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,

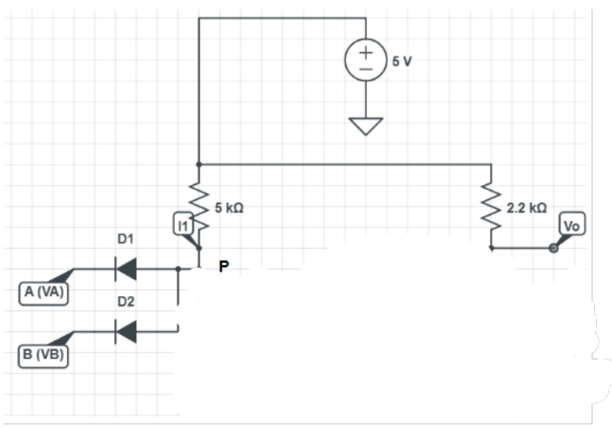
$V_P = 0.6 \times 2 + 0.5 = 1.7\ V$

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, $V_o = 5\ V$

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

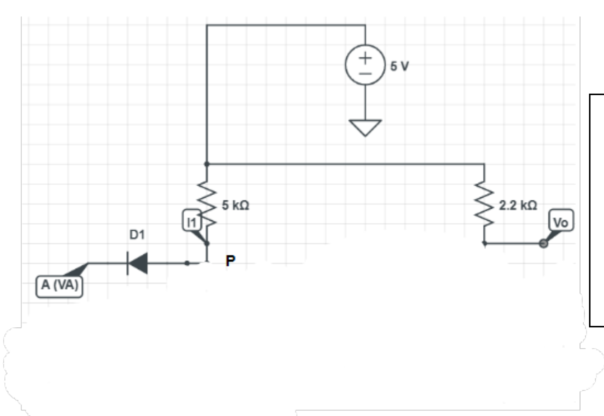
$$I_{D_1} = I_{D_2} = \frac{I_{5\ k\Omega}}{2} = 0.41\ mA$$

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-



$V_o = 5\ V$

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

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

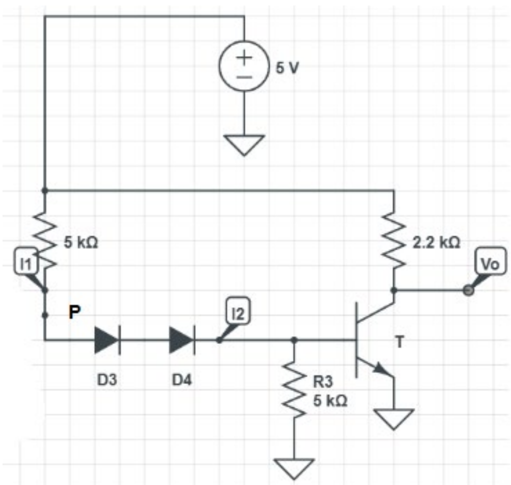
Case (1,0): Same as (0,1)

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:

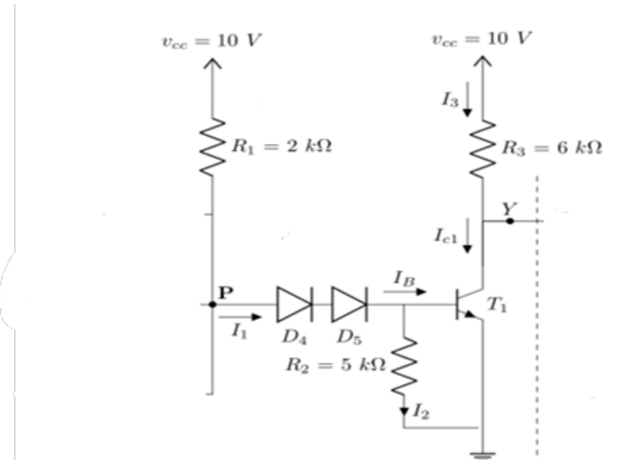


$$V_o = V_{CE_T} = 0.2\ V$$
$$I_{5\ V} = I_1 + I_{2.2\ k\Omega} = \frac{5-2.2}{5} + \frac{5-0.2}{2.2} = 2.74\ mA$$
$$I_{R_3} = \frac{0.8}{5} = 0.16\ mA$$

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.

$V_{P_{malfunction}} = \left(V_{D_1}\right)_{cut-in} + \left(V_{D_2}\right)_{cut-in} + V_{T_{1\gamma}} = 0.6 \times 2 + 0.5 = 1.7\ V$

$V_P = V_N + 0.1 + 0.7 = V_N + 0.8$

Considering marginal condition,

$V_P = V_{P_{malfunction}} \rightarrow V_N + 0.8 = 1.7 \rightarrow V_N = 0.9$

Exercise 3

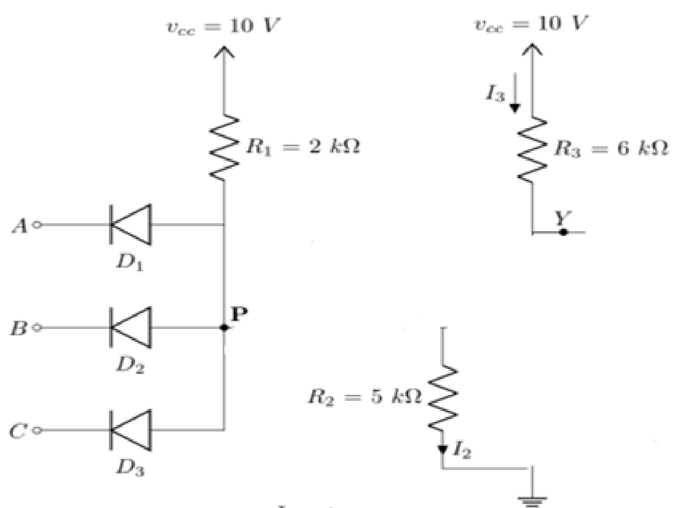
Solution:

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

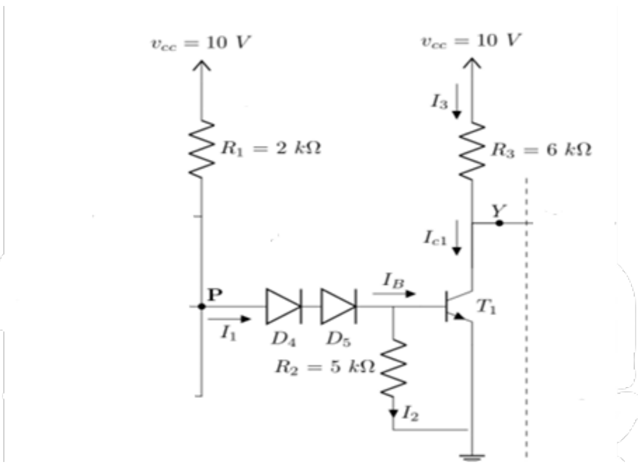


$$\boxed{P = (10 - 0.1) \times I_{R_1} = 9.9 \times \frac{10-0.8}{2} = 45.54\ mW}$$

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) $Y = AB$

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, $I_{2.2k} = \frac{12-0.2}{2.2} = 5.363\ mA$

Demand current by each load, $I_L = \frac{0.2}{115} = 1.74\ \mu A$

$\therefore Fanout = floor(\frac{5.363}{1.74\times10^{-3}}) = 3082$

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,

$P_{max} = (10-0) \times I_L + (12-0) \times I_{C_{load}} = 10 \times \frac{(10-0.8)}{15} + 12 \times \frac{12-0.2}{2.2} = 70.5\ mW$