# BRAC UNIVERSITY
## Department of Computer Science & Engineering
## Practice Problem sheet (Week 3)
## 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.*

## 1 Question 1

For *figure 1* assume common emitter current gain, $\beta_F = 30$ and $V_{OH} = 9.5\ V$, $V_{OL} = 0.1\ V$. Also assume for saturation mode $V_{BE} = 0.8\ V$, $V_{CE(SAT)} = 0.1\ V$ and cut in voltage for transistor $V_{\gamma.T} = 0.5\ V$, cut in voltage for transistor $V_{\gamma.D} = 0.6\ V$.

**(a)** Find the value of $\beta_{min}$ when all inputs are logical High ($10V$).

**(b)** Find the maximum fanout. *(Hint. find fanout for each case and calculate maximum fanout from it).*

**(c)** Find the power dissipation for all cases. [Assume $N$ load connected; $N = maximumFanout$]

**(d)** If all the inputs are high ($V_A = V_B = V_C = 10\ V$), what is the magnitude of the **noise voltage in V** at the *input A*, which will cause the gate to **malfunction**?

**(e)** If at least one input is low ($0.1\ V$), what is the magnitude of the **noise voltage in V** at the *input A*, which will cause the gate to **malfunction**?

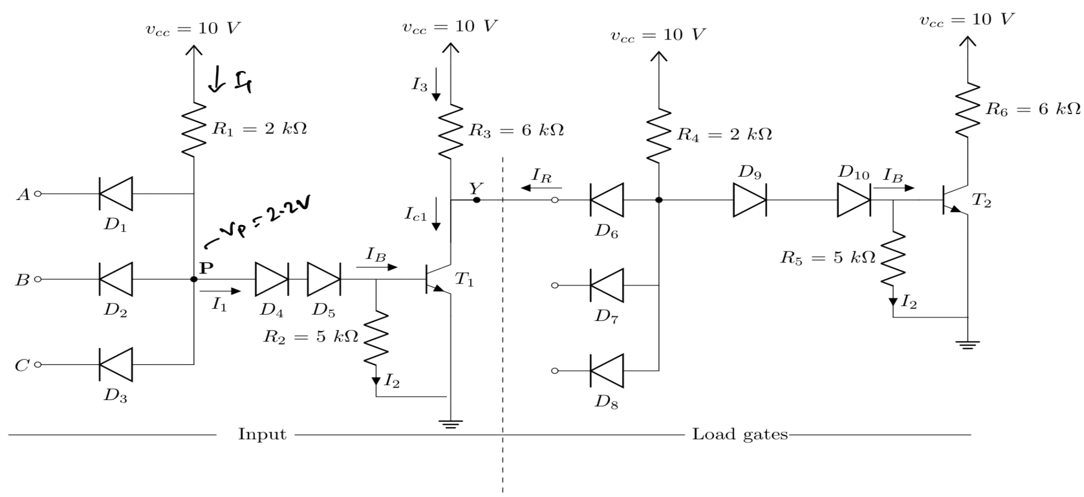



Figure 1

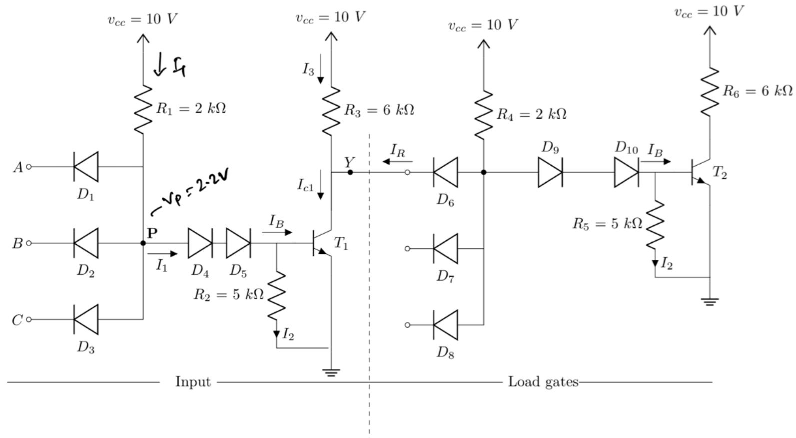



Figure 1

**(a)** Find the value of $\beta_{min}$ when all inputs are logical High ($10V$).

Assume $T_1$ in saturation as we need to find $\beta_{min}$.

