(1) For M_1 to stay in saturation,

$$V_{DS} > V_{GS} - V_{TH},$$

i.e. $$V_{DS} > V_{DD} - V_{TH}$$

$$V_{DS} > 1.4$$

$\because$ $$V_{DS} = V_{DD} - I_{DS}\,(R_L),$$

where $R_L = 1\,k\Omega$.

and $$I_{DS} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS} - V_{TH})^2$$

$$= \frac{1}{2} \times 200 \times 10^{-6} \left(\frac{W}{L}\right)_1 (1.4)^2$$

$\therefore$ $$V_{DS} = V_{DD} - 10^{-4}\left(\frac{W}{L}\right)_1 (1.96) \times 1000$$

i.e. $$1.8 - 1.96 \times 10^{-4}\left(\frac{W}{L}\right)_1 > 1.4$$

$$\frac{0.4}{1.96 \times 10^{-1}} > \left(\frac{W}{L}\right)_1$$

Maximum allowable $\left(\frac{W}{L}\right)_1$ is 2

② To get $I_{DS} = 1\ mA$,

$$\frac{1}{2}\mu C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS} - V_{TH})^2 = 1 \times 10^{-3}\ A.$$

$$\frac{1}{2}(200 \times 10^{-6})\left(\frac{20}{0.18}\right)_1 (V_{GS} - V_{TH})^2 = 10^{-3}$$

$$(V_{GS} - V_{TH})^2 = 0.09$$

$$V_{GS} - V_{TH} = 0.3,$$

$$\text{ie. } V_{GS} = 0.7.,$$

$$\text{Since} \quad V_{GS} = \frac{R_2}{R_1 + R_2} \times 1.8$$

$$0.7 = \frac{R_2}{R_1 + R_2} \times 1.8$$

$$0.7\ R_1 = .\ R_2,$$

$$\therefore \frac{R_1}{R_2} = \frac{11}{7}. \quad \text{———} ①$$

To get input impedance $\geqslant 20k$.

$$R_1 \parallel R_2 \geqslant 20\ k\Omega. \quad \text{———} ②$$

By inspection, setting $R_1 = 55\ k\Omega$ and $R_2 = 35\ k\Omega$ will satisfy both ① and ②.

(3) $V_G = 1.8V$

$V_S = I_{DS}(100)$

$V_D = 1.8 - 1000 I_{DS}$

For M_1 to be in saturation,

$$V_{DS} \geq V_{GS} - V_{TH}$$

$$\therefore V_D - V_S \geq V_G - V_S - V_{TH}$$

$$V_D \geq V_G - V_{TH}$$

$$V_D \geq 1.4V$$

$$\therefore I_{DS,max} = \frac{1.8 - 1.4}{1000} = 0.4mA.$$

and $\therefore V_S = (0.4 \times 10^{-3})(100)$

$$= 0.04V$$

$$V_{GS} = 1.76V$$

$$g_{m,max} = \frac{2 I_{DS,max}}{(1.76 - 0.4)}$$

$$= 0.588mS$$

④ a). $\because \quad V_{RS} = 200\ mV,$

$\therefore \quad I_{DS}\ R_S = 200\ mV$

$$I_{DS} = \frac{0.2}{100}$$

$$I_{DS} = 2\ mA.$$

For M_1 to stay in saturation,

$$V_{DS} \geqslant V_{GS} - V_{TH}.$$

$\because \quad V_{DS} = V_D - V_S$

$$= [1.8 - (2 \times 10^{-3}) \times 500] - 0.2$$

$$= 0.6,$$

$\therefore \quad V_{GS} - V_{TH} \leqslant 0.6,$

Since $\quad I_{DS} = \frac{1}{2}(\mu_n C_{ox})\left(\frac{W}{L}\right)(V_{GS} - V_{TH})^2,$

$\left(\frac{W}{L}\right)$ is min. when $(V_{GS} - V_{TH})$ is max,

$\therefore$ min $\left(\frac{W}{L}\right)_1$ is when $(V_{GS} - V_{TH}) = 0.6V,$

$$2 \times 10^{-3} = \frac{1}{2}(200 \times 10^{-6})\left(\frac{W}{L}\right)_1 (0.6)^2$$

$\therefore$ min. $\left(\frac{W}{L}\right)_1 \approx 56$

b) With $(V_{GS} - V_{TH}) = 0.6$,

$$V_{GS} = 1,$$

$$\therefore V_G = 1 + V_S$$

$$V_G = 1.2V,$$

i.e. $1.8 \times \dfrac{R_2}{R_1 + R_2} = 1.2V,$

$$\frac{R_2}{R_1} = 2 \qquad \text{——} ①$$

Input impedance $= R_2 // R_1$,

i.e. $R_2 // R_1 \geqslant 30k\Omega$ —— ②

Set $R_1 = 50k\Omega$ and $R_2 = 100k\Omega$ will satisfy both ① & ②.

⑤

$$V_S = V_{RS}$$
$$= I_{D1}\,(200) = 0.1V$$

$$I_{DS} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS} - V_{TH})^2$$

$$0.5mA = \frac{1}{2}(200 \times 10^{-6})\left(\frac{20}{0.18}\right)(V_{GS} - V_{TH})^2$$

$$\therefore V_{GS} = 0.612\ V$$

$$\therefore V_G = 0.612 + 0.1$$
$$= 0.712.$$
$$\because V_G = V_{DD} - I_{R1} \times R_1$$

$$R_1 = \underline{\underline{21.76\ k\Omega}}.$$

and $V_{GS} = I_{R2} \times R_2.$

$$\therefore R_2 = \frac{0.712}{0.05 \times 10^{-3}}$$

$$= \underline{\underline{14.24k\ \Omega}}$$

⑥. $g_m = \sqrt{2\beta I_{DS}} = \frac{1}{100}$,

$\because I_{DS} = 1mA, \quad \beta = 0.05$,

and $I_{DS} = \frac{1}{2}\beta(V_{GS} - V_{TH})^2$,

where $\beta = \mu_n C_{ox}\left(\frac{W}{L}\right)$,

$\therefore 1mA = \frac{1}{2}(0.05)(V_{GS} - V_{TH})^2$.

$V_{GS} = 0.6$.

$\because V_{GS} = V_{DS} = V_{DD} - I_{DS} R_D$,

$0.6 = 1.8 - (0.5 \times 10^{-3}) R_D$,

$R_D = \underline{\underline{2.4\ k\Omega}}$

⑦ $I_{DS} = \frac{1}{2}(\mu_n C_{ox})(\frac{W}{L})(V_{GS} - V_{TH})^2$

$0.5 \times 10^{-3} = (100 \times 10^{-6})(\frac{50}{0.18})(V_{GS} - V_{TH})^2$

$\therefore V_{GS} = 0.534V$

$\therefore R_2 = \frac{0.534}{0.05 \times 10^{-3}}$

$R_2 = \underline{\underline{10.68k\Omega}}$

$\because V_{D1} = 1.8 - (1.1 \times I_{DS} \times 2k\Omega) = 0.1 I_{DS}(R_1 + R_2)$,

$\therefore 14k\Omega = R_1 + 10.68k\Omega$.

$\therefore R_1 = \underline{\underline{3320\Omega}}$

⑧ Without defect,

$$V_{GS} = V_{DS}, \quad (\text{i.e. } V_G = V_D)$$

$$\therefore \frac{20k}{10k+20k} \times 1.8 = 1.8 - I_{DS}(1k\Omega)$$

$$I_{DS} = 0.6\,mA.$$

$$\because \quad V_{GS} = V_G - V_S$$
$$= 1.2 - (0.6\times10^{-3})(200)$$
$$= 1.08.$$

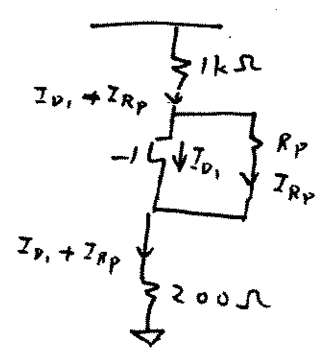
and. $0.6\,mA = \frac{1}{2}(200\times10^{-6})(\frac{W}{L})(V_{GS}-0.4)^2.$

$$\frac{W}{L} \approx 13 //$$

with R_P

$$V_{GS} = V_{DS} + V_{TH},$$
$$1.2 = V_{DS} + 0.4,$$
$$\therefore V_{DS} = 0.8\,V.$$

$$\because V_{DS} = V_{DD} - V_{1k\Omega} - V_{200\Omega},$$



$$\therefore I_{D_1} + I_{R_P} = \frac{1\,V}{1k\Omega + 200\Omega}$$
$$= 0.833\,mA$$

$$\because I_{R_P} = \frac{V_{DS}}{R_P} = \frac{0.8}{R_P}$$

and $I_{D_1} = 0.6\,mA$ (from above)

$$\therefore \quad \frac{0.8V}{R_p} + 0.6\,mA = 0.833\,mA$$

$$R_p \approx 3430\Omega$$

(a) Without defects,

$$V_{GS} = 1.8V$$

i.e. $V_{DS} = (1.8 - 0.1)V$

$$= 1.7V$$

$$I_{DS} = \frac{(1.8-1.7)V}{2000\,\Omega} = 0.05\,mA.$$

$$\therefore\ 0.05\,mA = \frac{1}{2}(200\times10^{-6})\left(\frac{W}{L}\right)(1.8-0.4)^2$$

$$\therefore \left(\frac{W}{L}\right) = 0.255$$

b) With defects,

$$V_{GS} = V_{DS} + 50\,mV$$

$$\therefore\ V_{Rp} = 50\,mV$$

$$I_{Rp} = \frac{50\,mV}{R_p}$$

$$V_{GS} = 1.8\,V - \frac{0.05V}{R_p}\times 30\,k\Omega \quad \text{—— (1)}$$

$$\because\ V_{DD} - \left(I_{DS} - \frac{50\,mV}{R_p}\right)2\,k\Omega = V_{DS}$$

$$V_{DD} - \left(I_{DS} - \frac{50\,mV}{R_p}\right)2\,k\Omega = V_{GS} - 50\,mV \quad \text{—— (2)}$$

