BRAC UNIVERSITY
Department of Computer Science & Engineering
Practice Problem sheet (Week 4)
CSE 350: Digital Electronics and Pulse Technique

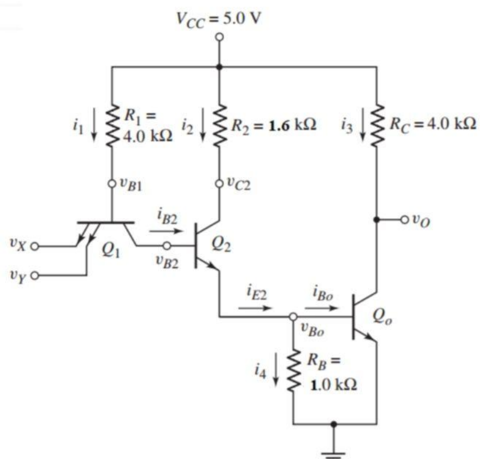
- *Use activation voltage* $V_\gamma(diode) = \mathbf{0.6V}$, $V_\gamma(transistor) = \mathbf{0.5V}$, $V_{BE}(forward\ active) = 0.7V$, $V_D = 0.7V$ *and* $V_{BE}(sat) = 0.8\,V$ *for all the questions.*

Question No. 1

Question No. 1

For the given TTL NAND circuit, assume common emitter current gain, $\beta_F = 25$ and reverse common emitter current gain of the transistors $\beta_R = 0.1$. Assume $V_{OH} = 3.4\ V$ and $V_{OL} = 0.1V$ and for saturation mode, $V_{BE} = 0.8V$, $V_{CE} = 0.1V$.

(a)	Assume no Loads are connected to the driver device. If at least one input is low (0.1*V*), find i_1, i_{B2}, i_2, i_{B_o} **and** i_3 ***in mA.***
(b)	Repeat the calculation of (a) if both the inputs are high ($v_X = v_Y = 5\ V$)
(c)	Find the maximum possible fanout of this TTL circuit.
(d)	Assume all inputs of the **Driver** circuit are high. (i) Find the maximum fanout if the "other" input of the **load, V_Y = 5V (High)**. (ii) If **both inputs** of the **Load** circuits = **0.1 V**, then what would be the maximum fanout? Compare and comment on the above two cases to identify which case has better fanout and why?
(d)	Find the power dissipation for all cases [Assume 4 loads are connected to driver's output]



Solution:

(a)	Assume no Loads are connected to the driver device. If at least one input is low (0.1*V*), find i_1, i_{B2}, i_2, i_{B_o} **and** i_3 ***in mA.***

Here, Vx = 0.1V and Vy = 5V

So, Q1 in Saturation, Q2 cutoff, Qo Cutoff.

Now, Q1 is in Saturation and emitter of Q1, Vx = 0.1V

$\therefore V_{B1} = 0.1 + 0.8 = 0.9V$

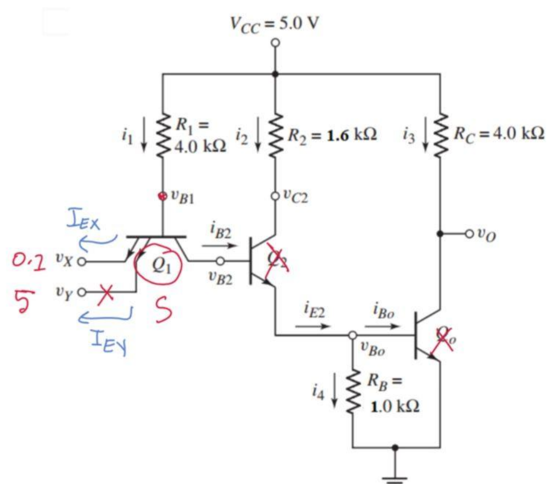
$I_{B1} = I_1 = \frac{5-0.9}{4K\Omega} = 1.025\ mA$

Emitter current of Q1,

$I_{EY} = 0$

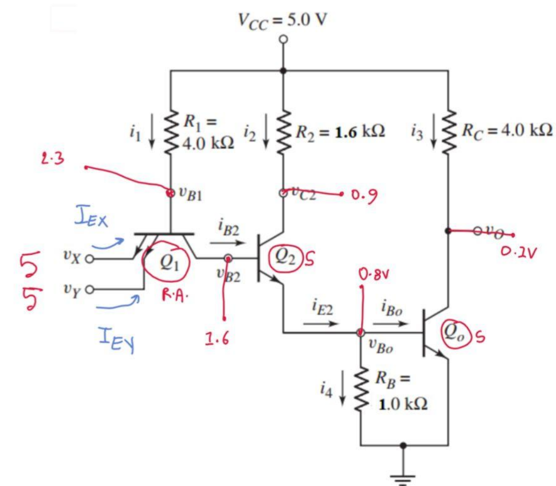
$I_{EX} = I_{B1} = 1.025\ mA$

As Q2 and Qo are cutoff, $I_{B2} = I_2 = I_{BO} = I_3 = 0mA$.



(b)	Repeat the calculation of (a) if both the inputs are high ($v_X = v_Y = 5\ V$)

Here, Vx = 5V and Vy = 5V
So, Q1 in Reverse active, Q2 and Qo in Saturation.
Begin calculation from the rightmost BJT Qo.
Now, Qo is in Saturation and emitter of Qo, V_{E0} = 0V
∴ $V_{BO} = 0 + 0.8 = 0.8V$
and, $V_{CO} = 0 + 0.1 = 0.1V = V_O$
Similarly, Q2 is in saturation.
∴ $V_{B2} = 0.8 + 0.8 = 1.6V$
and, $V_{C2} = 0.8 + 0.1 = 0.9V$



Now, Q1 is in R.A. mode and collector voltage of Q1,
$V_{C1} = V_{B2} = 1.6V$
∴$V_{B1} = 1.6 + 0.7 = 2.3V$

∴$I_{B1} = I_1 = \frac{5-2.3}{4K\Omega} = 0.675$ mA
Emitter current of Q1,
$I_{EY} = I_{EX} = \beta R * I_{B1} = (0.1)(0.675) = 0.0675$ mA
∴ $I_{B2} = I_{C1} = I_{B1} + I_{EX} + I_{EY} = 0.81$ mA
$I_{C2} = I_2 = \frac{5-0.9}{1.6K\Omega} = 2.5625$ mA
∴$I_{E2} = I_{B2} + I_{C2} = I_{B2} + I_2 = 3.3725$ mA

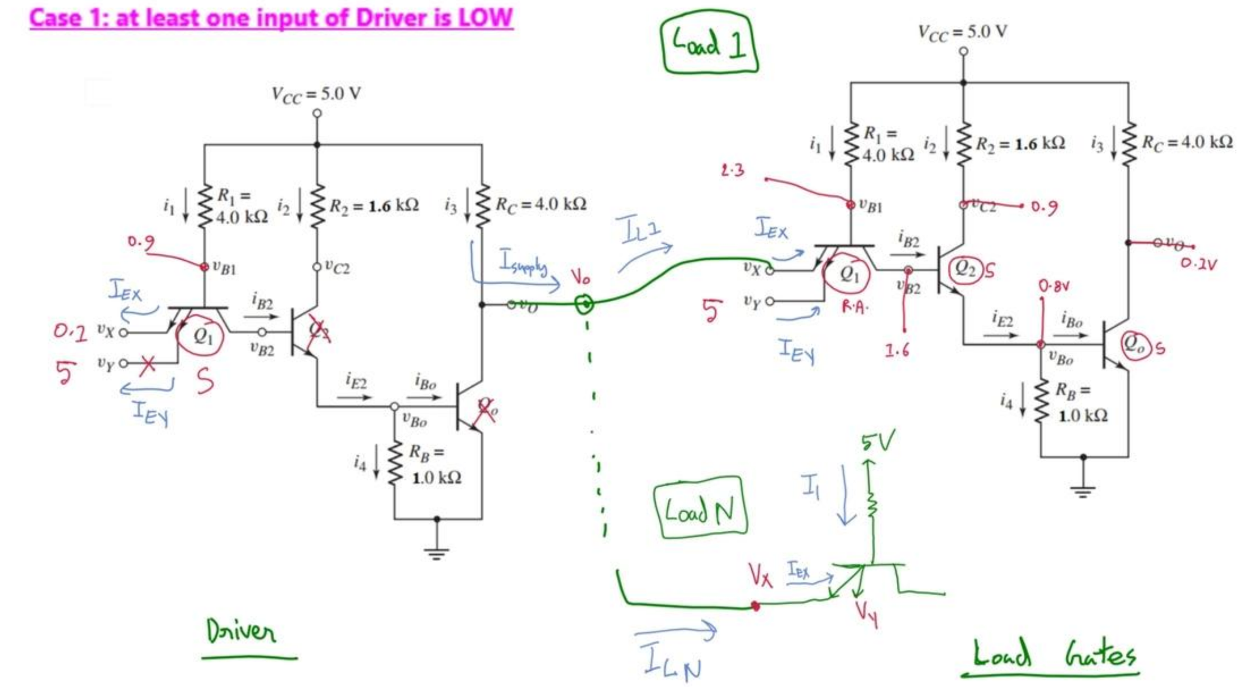
$I_4 = \frac{0.8-0}{1K\Omega} = 0.8$ mA

∴$I_{B0} = I_{E2} - I_4 = 2.5725$ mA

$I_{CO} = I_3 = \frac{5-0.1}{4K\Omega} = 1.225$ mA

(c)	Find the maximum possible fanout of this TTL circuit.