at node $V_p$. voltage $= 0.7 + 0.7 + 0.8V = 2.2V$

$V_{BE}(T_1) = 0.8V$; $V_{CE}(sat)_{T_1} = 0.1V$

$$I_1 = \frac{(10-2.2)V}{2k} = 3.9mA$$

$$I_2 = \frac{0.8V}{5k} = 0.16mA$$

$$I_{BT_1} = I_1 - I_2$$
$$= 3.9mA - 0.16mA$$
$$\boxed{I_{BT_1} = 3.74\ mA}$$

$$\boxed{I_{CT_1} = \frac{(10-0.1)V}{6k} = 1.65\ mA}$$

$$\boxed{\beta_{min} = \frac{I_{CT_1}}{I_{BT_1}} = 0.441 < \beta_{forward} = 30}$$

**(b)** Find the maximum fanout. *(Hint. find fanout for each case and calculate maximum fanout from it).*

$\boxed{\text{case I}}$ All input is logical high; $A = B = C = 10\,V$

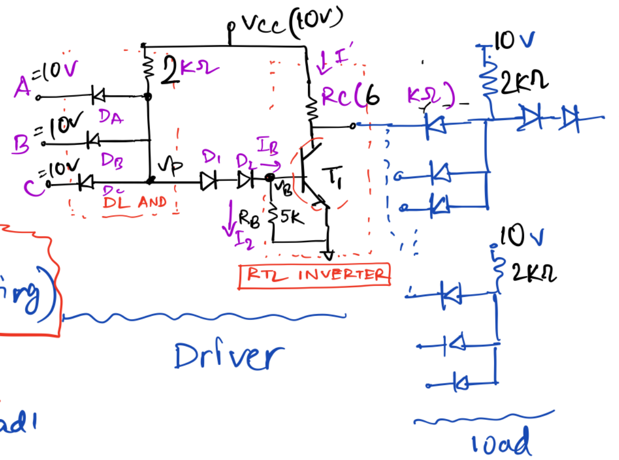
if $A = B = C = 10V$

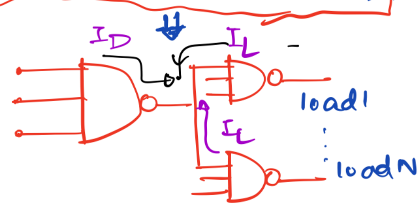
$V_o$ of Driver $= 0.1V$

($T_1$ in saturation)

$V_{in}$ of load $= 0.1V$

(DL AND gate ON → conducting)




$$\boxed{I_C \text{ (with load) at node } V_o = I' \text{ (No load current)} + I_L \times N}$$

$$I_C = I' + N \times I_L$$

Now, $I' = \dfrac{V_{CC} - V_o}{6K} = \dfrac{(10 - 0.1)V}{6K} = \boxed{1.65\,mA}$

$I_L$ (individual) $= \dfrac{V_{CC} - V_P}{5K} = \dfrac{10 - 0.8}{2K}$

$= \boxed{4.6\,mA}$

$I_C = 1.65\,mA + N \times 4.6\,mA.$

$\frac{I_C}{I_B} < \beta_{Forward}$ (as $T_1$ of Driver is in saturation.

$I_C < \beta_{forward} \times I_B$

$\boxed{I_{BT_1} = 3.74\,mA}$

$\Rightarrow I' + N \times I_L < \beta_{forward} \times I_B$

$\boxed{\beta_f = 30}$

$\Rightarrow N < \frac{\beta_f I_B - I'}{I_L}$

$\Rightarrow N < \frac{30 \times 3.74\,mA - 1.65\,mA}{4.6\,mA}$

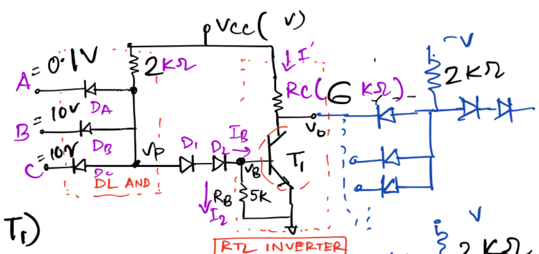
$\Rightarrow N < [24.03] \approx 24.$ $\boxed{N = 24}$ when $A=B=C$ $=5V$

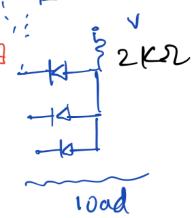
$\boxed{\text{case II}}$

Any input low; Let's say $A = 0.1V$; $B = C = 10V$; $\boxed{V_P = 0.8V}$

As, $T_1$ is in cutoff,

$\boxed{I' = 0}$ (No load collector current)




$V_O$ (at the output of $T_1$)

$= 10V$ so, Load AND gate is also in cut Off.