$\because \quad I_{DS} = \frac{1}{2}\left(\frac{W}{L}\right)(\mu_n C_{ox})\ (V_{GS} - V_{TH})^2$

$= \frac{1}{2}(0.255)(200 \times 10^{-6})(V_{GS} - 0.4)^2$

$= 2.55 \times 10^{-5}\ (V_{GS} - 0.4)^2$

$\therefore$ From ②,

$$1.8 - \left[2.55 \times 10^{-5}(V_{GS} - 0.4)^2 - \frac{0.2}{R_P}\right]2000$$

$$= V_{GS} - 0.05.$$

From ①, $\quad \frac{0.05}{R_P} = \frac{1.8 - V_{GS}}{30\ 000}$

$$\therefore\ 1.8 - \left[0.051(V_{GS} - 0.4)^2 - \frac{1.8 - V_{GS}}{15}\right] = V_{GS} - 0.3$$

$$1.85 - 0.051 V_{GS}^2 + 0.0408 V_{GS} - 0.00816 + \frac{1.8 - V_{GS}}{15} = V_{GS}$$

$$29.4276 - 15.388 V_{GS} - 0.765 V_{GS}^2 = 0$$

$$\therefore V_{GS} = 1.76\ V$$

$$R_P = \frac{0.05 \times 30\ 000}{1.8 - 1.76}$$

$$\approx 36.3\ k\Omega$$

(10) For M_1,

$$I_x = \frac{1}{2}(200 \times 100^{-6})\left(\frac{W_1}{0.25}\right)(0.8-0.4)^2 \times (1 + 0.1(0.8))$$

$$10^{-3} = 0.16 \times 10^{-4}\left(\frac{W_1}{0.25}\right)(1.08)$$

$$\therefore W_1 \approx 14.5\mu \;//$$

For M_2,

$$0.5 \times 10^{-3} = 0.16 \times 10^{-4}\left(\frac{W_2}{0.25}\right)(1.08)$$

$$\therefore W_2 = 7.25\mu \;//$$

Output resistance $= r_o$

$$= \frac{1}{\lambda} \times \frac{1}{I_D}.$$

$$\therefore \quad r_{o1} = \left(\frac{1}{0.1}\right)\left(\frac{1}{10^{-3}}\right)$$

$$= 10\,k\Omega \;//$$

$$r_{o2} = \left(\frac{1}{0.1}\right)\left(\frac{1}{0.5 \times 10^{-3}}\right)$$

$$= 20\,k\Omega \;//$$

(11)

$$R_{out} = \frac{1}{\lambda}\left(\frac{1}{I_D}\right)$$

$$= \frac{1}{0.5\times10^{-3}\,\lambda} = 20\,k\Omega$$

$$\therefore \lambda = 0.1\ V^{-1}$$

(12) For M_1, $\lambda_1 = \lambda_2 = 0.1$

$$0.5 \times 10^{-3} = \frac{1}{2}(200 \times 10^{-6})\left(\frac{W_1}{0.25}\right)(1-0.4)^2$$

$$W_1 \approx 3.47\ \mu m$$

For M_2,

$$0.5 \times 10^{-3} = \frac{1}{2}(200 \times 10^{-6})\left(\frac{W_2}{0.25}\right)(1.2-0.4)^2$$

$$W_2 \approx 1.95\ \mu m$$

$$\frac{r_{o1}}{r_{o2}} = \frac{\frac{1}{\lambda I_x}}{\frac{1}{\lambda I_y}}$$

$$= 1 \qquad (\because I_x = I_y)$$

$$\therefore r_{o1} = r_{o2}$$

(13) Impedance at source of M_1, $Z_S = \frac{1}{g_{mp}}$

$$g_{mp} = \sqrt{2 \mu_p C_{ox} \left(\frac{W}{L}\right) I_D (1+\lambda V_{DS})}$$

$$= \sqrt{2 \times 100 \times 10^{-6} \left(\frac{10}{0.25}\right)(1+0.1 \times 1.2) I_D}$$

$$= \sqrt{0.0896 \, I_D}$$

$$I_D = \frac{1}{2} \times 100 \times 10^{-6} \times \left(\frac{10}{0.25}\right)(V_{B1} - V_x + 0.4)^2 \times (1 + 0.1 \times 1.2)$$

$$\approx 0.806 \text{ mA}$$

$$\therefore g_{mp} = \sqrt{0.0896 \times 0.806 \times 10^{-3}}$$

$$\approx 8.50 \text{ mS}$$

$$\therefore Z_S \approx 118 \, \Omega$$

(14) $I_X = \frac{1}{2}(100\times10^{-6})\left(\frac{20}{0.25}\right)(1-1.8+0.4)^2$

$= 0.64mA$

$I_Y = \frac{1}{2}(100\times10^{-6})\left(2\times\frac{20}{0.25}\right)(1-1.8+0.4)^2$

$= 1.28mA$

$\because r_o \propto \frac{1}{I}$

and $I_Y = 2I_X$

$\therefore r_{out,M_1} = 2\, r_{out,M_2}$

(15) $|I_{DS1}| = |I_{DS2}|$,

$$\frac{1}{2}(200\times10^{-6})\left(\frac{10}{0.18}\right)(V_B-0.4)^2(1+0.1\times0.9)$$
$$= \frac{1}{2}(100\times10^{-6})(1.8-V_B-0.4)^2(1+0.1\times0.9)$$
$$\times\left(\frac{30}{0.18}\right)$$

$$2(V_B-0.4)^2 = 3(1.4-V_B)^2$$

$$\sqrt{\frac{2}{3}}(V_B-0.4) = (1.4-V_B)$$

$$1.816\,V_B = 1.7264$$

$$V_B = 0.95$$

(16) a) For M_1,

$$I_{D1} = \frac{1}{2}(200 \times 10^{-6})\left(\frac{5}{0.18}\right)(V_B - 0.4)^2 (1 + 0.1 \times 0.9)$$

$\therefore V_B \approx 0.806\ V$

b) There are 3 regions of operation:

For $V_X < V_B - V_{TH1}$, M_1 is in triode.

and $|I_{DS2}| > |I_{DS1}|$

For $|V_X - V_{DD}| > |V_B - V_{DD} - V_{TH2}|$, M_2 is in triode

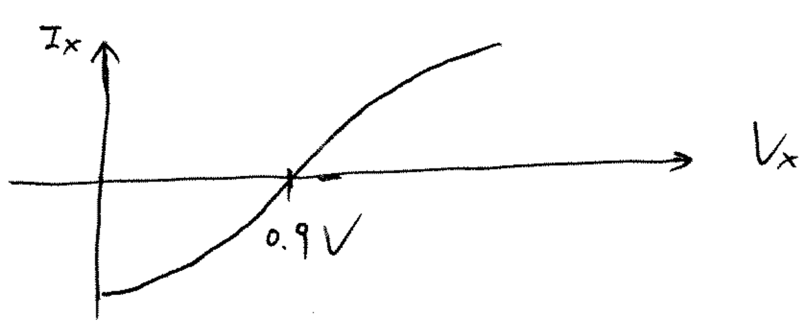
and $I_{DS1} > |I_{DS2}|$

For $V_B - V_{TH} < V_X$ and $|V_X - V_{DD}| < |V_B - V\ \ - V_{TH2}|$

M_1 and M_2 are in saturation.

and $I_{DS1} = |I_{DS2}| = 0.5\ mA$ at $V_X = 0.9\ V$

In all cases, $I_X = I_{DS1} - |I_{DS2}|$



(17) a) $0.5 \times 10^{-3} = \frac{1}{2}(200 \times 10^{-6})(\frac{30}{0.18})(V_{GS} - V_{TH})^2$

$\therefore V_{GS} = 0.573\text{ V}$

$V_{DS} = 1.8 - 0.5 \times 10^{-3} \times 2000$

$= 0.8.$

$\because V_{DS} > V_{GS} - V_{TH},$

M_1 is in saturation.

b) $\because \lambda = 0, \quad r_o = \infty.$

$\therefore A_v = g_m R_D$

$= \sqrt{2 \times (200 \times 10^{-6}) \times \frac{30}{0.18} \times 0.5\text{mA}} \times 2000$

$= 11.55$

(18) a) $0.25 \times 10^{-3} = \frac{1}{2} \times (200 \times 10^{-6}) \left(\frac{20}{0.18}\right) (V_{GS} - 0.4)^2$

$\therefore V_{GS} = 0.55$

b) $V_{DS,\,min} = V_{GS} - V_{TH}$

$= 0.15\,V.$

with $V_{DS} = 0.15V,$

$I_{DS,max} = \frac{1.8 - 0.15}{2000}$

$= 0.825\,mA.$

$\therefore \frac{0.825 \times 10^{-3}}{0.25 \times 10^{-3}} = \frac{\left(\frac{W}{L}\right)'}{\left(\frac{W}{L}\right)},$

where $\left(\frac{W}{L}\right)'$ is the new $\left(\frac{W}{L}\right)$.

