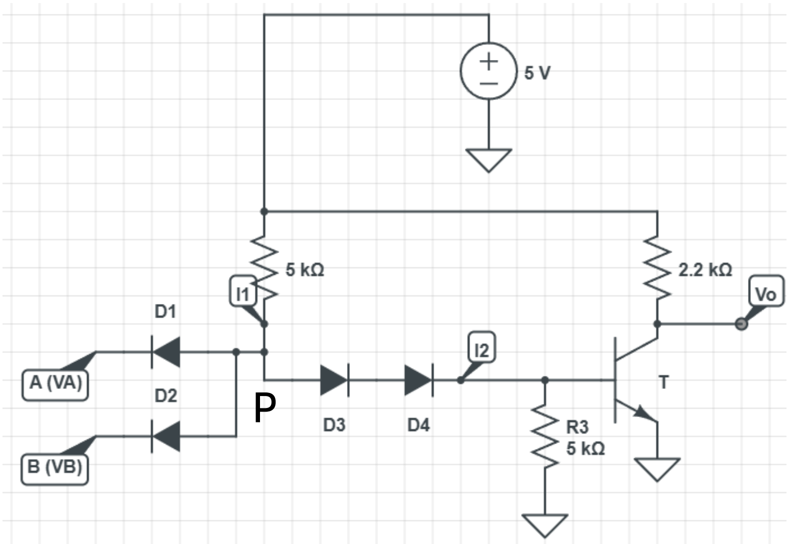
Basic Operation

Exercise 1



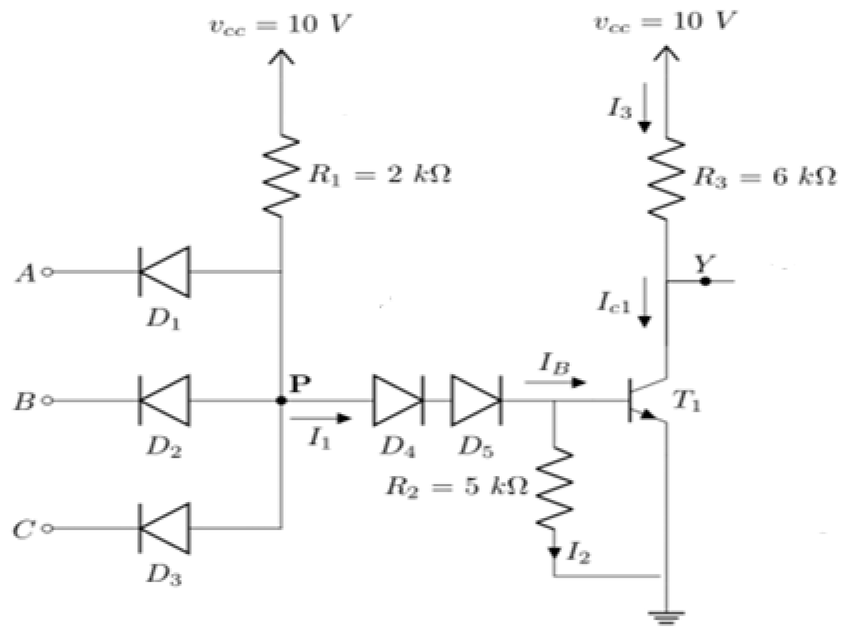
For the DTL NAND gate-
Find all the voltages & currents for all logic cases with verification of assumption.
Assume high input = 5 V, low input = 0.2 V

$V_o = 5\ V, 0.2\ V$

$I_{5\ k\Omega} = 0.82\ mA$

$I_{D_1} = I_{D_2} = 0.41\ mA$

Exercise 2



For the above circuit, $V_{OH} = 9.5\ V, V_{OL} = 0.1\ V, \beta_F = 30$

a) Find the value of β_{min} when all inputs are high.
b) If all the inputs are high, what is the magnitude of noise voltage at input A, that would cause the gate to malfunction?
c) If at least one input is low, what is the magnitude of noise voltage at input A, that would cause the gate to malfunction?

