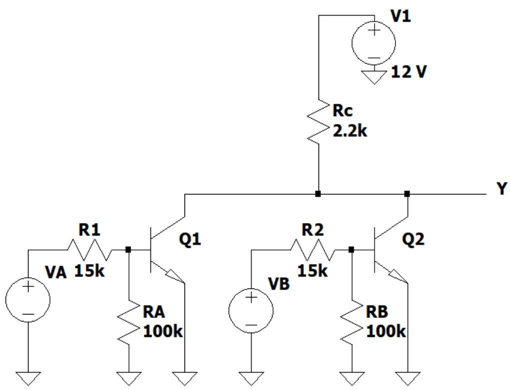
Basic Operation

Exercise 1



For the RTL NOR gate-

a) Determine the output voltage V_Y for all logic cases & make a table. Verify your operating mode assumptions.

b) What is the high & low threshold for output voltage?

c) If R_B is doubled, find the new base current of Q_2. Will it still satisfy saturation mode conditions for Q_2 for the cases (1,1) & (0,1)?

[Assume 0.2 V as low input voltage, $\beta_F = 30$]

$Ans: a)\ 12\ V, 0.2\ V, 0.2\ V, 0.2\ V$

$b)\ 12\ V, 0.2\ V$

$c)\ 0.742\ mA, Yes$

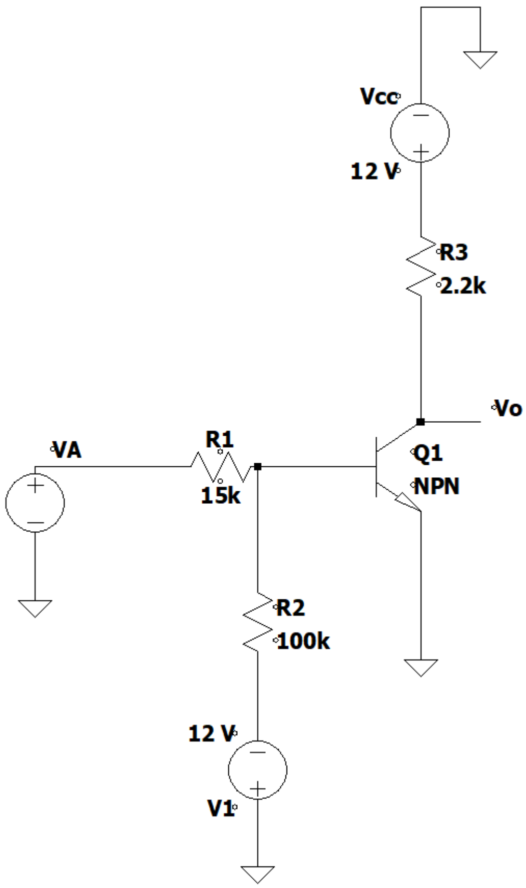
Practice Problem 1:

For the RTL NOR gate in **Exercise 1**, using the value or R_B in (d), find the base voltage of Q_2 and verify whether it meets the condition for cutoff for (0,0) & (1,0).

$Ans: V_B = 0.18\ V < 0.5\ V, satisfies$

Power Dissipation

Exercise 2



For the RTL inverter, find the maximum & average power dissipation.

[High input = 12 V, Low input = 0.2 V]

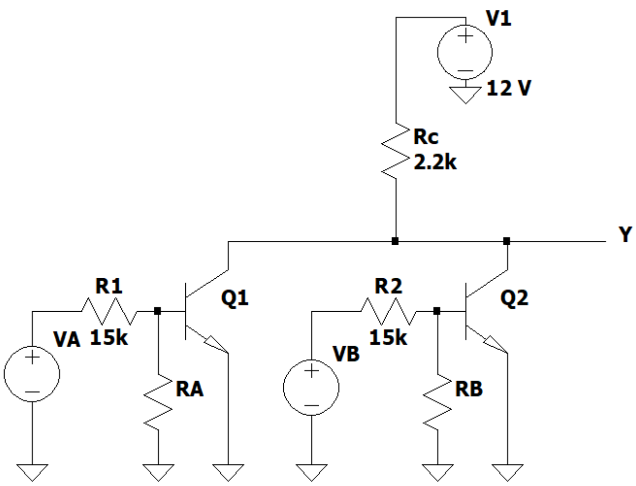
Ans: 82.7782 mW, 42.0362 mW

Practice Problem 2:

For the RTL inverter in **Exercise 2**, find the ratio of maximum & minimum power dissipation, **if $V_1(-12\ V)$ was missing.**

Ans: 212494.7:1

Exercise 3



For the RTL NOR gate shown-

a) If, $R_A = R_B$, and the power dissipation for logic case (0,0) is $0.5\ mW$, find the value of the resistances.