Case 1: at least one input of Driver is LOW



Driver:

This calculation is similar to ques (a)

Here, Vx = 0.1V and Vy = 5V
So, Q1 in Saturation, Q2 cutoff, Qo Cutoff.
$\therefore V_{B1} = 0.1 + 0.8 = 0.9V$
$I_{B1} = I_1 = \frac{5-0.9}{4K\Omega} = 1.025$ mA
As Qo is cutoff, I_3 flows completely to Load gates. This is the supply current, I_{Supply}.

The output voltage of Driver, Vo will be a High value. For Maximum possible fanout calculation, it will be equal to V_{OH}.

$\therefore I_{Supply} = I_3 = \frac{5-Vo}{4K\Omega} = \frac{5-V\_OH}{4K\Omega} = \frac{5-3.4}{4K\Omega} = 0.4$ mA

Load:

This calculation is similar to ques (b)
Here, Vx = Vo of Driver = High and Vy = 5V (assume)
If we assumed Vy = 0.1V, there would be no current flow between Load-Driver.
So, Q1 in Reverse active, Q2 and Qo in Saturation.
$\therefore V_{BO} = 0 + 0.8 = 0.8V$
and, $V_{CO} = 0 + 0.1 = 0.1V = V_O$
Similarly, Q2 is in saturation.
$\therefore V_{B2} = 0.8 + 0.8 = 1.6V$
and, $V_{C2} = 0.8 + 0.1 = 0.9V$

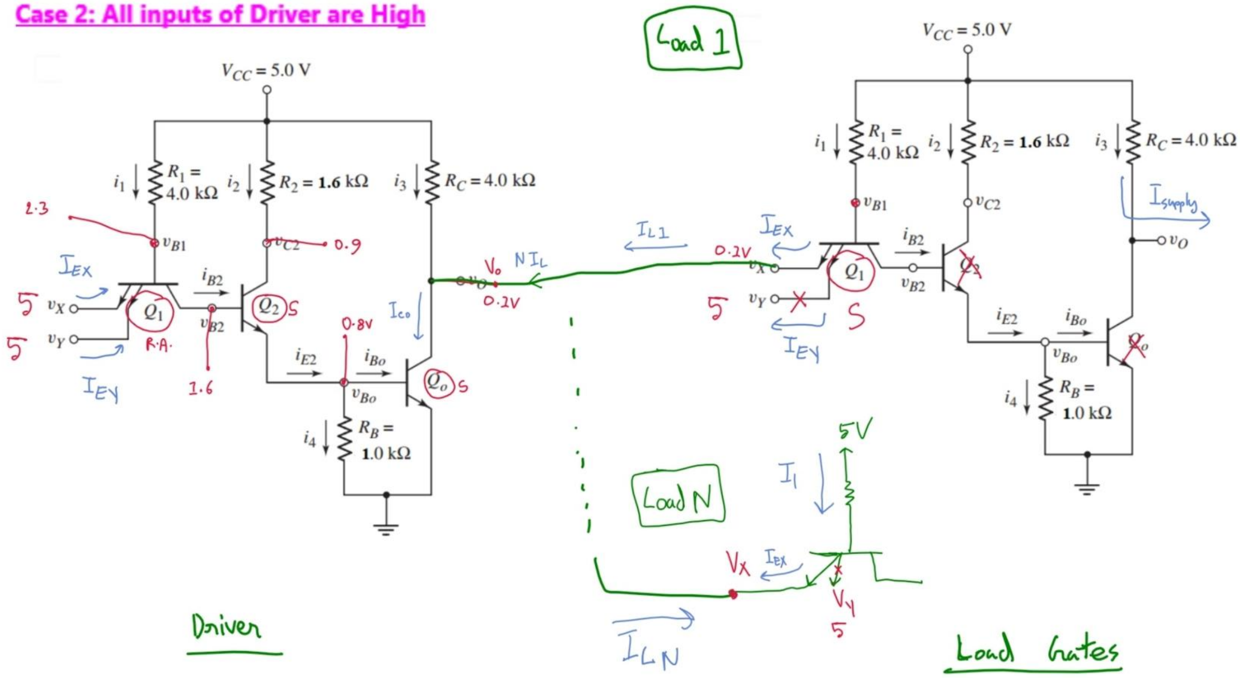
Now, Q1 is in R.A. mode,
$\therefore V_{B1} = 1.6 + 0.7 = 2.3V$
$\therefore I_{B1} = I_1 = \frac{5-2.3}{4K\Omega} = 0.675$ mA

Emitter current of Q1,
$I_{EY} = I_{EX} = \beta_R * I_{B1} = (0.1)(0.675) = 0.0675$ mA

$\therefore$ Individual Load current, $I_L = I_{EX} = 0.0675$ mA
$\therefore$ Total Demand current = $I_{Demand} = N*I_L$

Now,
$I_{Supply} = I_{Demand}$
or, $\frac{5-Vo}{4K\Omega} = N*I_L$
or, $0.4 = N*(0.0675)$
Solving, N = 5.92 ..... Floor (N) = 5

Case 2: All inputs of Driver are High



Driver:

This calculation is similar to the Load calculation of previous case.

Q1 in Reverse active, Q2 and Qo in Saturation.

∴ $V_{CO} = 0 + 0.1 = 0.1V = V_O$

$I_3 = \frac{5-Vo}{4K\Omega} = \frac{5-0.1}{4K\Omega} = 1.225$ mA

$I_{BO} = I_{E2} - I_4 = 2.5725$ mA

Here, $I_{CO} = I_3 + N*I_L$

Load:

This calculation is like the Driver calculation of previous case.

Here, Vx = Vo of Driver = 0.1V and Vy = 5V [assume]

We assumed Vy=5 to ensure all Load current come to Driver so that, we can find worst case fanout.

So, Q1 in Saturation, Q2 cutoff, Qo Cutoff.

∴ $V_{B1} = 0.1 + 0.8 = 0.9V$

$I_{B1} = I_1 = \frac{5-0.9}{4K\Omega} = 1.025$ mA

∴ Individual Load current, $I_L = I_{EX} = I_1 = 1.025$ mA

∴ Total Load current = $N*I_L = N*(1.025)$ mA

Now,

For Qo of Driver to remain in Saturation,

$\frac{Ico}{Ibo} < \beta_F$

or, $\frac{I3+N*I\_L}{Ibo} < 25$

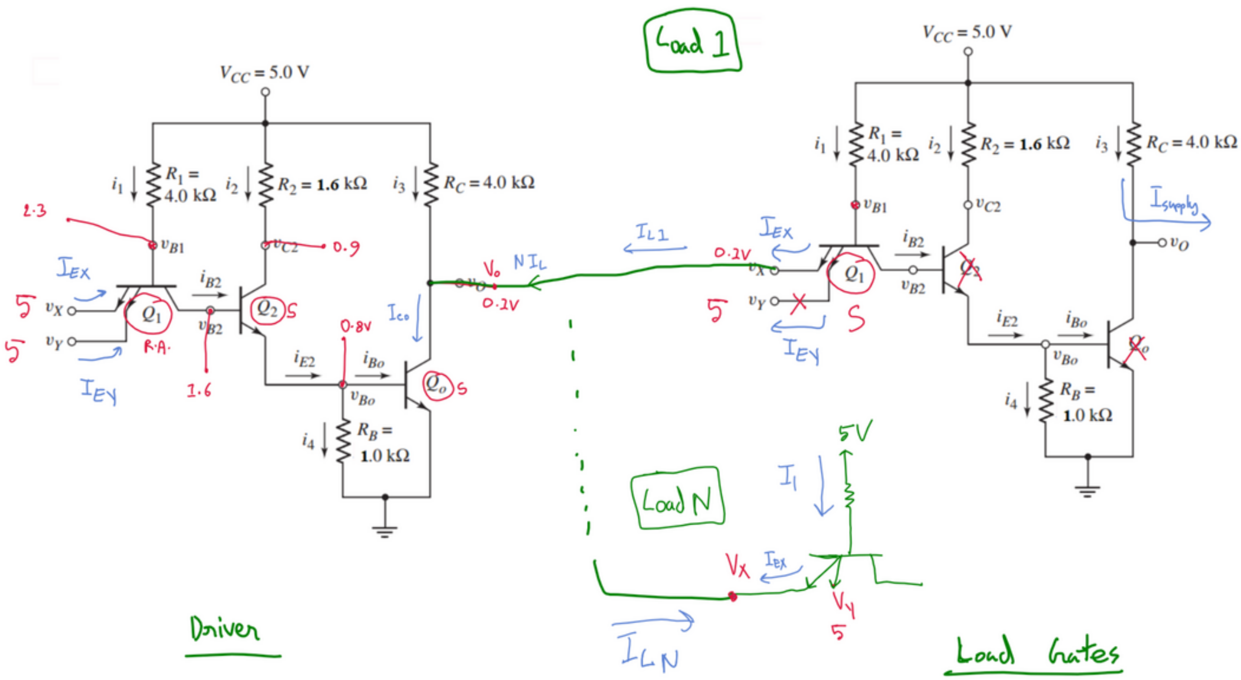
or, $\frac{1.225+N*1.025}{2.5725} < 25$

Solving, N = 61.55 ..... Floor (N) = 61

∴ Maximum Possible Fanout = min (61,5) = 5

(d)	Assume all inputs of the **Driver** circuit are high. (i) Find the maximum fanout if the "other" input of the **load, V_Y = 5V (High)**. (ii) If **both inputs** of the **Load** circuits = **0.1 V**, then what would be the maximum fanout? Compare and comment on the above two cases to identify which case has better fanout and why?