$Ans: a)\ 0.441$
$b)\ 8.4\ V$
$c)\ 0.9\ V$

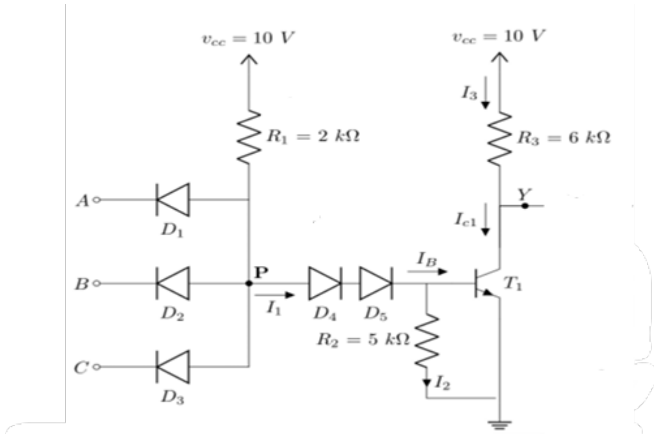
Practice Problem 1:

What is the current through D_B in the circuit of **Exercise 2**, for the logic case (1,0,0)?

$Ans: 2.3\ mA$

Power Dissipation

Exercise 3



a) Find power dissipation for all cases.
b) Maximum & average power dissipation.

Ans: a) 45.54 mW, 55.5 mW
b) 55.5 mW, 46.785 mW

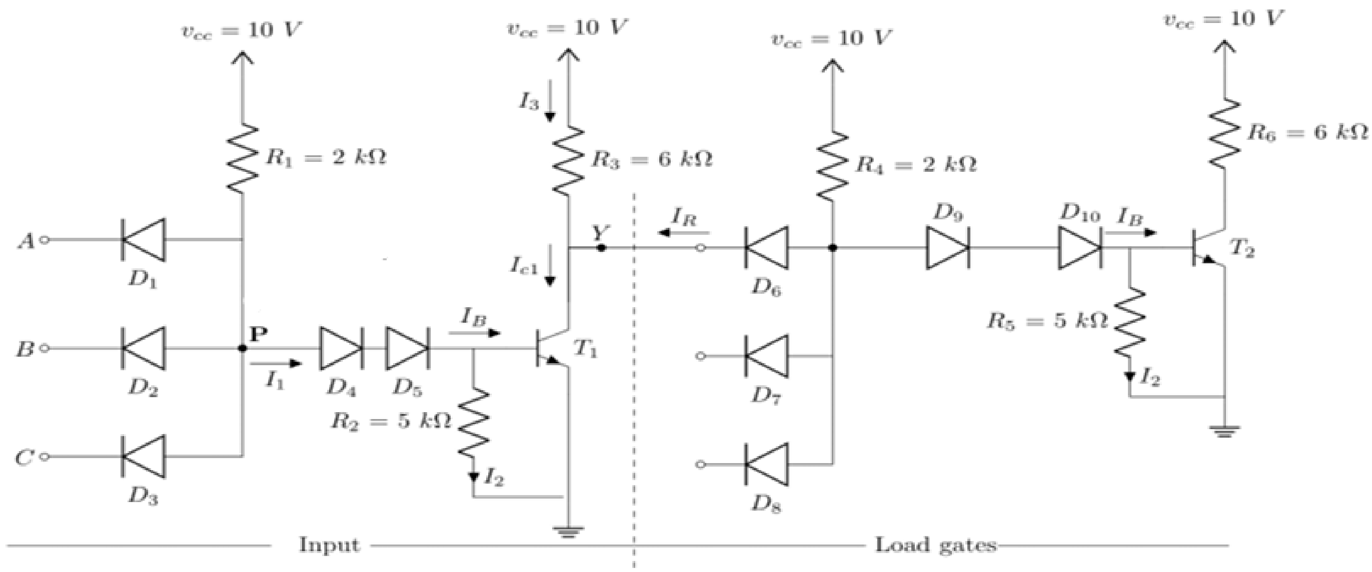
Practice Problem 2:

If the number of inputs to the DTL NAND gate in **Exercise 3**, is increased to 5, what will be the maximum & average power dissipation?

