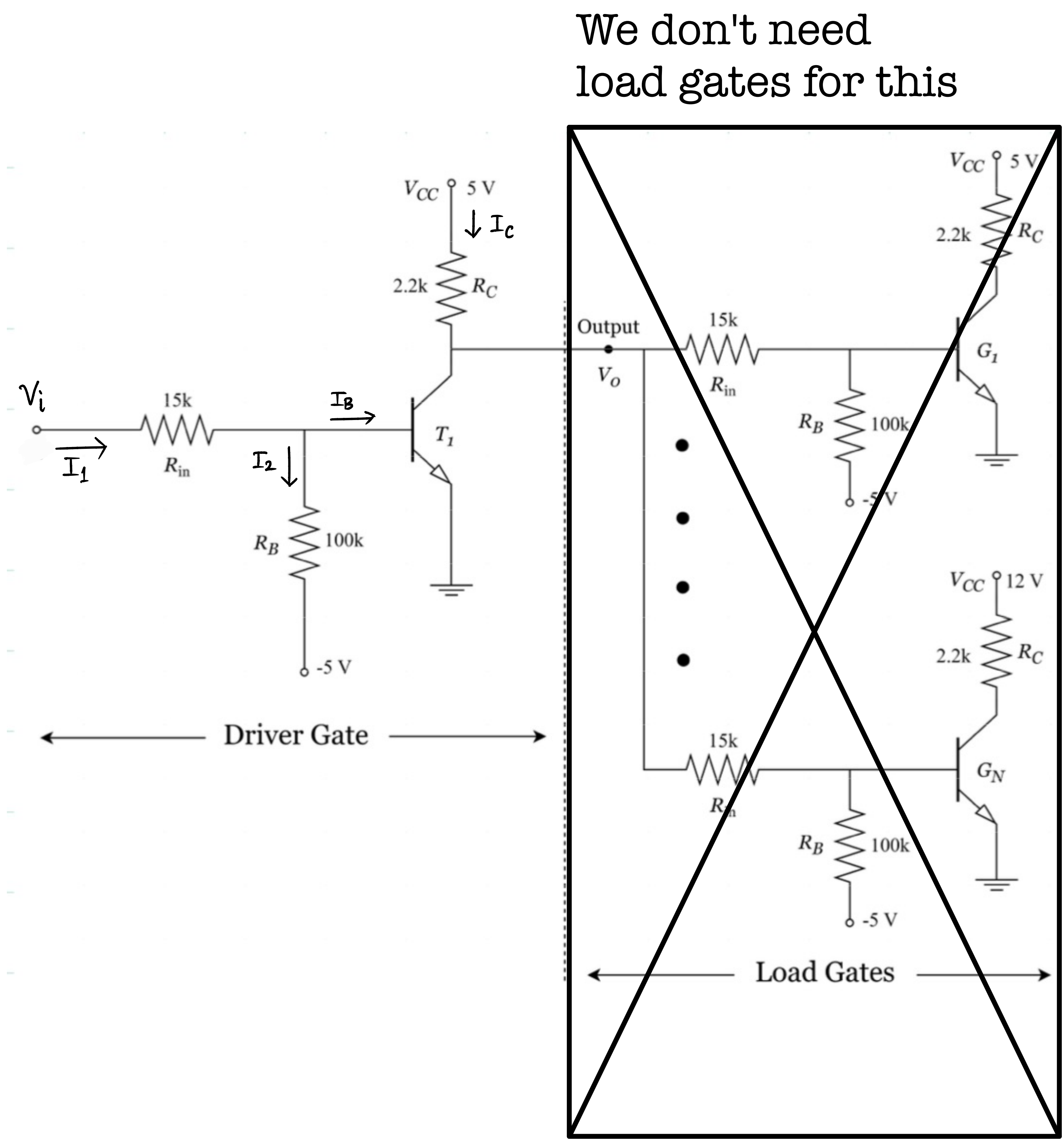
Question 3

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



Solution:

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

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

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

At this point, $I_B \approx 0\ mA$

$\therefore I_1 = I_2$

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

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

$$\Rightarrow V_i = 2.375\ V \longrightarrow V_{IL}$$

(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 $\frac{I_C}{I_B} = \beta_F$)

$\therefore V_{BE} = 0.8\ V \qquad I_C = \beta I_B$

$V_{CE} = 0.2\ V$

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

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

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

$$I_1 = I_2 + I_B = (0.128 + 0.1788)$$

$$= 0.3068 \text{ mA}$$

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

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

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

$$V_{NH} = V_{OH} - V_{IH} = 11.5 - 5.4018$$

$$= 6.0982 \text{ V}$$

$$V_{NL} = V_{IL} - V_{OL} = 2.375 - 0.2$$

$$= 2.175 \text{ V}$$

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

$$= 2.175 \text{ V}$$