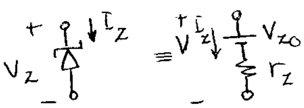
ECI.

Question #1

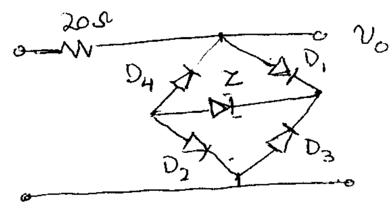
(a) Find V_{Z0}.



$V_Z = 8\ V \Big|_{@\ I = 10\ mA}$

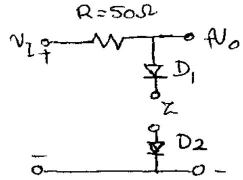
$V_Z = V_{Z0} + r_Z I_Z \Rightarrow V_{Z0} = 8 - 20 \times 10 \times 10^{-3} = 7.8$

(b)



① if $0 < v_I < V_{Z0} + 2V_D = 7.8 + 2 \times 0.7 = 9.2V$

- Z is reverse biased but not in breakdown.
- D_4 and D_3 : off

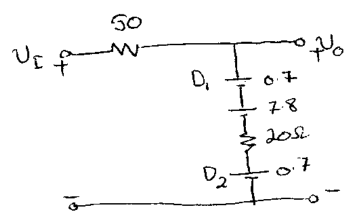


$\Rightarrow \boxed{v_I = v_O}$

② if $v_I \geq V_{Z0} + 2V_D = 9.2$

- D_4 and D_3 : off
- D_1 and D_2 : ON (use CVDM)
- Z : Zener breakdown

$\Rightarrow$



$\Rightarrow v_O = 9.2 + (v_I - 9.2)\frac{20}{20+50}$

$\Rightarrow \boxed{v_O = \frac{5}{7}9.2 + v_I \frac{20}{20+50} = 6.57 + \frac{2v_I}{7}}$

if $v_I = 20 \Rightarrow v_O = 9.2 + \frac{20 - 9.2}{7}$

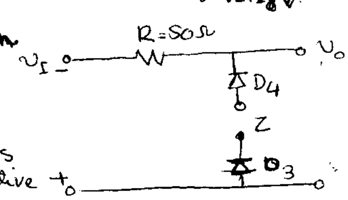
$v_O = 12.28\,V$.

③ if $-9.2 < v_I < 0$

- z is reverse biased but not in breakdown
- D_1 and D_2 : off

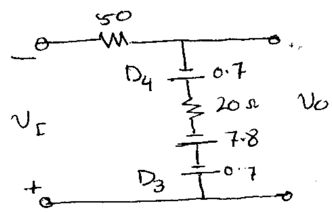
$\boxed{v_I = v_O}$

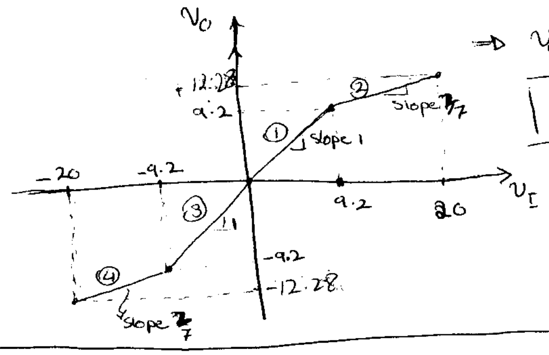
v_I is negative



(4). if $v_I \leq -9.2$

- D_1 and D_2 : off
- D_3 and D_4 : ON (CVDM)
- Z : Zener breakdown





$\Rightarrow v_O = -9.2 + (v_I + 9.2)\frac{20}{50+20} = v_I \times \frac{2}{7} + 9.2(-1.$

$$v_O = -6.57 + \frac{2v_I}{7}$$

(v_I is negative)

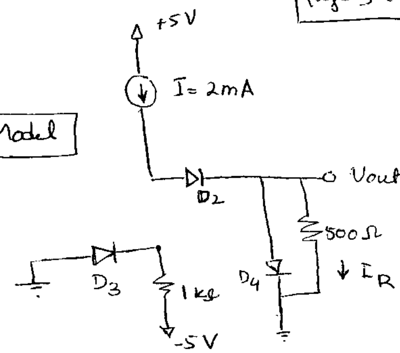
if $v_I = -20 \Rightarrow v_O = -9.2 + \frac{-20+9.}{7}$

$v_O = -12.28V$.