Ans: 55.5 mW, 45.85 mW

Fanout

Exercise 4



For the above circuit- $V_{OH} = 9.5\ V, V_{OL} = 0.1\ V, \beta_F = 30$

a) Find the maximum fanout.
b) Find the maximum power dissipation of the driver circuit, when N (maximum fanout) loads are connected.

Ans: a) 24
b) 66.54 *mW*

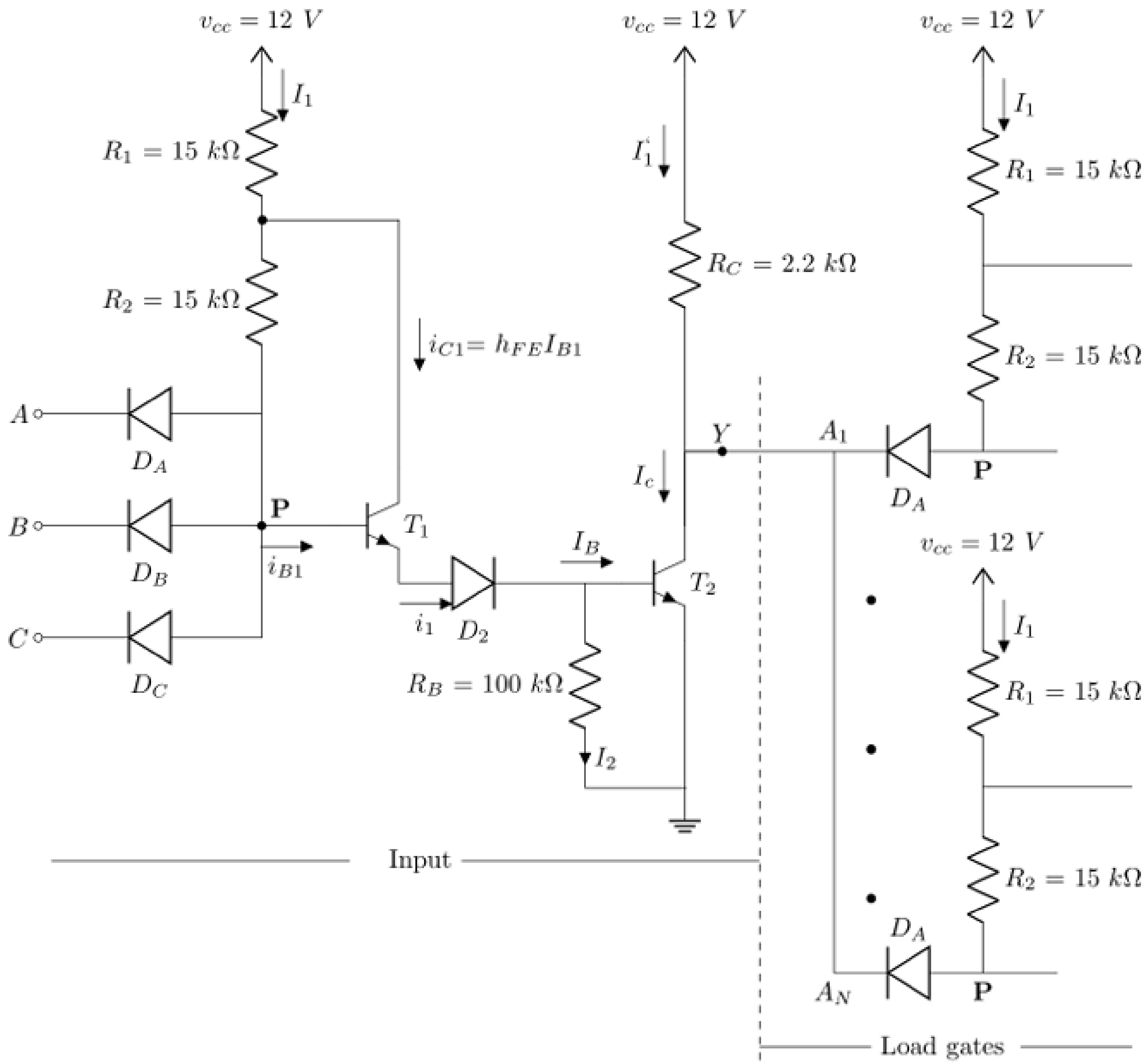
Practice Problem 3:

Find the value of R_3 that would reduce the maximum fanout found in **Exercise 4** to 20.