Case (i) : "other" input of the load, VY = 5V (High)



D case (i):

This will be exactly same as case 2 of the fanout calculation in ques. (b) when both inputs of Driver were High.

Driver:

Q1 in Reverse active, Q2 and Qo in Saturation.

$\therefore V_{CO} = 0 + 0.1 = 0.1V = V_O$

$I_3 = \frac{5-V_O}{4K\Omega} = \frac{5-0.1}{4K\Omega} = 1.225$ mA

$I_{BO} = I_{E2} - I_4 = 2.5725$ mA

Here, $I_{CO} = I_3 + N*I_L$

Load:

Here, Vx = Vo of Driver = 0.1V and Vy = 5V [given]

So, Q1 in Saturation, Q2 cutoff, Qo Cutoff.

As Vy=5V, all Load current (I_1) will come to Driver

$I_{B1} = I_1 = \frac{5-0.9}{4K\Omega} = 1.025$ mA

$\therefore$ Individual Load current, $I_L = I_{EX} = I_1 = 1.025$ mA

$\therefore$ Total Load current = $N*I_L$ = N*(1.025) mA

Now,

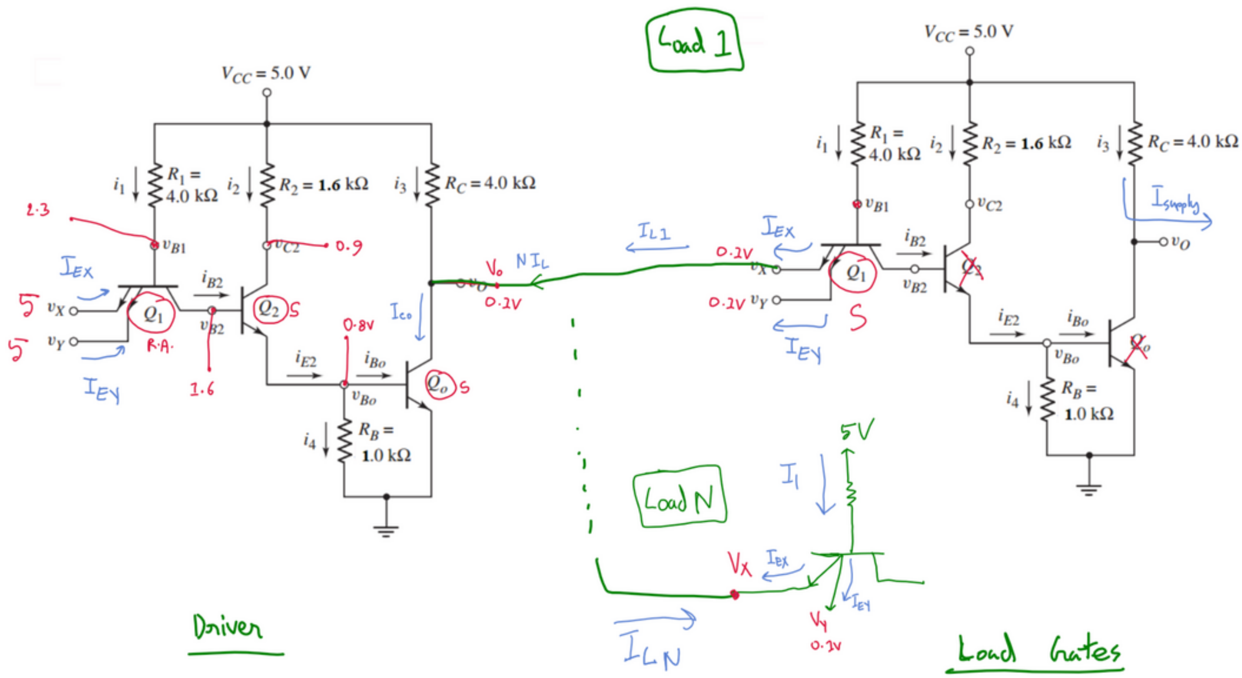
For Qo of Driver to remain in Saturation,

$\frac{Ico}{Ibo} < \beta_F$

or, $\frac{I3+N*I\_L}{Ibo} < 25$

Solving, N = 61.55 ….. Floor (N) = 61

Case (ii) : "other" input of the load, VY = 0.1V (LOW)



D case (ii): This will be slightly different from Maximum fanout calculation in ques. (b) when both inputs of Driver were High. The Load current will be halved.

Driver:

Q1 in Reverse active, Q2 and Qo in Saturation.

$\therefore V_{CO} = 0 + 0.1 = 0.1V = V_O$

$I_3 = \frac{5-Vo}{4K\Omega} = \frac{5-0.1}{4K\Omega} = 1.225$ mA

$I_{B0} = I_{E2} - I_4 = 2.5725$ mA

Here, $I_{C0} = I_3 + N{*}I_L$

Load:

Here, Vx = Vo of Driver = 0.1V and Vy = 5V [given]

So, Q1 in Saturation, Q2 cutoff, Qo Cutoff.

$I_{B1} = I_1 = \frac{5-0.9}{4K\Omega} = 1.025$ mA

As Vy=0.1V, half of current I_1 will flow through Vy.

This half will NOT come to Driver.

$\therefore$ Individual Load current, $I_L = I_{EX} = I_1/2 = 0.5125$ mA

$\therefore$ Total Load current = $N{*}I_L$ = N*(0.5125) mA

Now,

For Qo of Driver to remain in Saturation,

$\frac{Ico}{Ibo} < \beta_F$

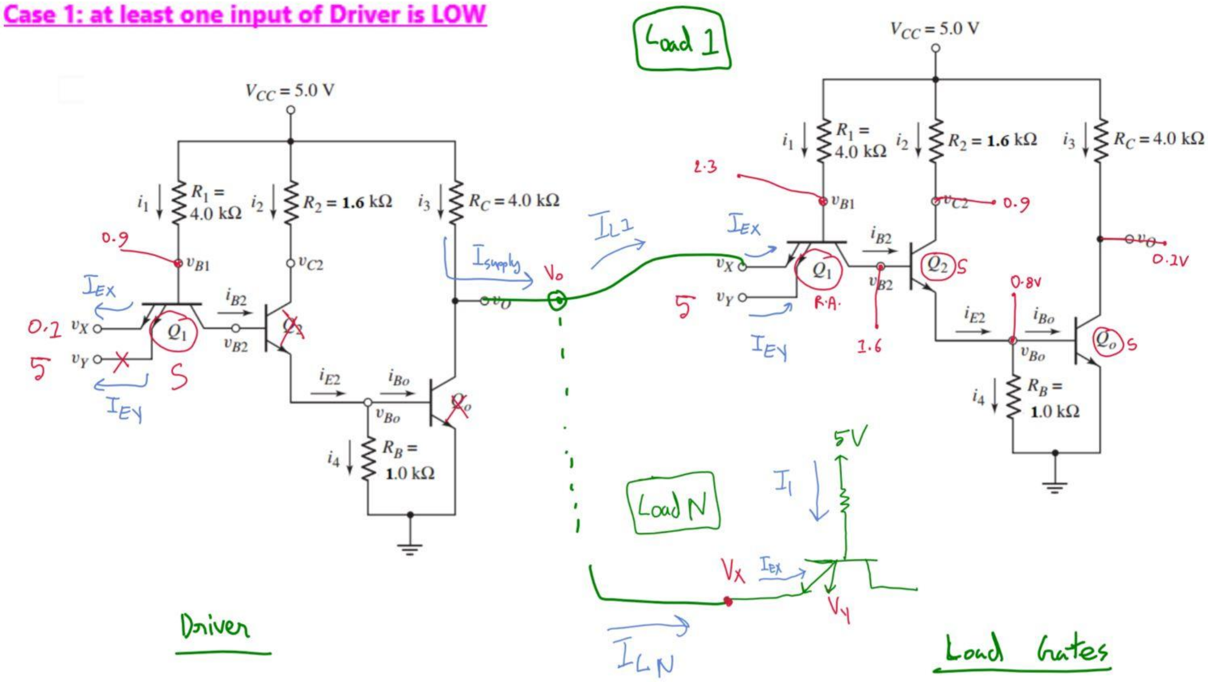
or, $\frac{I3+N*I\_L}{Ibo} < 25$

or, $\frac{1.225+N*0.5125}{2.5725} < 25$

Solving, N = 123.097 ..... Floor (N) = 123

(e)	Find the power dissipation in Driver for all cases [Assume 4 loads are connected to driver's output]

Case 1: at least one input of Driver is LOW



E case (i):

This will be similar to calculations in (a) and (c) case 1

Driver:

Here, Vx = 0.1V and Vy = 5V
So, Q1 in Saturation, Q2 cutoff, Qo Cutoff.
$I_{B1} = I_1 = \frac{5-0.9}{4K\Omega} = 1.025$ mA
$I_{EX} = I_{B1} = 1.025$ mA
As Q2 and Qo are cutoff, $I_{B2} = I_2 = I_{B0} = 0$mA.