$\therefore \left(\frac{W}{L}\right)$ can be increased by 3.3 times.

$\because \quad A_v \propto g_m$

$\propto \sqrt{\beta I}$

$\therefore$ A_v is also increased by 3.3 times.

(since both β & I increase by 3.3 times)

(19) Voltage gain (A_v) = 5,

i.e. $g_m R_D = 5.$

Power $(P) = I_{DS} \times V_{DD}$,

$\because P \leqslant 1\,mW$,

$I_{DS} \times 1.8 \leqslant 1\,mW.$

$I_{DS} \leqslant 0.556\,mA.$

$$g_m = \sqrt{2 \beta I_{DS}}$$

$$\therefore g_{m,max} = \sqrt{2 \times 200 \times 10^{-6} \times \left(\frac{20}{0.18}\right) \times 0.556\,mA}$$

$$= 0.00497\,\Omega^{-1}$$

$$\therefore R_D = \frac{5}{0.00497}$$

$$\approx 1006\,\Omega$$

$\therefore$ This is minimum value required for R_D.

(20) $|A_v| = g_{m1}\ (r_{o1} // r_{o2}) = 10.$

$$r_{o1} = \frac{1}{\lambda_1 I_1} = \frac{1}{0.1 \times 0.5 \times 10^{-3}}$$

$$= 20\,k\Omega.$$

$$r_{o2} = \frac{1}{\lambda_2 I_1} = \frac{1}{0.15 \times 0.5 \times 10^{-3}}$$

$$= 13.3\ k\Omega.$$

$$\therefore g_{m1} = \frac{10}{20k // 13.3k}$$

$$= 0.00138\,\Omega^{-1}$$

$$\because g_{m1} = \sqrt{2\beta_1\ I_{DS}}$$

$$\beta_1 = 0.00192$$

$$200 \times 10^{-6} \left(\frac{W}{L}\right)_1 = 0.00192$$

$$\therefore \left(\frac{W}{L}\right)_1 \approx 9.6$$

b) $$0.5 \times 10^{-3} = \frac{1}{2}(100 \times 10^{-6})(1.8 - V_B - 0.4)^2 \left(\frac{20}{0.18}\right)$$

$$\therefore V_B \approx 1.1\,V$$

(21) $|A_v| = g_{m1}\,(r_{o1} \,//\, r_{o2})$

$g_{m1} = \sqrt{2 \times (200 \times 10^{-6}) \left(\frac{20}{0.18}\right) \times (0.001)}$

(Since V_{ds1} is not given, assume $(1 + \lambda_1 V_{DS1})$ has minimal effect on g_{m1})

$= 6.67 \text{ mS.} \qquad (S = \Omega^{-1})$

$r_{o1} = \frac{1}{\lambda_1 \times I_{D1}}$

$= \frac{1}{0.1 \times 1mA}$

$= 10 \text{ k}\Omega.$

$r_{o2} \simeq \infty$

$(\because \lambda_2 << \lambda_1)$

$\therefore |A_v| = 6.67 \times 10^{-3} \times 10^3 \times 10$

$= 66.7$ //

(22) a) $A_v = g_{m1} \, (r_1 \,//\, r_{o2})$

when length of M_1 and M_2 double,

r_o doubles ($\because r_o \propto \quad \propto L$)

$$r_{o1} \,//\, r_{o2} = \frac{r_{o1} \, r_{o2}}{r_{o1} + r_{o2}}$$

$$\therefore (r_{o1} \,//\, r_{o2}) \propto \frac{L^2}{L},$$

i.e. $(r_{o1} \,//\, r_{o2}) \propto L$.

g_{m1} is constant because both $\left(\frac{W}{L}\right)_{1,2}$ and I_{DS} are constant.

$\therefore$ Voltage gain is doubled.

b) When both length and bias current double, r_o remains the same.

$\because g_{m1} \propto \sqrt{I_{DS}}$.

$\therefore$ Voltage gain increased by $\sqrt{2}$.

23. To get higher voltage gain,

(a) is preferred.

For the same dimensions of transistors and same bias current,

(a) has a high "g_m" than (b),

$\because g_{m1} > g_{m2}$.

(since $\mu_n C_{ox} > \mu_p C_{ox}$)

while $(r_{o1} // r_{o2})$ is the same for both cases.

(24) $A_v = g_{m2}(r_{o1} \,//\, r_{o2})$

$$r_{o1} = \frac{1}{0.15 \times 0.5mA}$$

$$= 13.3 \ k\Omega.$$

$$r_{o2} = \frac{1}{0.05 \times 0.5mA}$$

$$= 40 \ k\Omega.$$

$$\therefore r_{o1} // r_{o2} = 10 \ k\Omega.$$

$$\therefore 15 = \left[\sqrt{2 \times (100 \times 10^{-6})\left(\frac{W}{L}\right)_2 0.5mA}\,\right] \cdot (10 \ k\Omega)$$

$$\left(\frac{W}{L}\right)_2 = 22.5$$

(25) From Eq (7.57),

$$3 = \sqrt{\frac{20/0.18}{(W/L)_2}}$$

$\therefore (W/L)_2 \approx 12.3$ //.

(26)

a) For M_1,

$$0.5\times10^{-3} = \frac{1}{2}(200\times10^{-6})\left(\frac{10}{0.18}\right)(V_{GS_1}-0.4)^2$$

$$\therefore V_{GS1} = 0.7\,V$$

$$\therefore V_{DS1,\,min} = V_{GS1} - V_{TH}$$

$$= 0.3\,V$$

For M_2,

$$V_{S,\,min} = V_{DS1,\,min}$$

$$= 0.3\,V.$$

$$V_{GS,\,max} = 1.8 - 0.3$$

$$= 1.5\,V$$

$$\therefore I_{DS2} = \frac{1}{2}(200\times10^{-6})\left(\frac{W}{L}\right)_2(1.5-0.4)^2$$

$$= 0.5\,mA.$$

$$\left(\frac{W}{L}\right)_2 = 4.13$$

b) $$\text{volt. gain} = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}$$

$$\approx \underline{\underline{3.67}}$$

c) Because with M_1 at the edge of saturation, V_{GS} of M_2 is at maximum (V_S of M_2 is at minimum). Thus, a minimum (W/L) is required to set up the same bias current. With minimum (W/L), g_{m2} is at minimum. Since $A_v \propto \frac{1}{g_{m2}}$, A_v is at maximum.

(27) a) $A_v = \sqrt{\dfrac{(W/L)_1}{(W/L)_2}}$

$\therefore 5 = \sqrt{\dfrac{(W/L)_1}{(2/0.18)}}$

$\therefore (W/L)_1 \approx 277.8$

b) For M_2,

$I_{DS_2} = \frac{1}{2}(200 \times 10^{-6})\left(\frac{2}{0.18}\right)(1.8 - V_{S2} - 0.4)^2$.

$I_{DS_2} = (0.00111)(1.4 - V_{S2})^2$.

$\because V_{S2} =$ $\quad I_{DS_2} = (0.00111)(1.4 - V_{DS1})^2$.

For M_1,

$I_{DS1} = \frac{1}{2}(200 \times 10^{-6})(277.8)(V_{GS1} - 0.4)^2$

$= 0.02778\,(V_{GS1} - 0.4)^2$

$\because I_{DS_1} = I_{DS2}$

$\therefore (0.02778)(V_{GS1} - 0.4)^2 = (0.00111)(1.4 - V_{DS1})^2$

$5(V_{GS1} - 0.4) = (1.4 - V_{DS1})$

At edge of saturation,

$$V_{DS1} = V_{GS1} - 0.4,$$

Let $m = V_{DS1} = V_{GS1} - 0.4.$

$$\therefore 5m = 1.4 - m$$

$$m = 0.233$$

$$\because I_{DS1} = 0.02778(V_{GS1} - 0.4)^2$$

$$= I_{Bias}$$

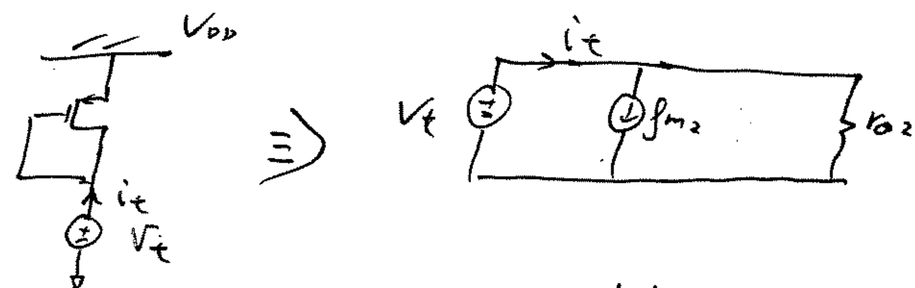
$$\therefore I_{Bias} = 0.02778(0.233)^2$$

$$= 6.48\,mA$$

(28) a). $A_v = -g_{m1} r_{o1} // Z_2$,

where Z_2 is the impedance presented by M_2.

To find Z_2, apply a test voltage (V_T) at the drain of M_2:



From the small-signal model,

$$i_t = g_{m2} V_t + \frac{V_t}{r_{o2}},$$

$$Z_2 = \frac{v_t}{i_t} = r_{o2} // \frac{1}{g_{m2}}.$$

$$\therefore A_v = -g_{m1} \left(r_{o1} // r_{o2} // \frac{1}{g_{m2}} \right)$$

b) $A_v = -g_{m1} (r_{o1} // Z_2 // Z_3)$

where Z_2 and Z_3 are impedances presented by M_2 and M_3 respectively.