Ans: 490 Ω

Modified DTL

Exercise 5



For the circuit above- $V_{OH} = 11.5\ V, V_{OL} = 0.2\ V, \beta_F = 30$

a) Find the value of β_{min} when all inputs are high.
b) Find the maximum fanout.
c) Find the power dissipation of the driver for all cases.
d) If all the inputs are high, what is the magnitude of noise voltage at the input A, that would cause the gate to malfunction?

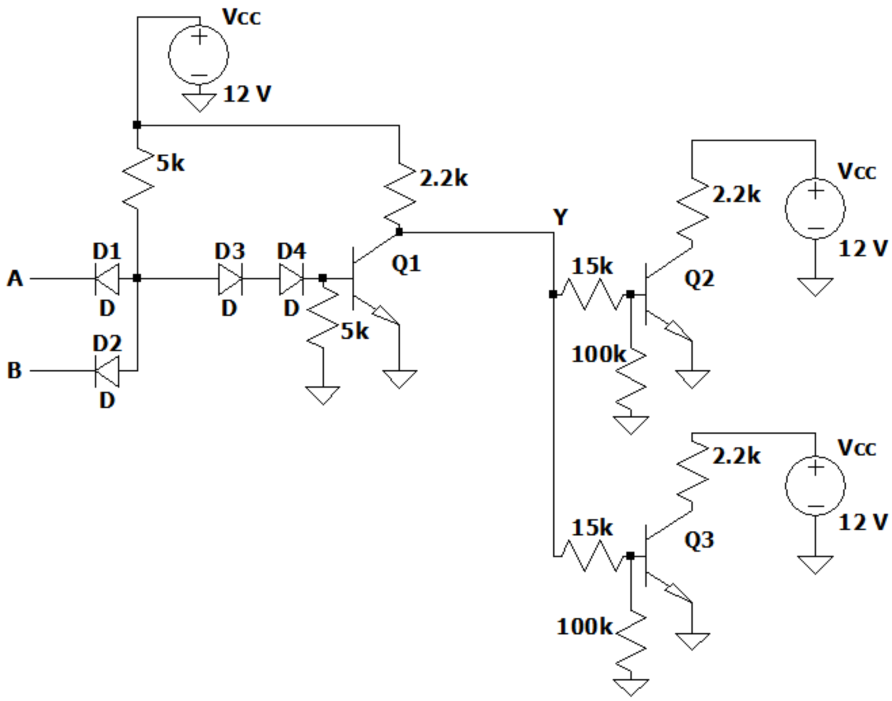
$Ans: a)$ 8.654
$b)$ 35
$c)$ 4.4387 mW, 73.82 mW
$d)$ 10.4 V

Practice Problem 4:

If at least one input is low, what is the magnitude of the noise voltage at input A, that would cause the gate to malfunction in **Exercise 5**?

Ans: 0.8 V

Exercise 6



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

a) When N=1, what logic function do we get from the output of the load?
b) Find the maximum fanout.
c) For N=maximum fanout, find the maximum power dissipation in the loads.