I_3 = Total Load current = 4* I_L = 0.27 mA

Now,
$I_3 = \frac{5-Vo}{4K\Omega}$ = 0.27 ma ---→ solving, Vo = 3.92V (Driver)

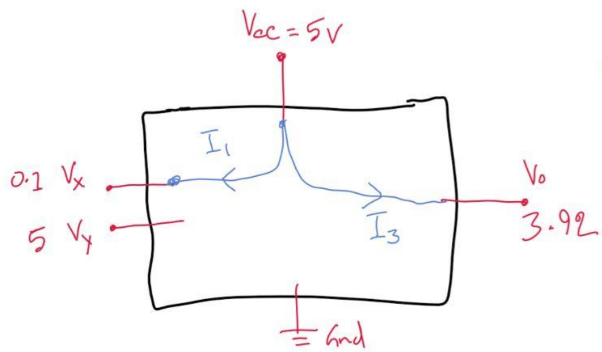
Load:

Here, Vx = Vo of Driver = High and Vy = 5V (assume)
So, Q1 in Reverse active, Q2 and Qo in Saturation.

$\therefore V_{B1} = 2.3$V
$\therefore I_{B1} = I_1 = \frac{5-2.3}{4K\Omega} = 0.675$ mA
$I_{EY} = I_{EX} = \beta_R * I_{B1} = (0.1)(0.675) = 0.0675$ mA

∴ Individual Load current, $I_L = I_{EX} = 0.0675$ mA

∴ Total Load current = $4*I_L = 4*I_{EX} = 0.27$ mA

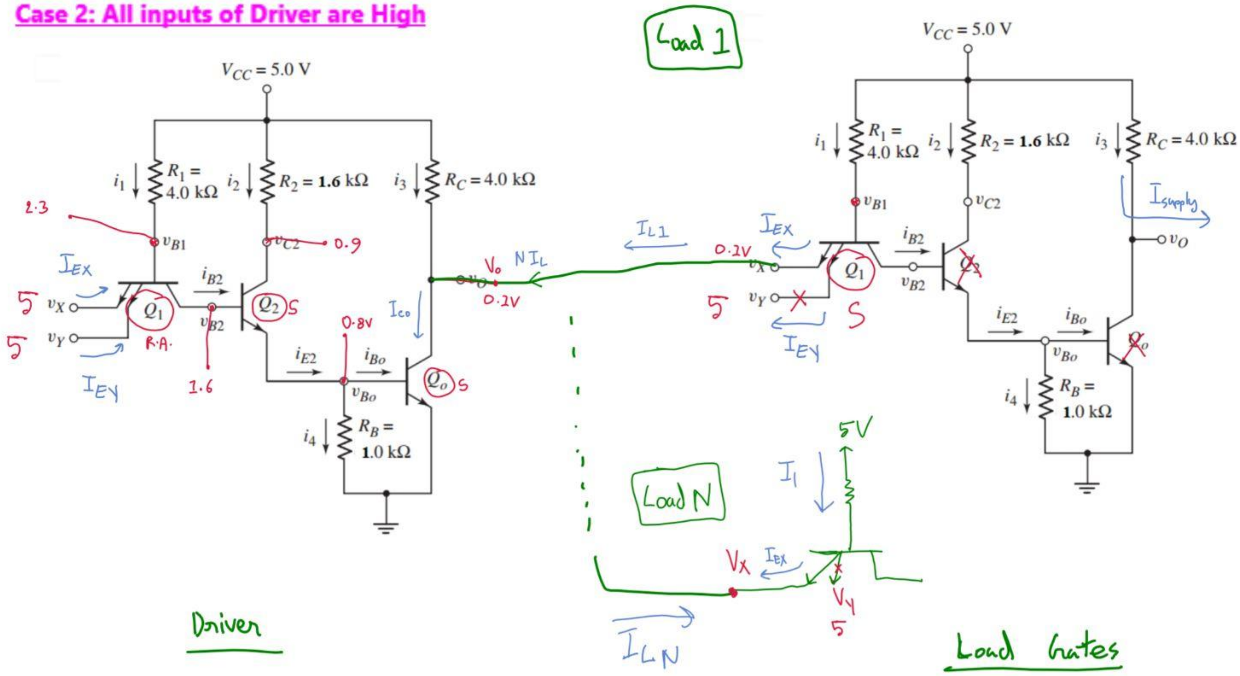


∴ Power dissipation = $(5 - V_X) I_1 + (5 - V_o) I_3$

$= (5 - 0.1) I_1 + (5 - 3.92) I_3$

$= 5.3141$ mW

Case 2: All inputs of Driver are High



E case (ii):

This will be similar to calculations in (b) and (c) case 2

Driver:

Here, Vx = 5V and Vy = 5V
So, Q1 in Reverse active, Q2 and Qo in Saturation.

$\therefore I_{B1} = I_1 = \frac{5-2.3}{4K\Omega} = 0.675$ mA

$I_{EY} = I_{EX} = \beta R * I_{B1} = (0.1)(0.675) = 0.0675$ mA

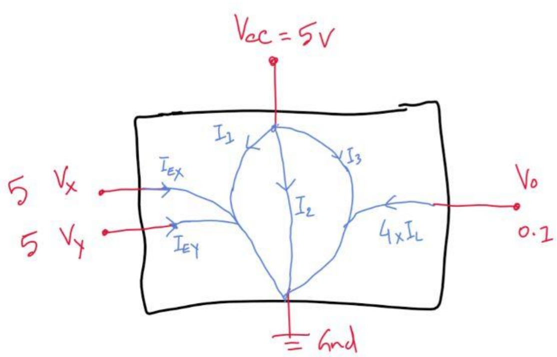
$I_{C2} = I_2 = \frac{5-0.9}{1.6K\Omega} = 2.5625$ mA

$I_3 = \frac{5-0.1}{4K\Omega} = 1.225$ mA

$I_{CO} = I_3 + 4*I_L = 1.225 + 4.1 = 5.325$ mA

Load:

Here, Vx = Vo of Driver = 0.1V and Vy = 5V
So, Q1 in Saturation, Q2 cutoff, Qo Cutoff.
$\therefore V_{B1} = 0.1 + 0.8 = 0.9$V
$I_{B1} = I_1 = \frac{5-0.9}{4K\Omega} = 1.025$ mA
$\therefore$ Individual Load current, $I_L = I_{EX} = I_1 = 1.025$ mA
$\therefore$ Total Load current = $4*I_L = 4*(1.025) = 4.1$ mA