$[V_{BE}(saturation) = 0.8\ V, V_{CE}(saturation) = 0.2\ V]$
Assume a low input voltage of 0.2 V

$Ans: 145\ k\Omega$

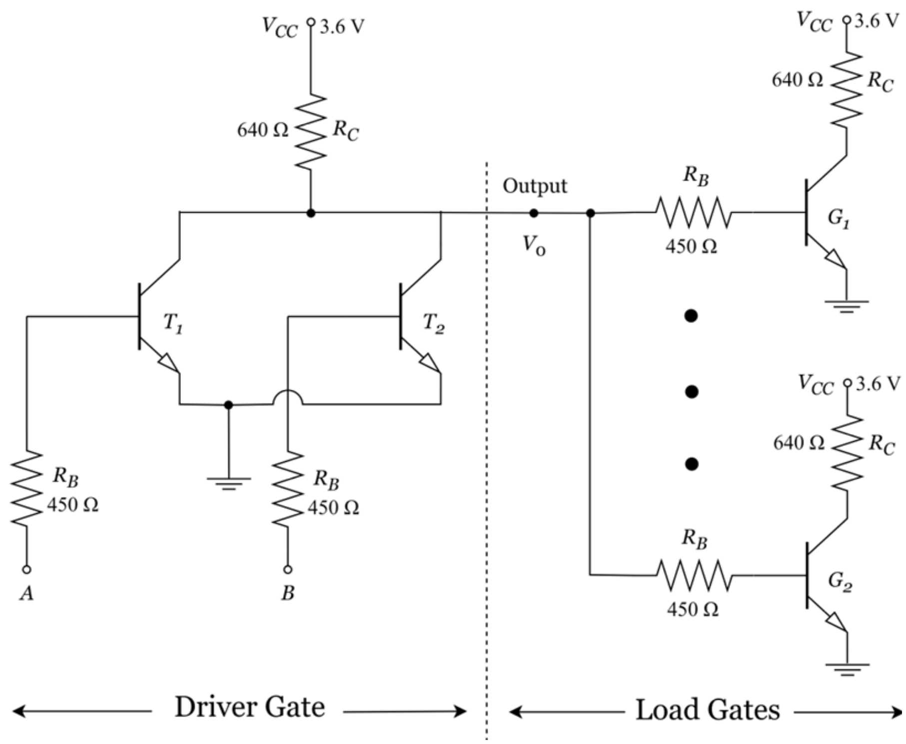
Practice Problem 3:

In the circuit of Exercise **3**, find a new value of R_c required to double the maximum power dissipation in the circuit.

$Ans: 0.966\ k\Omega$

Noise Margin

Exercise 4



For the RTL NOR driver & RTL NOT loads, find the noise margin.

Assume
$V_{OH} = 3.5\ V$
$V_{IL} = 0.2\ V$
$\beta_F = 30$

Ans: 0.3 V

Practice Problem 4:

In the circuit of **Exercise 4**, what value of R_B will make $N_H = N_L$?

Ans: 13.55 kΩ

Fanout

Exercise 5

For the RTL NOR driver in **Exercise 4** if $V_{OH} = 1.3\ V$-

a) Find maximum fanout.
b) Find the value of V_o if fanout (N) = 5, and both inputs are low.
c) Find $(\beta_F)_{min}$ (for the loads) the power dissipation of the loads only for conditions in (b).
d) Find the power dissipation in the driver only when both inputs are high.
e) If N=1, what logic function does the driver-load combination implement?

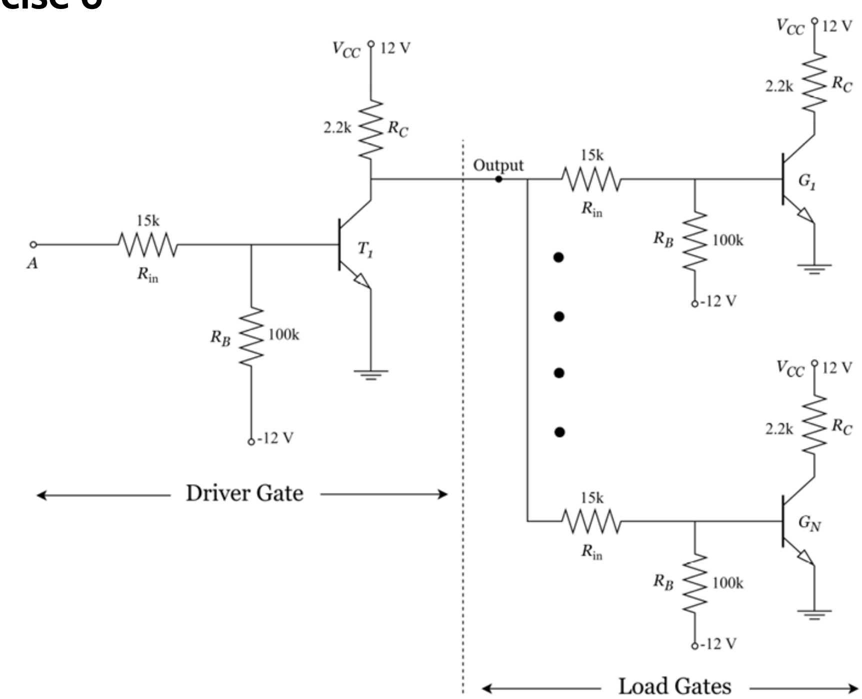
Practice Problem 5:

What value of V_{OH} would reduce the maximum fanout of the RTL NOR gate to 2 in **Exercise 5**?