Ans: a) $Y = \overline{AB}$

b) 1

c) 70.5 mW

Exercise 1

Solution:

For transistor T to be in saturation, at least 0.5 V must be between the base & emitter. For D_3 & D_4 both to be on, 0.6+0.6=1.4 V is required. Thus, the required voltage for D_3, D_4 & T to be on, at P,

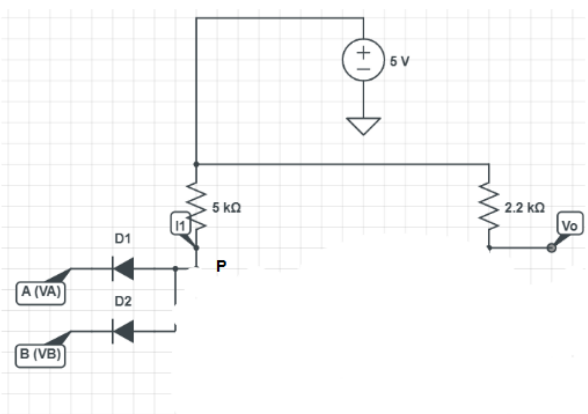
$V_P = 0.6 \times 2 + 0.5 = 1.7\ V$

Case (0,0):

Assuming D_1& D_2 to be on (since low voltage 0.2 V at cathode), we get,

$V_P = 0.2 + 0.7 = 0.9\ V < 1.7\ V$

Thus, D_3, D_4 & T will be off. This leads to an open circuit-



Thus, $V_o = 5\ V$

$I_{5\ k\Omega} = \frac{5-V_P}{5} = \frac{5-0.9}{5} = 0.82\ mA$

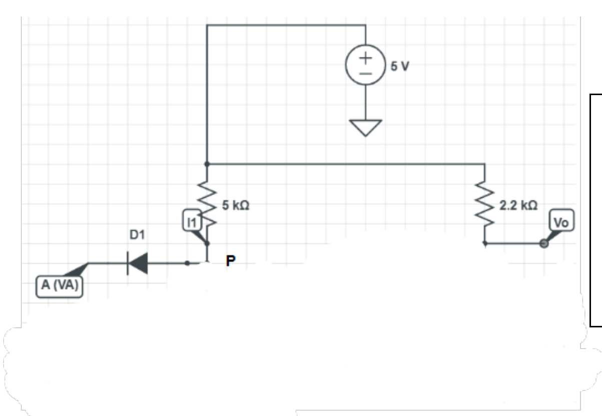
$I_{D_1} = I_{D_2} = \frac{I_{5\ k\Omega}}{2} = 0.41\ mA$

Case (0,1):

Assuming D_1 on & D_2 off,

$V_P = 0.2 + 0.7 = 0.9 < 1.7\ V$ again.

Thus, D_3, D_4 & T will be off. This leads to an open circuit-



$V_o = 5\ V$

$I_{5\ k\Omega} = \frac{5-0.9}{5} = 0.82\ mA$

$I_{D_1} = I_{5\ k\Omega} = 0.82\ mA$

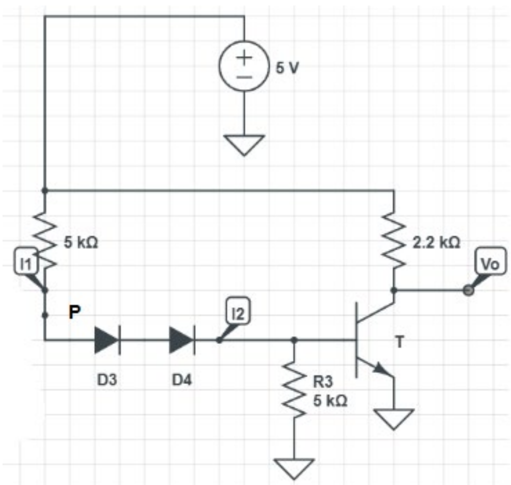
Case (1,0): Same as (0,1)

Case (1,1):

Assuming both D_1 & D_2 off, D_3 , D_4 & T can be assumed on, since there is no bound of V_P from the input diodes. Each diode will have 0.7 V & there will be 0.8 V between the base and emitter of T.