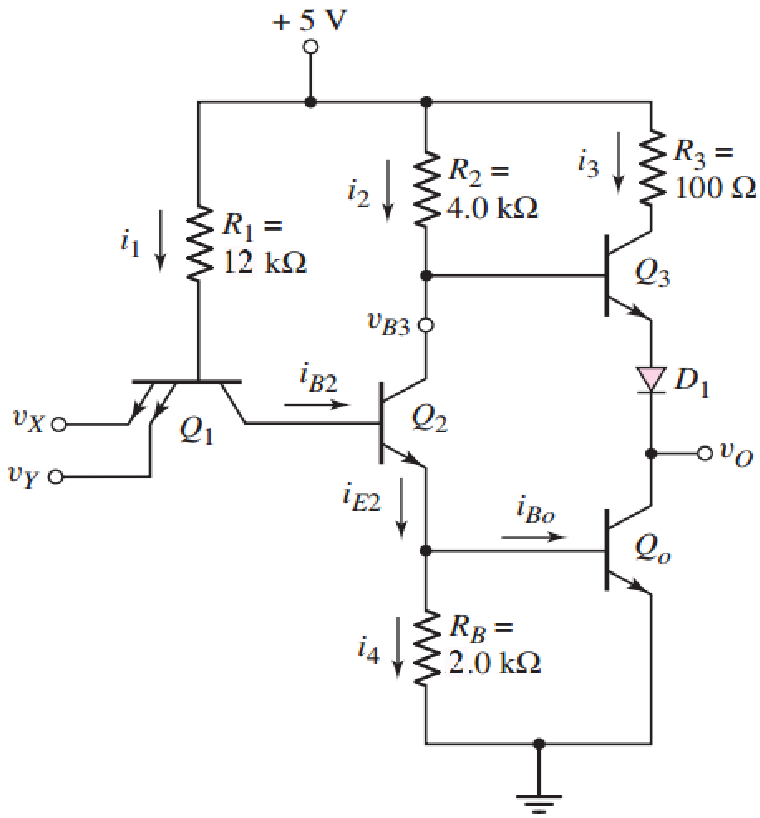


Power Dissipation

$= (I_{EX} + I_{EY} + I_1 + I_2 + I_3)(5-0) + (4 \times I_L)(0.1-0)$

$= 23.397$ mW

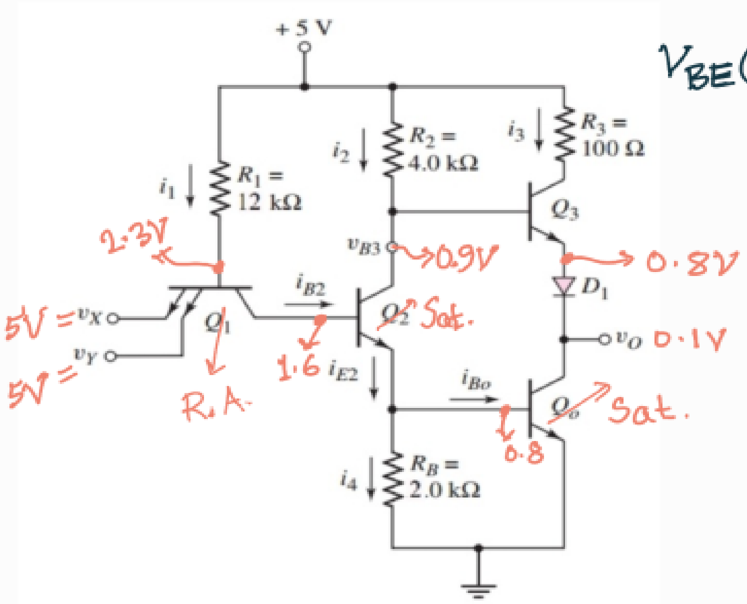
Question 2.



For the given TTL circuit with totem-pole output, assume common emitter current gain, $\beta_F = 25$ and reverse common emitter current gain of the transistors $\beta_R = 0.1$.

(a)	Find the value of $\boldsymbol{\beta_{Min}}$ for transistor Q_2 so that Q_2 can remain in saturation when both input is HIGH.
(b)	Assume inputs of the load devices are not connected to driver device. If at least one input is low (0.1*V*), find $\boldsymbol{i_1}$, $\boldsymbol{i_{B2}}$, $\boldsymbol{i_2}$, $\boldsymbol{i_{Bo}}$ **and** $\boldsymbol{i_3}$ ***in mA.***
(c)	Repeat the calculation of (b) if both the inputs are high ($v_X = v_Y = 3.6$ *V*)
(d)	Find the maximum fanout of this TTL circuit for the case mentioned in (c)
(e)	Find out the maximum power dissipation of the TTL circuit in *mW* when no load is connected.
(f)	Calculate maximum fanout for Vx = V_Y = 0.1V. Given that V_{OH} (No load) =3.5V. And, from this calculation prove that T4 is in **forward active mode**.

(a) Both input high. Q_1 in Reverse active
Q_2 in saturation



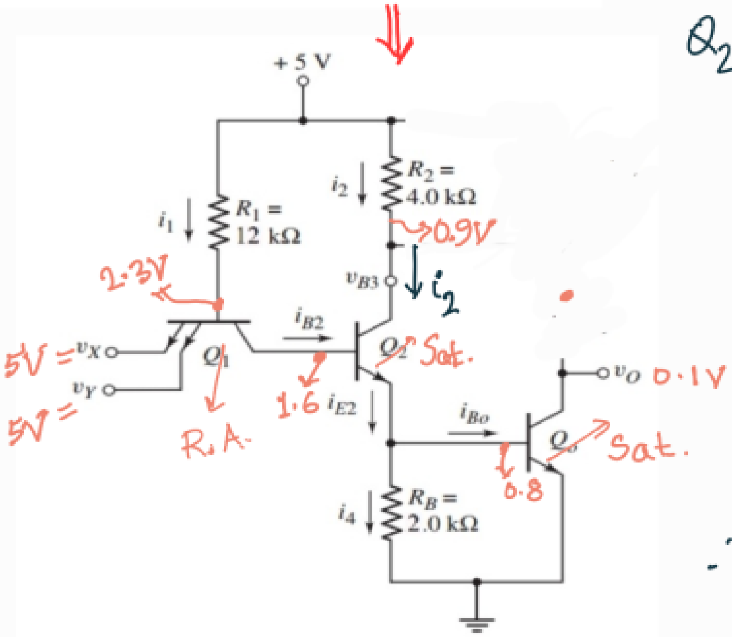
$V_{BE}(Q_3) = 0.9 - 0.8 = 0.1V$

So, Q_3 cutoff

$\boxed{Q_3, D_1 \text{ both off}}$

$i_1 = \frac{5-2.3}{12} = 0.225\,mA$

$i_{EX} = i_{EY} = \beta_R \times i_1$
$= 0.0225\,mA$



Q_2 collector current

$= i_2 = \frac{5-0.9}{4k\Omega}$

$= 1.025\,mA$

Base current

$= i_{B2} = i_1 + i_{EX} + i_{EY}$

$= 0.27\,mA$

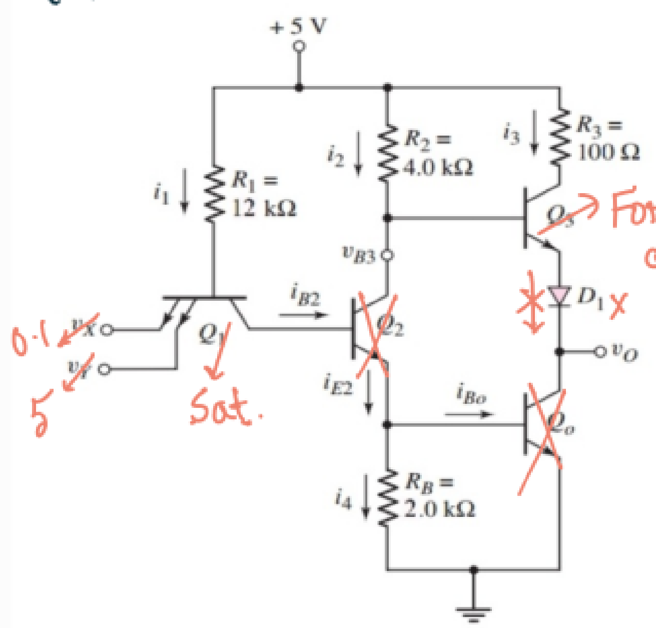
$\therefore \beta_{forced} = \frac{i_2}{i_{B2}}$

$= \boxed{3.796 = \beta_{min}}$

(b)	Assume inputs of the load devices are not connected to driver device. If at least one input is low (0.1*V*), find i_1, i_{B2}, i_2, i_{Bo} **and** i_3 *in mA.*

(b)

$V_B < V_C \rightarrow V_{BC} < 0$

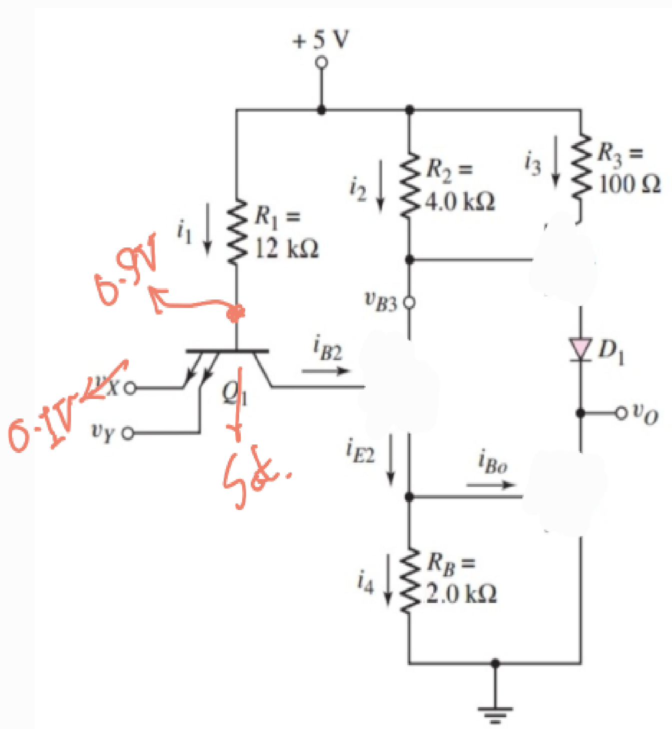


⇒ Q_3 F.A. But no current through emitter.