$\boxed{I_L = 0}$

$I_B = 0$ [$T_1$ in cutoff]

so, $\frac{I_C}{I_B} < \beta_f$

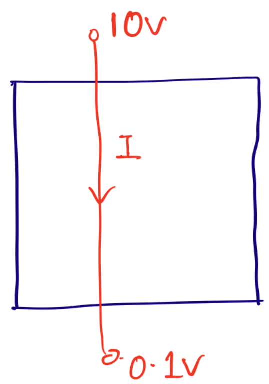
$\Rightarrow I_C = I' + N \times I_L < \beta_f I_B$ $= 0 + N \times 0 = 0$

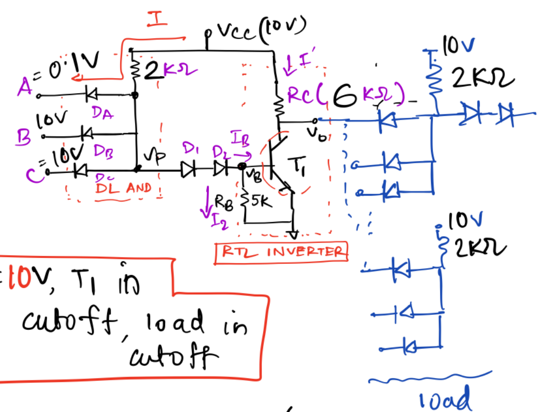
$\Rightarrow \boxed{N = \frac{\beta I_B - I'}{I_L} = \frac{0}{0} = \infty}$

$\boxed{\text{Maximum fanout} = \min(24, \infty) = 24}$

**(c)** Find the power dissipation for all cases. [Assume $N$ load connected; $N = maximumFanout$]

Case I  Any input $= 0.1V$ [LOAD CONDITION] ($N = 24$)



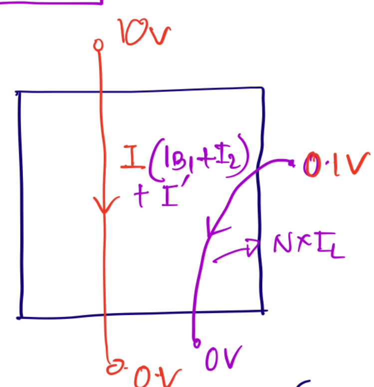




$V_o = 10V$, $T_1$ in cutoff, load in cutoff

$$P = \Delta V \times I = (10-0.1)\,I = (10-0.1)V \cdot \left(\frac{10-0.8}{2k}\right)$$

$\boxed{P = 45.54\,mW}$ $\boxed{\text{Any input} = 0.1V}$

Case II  ALL input $= 10V$ [LOAD CONDITION I]




$$\boxed{\begin{aligned} I' &= 1.65\,mA \\ I &= 3.9\,mA \\ I_L &= 4.6\,mA \end{aligned}}$$

$$P = \Delta V \times I = (10-0)V \times (I + I') + (0.1-0)\,N \times I_L$$

$$= (10-0)V \times (3.9 + 1.65)\,mA + 0.1 \times N I_L$$

$\boxed{P = 66.54\,mW}$ $\boxed{\text{All input} = 10V}$

**(d)** If all the inputs are high ($V_A = V_B = V_C = 10\ V$), what is the magnitude of the **noise voltage in V** at the *input A*, which will cause the gate to **malfunction**?

$V_A = 10 + V_N$ (Malfunction)

$V_{DA} = 0.6V$ [Turns the Diode on)

$V_A + V_{DA} = V_P = 2.2V$

$10 + V_N + V_{DA} = V_P$

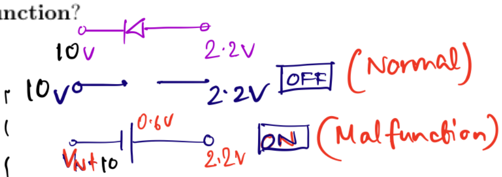
$\Rightarrow 10 + V_N + 0.6V = 2.2V$

$\Rightarrow V_N = (2.2 - 10 - 0.6)V$

$\boxed{V_N = -8.4V}$

Magnitude of $V_N = |V_N|$

$= |-8.4V| = 8.4V$




$V_A = 10V$ [NORMAL]

$V_P = 2.2V$

As, $D_A$ turns on and all the current flows through it, $T_1$ goes to cutoff

**(e)** If at least one input is low ($0.1\ V$), what is the magnitude of the **noise voltage in V** at the *input A*, which will cause the gate to **malfunction**?