Thus, $V_P = 0.7 + 0.7 + 0.8 = 2.2\ V$

The circuit looks like:



$$V_o = V_{CE_T} = 0.2\ V$$

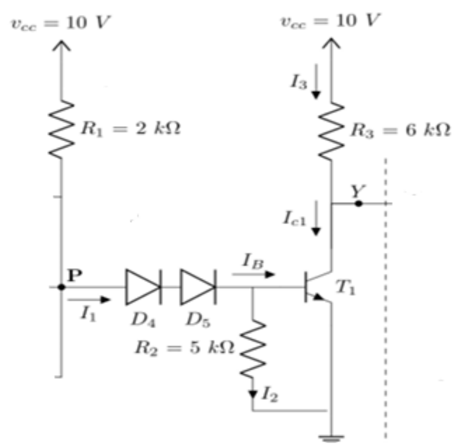
$$I_{5\ V} = I_1 + I_{2.2\ k\Omega} = \frac{5-2.2}{5} + \frac{5-0.2}{2.2} = 2.74\ mA$$

$$I_{R_3} = \frac{0.8}{5} = 0.16\ mA$$

Exercise 2

Solution:

a) D_1, D_2, D_3 all off. $V_P = 0.7 \times 2 + 0.8 = 2.2\ V$



$$I_{R_1} = \frac{10 - V_P}{2} = \frac{10 - 2.2}{2} = 3.9\ mA$$

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

$$\therefore I_B = I_{R_1} - I_B = 3.9 - 0.16$$
$$= 3.74\ mA$$

$$I_C = I_{R_3} = \frac{10 - 0.1}{6} = 1.65\ mA$$

$$\therefore \beta_{min} = \frac{I_C}{I_B} = 0.441$$

This is the minimum value of β to keep T in saturation.

b) Let V_N be the noise voltage at A, that would cause the malfunction.
Thus, total voltage at input A $= 10 + V_N$
It will malfunction if D_A turns on. The marginal voltage across the diode for this situation is the cut-in voltage (0.6 V) of the diode.
Thus, $V_{D_A} = 0.6 = V_P - (10 + V_N\ )$
Now, we found in (a), $V_P = 2.2\ V$ when all inputs are high.
So, $V_N = 2.2 - 0.6 - 10 = -8.4\ V$
Magnitude of $V_N = |-8.4| = 8.4\ V$

c) If at least one input is low, it will cause $D_4, D_5\ \&\ T_1$ to be off.
Thus, $V_P = 0.1 + 0.7 = 0.8\ V$ when no noise is present.
Let, V_N is the noise voltage.
Then, malfunction will happen when due to V_N, V_P will be high enough to turn $D_4, D_5\ \&\ T_1$ on.

$V_{P_{malfunction}} = (V_{D_1})_{cut-in} + (V_{D_2})_{cut-in} + V_{T_{1\gamma}} = 0.6 \times 2 + 0.5 = 1.7\ V$
$V_P = V_N + 0.1 + 0.7 = V_N + 0.8$
Considering marginal condition,
$V_P = V_{P_{malfunction}} \rightarrow V_N + 0.8 = 1.7 \rightarrow V_N = 0.9$

Exercise 3

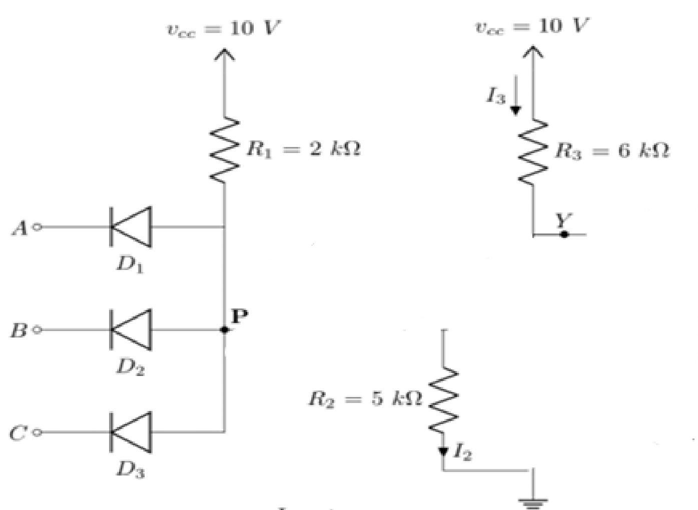
Solution:

a) Case (at least one input low) [(0,0,0), (0,0,1), (0, 1, 0), (0, 1, 1), (1, 0, 0), (1, 0, 1), (1, 1, 0)]:

As we found in **Exercise 2**,

$V_P = 0.1 + 0.7 = 0.8\ V$

D_4, D_5, T_1 all off

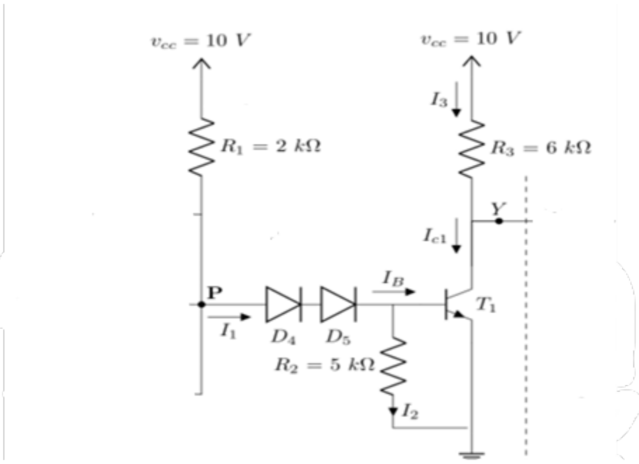


$$\boxed{P = (10 - 0.1) \times I_{R_1} = 9.9 \times \frac{10-0.8}{2} = 45.54\ mW}$$

Case (1,1,1):

From **Exercise 2**, we found that for this case, $V_P = 2.2\ V$

D_4, D_5, T_1 all on



$$\boxed{\begin{aligned} P &= (10-0) \times I_{R_1} + (10-0) \times I_{R_3} \\ &= 10 \times \frac{10-2.2}{2} + 10 \times \frac{10-0.1}{6} = 55.5\ mW \end{aligned}}$$

b) $P_{max} = \max(55.5, 45.54) = 55.5\ mW$

$P_{avg} = \frac{7 \times 45.54 + 55.5}{8} = 46.785\ mW$

Exercise 4

Solution:

a) **Step 1:**
Current flows from loads toward the driver circuit. Thus, the condition for maximum fanout is the marginal case, when T_1 transitions from saturation to forward active.
Step 2:
Case (at least 1 input low at the driver):
Output V_Y is high, which turns D_6 of loads off. Thus, no current enters the driver circuit.
$\therefore\ Fanout = \infty$
Case (all inputs high):
Output V_Y is low, D_6 is on. KCL at Y,
$I_{c1} = I_3 + I_R = \frac{10-0.1}{6} + \frac{10-0.8}{2} \times N = 1.65 + 4.6N$

Here, we have considered the case (1,0,0) at all N loads connected. This is because maximum current will flow through D_6 in this situation, as all other diodes & T_2 will be off. The anode node voltage of D_6 will be 0.8 V for the same reasons described in previous examples (0.1+0.7).

$I_B = I_1 - I_2 = \frac{10-2.2}{2} - \frac{0.8}{5} = 3.74\ mA$

Now, $\beta_{forced} = \frac{I_C}{I_B} = \beta_F = 30 \rightarrow \frac{1.65+4.6N}{3.74} = 30 \rightarrow N =$
$floor\left(\frac{3.74\times30-1.65}{4.6}\right) = 24$

Step 3:

$\therefore\ Maximum\ fanout = \min(\infty, 24) = 24$

b) We see, the difference in this case from the previous problem is that, the load currents will add to the collector current of T_1. The load currents I_R will flow between V_Y & ground. Thus,

$P_{max} = (10-0)\times I_1 + (10-0)\times I_3 + (V_Y - 0)\times I_R \times N$
$= 10\times\frac{10-2.2}{2} + 10\times\frac{10-0.1}{6} + (0.1-0)\times 24\times\frac{10-0.8}{2} = 66.54\ mW$

Exercise 5

Solution:

a) When all inputs are high,

$T_1\ in\ forward\ active\ mode, D_2\ on, T_2\ in\ saturation\ mode$, and load diodes are off. Hence, loads are disconnected.