→ Forward active

So, Q_3 works like $\boxed{\text{cutoff.}}$ in steady state

$\therefore \boxed{i_3 = 0mA}$



$\boxed{i_2 = 0\,mA}$

$i_4 = 0\,mA$

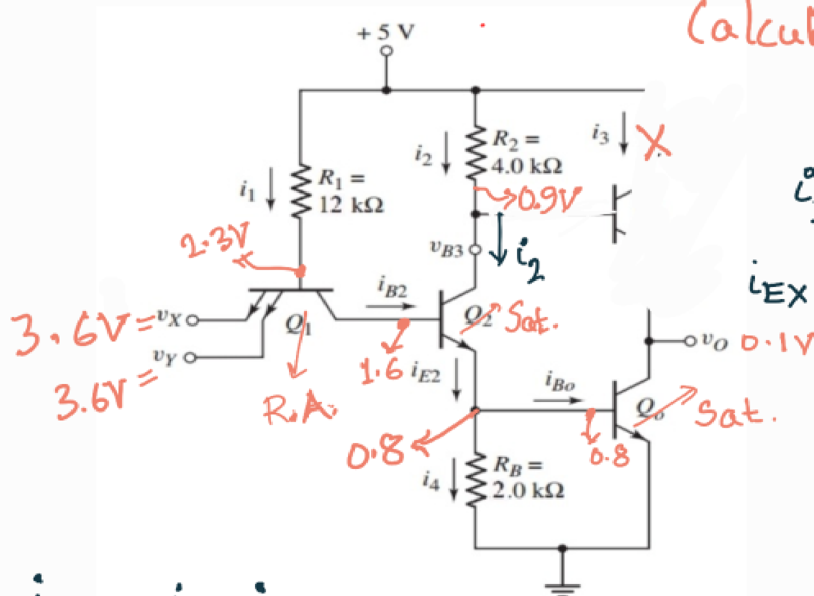
$\boxed{i_{B0} = 0\,mA}$

$\boxed{i_{B2} = 0\,mA}$

$$i_1 = \frac{5-0.9}{12K} = \boxed{0.3416mA}$$

(c)	Repeat the calculation of (b) if both the inputs are high ($v_X = v_Y = 3.6\ V$)
(d)	Find the maximum fanout of this TTL circuit for the case mentioned in (c)

(C)



Calculation same as (a).

$$i_1 = \frac{5-2.3}{12} = \boxed{0.225\,mA}$$

$$i_{EX} = i_{EY} = \beta_R \times i_1$$
$$= 0.0225\,mA$$

$$i_2 = \frac{5-0.9}{4k\Omega}$$
$$= \boxed{1.025\,mA}$$

Base current

$$= i_{B2} = i_1 + i_{EX} + i_{EY}$$
$$= \boxed{0.27\,mA}$$

$$\boxed{i_3 = 0\,mA}$$

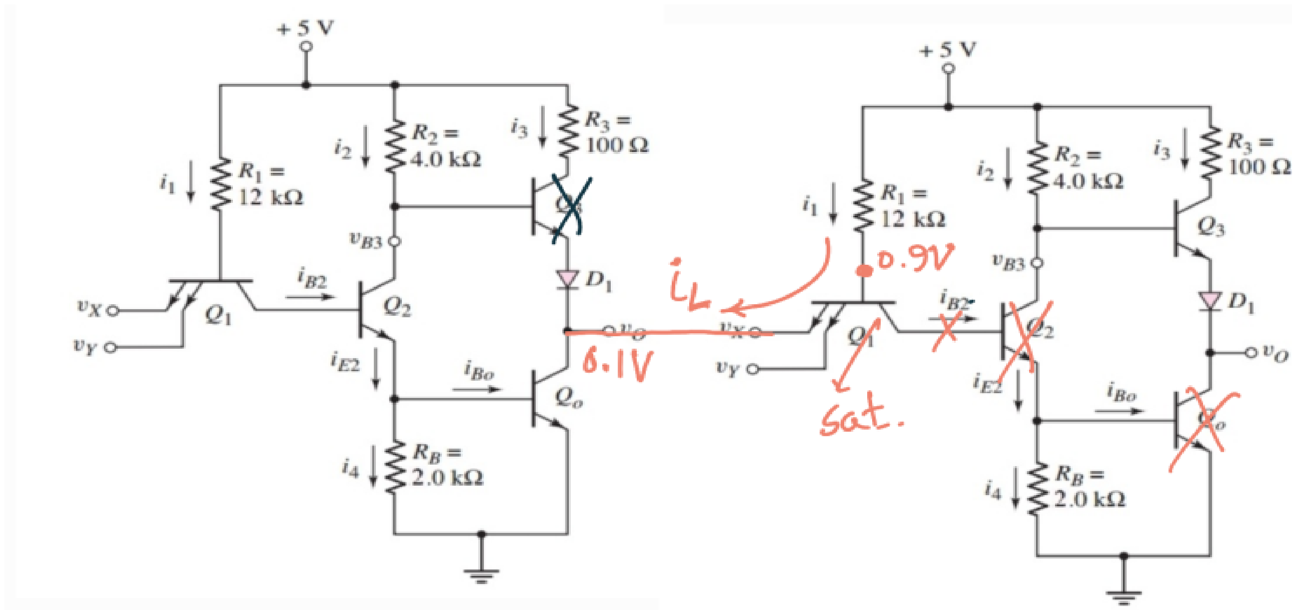
$$i_{E2} = i_2 + i_{B2}$$
$$= 1.295\,mA$$

$$i_{Bo} = i_{E2} - i_4 = i_{E2} - \frac{0.8}{2K}$$
$$= \boxed{0.895\,mA}$$

(d) Fanout calculation

$$Q_0 \Rightarrow i_{C,max} = \beta_F \times i_{B0} = 25 \times 0.895$$

$$= 22.375\,mA$$



Individual standard load current,

$$i_L = i_1 = \frac{5-0.9}{12K} = 0.3416 mA$$

for load

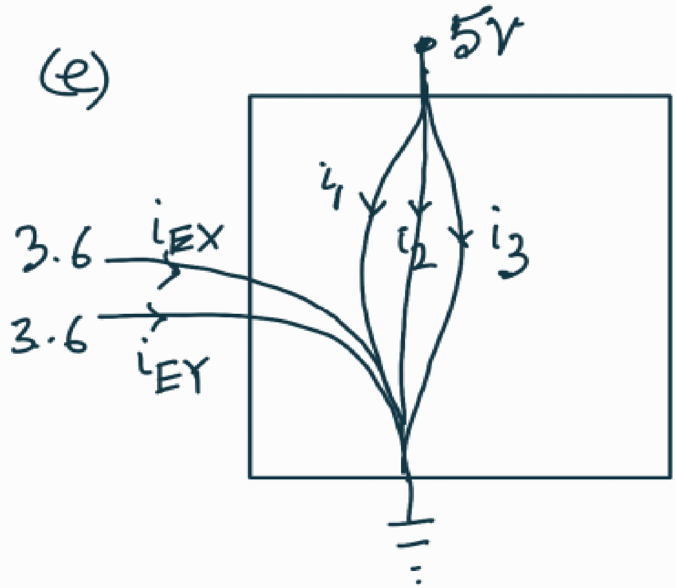
$$i_C(max) = \overset{0 mA}{\cancel{i_{c, no\ load}}} + N \times i_L = 22.375$$

$$\Rightarrow N = \lfloor 65.48 \rfloor$$

$$\boxed{N = 65}$$

(e)	Find out the maximum power dissipation of the TTL circuit in mW when no load is connected.

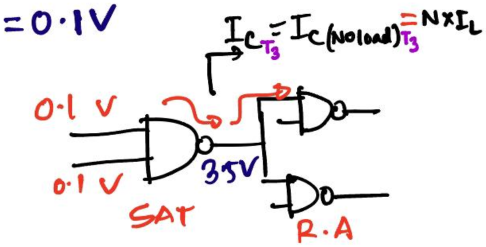
(e)



$$P = (3.6-0)\times(i_{EX}+i_{EY}) + (5-0)\times(i_1+i_2+i_3) = \boxed{6.412\,mW}$$

(f)	Calculate maximum fanout for Vx = V_Y = 0.1V. Given that V_{OH} (No load) =3.5V. And, from this calculation prove that T4 is in **forward active mode**.

f) Calculate Maximum fanout for $V_x = V_y = 0.1V$



V_{OH} (No load) $= 3.5V$

$V_0 = V_{OH} = V_{D(cathode)} = 3.5V$

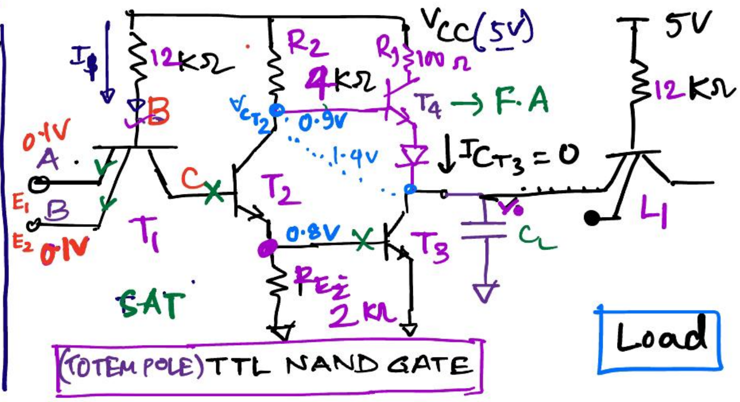
$V_{D(ANODE)} = V_{D(cathode)} + 0.7V$

$\rightarrow V_{D(ANODE)} = 3.5V + 0.7V = 4.2V$

$V_{C_{T_2}} = V_{D(ANODE)} + 0.7V \; [V_{BE_{T_2}}]$

$\rightarrow \boxed{V_{C_{T_2}} = 4.9V}$

$I_{R_2} = \dfrac{(5-4.9)V}{4\,K\Omega} = 0.025mA$
$= I_{B_{T4}}$



$I_{C_{T4}} = \beta_F \cdot I_{B4} = 25 \times 0.025mA$
$= 0.625mA$

$I_{E_{T_4}} = (\beta+1) I_{B4} = 0.65mA$. [Driver's current]