From (a) $Z_3 = r_{o3} // \frac{1}{g_{m3}}$

By inspection, $Z_2 = r_{o2}$

$$\therefore A_v = -g_{m1} \left(r_{o1} // r_{o2} // r_{o3} // \frac{1}{g_{m3}} \right)$$

c) $A_v = -g_{m1}\, r_{o1} \,//\, Z_2 \,//\, Z_3$.

Similar to (b),

$$Z_2 = r_{o2},$$

and $Z_3 = r_{o3} \,//\, \frac{1}{g_{m3}}$

(the small signal model of M_3 in this case is equivalent to that of M_2 in (a))

$\therefore\ A_v = -g_{m1}\left(r_{o1} \,//\, r_{o2} \,//\, r_{o3} \,//\, \frac{1}{g_{m3}} \right)$

d). M_2 is in CS arrangement. (similar to (c))

$A_v = g_{m2}\, r_{o2} \,//\, Z_1 \,//\, Z_3$.

$Z_3 = \frac{1}{g_{m3}} \,//\, r_{o3}$

$Z_1 = r_{o1}$

$\therefore\ A_v = g_{m2}\left(r_{o2} \,//\, r_{o1} \,//\, \frac{1}{g_{m3}} \,//\, r_{o3} \right)$

e). $A_v = g_{m2}\left(r_{o2} \,//\, Z_1 \,//\, Z_3 \right)$

$Z_1 = r_{o1}$

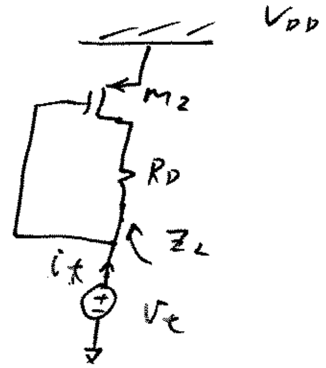
$Z_3 = \frac{1}{g_{m3}} \,//\, r_{o3}$

(recall: impedance looking into source $= \frac{1}{g_m}$)

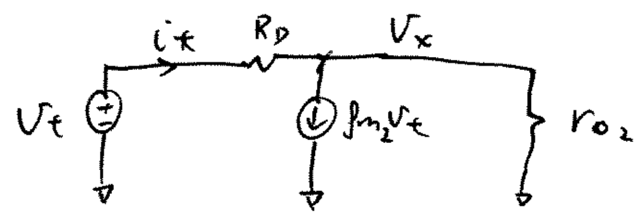
$\therefore\ A_v = g_{m2}\left(r_{o2} \,//\, r_{o1} \,//\, \frac{1}{g_{m3}} \,//\, r_{o3} \right)$

(28) f) $A_v = -g_{m1} (r_{o1} \parallel Z_L)$,

where Z_L is the impedance depicted as follows:



The equivalent small-signal model is:



$$i_t = g_{m2} V_t + \frac{V_x}{r_{o2}},$$

$$V_x = V_t - R_D i_t$$

$$\therefore i_t = g_{m2} V_t + \frac{V_t}{r_{o2}} - \frac{R_D i_t}{r_{o2}}$$

$$i_T \left(1 + \frac{R_D}{r_{o2}}\right) = V_t \left(g_{m2} + \frac{1}{r_{o2}}\right)$$

$$\frac{V_t}{i_t} = \frac{r_{o2} + R_D}{g_{m2} r_{o2} + 1}$$

$$\therefore A_v = -g_{m1} \left(r_{o1} \parallel \frac{r_{o2} + R_D}{1 + g_{m2} r_{o2}} \right)$$

(30) a) From Eq. (7.67)

$$|A_v| = \frac{R_D}{\frac{1}{g_m} + R_S},$$

$$4 = \frac{1000}{\frac{1}{g_m} + \frac{0.2V}{1mA}}$$

$$\frac{4}{g_m} + 800 = 1000$$

$$\therefore g_m = 20 \text{ mS.}$$

$$\therefore 20 \times 10^{-3} = \sqrt{2 \times (200 \times 10^{-6})(\tfrac{W}{L})(1 \times 10^{-3})}$$

$$\therefore W/L = 1000$$

To check if M_1 is in saturation:

$$V_{DS} = V_D - V_S$$
$$= [1.8 - (10^{-3} \times 1k)] - 0.2$$
$$= 0.6 \text{ V}$$

and $10^{-3} = \frac{1}{2}(200 \times 10^{-6})(1000)(V_{GS} - 0.4)^2$

$$V_{GS} = 0.5$$

$\therefore$ $V_{DS} > V_{GS} - V_t$,

i.e. transistor is in operation.

b) $g_m = \sqrt{2 \times (200 \times 10^{-6}) \times \left(\frac{50}{0.18}\right) \times 10^{-3}}$

$\approx 10.5\ mS$

$$|A_v| = \frac{R_D}{\frac{1}{g_m} + R_S},$$

$$4 = \frac{R_D}{\frac{1}{10.5 \times 10^{-3}} + 200}$$

$\therefore R_D \approx 1179\,\Omega.$

To check if M_1 is in saturation:

$$V_{DS} = [1.8 - (1179 \times 10^{-3})] - 0.2$$

$$= 0.421$$

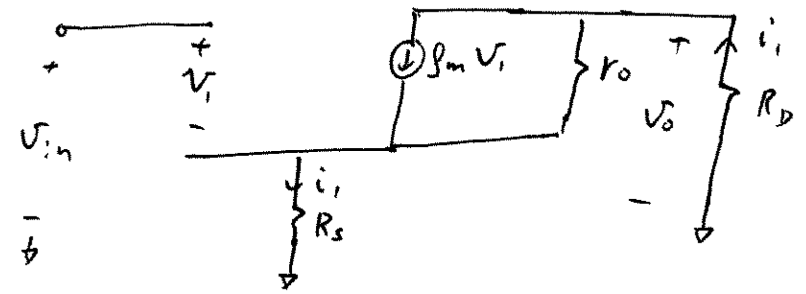
and $10^{-3} = \frac{1}{2} (V_{GS} - 0.4)^2 (200 \times 10^{-6}) \left(\frac{50}{0.18}\right)$

$V_{GS} \approx 0.590$

$\because V_{DS} > V_{GS} - V_t,$

Transistor is in saturation.

(31) The small signal model is:



$$v_o = -i_1 R_D \quad \text{——— (1)}$$

$$i_1 = g_m v_1 + \frac{v_o - v_1}{r_o}$$

$$= \frac{(g_m r_o - 1)v_1 + v_o}{r_o}$$

$$i_1 \approx g_m v_1 + \frac{v_o}{r_o}$$

$$\therefore -\frac{v_o}{R_D} = g_m v_1 + \frac{v_o}{r_o} \quad \text{——— (2)}$$

$$v_{in} = v_1 + i_1 R_s$$

$$\therefore v_1 = v_{in} + \frac{v_o}{R_D} R_s \quad \text{——— (3)}$$

(2) combines with (3):

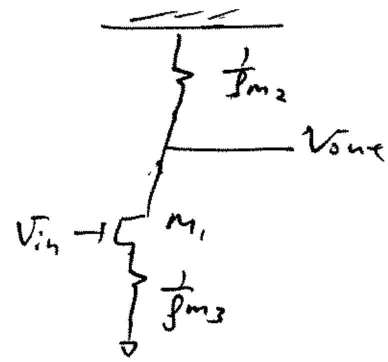
$$-\frac{v_o}{R_D} = g_m v_{in} + g_m v_o \frac{R_s}{R_D} + \frac{v_o}{r_o}$$

$$-v_o\left[\frac{1}{R_D} + g_m \frac{R_s}{R_D} + \frac{1}{r_o}\right] = g_m v_{in}$$

$$\therefore \text{Volt. gain} = \frac{v_o}{v_{in}} = -\left[\frac{g_m}{r_o + g_m R_s r_o + R_D}\right](r_o R_D)$$

//

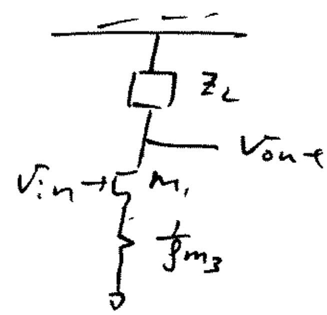
(32) a). Equivalent circuit is:



$$\therefore\ A_v = -\frac{\frac{1}{g_{m2}}}{\frac{1}{g_{m1}} + \frac{1}{g_{m3}}}$$

b) Similar to Prob. 28(f),

Equivalent circuit is:

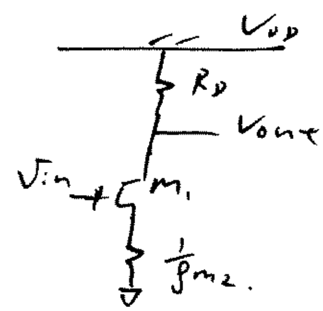


From Prob. 28(f),

$$Z_L = \frac{1}{g_{m2}} \quad (\text{as } r_{o2} \to \infty)$$

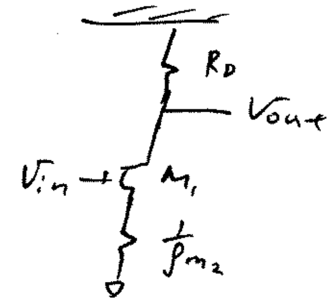
$$\therefore\ A_v = -\frac{\frac{1}{g_{m2}}}{\frac{1}{g_{m1}} + \frac{1}{g_{m3}}}$$

c). Equivalent circuit is:



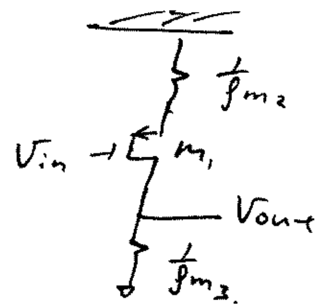
$$\therefore\ A_v = -\frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

(d). Equivalent circuit is



$$A_v = -\frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

(e) Equivalent circuit is



$$A_v = \frac{\frac{1}{g_{m3}}}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

(33) a) From Eq. (7.71),

$$R_{out} = (1 + g_{m1} r_{o1}) \frac{1}{g_{m2}} + r_{o1}$$

b) From Eq. (7.71),

$$R_{out} = (1 + g_{m1} r_{o1}) \frac{1}{g_{m2}} + r_{o1}$$

c) From Eq. (7.71),

$$R_{out} = (1 + g_{m2} r_{o2}) \left(r_{o1} \parallel \frac{1}{g_{m3}}\right) + r_{o2}$$

d) From Eq. (7.71),

$$R_{out} = (1 + g_{m1} r_{o1}) \left(r_{o2} \parallel \frac{1}{g_{m3}}\right) + r_{o1}$$

(34) To find $\left(\frac{W}{L}\right)$,

$$10^{-3} = \frac{1}{2}(200\times10^{-6})\left(\frac{W}{L}\right)(1-0.4)^2 \times (1+0.1\,V_{DS}),$$

where $V_{DS} = 1.8 - 1k\Omega \times 1mA$

$= 0.8V$,

$\therefore \left(\frac{W}{L}\right) \simeq 25.7$

Voltage gain $(A_v) = -g_{m1}(r_{o1} \parallel R_D)$

$$g_{m1} = \sqrt{2(200\times10^{-6})(25.7)\times10^{-3}\times(1+0.1\times0.8)}$$

$= 3.33\ mS$.

$$r_{o1} = \frac{1}{0.1\times10^{-3}}$$

$= 10k\Omega$.

$\therefore A_v = (-3.33\times10^{-3})(10k\Omega \parallel 1k\Omega)$

$= -3.03$

(35) with $\lambda = 0$,

$$10^{-3} = \frac{1}{2}(200 \times 10^{-6})\left(\frac{W}{L}\right)(1-0.4)^2$$

$$\therefore \left(\frac{W}{L}\right) \fallingdotseq 27.8$$

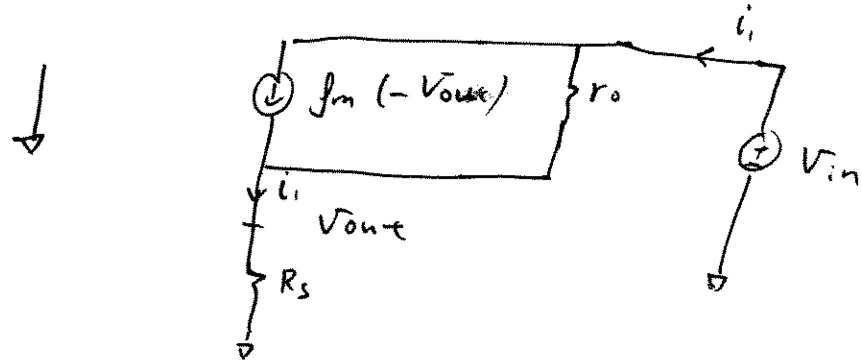
$$A_v = -g_{m_1} R_D$$

$$= -\sqrt{2(200\times10^{-6})(27.8)\times10^{-3}} \times 1000$$

$$= -3.33$$

Without r_o, gain increases due mainly to increase in load resistance.

(3 b) The small-signal circuit is:



$$i_1 = \frac{V_{out}}{R_s} \quad \text{—— (1)}$$

$$i_1 = g_m(-V_{out}) + \frac{V_{in} - V_{out}}{r_o} \quad \text{—— (2)}$$

$$\therefore \frac{V_{out}}{R_s} = -g_m V_{out} + \frac{V_{in}}{r_o} - \frac{V_{out}}{r_o}$$

$$V_{out}\left(\frac{1}{R_s} + g_m + \frac{1}{r_o}\right) = \frac{V_{in}}{r_o}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{r_o}\left(\frac{R_s r_o}{r_o + g_m r_o R_s + R_s}\right)$$

$$= \frac{R_s}{g_m r_o R_s + r_o + R_s}$$

Since $(g_m r_o R_s + r_o) > 0$, the voltage gain < 1.

This is expected: Any variation in V_{in} causes minimal change in the bias current.

$\because V_{out}$ is determined largely by the amount of bias current ($\because V_{out}$ is set by V_{GS1})

$\therefore$ There is almost no variation in V_{out}. (ie. $\frac{V_{out}}{V_{in}} << 1$)

37 a/ $|\text{Voltage gain}| = g_m R_D$

$$= 5$$

$$\therefore \quad g_m = \frac{5}{500}$$

$$= 10\,mS.$$

$$= \sqrt{2(200\times10^{-6})\left(\frac{W}{L}\right)\times10^{-3}}$$

$$\therefore \frac{W}{L} = 250$$

b/ $$V_D = 1.8 - 500\times10^{-3}$$

$$= 1.3V$$

To obtain $V_{DS} \geqslant V_{GS} - V_{TH} + 0.2$,

$$V_D \geqslant V_G - 0.2$$

$$\therefore \quad V_G \leqslant 1.5$$

Also, $I_{R_1+R_2} = 0.1\times10^{-3}A.$

$$\therefore \quad R_1+R_2 = \frac{1.8}{0.1\times10^{-3}}$$

$$= 18\,k\Omega.$$

choose $R_2 = 15\,k\Omega$ & $R_1 = 3\,k\Omega$

c) With twice of (W/L), M_1 will go further away from triode. As (W/L) doubles, & I_{bias} is fixed by the current source, V_{GS} is forced to decrease (so M_1 will have same I_{DS}). Thus, $(V_{GS} - V_{TH})$ decreases, and V_{DS} can be allowed to drop more before M_1 goes into triode.

Gain will be increased by $\sqrt{2}$, because gain $\propto g_m$, and $g_m \propto \sqrt{W/L}$.

(38) a) $V_G = 1.8V.$

$\therefore V_{D,min} = 1.8 - 0.4$ (for M_1 stays in saturation)

$= 1.4V$

$\therefore R_{D,max} = \frac{1.4V}{1mA}$

$= 1.4k\Omega$

b) $|\text{Voltage gain}| = g_m R_D$

$= 5.$

$\therefore g_m = \frac{5}{R_D}$

$= 3.57mS.$

$= \sqrt{2 \times (200 \times 10^{-6}) (\frac{W}{L}) \times 10^{-3}}$

$\therefore (\frac{W}{L}) = 31.9$

(39) To get $R_{in} = 50\Omega$,

$$\frac{1}{g_m} = 50\Omega$$

$$\therefore g_m = 20\,mS.$$

volt gain $(A_v) = g_m R_D$

$$= 4,$$

$$\therefore R_D = \frac{4}{0.02}$$

$$R_D = 200\,\Omega$$

$$\because g_m = \sqrt{2 \times (200 \times 10^{-6}) \left(\frac{W}{L}\right) \times 0.5 \times 10^{-3}}$$

$$\therefore \left(\frac{W}{L}\right) = 2000$$

(40) To get $R_{in} = 50\Omega$,

$$g_m = \frac{1}{50}$$

$$= 20\,mS.$$

Voltage gain $(A_v) = g_m R_D$

$$g_m = \sqrt{2 \times (200 \times 10^{-6}) \left(\frac{W}{L}\right) \times 0.5 \times 10^{-3}}$$

$$\therefore \frac{W}{L} = 2000.$$

$\because$ $V_G = V_B = 1\,V$,

$$V_{D,min} = V_G - V_{TH}$$

$$= 0.6\,V$$

$$\therefore R_{D,max} = \frac{1.8 - 0.6}{0.5 \times 10^{-3}}$$

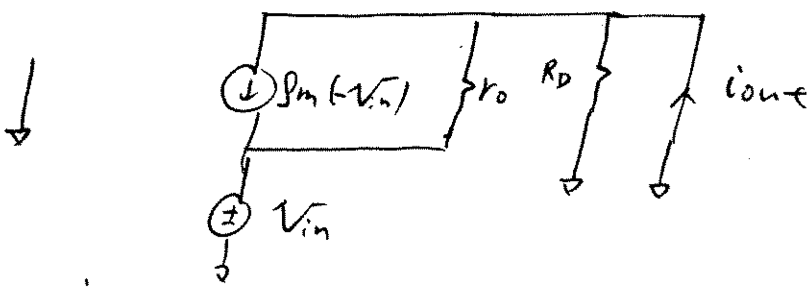
$$= 2400$$

$\therefore$ max. Voltage gain $= 0.02 \times 2400$

$$= 48$$

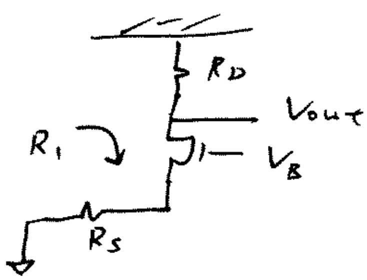
(41) Voltage gain $(A_v) = G_m R_{out}$,
where G_m and R_{out} are the transconductance and output resistance of the circuit respectively.