$V_A = 0.1 + V_N$ (Malfunction)

$V_{D_{1,2}} = 0.6V$ [Turns the Diode on)

$V_A + V_{DA} = V_P = V_N + 0.8V$

$\boxed{\begin{aligned} V_P &= V_{D_1} + V_{D_2} + V_\gamma \\ &= 0.6 + 0.6 + 0.5 = 1.7V \end{aligned}}$

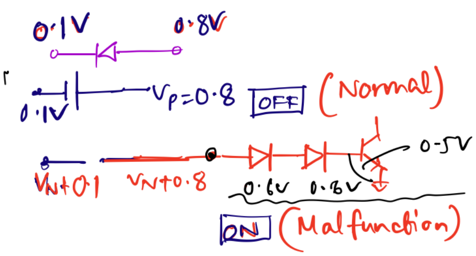
$\Rightarrow$ As, $V_P = V_N + 0.8V$

$V_N = V_P - 0.8 = (1.7 - 0.8)V$

$\boxed{V_N = 0.9V}$

Magnitude of $V_N = |0.9V|$

$= 0.9V$




$V_A = 0.1V$ [NORMAL]

$V_P = 0.8\ V$

As, $T_1$ turns on and all the current flows through it, $D_A$ goes to cutoff.

## 2 Question 2

For figure 2 assume common emitter current gain, $\beta_F = 30$ and $V_{OH} = 11.5\ V$, $V_{OL} = 0.1\ V$. Also assume for saturation mode $V_{BE} = 0.8\ V$, $V_{CE(SAT)} = 0.1\ V$ and cut in voltage for transistor $V_{\gamma.T} = 0.5\ V$, cut in voltage for transistor $V_{\gamma.D} = 0.6\ V$.

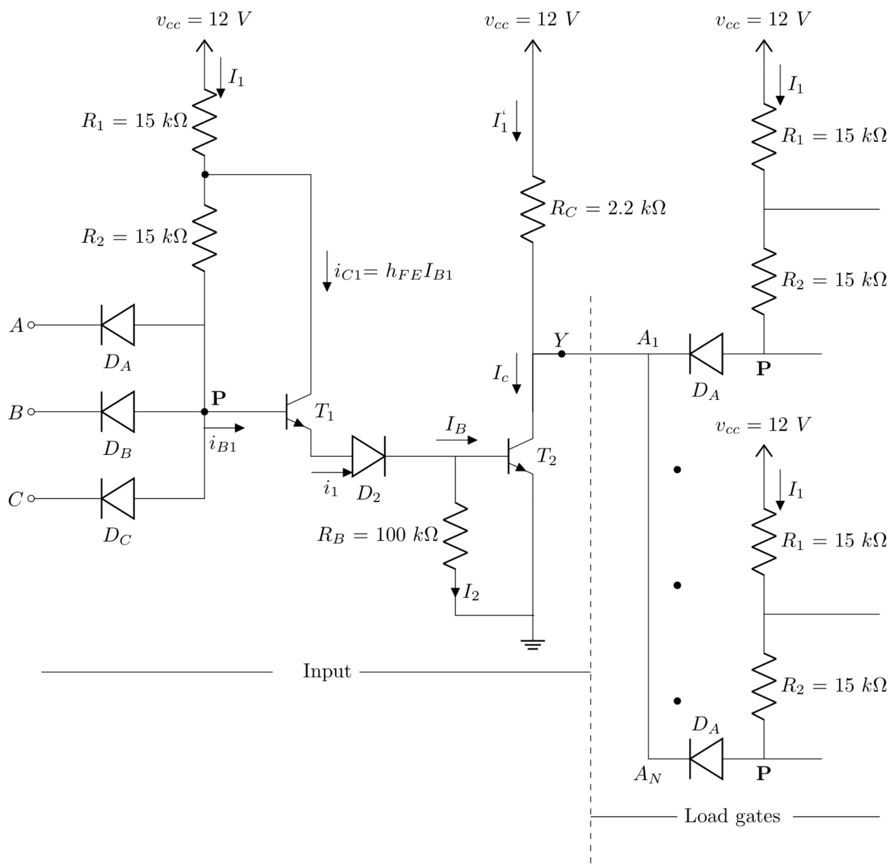



Figure 2

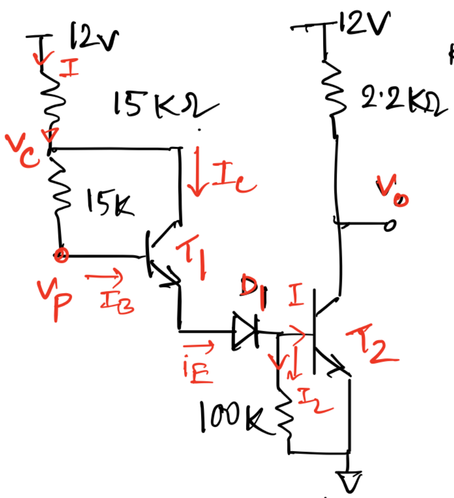
**(a)** Find the value of $\beta_{min}$ when all inputs are logical High ($12V$).