$Ans: 2.18\ V$

Mixed

Exercise 6

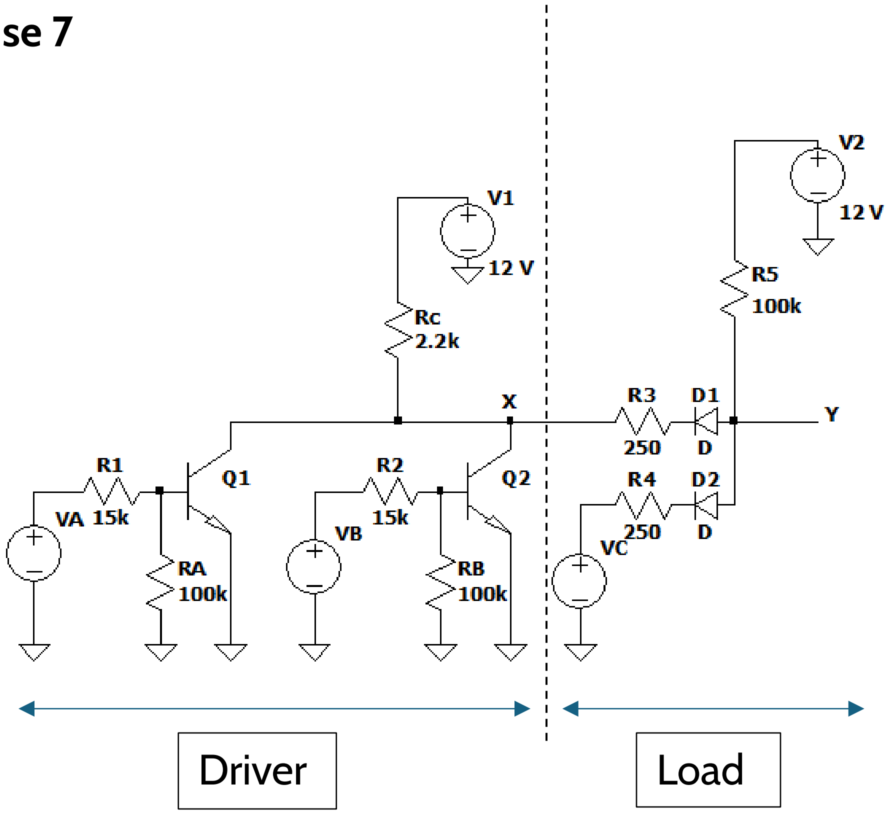


For the given RTL inverters,
$V_{OH} = 10\ V, V_{OL} = 0.2\ V$
$\beta_F = 30$

a) Find maximum fanout.
b) Find V_o for N=2 loads, and the input of the driver is low.
c) If V_{in} is high, find the power dissipation of the driver circuit.
d) If V_{in} is low and fanout=2, find the power dissipation of the total circuit (driver + loads).
e) Find the noise margin.

$Ans:$ a) 1
b) $9.46\ V$
c) $74.86\ mW$
d) $15.15\ mW$
e) $0.375\ V$

Exercise 7



For the circuit given-

a) What logic function does it implement?
b) Find maximum fanout.
c) Find the max power dissipation of the circuit.

Assume
$V_{OH} = 11.5\ V$
$V_{OL} = 0.2\ V, \beta_F = 25$

Ans:

$a)\ Y = \overline{A + B}.C$

$b)\ 13$

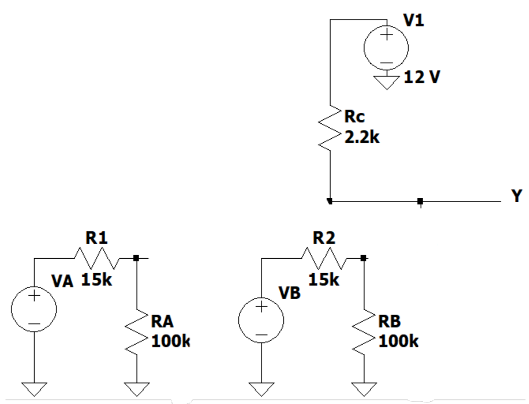
$c)\ 65.7\ mW$

Exercise 1

Solution:

a) We assume cutoff mode for input logic '0' & saturation mode for input logic '1'.