To find G_m:



$$G_m = \frac{i_{out}}{V_{in}} = g_m + \frac{1}{r_o}$$
$$\approx g_m \quad (\because g_m r_o \gg 1)$$

To find R_{out}:



$$R_{out} = R_D // R_1$$
$$= R_D // [(1 + g_m r_o) R_S + r_o]$$
(from Eq. (7.110))
$$\approx R_D // (g_m r_o R_S + r_o) \quad (\because g_m r_o \gg 1)$$
$$= \frac{g_m r_o R_S R_D + r_o R_D}{R_D + g_m r_o R_S + r_o}$$

$$\therefore \text{Voltage gain} = g_m \left[\frac{g_m r_o R_D R_S + r_o R_D}{R_D + g_m r_o R_S + r_o} \right]$$

(42) a) To get $R_{in} = 50\,\Omega$,

$$g_m = \frac{1}{50} = 20\,mS.$$

To get $R_{out} = 500\,\Omega$,

$$R_D = 500\,\Omega. \quad (\because r_o = \infty)$$

$$\because \quad V_{D,min} = 1.8 - 0.4 = 1.4\,V$$

$$\therefore \quad I_{D,max} = \frac{1.8 - 1.4}{500} = 0.8\,mA$$

b) $$g_m = \sqrt{2 \times (200 \times 10^{-6}) \left(\frac{W}{L}\right) \times 0.8 \times 10^{-3}}$$

$$\therefore \left(\frac{W}{L}\right) = 1250$$

c) $$\text{Voltage gain} = 0.02 \times 500 = 10$$

43 a) To place M_1 100mV away from triode,

$$V_{D,min} = V_G - V_{TH} + 0.1V$$
$$= 1.5V.$$

$$\therefore R_D = \frac{(1.8 - 1.5)V}{1mA}$$

$$= 300\,\Omega$$

b) Voltage gain = $g_m R_D$

$$\therefore g_m = \frac{5}{300}$$

$$\because \quad g_m = \sqrt{2 \times (200 \times 10^{-6}) \left(\frac{W}{L}\right) 10^{-3}}$$

$$\therefore \left(\frac{W}{L}\right) \approx 694$$

(44) a) Voltage gain $(A_v) = \left[\dfrac{\frac{1}{g_{m1}}}{R_S + \frac{1}{g_{m1}}}\right] \dfrac{g_{m1}}{g_{m2}}$

$$= \frac{g_{m1}/g_{m2}}{1 + g_{m1}R_S}$$

b) Voltage gain $(A_v) = g_{m1} Z_2$

(similar to prob. 32(b))

$$= \frac{g_{m1}}{g_{m2}}$$

c) Voltage gain $= \left[\dfrac{\frac{1}{g_{m1}} \parallel R_1}{R_S + \frac{1}{g_{m1}} \parallel R_1}\right] \dfrac{g_{m1}}{g_{m2}}$

d) Voltage gain $= g_{m1}\left[R_D + r_{o3} \parallel \frac{1}{g_{m2}}\right]$,

$\because r_{o3} = \infty$,

gain $= g_{m1}\left[R_D + \frac{1}{g_{m2}}\right]$

e) Voltage gain $= g_{m1}\left[R_D + \frac{1}{g_{m2}}\right]$

(45) a) $$\frac{V_x}{V_{in}} = -g_{m1}\left[R_{D1} \parallel \frac{1}{g_{m2}}\right]$$

$$\frac{V_{out}}{V_x} = g_{m2} R_{D2}$$

$$\therefore \frac{V_{out}}{V_{in}} = -(g_{m2} R_{D2})\left[g_{m1}\left(R_{D1} \parallel \frac{1}{g_{m2}}\right)\right]$$

b) if $R_{D1} \to \infty$,

$$\frac{V_{out}}{V_{in}} = (-g_{m2} R_{D2})\left(\frac{g_{m1}}{g_{m2}}\right)$$

$$= -g_{m1} R_{D2}$$

This is expected, because the circuit reduces to a cascode stage.

($\therefore$ gain is the same as that of a cascode stage.)

(46) $$\frac{v_X}{v_{in}} = \left(R_{D1} \parallel \frac{1}{g_{m2}}\right) g_{m1}$$

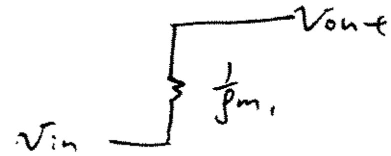
$$\frac{v_{out}}{v_X} = g_{m2} R_{D2}.$$

$$\therefore \frac{v_{out}}{v_{in}} = g_{m1} g_{m2} R_{D2} \left(R_{D1} \parallel \frac{1}{g_{m2}}\right)$$

Similar to prob. (45), voltage gain approaches that of cascode stage as R_{D1} approaches infinity. The gain is $g_{m1} R_{D2}$.

(47) with $\lambda = 0$, M_1 appears as a diode-connected device.

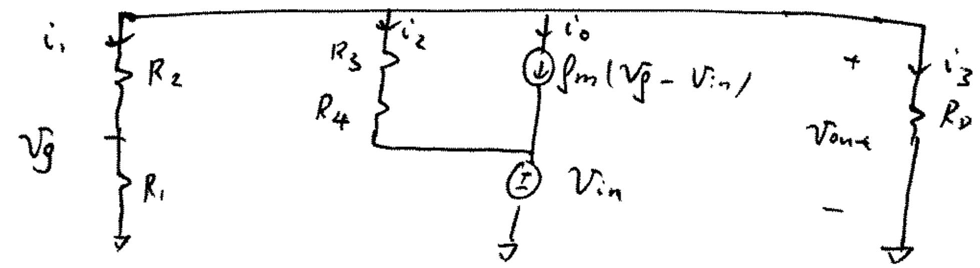
$\therefore$ the circuit becomes:



ie. $\frac{V_{out}}{V_{in}} = 1$

This is not a common-gate (CG) amplifier, because the gate is not fixed. (ie. gate is not at an "a.c. ground")

(48) The small-signal model is:



$$\because -i_0 = i_1 + i_2 + i_3$$

$$-g_m(V_g - V_{in}) = \frac{V_{out}}{R_2 + R_1} + \frac{V_{out} - V_{in}}{R_3 + R_4} + \frac{V_{out}}{R_D}$$

$$g_m\left(V_{in} - \frac{R_1}{R_1+R_2}V_{out}\right) = V_{out}\left(\frac{1}{R_1+R_2} + \frac{1}{R_3+R_4} + \frac{1}{R_D}\right) - \frac{V_{in}}{R_3+R_4}$$

$$V_{in}\left(g_m + \frac{1}{R_3+R_4}\right) = V_{out}\left(\frac{g_m R_1 + 1}{R_1+R_2} + \frac{1}{R_3+R_4} + \frac{1}{R_D}\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{\left(g_m + \frac{1}{R_3+R_4}\right)}{\frac{1}{R_D} + \frac{1}{R_3+R_4} + \frac{g_m R_1 + 1}{R_1+R_2}}$$

(49) Voltage gain $(A_v) = \dfrac{r_o // R_s}{\dfrac{1}{g_m} + r_o // R_s}$

To find I_{DS},

$$I_{DS} = \frac{1}{2}(200 \times 10^{-6})\left(\frac{20}{0.18}\right)(1.8 - V_s - 0.4)^2$$

$$= 0.0111 \; (1.4 - I_{DS} \times 1000)^2$$

$$11100 I_{DS}^2 - 32.08 I_{DS} + 0.021756 = 0$$

$$\therefore I_{DS} = 1.80 \text{mA or } 1.08 \text{mA}$$

Reject $I_{DS} = 1.80$mA.

($\because V_s = 1.80$V $> V_{DD}$)

$$\therefore g_m = \sqrt{2 \times (200 \times 10^{-6}) \times 1.08 \times 10^{-3}}$$

(ignore channel-length modulation)

$$g_m = 0.659 \text{mS}$$

$$r_o = \frac{1}{0.1 \times 1.08 \times 10^{-3}} \approx 9260 \,\Omega$$

$$\therefore A_v = \frac{9260\,\Omega // 1000\,\Omega}{\dfrac{1}{0.659\text{mS}} + 9260\,\Omega // 1000\,\Omega}$$

$$\approx 0.372$$

(5)

$$A_v = \frac{R}{\frac{1}{g_m} + R}$$

$$= 0.8$$

$$\therefore 0.8 = \frac{500}{\frac{1}{g_m} + 500}$$

$$\frac{0.8}{g_m} + 400 = 500$$

$$\therefore g_m = 8\,mS.$$

$$\because g_m = \sqrt{2 \times (200 \times 10^{-6}) \times \left(\frac{30}{0.18}\right) I_{DS}}$$

$$\therefore I_{DS} = 0.96\,mA$$

$$\therefore V_S = 0.96 \times 10^{-3} \times 500$$

$$= 480\,mV$$

To find V_G :

$$0.96 \times 10^{-3} = \frac{1}{2}\,(200 \times 10^{-6})\left(\frac{30}{0.18}\right)(V_G - 0.48 - 0.4)^2$$

$$\therefore V_G = 1.12\,V$$

(51)

$$A_v = \frac{R_s}{\frac{1}{g_m} + R_s}$$

$$= 0.8$$

$$0.8 = \frac{500}{\frac{1}{g_m} + 500}$$

$$\therefore g_m = 8\,mS.$$

$$\because I_{ds} = \frac{1}{2}\beta\,(V_{GS} - V_t)^2,$$

where $\beta = \left(\frac{W}{L}\right)\mu_n C_{ox}$

and $g_m = \beta\,(V_{GS} - V_t)$.