$I_{LT_1}(I_{E1}) = \beta_R I_{B_{T_1}} = \dfrac{(5-2.3)V}{12K} \times 0.1 = 0.0225mA.$

$I_{DRIVER} \geq N \times I_{LOAD}$

$\Rightarrow N \leq \dfrac{I_{E_{T4}}}{I_{LT_1}(load)} \Rightarrow N \leq \dfrac{0.65mA}{0.0225mA} \Rightarrow N \leq [28.88]$ $\boxed{N = 28}$

$\boxed{\text{** From above calculation, prove } T_4 \text{ is in Forward Active.}}$

[Approach 1]

$I_{C_{T4}} = \dfrac{V_{CC} - V_{C_{T4}}}{100\,\Omega}$

$\Rightarrow V_{C_{T4}} = 5 - 0.0625 = 4.94V$

$V_{E_{T4}} = V_{D(ANODE)} = 4.2V$

$V_{CE_{T4}} = (4.94 - 4.2)V$

$V_{CE_{T4}} = 0.74V > 0.1 \; (V_{CE(sat)})$

[Forward active proved]

[Approach 2]

$I_{C_{T4}} = \dfrac{V_{CC} - V_{C_{T4}}}{100\,\Omega}$

$V_{C_{T4}} = 5 - 0.0625 = 4.94V$

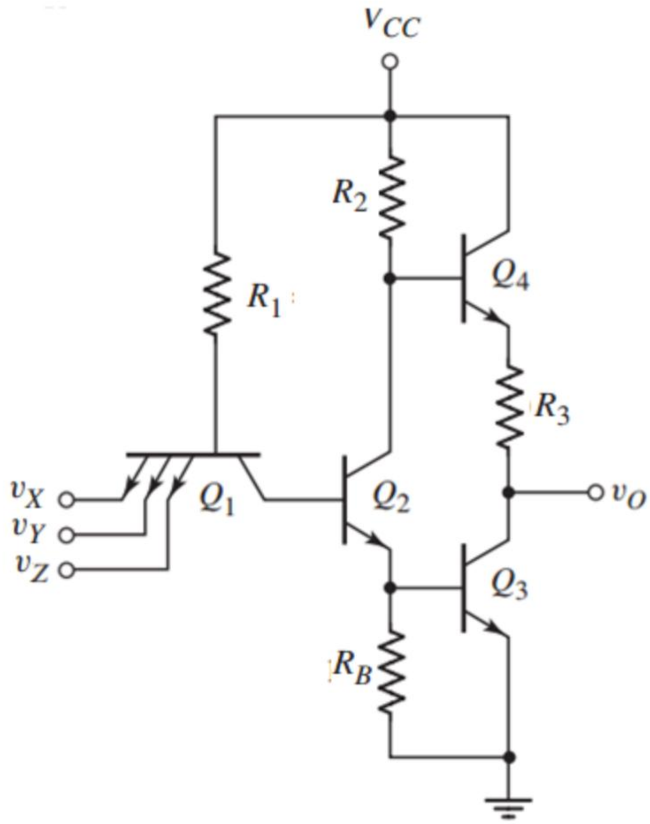
$V_{B_{T4}} = V_{C_{T2}} = 4.9V$

$\Rightarrow V_{BC_{T4}} = (4.9 - 4.94)V = -0.04V$ (-ve)

$V_{BE_{T4}} = (4.9 - 4.2)V = 0.7V$ (+ve)

[Forward active proved]

Question 3.



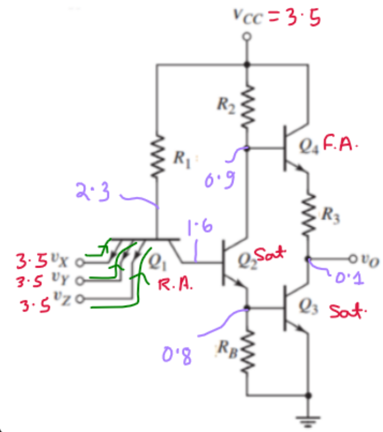
For the given TTL circuit, given $R_1 = 3.0\ k\Omega$, $R_2 = 1.3\ k\Omega$, $R_3 = 0.55\ k\Omega$ and $R_B = 8\ k\Omega$. assume, $V_{CC} = 3.5$ V, common emitter current gain, $\beta_F = 15$ and reverse common emitter current gain of the transistors $\beta_R = 0.8$.

(a)	If all inputs are High ($v_X = v_Y = v_Z = 3.5\ V$), find i_{B1}, i_{B2}, i_{B3}, i_{B4} **and** i_{E3} ***in mA.***
(b)	Assume inputs of the load devices are not connected to the driver device. If at least one input is low ($0.1V$), find i_{B1}, i_{EX}, i_{B2} and v_o ***in mA.***
(c)	Find out the power dissipation of the TTL circuit in mW for both (a) and (b).
(d)	Find the maximum fanout of this TTL circuit for the case described in (a).
(e)	If at least one input is low ($0.1V$) and **2 loads** are connected to the output, find the new value for v_o.

(a)

For the given TTL circuit, given $R_1 = 3.0\ k\Omega$, $R_2 = 1.3\ k\Omega$, $R_3 = 0.55\ k\Omega$ and $R_B = 8\ k\Omega$. assume, $V_{CC} = 3.5$ V, common emitter current gain, $\beta_F = 15$ and reverse common emitter current gain of the transistors $\beta_R = 0.8$.

(a)	If all inputs are High ($v_X = v_Y = v_Z = 3.5$ V)), find i_{B1}, i_{B2}, i_{B3}, i_{B4} and i_{E3} *in mA.*



(a) $V_X = V_Y = V_Z = 3.5$ V | So, Q_1 will be in 'Reverse-Active'
Q_2, Q_3 will be in 'Saturation'

But, what's the mode of Q_4?

$V_{B4} = 0.9$V, $V_{C4} = 3.5$V $\Rightarrow (V_{BC})_{Q4} < 0$

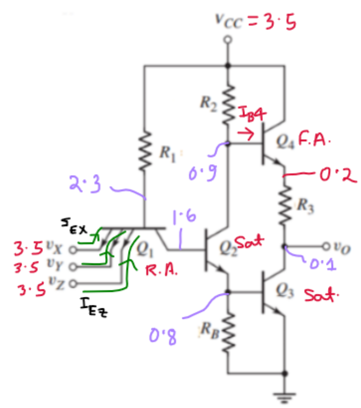
As, V_{BC} for Q_4 is negative, Q_4 will be in forward-active, if V_{BE} is positive.

There is enough voltage to turn-on B-E junction of Q_4 (0.9 at base; output node connected through a resistor having 0.1 V. So, roughly 0.8 V available to turn-on B-E junction)

Now, $I_{B1} = \dfrac{V_{CC} - 2.3}{R_1}$

$\therefore I_{B1} = \dfrac{3.5 - 2.3}{3} = 0.4$ mA ; $I_{EX} = I_{EY} = I_{EZ} = \beta_R I_{B1} = 0.8 \times 0.4$
$= 0.32$ mA.

$\therefore I_{C1} = I_{B2} = I_{B1} + I_{EX} + I_{EY} + I_{EZ}$
$= (1 + 3\beta_R) I_{B1} = 1.36$ mA



Now, $I_{R3} = \dfrac{0.2 - 0.1}{R_3} = \dfrac{0.1}{0.55} = 0.182$ mA $= I_{E4} = I_{C3}$

As Q_4 is in F.A. ; $I_{B4} = \dfrac{I_{E4}}{\beta_F + 1} = \dfrac{0.182}{16} = 0.0114$ mA.

So, $I_{C2} = I_{R2} - I_{B4} = \dfrac{V_{CC} - 0.9}{R_2} - 0.0114 = \dfrac{3.5 - 0.9}{1.3} - 0.0114$
$= 1.989$ mA.

Then,
$I_{E2} = I_{C2} + I_{B2} = 1.989 + 1.36$ mA
$= 3.349$ mA.

and, $I_{B3} = I_{E2} - I_{RB}$

$$= 3.349 - \frac{0.8-0}{R_B} = 3.349 - \frac{0.8}{8} = 3.249 \text{ mA}.$$

and, $I_{E3} = I_{B3} + I_{C3} = 3.249 + 0.182 \text{ mA} = 3.431 \text{ mA}.$

(b)

(b)	Assume inputs of the load devices are not connected to the driver device. If at least one input is low (0.1V), find i_{B1}, i_{EX}, i_{B2} and v_o *in mA.*

Suppose, $V_x = V_y = 0.1\text{ V}$, $V_z = 3.5\text{ V}$.

so, Q_1 will be in 'saturation'. Q_2, Q_3 will be in 'cut-off'.