**(a)** Find the value of $\beta_{min}$ when all inputs are logical High ($12V$).

$\boxed{\text{Assume } T_2 \text{ in saturation as we need to find } \beta_{min}}$.

at node $V_p$. voltage $= 0.7 + 0.7 + 0.8V = 2.2V$

$V_{BE}(T_2) = 0.8V$; $V_{CE}(sat)\, T_1 = 0.1V$; $V_{BE}(T_2) = 0.7V$ $\boxed{\text{as } T_1 \text{ in FA}}$




KCL at node $V_c$; $I = I_{C_1} + I_{B_2}$

$I = \beta I_{B_2} + I_{B_2} = (\beta+1) I_{B_2}$

$$\Rightarrow \frac{V_{cc} - V_c}{15K} = (\beta+1)\frac{V_c - V_p}{15K}$$

$$\Rightarrow \frac{12 - V_C}{15K} = \frac{31}{15K}(V_C - 2.2V)$$

$$\boxed{V_C = 2.51\,V}$$

$$\boxed{\beta_f = 30}$$

$$I = \frac{V_{cc} - V_c}{15\,K\Omega} = \frac{(12 - 2.51)V}{15K\Omega} = 0.633\,mA = I_{E_{T_2}}$$

$$I_{B_{T_2}} = I - I_2 = 0.633\,mA - \frac{0.8V}{100K} = 0.633\,mA - 0.008\,mA$$

$$\Rightarrow \boxed{I_{B_{T_2}} = 0.625\ mA}$$

$$I_2 = \frac{0.8}{100K} = 0.008\,mA$$

$$\boxed{I_{B_{T_2}} = 0.625\,mA}$$

$$\boxed{I_{C_{T_2}} = \frac{12 - 0.1}{2.2K\Omega} = 5.41\ mA}$$

$$\beta_{min} = \frac{I_C}{I_B} = \frac{5.41\,mA}{0.625\,mA}$$

$$\boxed{\beta_{min} = 8.659 < \beta_f\,(30)}$$

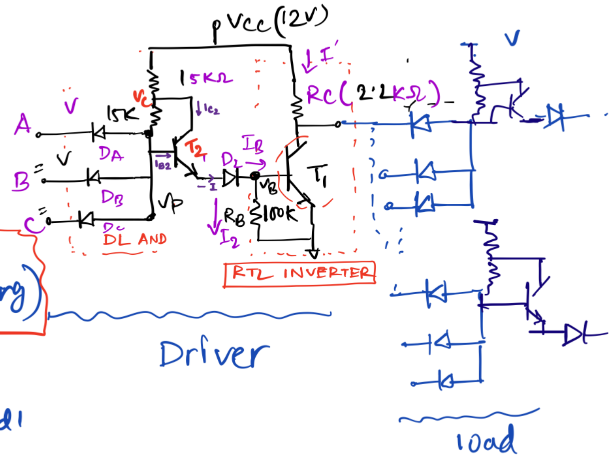
**(b)** Find the maximum fanout. *(Hint. find fanout for each case and calculate maximum fanout from it).*

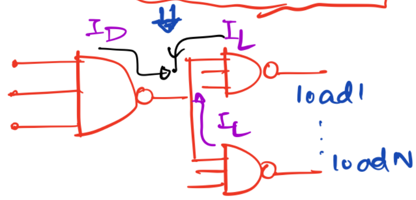
**Case I** All input is logical high; $A = B = C = 12V$

if $A = B = C = 12V$

$V_o$ of Driver $= 0.1\,V$ ($T_1$ in saturation)

$V_{in}$ of load $= 0.1\,V$ (DL AND gate ON → conducting)




$$\boxed{I_c \text{ (with load) at node } V_o = I' \text{ (No load current)} + I_L \times N}$$

$$I_C = I' + N \times I_L$$

Now, $I' = \dfrac{V_{CC} - V_o}{2.2K} = \dfrac{12V - 0.1V}{2.2K} = \boxed{5.41\ mA}$

$$I_L \text{ (individual)} = \frac{V_{CC} - V_P}{(15+15)K} = \frac{(12 - 0.8)V}{30\,K} = \boxed{0.373\ mA}$$

$$I_C = 5.41\,mA + N \times 0.373\,mA$$

KCL at node $V_C$; $I = I_{C_2} + I_{B_2}$

$I = \beta I_{B_2} + I_{B_2} = (\beta+1) I_{B_2}$

$$\Rightarrow \frac{V_{CC} - V_C}{K} = (\beta+1)\frac{V_C - V_P}{K} \qquad \boxed{\beta_f = 30}$$

$$\Rightarrow \frac{12 - V_C}{15K} = \frac{31}{15K}(V_C - 2.2V)$$

$$\Rightarrow 12 - V_C = \frac{15K \times 31}{15K}(V_C - 2.2V)$$

$$\Rightarrow \boxed{V_C = 2.51V}$$

$$I = \frac{V_{CC} - V_C}{15K\Omega} = 0.633\,mA = I_{E_2} = I_{B_1} + I_2$$

$\boxed{I_2 = 0.008\,mA} \longrightarrow \boxed{I_{BT_2} = 0.625\,mA}$

$\frac{I_C}{I_B} < \beta_{Forward}$ (as $T_1$ of Driver is in saturation.