Question #2

(a) D_1 : off $\rightarrow I_{D_1} = 0$

DC Model



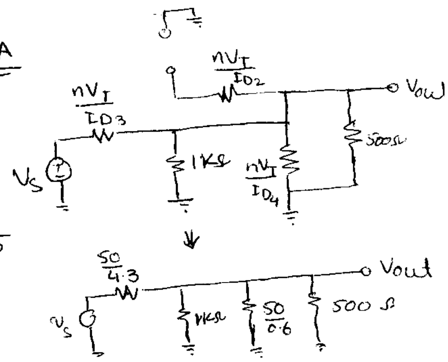
D_3 : $I_{D_3} = \frac{-0.7+5}{1k} = 4.3\,mA$

D_2 : $I_{D_2} = 2\,mA$

D_4 : $I_R = \frac{0.7}{500\Omega} = 1.4\,mA$

$I_{D4} = 2 - 1.4 = 0.6\,mA$

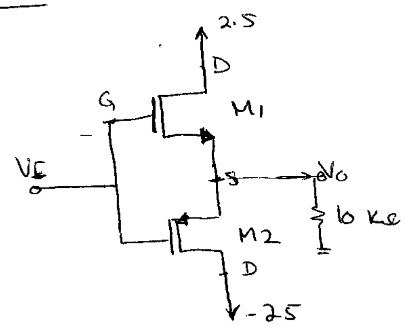
(b) small-signal model



$$\frac{V_{out}}{V_s} = \frac{500 \| 1k\Omega \| 83.3}{500 \| 1k\Omega \| 83.3 + 11.63} = 0.85\ V/V$$

Question #3

(a) $v_I = 0$



M_1: nMOS

sat. $\begin{cases} V_{GS} > V_{tn} \\ V_{DS} > V_{GS} - V_{tn} \end{cases}$

$V_D > V_G - V_{tn}$

$V_{GD} < V_{tn}$

M_2: PMOS

Sat. $\begin{cases} V_{GS} < V_{tp} \\ V_{DS} < V_{GS} - V_{tp} \end{cases}$

$V_D < V_G - V_{tp}$

$V_{GD} > V_{tp}$

If $v_I = 0$ because of symmetry $\Rightarrow$ $\boxed{V_o = 0}$

M1:

$\Rightarrow$ $v_{GS1} = 0 < V_{tn}$ $\Rightarrow$ M1 Cutoff

$\Rightarrow$ M2 $V_{GS2} = 0 > V_{tp}$ $\Rightarrow$ M_2 Cutoff

$\Rightarrow$ $\boxed{i_{DN} = i_{DP} = 0}$

(b) $V_I = 2.5$ V

M_2: $V_{GD} = 2.5 - (-2.5) = 5$ V

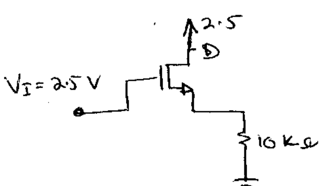
If M_2 is not in cutoff then $V_{GS} < V_{tp} \Rightarrow V_G - V_S < V$

$\Rightarrow V_S > V_G - V_{tp} = 2.5 + (-1) = 3.$

Not possible

Therefore, M_2 is in cutoff $\Rightarrow$ $i_{DP} = 0$

Assume M_1



$V_{GD} = 0 < V_{tn} = 1$

$V_S < 2.5$ V

$\Rightarrow$ Assume M_1 is i Saturation

$$I_{DN} = \frac{1}{2} k_n' \frac{W}{L} (V_{GS1} - V_{tn})^2$$

$$(V_G - V_S - 1)^2, \quad V_G = 2.5$$

$$V_S = I_{DN}\, 10k$$

$\Rightarrow$ $I_{DN} = 0.105$ mA $\Rightarrow$ $V_S = 1.04$ V $\Rightarrow$ $V_{GS} = 2.5 - 1.04 > V_{tn}$

$V_{DS} > 2.5 - V_t$

$\Rightarrow$ Saturation ✓

b) Another discussion

Notice that

$V_{GS1} = V_{GS2} = V_I - V_o = 2.5 - V_o$.