Case (0,0):



Due to the open circuit, we see, $V_Y = 12\ V$

Verification:

$V_{E_{Q_1}} = V_{E_{Q_2}} = 0\ V$

$V_A = V_B = 0.2\ V$

Applying KCL at the base of Q_1,

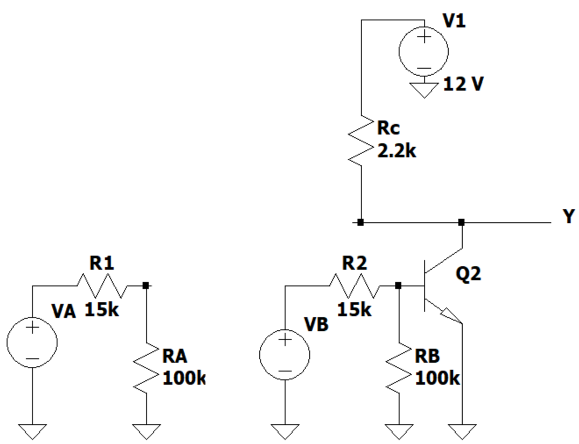
$$\frac{V_A - V_{B_{Q_1}}}{15} = \frac{V_{B_{Q_1}} - 0}{100k} \rightarrow V_{B_{Q_1}} = 0.17\ V$$

$\therefore V_{BE_{Q_1}} = 0.17 - 0 = 0.17\ V < 0.5\ V$

$Hence\ Q_1 will\ be\ off$

Similarly, we can show Q_2 will be off too, as it has the same parameters.

Case (0,1):



Since Q_2 will be on, we can assume it will be in saturation.

$\therefore V_{CE_{Q_2}} = 0.2\ V$

$\therefore V_Y = V_{CE_{Q_2}} = 0.2\ V$

Verification:

$$I_{C_{Q_2}} = \frac{12 - V_Y}{2.2} = 5.363\ mA$$

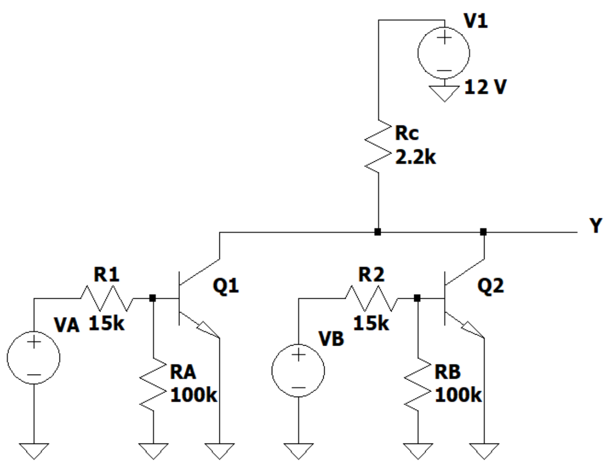
$$I_{B_{Q_2}} = I_{R_2} - I_{R_B} = \frac{12 - V_{B_{Q_2}}}{15} - \frac{V_{B_{Q_2}} - 0}{100}$$

$$= \frac{12 - 0.8}{15} - \frac{0.8}{100} = 0.738\ mA$$

$$\therefore \beta_{Q_2} = \frac{I_{C_{Q2}}}{I_{B_{Q2}}} = \frac{5.363}{0.738} = 7.27 < \beta_F(30)$$

Case (1,0): Same as Case (0,1) since both BJTs' parameters are identical.

Case (1,1):



$V_Y = V_{CE_{Q_1}} = V_{CE_{Q_2}} = 0.2\ V$

Verification:

KCL at Y,

$$I_{R_C} = I_{C_{Q_1}} + I_{C_{Q_2}} \rightarrow \frac{12-0.2}{2.2} = 2 \times I_{C_{Q_1}} \rightarrow$$
$$I_{C_{Q_1}} = 2.681\ mA$$

$$I_{B_{Q_1}} = I_{B_{Q_2}} =$$
$$0.738\ mA\ [Similarly\ as\ in\ Case\ (0,1)]$$

$$\beta_{Q_1} = \beta_{Q_2} = \frac{I_{C_{Q_1}}}{I_{B_{Q_1}}} = 3.63 < \beta_F(30)$$

Case	V_Y
0,0	12
0,1	0.2
1,0	0.2
1,1	0.2

b) High threshold = min (12) = 12 V, Low threshold = max (0.2, 0.2, 0.2) = 0.2 V

c) Applying KCL at the base of Q_2, $I_{B_{Q_2}} = I_{R_2} - I_{R_B} = \frac{12-0.8}{15} - \frac{0.8}{2\times100} = 0.742\ mA$

Now, $\beta_{0,1} = \frac{(I_{C_{Q2}})_{0,1}}{0.742} = \frac{5.363}{0.742} = 7.23 < \beta_F(30)$ & $\beta_{1,1} = \frac{(I_{C_{Q2}})_{1,1}}{0.742} = \frac{2.681}{0.742} = 3.61 < \beta_F(30)$

Thus, it will still satisfy saturation mode conditions for (1,1) & (0,1).