$I_C < \beta_{forward} \times I_B$

$\Rightarrow I' + N \times I_L < \beta_{forward} \times I_B$

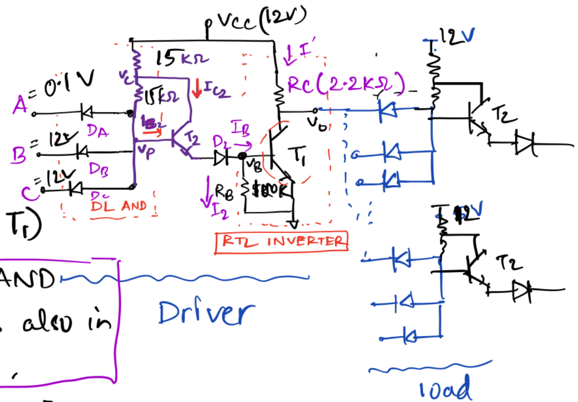
$$\Rightarrow N < \frac{\beta_f I_{B_2} - I'}{I_L}$$

$$\Rightarrow N < \frac{30 \times 0.625\,mA - 5.41\,mA}{0.373\,mA}$$

$\Rightarrow N < [35.76] \approx 35.$ $\boxed{N = 35}$ when $A = B = C = 10V$

$\boxed{\text{case II}}$

Any input low; Let's say $A = 0.1\,V$; $B = C = 12\,V$




As, $T_1$ is in cutoff,

$\boxed{I' = 0}$ (No load collector current)

$v_o$ (at the output of $T_1$)

$= 12V$ so, Load AND gate is also in cut-off.

Driver

$\boxed{I_L = 0}$

$I_B = 0$ [$T_1$ in cutoff]

$= 0 + N \times 0 = 0$

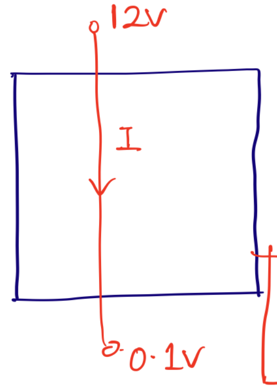
so, $\frac{I_C}{I_B} < \beta_f$

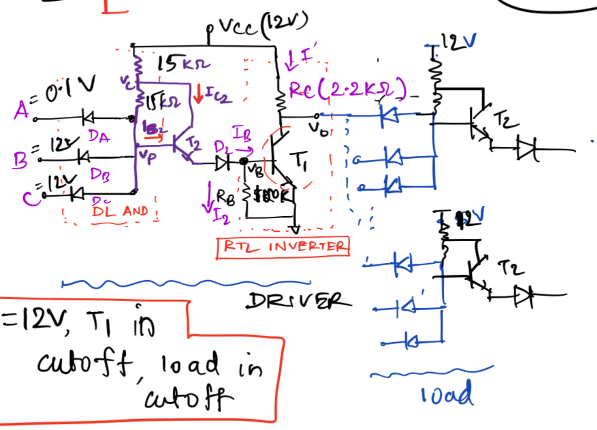
$\Rightarrow I_C = I' + N \times I_L < \beta_f I_B \Rightarrow$ $\boxed{N = \frac{\beta I_B - I'}{I_L} = \frac{0}{0} = \infty}$

$\boxed{\text{Maximum fanout} = \min(35, \infty) = 35}$

**(c)** Find the power dissipation for all cases. [Assume $N$ load connected; $N = maximumFanout$]

$\boxed{\text{case I}}$ Any input $= 0.1V$ [LOAD CONDITION] (N = 35)



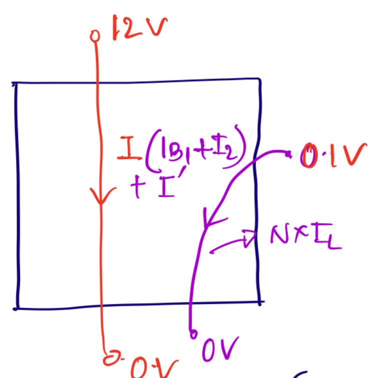




$V_o = 12V$, $T_1$ in cutoff, load in cutoff

$$P = \Delta V \times I = (12-0.1)\,I = (12-0.1)V \times \left(\frac{12-0.8}{30k}\right)$$

$\boxed{P = 4.4387\text{ mW}}$ $\boxed{\text{Any input} = 0.1V}$

$\boxed{\text{case II}}$ ALL input $= 12V$ [LOAD CONDITION]