Thus, $I_{C_{T_2}} = I_1' = \frac{12-0.1}{2.2} = 5.41\ mA$

$I_{B_{T_2}} = i_1 - \frac{0.8}{100} = (\beta_F + 1)\times I_{C_{T_1}} - 0.008 = (30+1)\times\frac{V_{C_{T_1}}-2.2}{15} - 0.008$

Now, KCL at $V_{C_{T_1}}$,

$\frac{V_{C_{T_1}}-2.2}{15} + 30\times\frac{V_{C_{T_1}}-2.2}{15} = \frac{\left(12-V_{C_{T_1}}\right)}{15} \rightarrow V_{C_{T_1}} = 2.51\ V$

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

$\therefore\ \beta_{forced} = \frac{I_{C_{T_2}}}{I_{B_{T_2}}} = 8.654 < \beta_F(30)$

b) **Step 1:**
The current flows from the loads toward the driver. Thus, the condition for maximum fanout is the marginal condition when T_2transitions from saturation to forward active.
Step 2:
Cases with at least one low input:
$T_1, D_2, T_2\ all\ off$
Output is high, and all load diodes will be off.
$\therefore Fanout = \infty$
Case (1,1,1):
$T_1\ in\ forward\ active\ mode, D_2\ on, T_2\ in\ saturation\ mode$
$I_{C_{T_2}} = I_1' + N \times I_L = \frac{12-0.1}{2.2} + N \times \frac{12-0.1-0.7}{15+15} = 5.41 + 0.373N$
$I_{B_{T_2}} = 0.625\ mA$
$\therefore \frac{5.41+0.373N}{0.625} = 30 \rightarrow N = 35$

c) $P_{at\ least\ one\ input\ is\ low\ cases} = (12-0.1) \times I_1 = 11.9 \times \frac{12-0.7-0.1}{15+15} = 4.4387\ mW$
$P_{1,1,1} = (12-0) \times \frac{12-V_{C_{T_1}}}{15} + (0.1-0) \times N \times I_1 = 12 \times \frac{12-2.51}{15} + 0.1 \times 35 \times 0.373 = 73.82\ mW$

d) $V_A + V_{D_A} = V_P = 2.2 \rightarrow 12 + V_N + 0.6 = 2.2 \rightarrow V_N = -10.4\ V$
$\therefore |V_N| = 10.4\ V$

Exercise 6

Solution:

a) $Y = \overline{AB}$

b) **Step 1:**
Current flows from driver to loads. Hence, the condition for maximum fanout is supply-demand balance.

Step 2:
Case (1,1):
$D_3, D_4, Q_1\ on, D_1 \&\ D_2\ off$

Maximum supply current from the driver, $I_{2.2k} = \frac{12-0.2}{2.2} = 5.363\ mA$
Since the output of the driver is low, loads will be off. Thus, demand current = 0.
$\therefore\ Fanout = \frac{5.363}{0} = \infty$
Case (0,0)/(0,1)/(1,0):

$D_3, D_4, Q_1\ off, D_1 \&\ D_2\ on$
Maximum supply current from the driver, $I_{2.2k} = \frac{12-10}{2.2} = 0.91\ mA$
Since the output of the driver is high, loads will be in saturation. Thus demand current,
$I_L = \frac{10-0.8}{15} = 0.613\ mA$
$\therefore\ Fanout = floor\left(\frac{0.91}{0.613}\right) = 1$

Step 3:
$\therefore\ Maximum\ fanout = \min(1, \infty)$

c) N=1 load will be in saturation mode when driver output is high. Thus, maximum power dissipation in the single load,
$P_{max} = (10-0) \times I_L + (12-0) \times I_{C_{load}} = 10 \times \frac{(10-0.8)}{15} + 12 \times \frac{12-0.2}{2.2} = 70.5\ mW$