So if $V_{GS1} > V_{tn} > 0$ $V_{GS2} > 0 > V_{tp}$.

M_2 must be cut off.

And notice that for $V_I = 2.5V$.

$V_{GS1} = V_{DS1} = 2.5 - V_o$.

So if M_1 is ON. M_1 must be in saturation.

Assume M_1 sat. M_2 off.

$$\frac{1}{2} k_n' \frac{W}{L} (2.5 - V_o - 1)^2 = \frac{V_o}{10k}$$

$$\frac{1}{2} (1.5 - V_o)^2 = \frac{V_o}{10}$$

$$V_o^2 - 3.2V_o + 2.25 = 0$$

$$V_o = \begin{cases} 2.1\,V & \longrightarrow \text{drop.} \quad V_I - V_o < V_t \\ 1.04\,V & \end{cases}$$

↓

verify M_2

$V_{GS2} = V_I - V_o = 1.16V > V_{tp} = -1V$. M_2 cutoff.

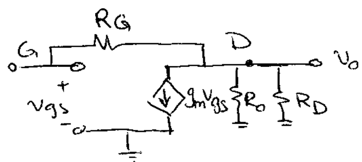
So M_1 sat. M_2 off.

$i_{DN} = \frac{1}{2} k_n' \frac{W}{L} (1.5 - 1.04)^2 = 0.105$ mA

$i_{DP} = 0$

Question #4

a) $\lambda = 0.05\ V^{-1}$ $\quad V_{tn} = 1\ V$



$V_{GS} = V_G - V_S = 3 - 1.5 = 1.5 > V_t = 1$

$V_{DS} = V_D - V_S = 3 - 1.5 = 1.5 > V_{GS} - V_t = 1.5 - 1$

$\Rightarrow$ Saturation

$V_S = 1.5\ V, \quad V_{out}(DC) = 3V$

$I_D = \frac{V_S}{R_S} = \frac{1.5}{7.5} = 0.2\ mA = \frac{5-3}{10k} = 0.2\ mA$

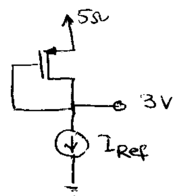
Assume $i_G = 0 \rightarrow A_v = \frac{v_o}{v_{in}} = \frac{-g_m v_{gs}(R_o \| R_D)}{v_{gs}}$, $\quad g_m = \frac{2 I_D}{V_{GS} - V_t} = \frac{2 \times 0.2 \times 10^{-3}}{V_G - V_S - V_t} = \frac{0.4 \times 10^{-3}}{0.5} = 0.8$

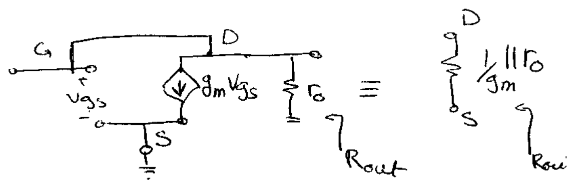
$\quad 3 - 1.5 - 1$

$R_o = \frac{V_A}{I_D} = \frac{1}{0.05} \cdot \frac{1}{0.2 \times 10^{-3}} = \frac{20}{0.2 \times 10^{-3}} = 100\ k\Omega$

b) $A_v = -0.8 \times 10^{-3}(100 \| 10) \times 10^3 = -0.8\ \frac{10 \times 100}{110} = -\frac{80}{11} = -7.27$

c) $I_{Ref} = 0.2\ mA$





$R_{out} = \frac{1}{g_m} \| r_o$

$r_o = \frac{V_A}{I_{ref}} = \frac{20}{0.2 \times 10^{-3}} = 100\ k\Omega$

$g_m = \frac{2 I_{ref}}{V_{GS} - V_{tp}} = \frac{2 \times 0.2 \times 10^{-3}}{V_G - V_S - V_{tp}} = \frac{0.4 \times 10^{-3}}{|3 - 5 - (-1)|} = \frac{0.4 \times 10^{-3}}{1} = 0.4 \times 10^{-3}$

$\frac{1}{g_m} = 2.5\ k\Omega$

$R_{out} = 2.5k \| 100k = \frac{2.5 \times 100}{102.5} k = \frac{250}{102.5}\ k\Omega = 2.44\ k\Omega$