$I' = 5.41$ mA

$I = 0.633$ mA

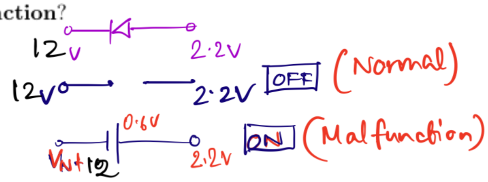
$I_L = 0.373$ mA

$$P = \Delta V \times I = (12-0)V \times (I + I') + (0.1-0)\,N \times I_L$$

$$= (12-0)V \times (5.41 + 0.633)\text{ mA} + 0.1 \times N I_L$$

$\boxed{P = 73.82\text{ mW}}$ $\boxed{\text{All input} = 12V}$

**(d)** If all the inputs are high ($V_A = V_B = V_C = 12V$), what is the magnitude of the **noise voltage in V** at the *input A*, which will cause the gate to **malfunction**?




$V_A = 12 + V_N$ (Malfunction)

$V_{DA} = 0.6V$ [Turns the Diode on]

$V_A + V_{DA} = V_P = 2.2V$

$12 + V_N + V_{DA} = V_P$

$\Rightarrow 12 + V_N + 0.6V = 2.2V$

$\Rightarrow V_N = (2.2 - 12 - 0.6)V$

$\boxed{V_N = -10.4V}$

Magnitude of $V_N = |V_N|$

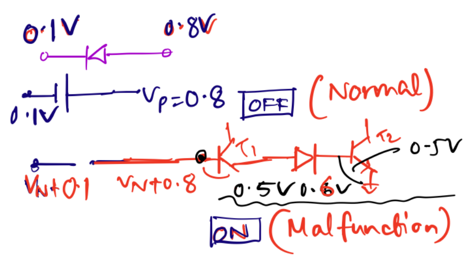
$= |-10.4V| = 10.4V$

$V_A = 12V$ [NORMAL]

$V_P = 2.2V$

As, $D_A$ turns on and all the current flows through it, $T_2$ goes to cutoff

**(e)** If at least one input is low ($0.1\ V$), what is the magnitude of the **noise voltage in V** at the *input A*, which will cause the gate to **malfunction**?




$V_A = 0.1 + V_N$ (Malfunction)

$V_{D1} = 0.6V$ [Turns the Diode on]

$V_A + V_{DA} = V_P = V_N + 0.8V$

$$\boxed{\begin{aligned} V_P &= V_{\gamma T_1} + V_{D_2} + V_{\gamma T_2} \\ &= 0.5 + 0.6 + 0.5 = 1.6V \end{aligned}}$$

$\Rightarrow$ As, $V_P = V_N + 0.8V$

$V_N = V_P - 0.8 = (1.6 - 0.8)V$

$\boxed{V_N = 0.8V}$

Magnitude of $V_N = |0.8V|$

$= 0.8V$

$V_A = 0.1V$ [NORMAL]

$V_P = 0.8\ V$

As, $T_2$ turns on and all the current flows through it, $D_A$ goes to cutoff.

## 3 Question 3

For *figure 3* assume common emitter current gain, $\beta_F = 30$ Also assume for saturation mode $V_{BE} = 0.8\ V$, $V_{CE(SAT)} = 0.1\ V$ and cut in voltage for transistor $V_{\gamma,T} = 0.5\ V$, cut in voltage for transistor $V_{\gamma,D} = 0.6\ V$.