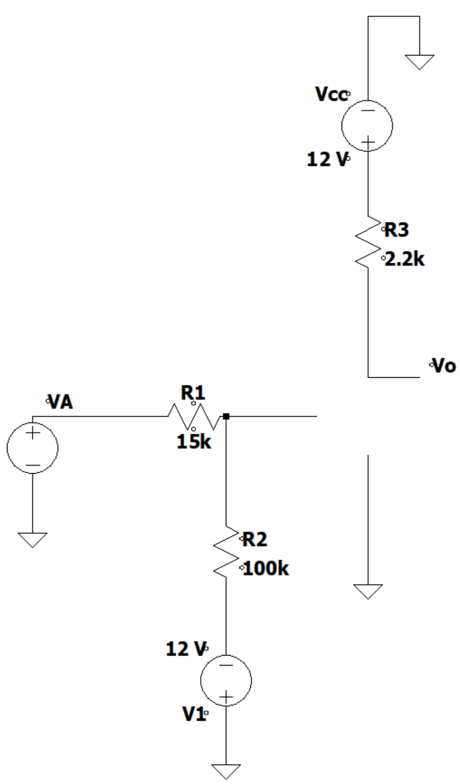
Exercise 2

Solution:

Step 1:

Case	BJT Q1
0	Cutoff
1	Saturation

Case 0:



Step 2:

$I_B = I_C = I_E = 0$

$V_o = V_{cc} = 12\ V$

$I_{R1} = I_{R2} = \frac{V_A-(-12)}{R_1+R_2} = \frac{0.2+12}{15+100}\ mA$

$= 0.106\ mA$

$V_A = 0.2\ V, V_1 = -12\ V$

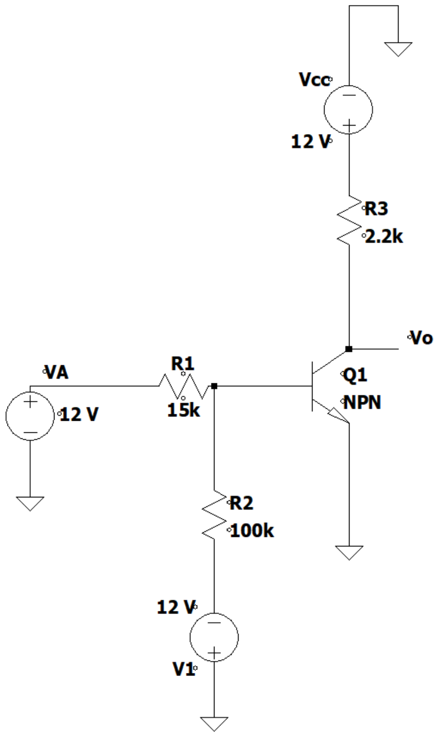
Current flows only through R_1 & R_2

Step 3:

$P_0 = (V_A - V_1) \times I_{R1} = (0.2 - (-12)) \times 0.106\ mW$

$= 1.2932\ mW$

Case 1:



Step 2:

$V_o = V_{CE} = 0.2\ V, V_B = V_{BE} = 0.8\ V$

$I_{R1} = \frac{V_A - V_B}{15} = \frac{12-0.8}{15}\ mA = 0.747\ mA$

$I_{R2} = \frac{V_B-(-12)}{100} = \frac{0.8+12}{100}\ mA = 0.128\ mA$

Using KCL, $I_B = I_{R1} - I_{R2} = 0.619\ mA$

$I_c = \frac{V_{CC}-V_O}{2.2} = \frac{12-0.2}{2.2}\ mA = 5.363\ mA$

I_{R2} flows between $V_A \& -12\ V$

I_B flows between $V_B \& \ 0\ V$

I_C flows between $V_{cc} \& \ 0\ V$

Step 3:

$\therefore P_1 = \left(V_A - (-12)\right) \times I_{R1} + (V_B - 0) \times I_B + (V_{CC} - 0) \times I_C$

$= (12 + 12) \times 0.747 + (0.8 - 0) \times 0.619 + (12 - 0) \times 5.363$

$= 82.7792\ mW$

$\therefore$ Maximum power dissipation $= P_1 = 82.7792\ mW$

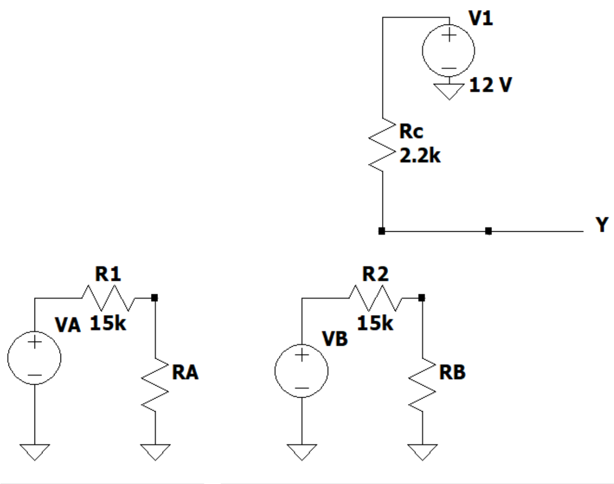
$\therefore$ Average power dissipation $= \frac{P_0+P_1}{2} = 42.0362\ mW$

Exercise 3

Solution:

Both $Q_1 \& Q_2$ will be off for (0,0).