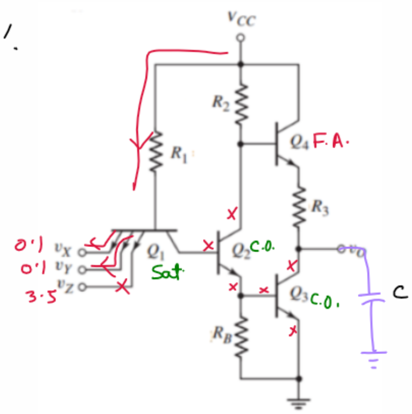
What is the operating mode of Q_4?

For the output voltage V_o to become HIGH, initially a current flows through Q_4 and C.

As Q_4 is ON and $V_{C4} = 3.5\text{V} < V_{B4}$

Q_4 will be in Forward-Active.

(so, for this circuit, Q_4 remains in F.A. in both the cases.)



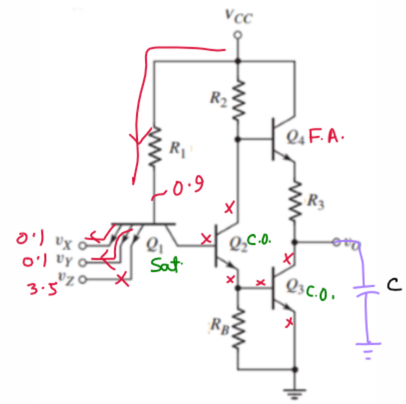
(ERROR: V_C4 = 3.5 V is actually greater than V_B4;

So V_C4 = 3.5 V > V_B4)

As Q_1 in Saturation, $V_{B1} = V_{EX} + 0.8 = 0.1 + 0.8 = 0.9\,V$

$\therefore I_{B1} = \frac{V_{cc} - 0.9}{R_1} = \frac{3.5 - 0.9}{3} = 0.867\,mA.$

and $I_{EX} = I_{EY} = \frac{I_{B1}}{2} = \frac{0.867}{2} = 0.433\,mA.$



As, Q_2, Q_3 in cut-off, all of their currents are 'zero'.

Now, when steady-state approaches (when capacitor is almost fully charged),

$I_{E4} \to 0$ (I_{E4} approaches 0)

As a result, $I_{B4} \to 0$

so, $V_{E4} \to V_o$ and, $V_{B4} \to V_{cc}$

But, $(V_{BE})_{Q4} = 0.7$ (As, Q_4 in F.A.)

so, $V_{B4} - V_{E4} = 0.7$

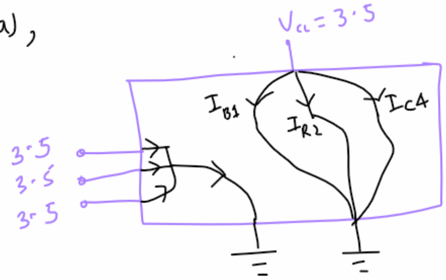
$\Rightarrow V_{E4} = V_{B4} - 0.7$

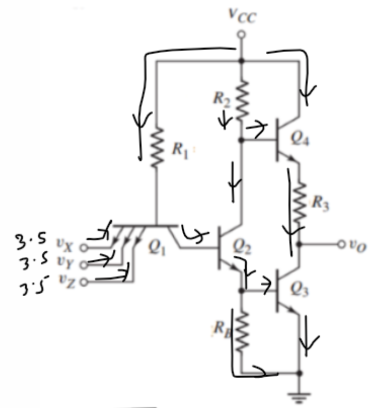
$$\boxed{\begin{aligned} \text{so, } V_{E4} = V_o &= V_{cc} - 0.7 \\ &= 3.5 - 0.7 \\ &= 2.8\,V \\ &\text{(In steady-state).} \end{aligned}}$$

(c)

(c)	Find out the power dissipation of the TTL circuit in mW for both (a) and (b).

for (a),

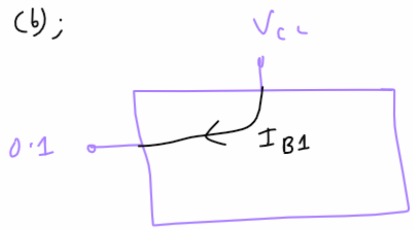




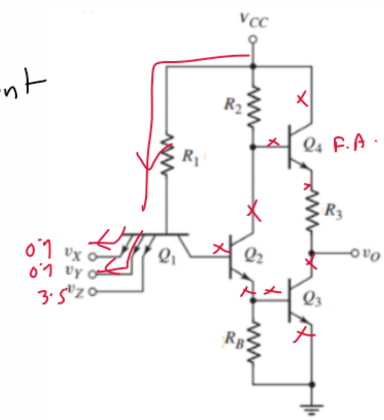
$$\therefore P = (3.5 - 0) \times (I_{EX} + I_{EY} + I_{EZ}) + (3.5 - 0) \times (I_{B1} + I_{R2} + I_{C4})$$

$$= 3.5 \times (3 \times 0.32) + 3.5 \times (0.4 + 2 + 15 \times 0.0114) = \boxed{12.36\ mW}$$

for (b);



(no other current flows in the steady-state)



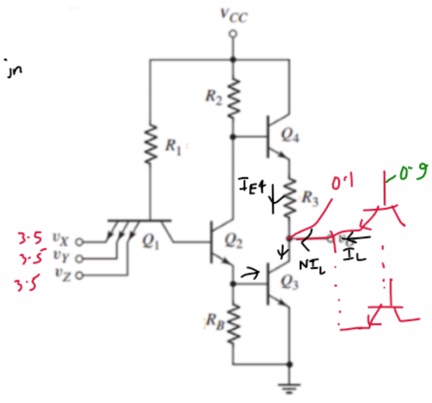
$$\therefore P = (3.5 - 0.1) \times I_{B1} = 3.4 \times 0.867\ mW = \boxed{2.9478\ mW}$$

(d)

(d)	Find the maximum fanout of this TTL circuit for the case described in (a).

As, output of driver is LOW; the load current comes 'towards' the driver circuit.

So, we will use the constraint that 'Q_3' must be in saturation.



$$\frac{I_{C3}}{I_{B3}} < \beta_F$$

$$\Rightarrow \frac{I_{E4} + NI_L}{I_{B3}} < \beta_F$$

$$\Rightarrow \frac{0.182 + N \times 0.867}{3.249} < 15$$

$$\Rightarrow N < 56.001$$

$$\therefore \boxed{N = 56}$$

$$I_L = \frac{V_{cc} - 0.9}{R_1} = 0.867\text{ mA}.$$

$$\left.\begin{aligned} I_{E4} &= 0.182\text{ mA}. \\ I_{B3} &= 3.249\text{ mA} \end{aligned}\right\} \text{from (a)}$$

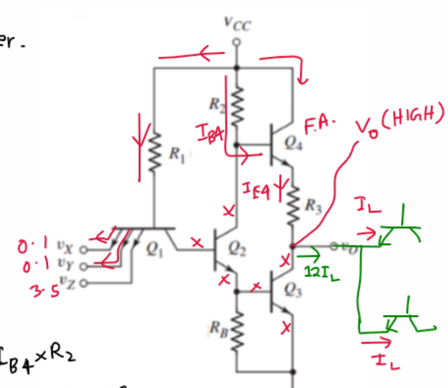
(e)

(e)	If at least one input is low (0.1*V*) and **2 loads** are connected to the output, find the new value for v_o

Output of the driver circuit should be logic HIGH.

So, the direction of I_L should be away from the driver.

$$I_L = \beta_R I_{B1(load)} = 0.8 \times \frac{3.5 - 2.3}{3} = 0.32\text{ mA}.$$



Now, total load current $= 2 \times I_L = 2 \times 0.32 = 0.64$ mA.

Also, $2I_L$ = Supply current of driver $= I_{E4}$

$$\therefore I_{E4} = 2I_L = 0.64\text{ mA}.$$

$$\Rightarrow I_{B4} = \frac{I_{E4}}{\beta_F + 1} = \frac{I_{E4}}{16} = 0.04\text{ mA}$$

So, $V_{B4} = V_{cc} - I_{B4} \times R_2$

$= 3.5 - 0.04 \times 1.3$

$= 3.448$ V

Now, as Q_4 in F.A;

$$V_{BC} = 0.7 \quad \Rightarrow V_{E4} = V_{B4} - 0.7 = 2.748 \text{ V}$$

and $\dfrac{V_{E4} - V_0}{R_3} = I_{E4}$ $\quad \therefore V_0 = V_{E4} - I_{E4} \times R_3 = 2.748 - 0.64 \times 0.55$

$$\boxed{= 2.396 \text{ V}}$$