$$\therefore I_{ds} = \frac{1}{2} g_m\,(V_{GS} - V_t)$$

$$= \frac{1}{2} g_m\,(1.8 - I_{ds}(500) - 0.4)$$

$$I_{ds} = 4\times10^{-3}\,(1.4 - 500\,I_{ds})$$

$$\therefore I_{ds} = 1.87\,mA.$$

$$\because g_m = \sqrt{2\,(200\times10^{-6})\,\frac{W}{L}\times1.87\times10^{-3}}$$

$$\therefore \frac{W}{L} \approx 85.7$$

(52). To get $R_{out} = 100\,\Omega$,

$$\frac{1}{g_m} = 100$$

$$\therefore g_m = 10\,mS.$$

$$\because \quad I_{ds} = \frac{1}{2}\beta(V_{GS} - V_{TH})^2.$$

where $\beta = \mu_n C_{ox} \frac{W}{L}$.

and $g_m = \beta\,(V_{GS} - V_{TH})$

$$\therefore I_{ds} = \frac{1}{2} g_m (V_{GS} - V_{TH})$$

$$= \frac{1}{2}(10 \times 10^{-3})(0.9 - 0.4)$$

$$\therefore I_{ds} = 2.5\,mA.$$

$$\because g_m = \sqrt{2 \times (200 \times 10^{-6})\left(\frac{W}{L}\right)(2.5 \times 10^{-3})}$$

$$\therefore \left(\frac{W}{L}\right) = 100$$

(53). To get $R_{out} = 50\Omega$,

$$\frac{1}{g_m} = 50\Omega$$

$$\therefore g_m = 20\,mS.$$

$$\text{Power } (P) = 1.8 \times I_{DS}$$

$$= 2 \times 10^{-3}\,W.$$

$$\therefore I_{DS} = 1.11\,mA.$$

$$\because g_m = \sqrt{2 \times (200 \times 10^{-6})\left(\frac{W}{L}\right)(1.11mA)}$$

$$\therefore \frac{W}{L} = 900$$

(54) $$A_v = \frac{R_L}{\frac{1}{g_m} + R_L}$$

$$\therefore 0.8 = \frac{50}{\frac{1}{g_m} + 50}$$

$$g_m = 80\ mS$$

$$\text{Power } (P) = 1.8 \times I_{DS}$$

$$= 3\ mW$$

$$\therefore I_{DS} = 1.67\ mA$$

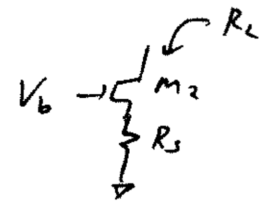
$$g_m = \sqrt{2 \times (200 \times 10^{-6}) \left(\frac{W}{L}\right) (1.67 \times 10^{-3})}$$

$$\therefore \left(\frac{W}{L}\right) = 9600$$

(55) a) $$A_v = \frac{r_{o1} // (R_s + r_{o2})}{\frac{1}{g_{m1}} + r_{o1} // (R_s + r_{o2})}$$

b) $$A_v = \frac{r_{o1} // R_L}{\frac{1}{g_{m1}} + (r_{o1} // R_L)}$$

where R_L is :



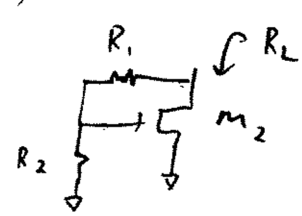
$$R_L = (1 + g_{m2} r_{o2}) R_s + r_{o2} \quad \text{Eq. (7.110)}$$

$$\therefore A_v = \frac{r_{o1} // [(1 + g_{m2} r_{o2}) R_s + r_{o2}]}{\frac{1}{g_{m1}} + r_{o1} // [(1 + g_{m2} r_{o2}) R_s + r_{o2}]}$$

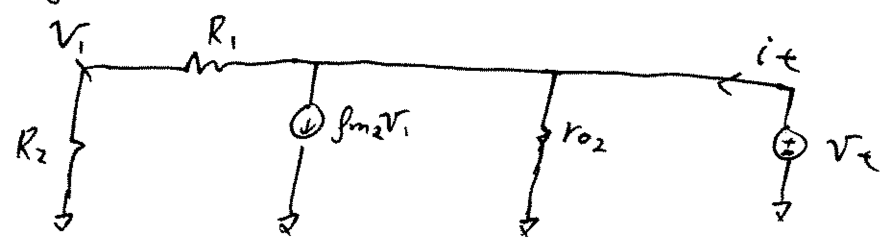
c). $$A_v = \frac{r_{o1} // \frac{1}{g_{m2}}}{\frac{1}{g_{m1}} + (r_{o1} // \frac{1}{g_{m2}})}$$

d) $$A_v = \frac{r_{o1} // R_L}{\frac{1}{g_{m1}} + (r_{o1} // R_L)}$$

where R_L is :



(c) Finding R_L with small-signal model:
(cont'd)



$$R_L = \frac{v_t}{i_t},$$

$$\text{where } i_t = \frac{v_t}{r_{o2}} + g_{m2} v_1 + \frac{v_t}{R_1 + R_2}$$

$$= \frac{v_t}{r_{o2}} + \frac{g_{m2} R_2 v_t}{R_1 + R_2} + \frac{v_t}{R_1 + R_2}$$

$$\therefore R_L = \frac{r_{o2}(R_1 + R_2)}{R_2 + R_1 + r_{o2} + g_{m2} r_{o2} R_2}$$

$$\therefore A_v = \frac{r_{o1} \,//\, \dfrac{r_{o2}(R_1+R_2)}{R_2+R_1+r_{o2}+g_{m2}r_{o2}R_2}}{\dfrac{1}{g_{m1}} + r_{o1} \,//\, \dfrac{r_{o2}(R_2+R_1)}{R_2+R_1+r_{o2}+g_{m2}r_{o2}R_2}}$$

e) $$A_v = \frac{r_{o2} \,//\, \left(\frac{1}{g_{m1}} \,//\, r_{o3}\right)}{\frac{1}{g_{m2}} + r_{o2}\left(\frac{1}{g_{m1}} \,//\, r_{o3}\right)}$$

f) $$A_v = \frac{r_{o1} \,//\, [(1+g_{m2} r_{o2}) r_{o3} + r_{o2}]}{\frac{1}{g_{m1}} + \{r_{o1} \,//\, [(1+g_{m2} r_{o2}) r_{o3} + r_{o2}]\}}$$

5 6

$$\frac{v_x}{v_{in}} = \frac{\frac{1}{g_{m2}}}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}.$$

$$\frac{v_{out}}{v_x} = g_{m2} R_D$$

$$\therefore \frac{v_{out}}{v_{in}} = \frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

b) if $g_{m1} = g_{m2}$,

$$\frac{v_{out}}{v_{in}} = \frac{g_{m1} R_D}{2}.$$

(57) $\because R_{out} = 1k\Omega.$

$\therefore R_D = 1k\Omega.$

$\because A_v = 5$

$= g_{m1} R_D$

$\therefore g_{m1}(1000) = 5$

$g_{m1} = 5mS.$

$\because M_1$ is 00 mV away from triode,

$V_D = (V_G - V_{TH}) + 0.1.$

$V_D = (1.8 - 0.4) + 0.1$

$V_D = 1.5V$

$\therefore I_{DS} = \dfrac{1.8 - 1.5}{R_D} = \dfrac{0.3}{R_D}$

$= 0.3mA$

$\because g_{m1} = \sqrt{2 \times (200 \times 10^{-6}) (\frac{W}{L}) I_{DS1}}$

$\therefore (\frac{W}{L}) \approx 208$

$\therefore R_D = 1k\Omega$, $R_G = 10k\Omega$, $(\frac{W}{L}) = 208$

(58) $\because$ Power $(P) = 2mW$,

$$\therefore I_{DS} = \frac{2 \times 10^{-3}}{1.8}$$

$$= 1.11 \ mA.$$

$\because R_D I = 1$

$$\therefore R_D = 900 \Omega.$$

$\because |\text{gain } (A_v)| = 5$,

$$g_m R_D = 5$$

$$g_m = 5.56 \ mS.$$

$$\because g_m = \sqrt{2(200 \times 10^{-6})\left(\frac{W}{L}\right)(1.11 \times 10^{-3})}$$

$$\frac{W}{L} \approx 69.4$$

(58) $|A_v| = g_m R_L$.

$\therefore$ To achieve maximum gain, use maximum R_L

i.e. set $R_D = 500\,\Omega$.

For maximum g_m, use maximum I_{DS}

(while keeping M_1 in saturation),

i.e. $V_D \geq V_G - V_{TH}$

$1.8 - (I_{DS})(500) \geq 1.8 - 0.4$,

$\therefore \quad I_{DS} \leq \frac{0.4}{500}$

$I_{DS,max} = 0.8\,mA$.

Note: Setting a large R_D in this case would force $I_{DS,max}$ to be lower (in order to keep M_1 in saturation).

But since $A_v \propto R_D$, while $A_v \propto \sqrt{I_{DS}}$, sacrificing I_{DS} to get higher R_D would yield a higher gain.