Step 1:



Step 2:

$I_{R_C} = 0\ (open\ circuit)$

$V_A = V_B = 0.2\ V$

Step 3:

$P_{0,0} = 2 \times (V_A - 0) \times I_{R_A} = 2 \times 0.2 \times \frac{0.2-0}{15+R_A}$

$\rightarrow 0.5 = 0.4 \times \frac{0.2}{15+R_A}$

$\therefore R_A = R_B = 145\ k\Omega$

Exercise 4

Solution:

Step 1:

$V_{OH} = 11.5\ V, V_{OL} = 0.2\ V$

Step 2:

Determination of V_{IH}:

V_{IH} is the lowest input voltage that would drive the RTL Not gate loads to forward active mode from saturation. Thus, the marginal condition here is,

$\beta_{loads} = \beta_F = 30$

For saturation mode, we know, $V_{BE} = 0.8\ V, V_{CE} = 0.2\ V$

Thus, $I_{B_{loads}} = \frac{V_{IH}-V_B}{0.45} = \frac{V_{IH}-(0.8-0)}{0.45} = \frac{V_{IH}-0.8}{0.45}$

And $I_{C_{loads}} = \frac{V_{cc}-V_{CE}}{0.64} = \frac{3.6-0.2}{0.64} = 5.3125\,mA$

Now, $\beta_{loads} = \frac{I_{C_{loads}}}{I_{B_{loads}}} = 30 \rightarrow \frac{V_{IH}-0.8}{0.45} = \frac{5.3125}{30} \rightarrow V_{IH} = 0.88\,V$

Determination of V_{IL}:

V_{IL} is the highest input voltage that would turn the RTL Not gates on & violate cutoff condition of $V_{BE} < 0.5\,V$ So, the marginal $V_{BE} = V_B = 0.5\,V$

Since $V_E = 0\,V$,

$V_{BE} = V_B = V_{IL} - I_B \times 0.45 = V_{IL} - 0 \times 0.45 = V_{IL}(In\ cutoff\ I_B = 0)$

Thus, $V_{IL} = 0.5\,V$

Step 3:

$N_H = V_{OH} - V_{IH} = 3.5 - 0.88 = 2.62\,V$

$N_L = V_{IL} - V_{OL} = 0.5 - 0.2 = 0.3\,V$

$\therefore N_M = \min(N_H, N_L) = 0.3\,V$

Exercise 5

Solution:

a) **Step 1:**
The current from the driver circuit is going outward to the NOT gate loads. Hence, the condition for maximum fanout is supply & demand current balance.
Step 2:
Case (1,1):
Both $T_1 \& T_2$ on, output = V_{OL}
Supply current from the driver, $I_{R_C} = \frac{V_{cc}-V_{OL}}{R_C} = \frac{3.6-0.2}{0.64} = 5.3125\,mA$
Loads will be cutoff due to low voltage at the base. Thus, demand current, $I_L = 0$.
$\therefore Fanout = \infty$

Case (0,1):
T_1 off & T_2 on, output = V_{OH}
Supply current from the driver, $I_{R_C} = \frac{V_{cc}-V_{OH}}{R_C} = \frac{3.6-1.3}{0.64} = 3.6\ mA$
Loads will be in saturation due to high voltage at the base. Thus, demand current, $I_L = \frac{V_{OH}-V_B}{R_B}$
$= \frac{1.3-0.8}{0.45} = 1.11\ mA$
$\therefore Fanout = floor\left(\frac{I_{R_C}}{I_L}\right) = 3$

Case (1,0): Same as Case (0,1)
Case (1,1): Same as Case (0,1)
Step 3: $\therefore Maximum\ fanout = \min(\infty, 3) = 3$

b) Applying KCL at output node,
$I_{R_C} = N \times I_L \rightarrow \frac{V_{cc}-V_o}{R_C} = 5 \times \frac{V_o-V_B}{R_B} \rightarrow \frac{3.6-V_o}{0.64} = 5 \times \frac{V_o-0.8}{0.45} \rightarrow V_o = 1.145\ V$