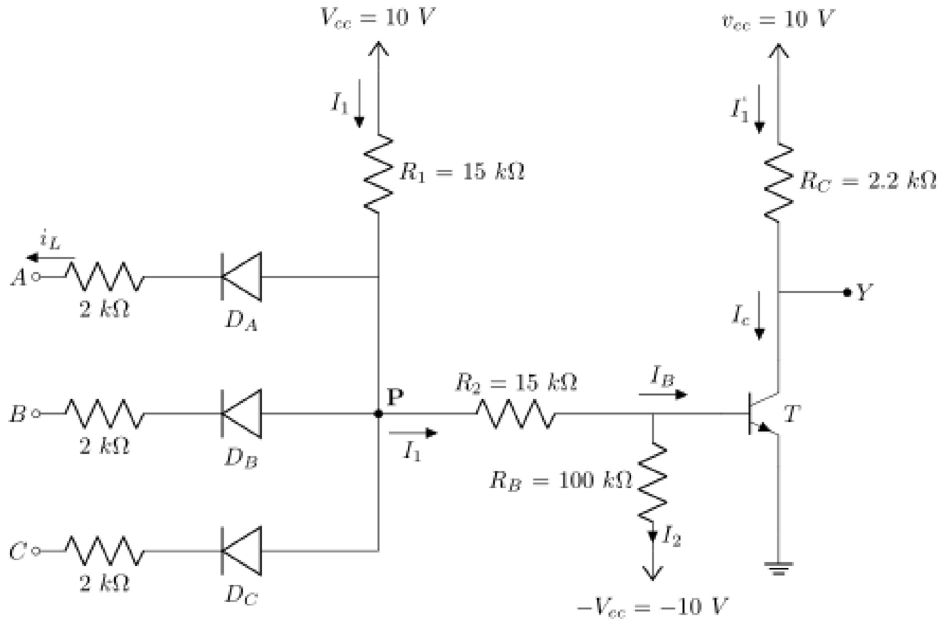



Figure 3

**(a)** Find $I_1$, $I_2$, $I_B$,$I_C$ and $I_L$ if any input is logical low (0.1 $V$).

**(b)** Find $I_1$, $I_2$, $I_B$,$I_C$ and $I_L$ if all inputs are logical high (10 $V$).

**(c)** Find the value of $\beta_{Min}$ when all inputs are logical High (10 $V$). ( *Hint: find only for Transistor T of driver*)

**(d)** Find the power dissipation for the conditions of both (a) and (b) for the driver [*Assume no load connected*]

**(e)** Find the maximum fanout (**Hint: find fanout for each case and calculate maximum fanout from it**)

ⓐ If any input is low, that diode is in forward bias and the rest are in reverse bias.

$$i_1 = \frac{10 - V_P}{15k} \quad / \quad i_L = \frac{(V_P - 0.7) - 0.1}{2k} = \frac{V_P - 0.8}{2k}$$

since input low, assume transistor in cutoff. $i_B = i_C = 0$

$$i_2 = \frac{V_P + 10}{115k}$$

$$i_1 = i_2 + i_L \Rightarrow \frac{10 - V_P}{15k} = \frac{V_P + 10}{115k} + \frac{V_P - 0.8}{2k}$$

$$\Rightarrow V_P = 1.703\,V$$

$i_1 = 0.553\,mA$ / $i_2 = 0.102\,mA$ / $i_L = 0.4515\,mA$

Base voltage
$= V_P - i_2 \times 15k$
$= 1.703 - 15 \times 0.102$
$= 0.173 < V_\gamma$
thus, cutoff assumption true.

ⓑ If all inputs logical high, all diodes reverse bias.
Assume transistor is in saturation mode. $V_{BE} = 0.8V$
$V_{CE} = 0.1V$

$V_{out} = 0.1V$

$$i_C = \frac{10 - 0.1}{2.2k} = 4.5\,mA \qquad i_L = 0$$

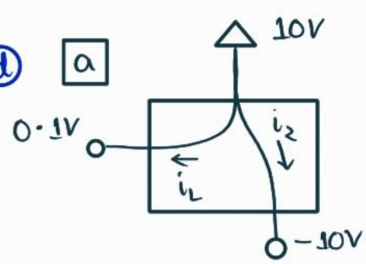
$$i_2 = \frac{0.8 + 10}{100k} = 0.108\,mA$$

$$i_1 = \frac{10 - 0.8}{15k + 15k} = 0.307\,mA$$

$$i_B = i_1 - i_2 = 0.199\,mA$$

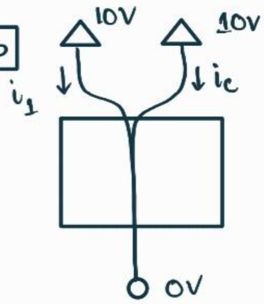
ⓒ $$\beta_{Forced} = \beta_{min} = \frac{i_C}{i_B} = \frac{4.5mA}{0.199\,mA} = 22.613$$

ⓓ $\boxed{a}$




$$\text{power} = (10 - 0.1)\, i_L + (10 + 10)\, i_2$$
$$= 9.9 \times 0.452 + 20 \times 0.102$$
$$= 6.515\,mW$$

$\boxed{b}$




$$\text{Power} = 10 \times (i_1 + i_c)$$
$$= 10 \times (0.307 + 4.5)$$
$$= 48.07 \text{ mW}$$

(c) $\boxed{\text{Case 1 - output low}}$

Driver side base current, $i_B = 0.199$ mA

collector current, $i_C = 4.5$ mA

$\uparrow$ from (b)

worst case load current, $i_L = 0.452$ mA

from (a)

we have, $\beta_F i_B = i_c + n i_L$

$$\Rightarrow n = \frac{\beta_F i_B - i_c}{i_L} = \frac{30 \times 0.199 - 4.5}{0.452} = \lfloor 3.25 \rfloor$$
$$= 3$$

$\boxed{\text{Case 2 - output high}}$

worst case load current, $i_L = 0$

$n = \infty$

Thus, fanout $= \min(\infty, 3) = 3$