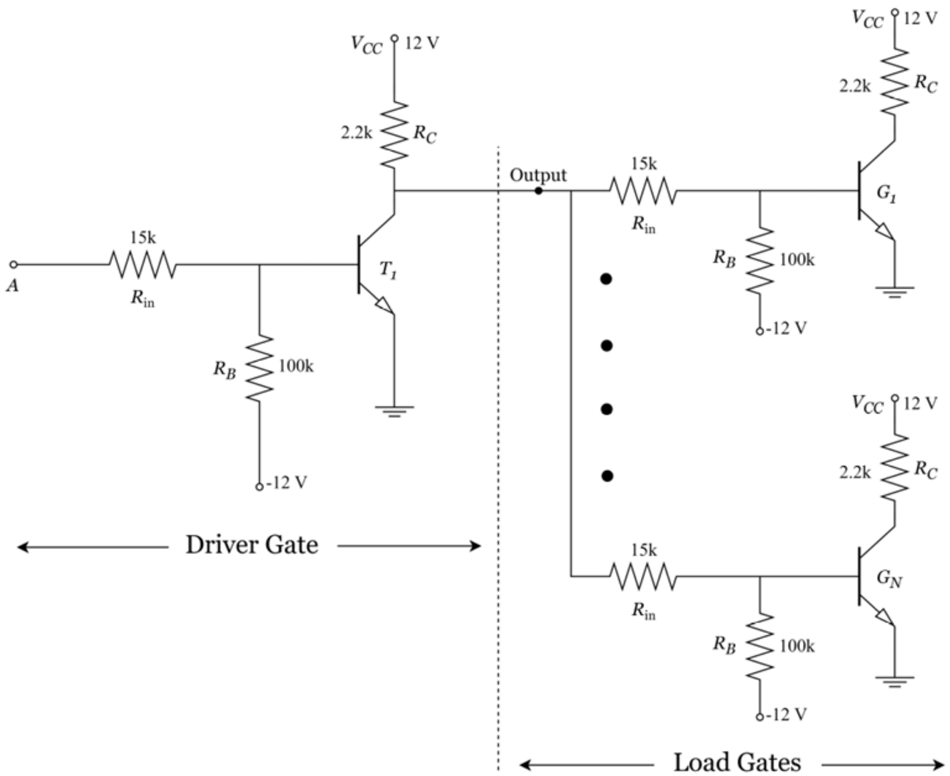
c) For $(\beta_F)_{min}$, $V_{CE} = 0.2\ V, V_{BE} = 0.8\ V$
$I_B = \frac{V_o-V_B}{R_B} = \frac{1.145-0.8}{0.45} = 0.767\ mA$
$I_C = \frac{V_{cc}-V_C}{R_C} = \frac{3.6-0.2}{0.64} = 5.3125\ mA$
$\therefore (\beta_F)_{min} = \frac{I_C}{I_B} = 6.93$
$P_{loads} = 5 \times (V_{cc} - 0) \times I_C = 5 \times 3.6 \times 5.3125 = 95.625\ mW$

d) $P_{driver} = \Delta V_{(base-ground)_A} \times I_{B_A} + \Delta V_{(base-ground)_B} \times I_{B_B} + \Delta V_{cc-ground} \times I_{R_C}$
$= (V_A - 0) \times I_{B_A} + (V_B - 0) \times I_{B_B} + (V_{cc} - 0) \times I_{R_C}$
$= (3.6 - 0) \times \frac{3.6-0.8}{0.45} + (3.6 - 0) \times \frac{3.6-0.8}{0.45} + (3.6 - 0) \times \frac{3.6-V_{OL}}{R_C}$
$= 2 \times 3.6 \times \frac{2.8}{0.45} + 3.6 \times \frac{3.6-0.2}{0.64} = 63.925\ mW$

e) $Y = \overline{A + B}$

Exercise 6

Solution:



a) **Step 1:**
The current from the driver circuit is going outward to the NOT gate loads. Hence, the condition for maximum fanout is supply & demand current balance.
Step 2:
Case (0):
T_1 off, loads on due to high voltage at base.
Supply current from driver, $I_{R_C} = \frac{12-V_{OH}}{R_C} = \frac{12-10}{2.2} = 0.91\ mA$
Demand current, $I_L = \frac{V_{OH}-V_B}{R_{in}} = \frac{10-0.8}{15} = 0.61\ mA$
$\therefore Fanout = floor\left(\frac{0.91}{0.61}\right) = 1$

Case (1):
T_1 on, loads off due to low voltage at base.
Supply current from driver, $I_{R_C} = \frac{12-V_{OL}}{2.2} = 5.363\ mA$

Demand current, $I_L = \frac{V_{OL}-(-12)}{15+100} = 0.106\ mA$

$\therefore Fanout = floor\left(\frac{5.363}{0.106}\right) = 50$

Step 3:

$\therefore Maximum\ fanout = \min(50,1) = 1$

b) KCL at output of driver,

$I_{R_C} = \frac{12-V_O}{R_C} = N \times I_L = 2 \times \frac{V_O - V_B}{R_{in}} \rightarrow \frac{12-V_O}{2.2} = 2 \times \frac{(V_O-0.8)}{15} \rightarrow V_o = 9.46\ V$

c) If the input is high, $V_{CE} = 0.2\ V$. Thus, we have,

$P_{driver} = (V_{cc} - 0) \times I_{R_C} + (12-0) \times I_B + \left(12 - (-12)\right) \times I_{R_B}$

$= (V_{cc} - 0) \times I_{R_C} + (12-0) \times I_B + \left(12 - (-12)\right) \times I_{R_B}$

$= 12 \times \frac{12-0.2}{2.2} + 12 \times \left(\frac{12-0.8}{15} - \frac{12.8}{100}\right) + 12.8 \times \frac{12.8}{100}$

$= 74.86\ mW$

d) $P = (V_{cc} - 0) \times I_{R_C} + \left(0.2 - (-12)\right) \times I_{R_{in}} = (12-0) \times \frac{12-9.46}{2.2} +$
$12.2 \times \frac{0.2-(-12)}{15+100} = 15.15\ mW$

e) **Step 1:**

$V_{OH} = 10\ V, V_{OL} = 0.2\ V$

Step 2:

Determination of V_{IH}:

V_{IH} is the lowest input voltage that would drive the RTL NOT gate loads to forward active mode from saturation. Thus, the marginal condition here is,

$\beta_{loads} = \beta_F = 30$

Now, $I_{C_{load}} = \frac{V_{cc}-V_{OL}}{R_C} = \frac{12-0.2}{2.2} = 5.363\ mA$

$I_{B_{load}} = \frac{V_{IH}-0.8}{15} - \frac{0.8-(-12)}{100}$

$\therefore \beta_F = 30 \rightarrow \frac{5.363}{\frac{V_{IH}-0.8}{15} - \frac{12.8}{100}} = 30 \rightarrow V_{IH} = 5.4015\ V$

Determination of V_{IL}:
V_{IL} is the highest input voltage that would turn the RTL NOT gate on & violate cutoff condition of $V_{BE} < 0.5\ V$. So, the marginal $V_{BE} = V_B = 0.5\ V$
KCL at base,
$\frac{V_{IL}-V_B}{15} = \frac{V_B-0}{100} \rightarrow V_{IL} = \frac{V_B}{100} \times 15 + V_B = 0.575\ V$

Step 3:
$N_H = V_{OH} - V_{IH} = 4.5985\ V$
$N_L = V_{IL} - V_{OL} = 0.375\ V$
$N_M = \min(N_H, N_L) = 0.375\ V$

Exercise 7

Solution:

a) $Y = \overline{A + B}.C$

b) **Step 1:**
Current from load flows toward driver circuit. Thus, the condition for maximum fanout is determined by driving driver BJTs into forward active mode.
Maximum current from load comes when C=0. Thus, we will ignore C=1 cases.
Step 2:

Case (0,0):
High voltage at the negative terminal of D_1, thus it remains off.
$\therefore\ Fanout = \infty$

Case (0,1):
$V_X = V_{OL} = 0.2\ V, D_1$ on
Now, $I_{C_{Q_2}} = I_{C_{R_C}} + N \times I_{D_1} = \frac{12-0.2}{2.2} + N \times \frac{12-0.2-0.7}{100+0.25} = 5.363 + 1.11N$
$I_{B_{Q_2}} = \frac{12-0.8}{15} - \frac{0.8-0}{100} = 0.739\ mA$

Thus, $\beta_{max} = \frac{I_{C_{Q_2}}}{I_{B_{Q_2}}} = \beta_F = 25 \rightarrow 5.363 + 1.11N = 25 \times 0.739$

$\rightarrow N = floor(13.112) = 13$

Case (1,0): Same as Case (0,1)

Case (1,1):

$V_X = V_{OL} = 0.2\,V$, D_1 on

$I_{C_{Q_1}} + I_{C_{Q_2}} = 2I_{C_{Q_1}} = I_{C_{R_C}} + N \times I_{D_1} = \frac{12-0.2}{2.2} + N \times \frac{12-0.2-0.7}{100+0.25}$

$= 5.363 + 1.11N$

$\therefore I_{C_{Q_1}} = \frac{1}{2}(5.363 + 1.11N)$

$I_{B_{Q_1}} = I_{B_{Q_2}} = \frac{12-0.8}{15} - \frac{0.8-0}{100} = 0.739\,mA$

Thus, , $\beta_{max} = \frac{I_{C_{Q_2}}}{I_{B_{Q_2}}} = \beta_F = 25 \rightarrow \frac{1}{2}(5.363 + 1.11N) = 25 \times 0.739$

$\rightarrow N = floor(31.587) = 31$

Step 3:

$\therefore Maximum\ fanout = \min(\infty, 13, 31) = 13$

c) Maximum power will be dissipated in the case (1,1,0). This case turns on all the diodes & BJTs.

$P_{max} = P_{driver} + P_{load} = (12 - 0.2) \times I_{R_C} + (12 - 0) \times I_{R_5}$

$= 12 \times [\frac{12-0.2}{2.2} + \frac{12-V_Y}{100}]$

KCL at Y,

$\frac{(12-V_Y)}{100} = \frac{V_Y-0.2-0.7}{.25} + \frac{V_Y-0-0.7}{.25} \rightarrow V_Y = 0.81\,V$

$\therefore P_{max} = 65.7\,mW$