(60) $\because$ Power $(P) = 2mW$,

$$\therefore I_{DS} = (0.95)\left(\frac{2\times10^{-3}}{1.8}\right)$$

(assuming $(R_1 + R_2)$ consumes 5% of total power)

$$I_{DS} = 1.06mA$$

$$\therefore R_S = \frac{0.2\ V}{1.06\ mA}$$

$$\approx 189\ \Omega$$

$$\because g_m = \beta V_{eff}$$

(where $\beta = \mu_n C_{ox}\left(\frac{W}{L}\right)$; $V_{eff} = V_{GS} - V_{TH}$)

and $I_{DS} = \frac{1}{2}\beta V_{eff}^2$

$$\therefore I_{DS} = \frac{1}{2} g_m V_{eff}.$$

Set $V_{eff} = 0.1\ V$ (< maximum allowable overdrive)

$$1.06\times10^{-3} = \frac{1}{2} g_m (0.1)$$

$$g_m = 21.2\ mS.$$

$$\because |A_V| = \frac{g_m R_D}{1 + g_m R_S} = 4.$$

$$\therefore \frac{21.2\times10^{-3}\times R_D}{1+(21.2\times10^{-3})\times189} = 4$$

$$R_D \approx 947\ \Omega.$$

With $V_{GS} - V_{TH} = 0.1V$,

$$V_{GS} = 0.1 + 0.4V$$
$$= 0.5V$$
$$= V_G - V_S$$

$\therefore V_G - 0.2V = 0.5V$

$\therefore V_G = 0.7V$

To find R_1 & R_2,

$\because I_{R_1+R_2} = (0.05)\left(\frac{2\times10^{-3}}{1.8}\right)$

$= 5.56\times10^{-5}A$.

$\therefore R_1 + R_2 = \frac{1.8V}{5.56\times10^{-5}A}$

$= 32.4k\Omega$.

$V_G = \frac{R_2}{R_1+R_2} \times 1.8 = 0.7V$

$\therefore R_2 = 12.6k\Omega$,

$R_1 = (32.4 - 12.6)k\Omega = 19.8k\Omega$.

To find $(\frac{W}{L})$,

$g_m = \sqrt{2\times200\times10^{-6}\times(\frac{W}{L})\times1.06\times10^{-3}} = 21.2mS$

$\therefore (\frac{W}{L}) = 1060$

$\therefore R_1 = 19.8k$, $R_2 = 12.6k$, $R_S = 189\Omega$, $R_D = 947\Omega$

$(\frac{W}{L}) = 1060$, $I_{DS} = 1.06mA$

(61) Power $(P) = 6\, mW$

$\therefore I_{DS} = (0.95)\left(\frac{6\times10^{-3}}{1.8}\right) = 3.17\, mA$

Gain $(A_v) = 5$,

$\therefore \frac{g_m R_D}{1+g_m R_S} = 5$

$5 = (R_D - 5R_S)\, g_m$

for g_m to be positive,

$R_D > 5R_S$, i.e. $R_S < 50\,\Omega$

choose $R_S = 30\,\Omega$

$\because V_{ov}$ (over drive voltage) $= V_{RS}$

$\therefore V_{ov} = 3.17\times10^{-3} \times 30$

$= 95.1\, mV$.

From $A_v = \frac{g_m R_D}{1+g_m R_S} = 5$,

$g_m = 100\, mS$

$\because g_m = (\mu_n C_{ox})\left(\frac{W}{L}\right) V_{ov}$

$\therefore \left(\frac{W}{L}\right) \approx 5260$

To find R_1 and R_2,

$I_{R_1+R_2} = (0.05)\left(\frac{6\times10^{-3}}{1.8}\right) = 0.167\, mA$

$\therefore R_1 + R_2 = \frac{1.8}{0.167\times10^{-3}} = 10.8\, k\Omega$

$\because \quad V_{GS} - V_{TH} = V_{OV} = 95.1\,mV,$

and $\quad V_S = 95.1\,mV,$

$\therefore (V_G - 95.1\,mV) - 0.4 = 95.1\,mV$

$$V_G = 0.5902$$

$$\because \quad V_G = \frac{R_2}{R_1 + R_2} \times 1.8$$

$$\therefore \quad R_2 = 3.54\,k\Omega$$

$$\text{and} \quad R_1 = 10.8\,k\Omega - 3.54\,k\Omega$$

$$= 7.26\,k\Omega$$

$\therefore R_1 = 7.26\,k\Omega, \quad R_2 = 3.54\,k\Omega, \quad R_S = 30\,\Omega$

$\left(\frac{W}{L}\right) = 5260 \qquad I_{DS} = 3.17\,mA.$

(62) Power $(P) = 2mW$.

$\therefore \quad I_{DS} = \dfrac{2mW}{1.8V}$

$= 1.11\ mA.$

$\because$ M_1 operates 200 mV away from triode

$V_{DS} = (V_{GS} - V_{TH}) + 0.2$

$\therefore \quad V_D = 1.6\ V$

$R_D = \dfrac{V_{RD}}{1.11 \times 10^{-3} A} = \dfrac{(1.8 - 1.6) V}{1.11 \times 10^{-3} A}$

$= 180\ \Omega$

$\because$ gain $(A_v) = \dfrac{g_m R_D}{1 + g_m R_S} = 6$,

$\therefore \quad 6 = (R_D - 6 R_S)\, g_m$,

for $g_m > 0$, $R_D - R_S > 0$, i.e. $R_S < 30\,\Omega$.

Set $R_S = 20\,\Omega$,

$g_m = \dfrac{6}{180 - 6 \times 20} = 100 mS.$

$\because \quad g_m = (\mu_n C_{ox}) \left(\frac{W}{L}\right) (V_{GS} - V_{TH})$

$0.1 = 200 \times 10^{-6} \left(\frac{W}{L}\right) (1.8 - 1.11 \times 10^{-3} \times 20 - 0.4)$

$\therefore \frac{W}{L} \approx 363$

$$R_{in} = \frac{1}{sC_1} + R_1$$

$\because$ $\frac{1}{sC_1}$ is negligible,

$$R_{in} = R_1 = 20\,k\Omega.$$

To make $\frac{1}{sC_1}$ negligible,

$$\frac{1}{sC_1} \ll R_1$$

$$\frac{1}{2\pi(10^6)C_1} \ll .$$

$$\therefore C_1 \ll 7.96\,pF$$

Set $C_1 = 0.796\,pF$

To make $\frac{1}{sC_s}$ negligible,

$$\frac{1}{sC_s} \ll R_s \,//\, \frac{1}{g_m},$$

$$\frac{1}{2\pi(10^6)C_s} \ll 20 \,//\, \frac{1}{100\,ms}$$

$$C_s \ll 23.9\,nF$$

Set $C_s = 2.39\,nF$

$\therefore R_D = 180\,\Omega$, $R_s = 20\,\Omega$, $R_1 = 20\,k\Omega$, $\frac{W}{L} = 363$

$C_1 = 0.796\,pF$, $C_s = 2.39\,nF$

(63). Power $(P) = 2mW$.

$\therefore I_{DS1} = |I_{DS2}| = \dfrac{2mW}{1.8V} = 1.11mA$.

$r_{o1} = r_{o2} = \dfrac{1}{\lambda I_{DS}}$

$= \dfrac{1}{0.1 \times 1.11 \times 10^{-3}}$

$= 9000\,\Omega$.

Gain $(A_V) = g_{m1}\,(r_{o1} \,//\, r_{o2}) = 20$.

$g_{m1}\left(\dfrac{9000}{2}\right) = 20$.

$\therefore g_{m1} = 4.44\ mS$.

Set V_{DS1} (i.e. V_{out}) $= 1.2V$
(which is $< 1.5V$)

$\therefore V_{IN} = V_{GS1} \leq 1.2 + V_{TH}$
(for M_1 to stay in saturation)

Set $V_{GS1} = 1.2V$

$\because g_{m1} = \mu_n C_{ox} \left(\frac{W}{L}\right)_1 (V_{GS1} - V_{TH})$

$\left(\frac{W}{L}\right)_1 = 27.75$

For M_2, $\because M_2$ must be in saturation for $V_{out} \leq 1.5V$.

$\therefore V_{DD} - V_B \leq V_{DD} - 1.5V + V_{TH}$.

$\therefore V_B \geq 1.1V$

Set $V_B = 1.2V$

$$|I_{DS2}| = \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_2 (|V_{GS2}| - V_{TH})^2 (1 + \lambda |V_{DS2}|)$$

$$1.11 \times 10^{-3} = \frac{1}{2} \times 100 \times 10^{-6} \left(\frac{W}{L}\right)_2 (0.6 - 0.2)^2 (1 + 0.1 \times (1.8 - 1.5))$$

(assuming $V_{out} = 1.5V$)

$$\therefore \left(\frac{W}{L}\right)_2 \approx 135$$

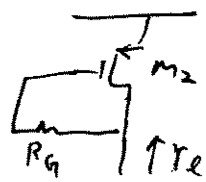
$\therefore \left(\frac{W}{L}\right)_1 = 27.75 \qquad \left(\frac{W}{L}\right)_2 = 135$

$V_{IN} = 1.2 \qquad V_b = 1.1$

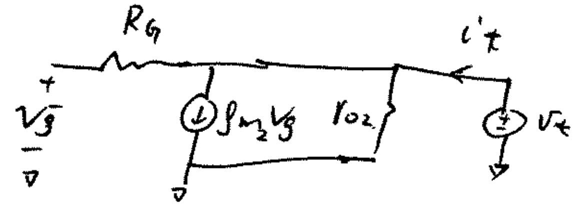
$I_{DS1} = I_{DS2} = 1.11mA$

(64) a) gain $(A_v) = -g_{m1}\, r_{o1} \,//\, r_\ell$,

where R_L is:



The small-signal model is:



$$r_\ell = \frac{v_t}{i_t} = r_{o2} \,//\, \frac{1}{g_{m2}}$$

$$\therefore \quad A_v = -g_{m1}\; r_{o1} \,//\, r_{o2} \,//\, \frac{1}{g_{m2}}$$

b) $\text{Power} = 3mW$

$$\therefore \; I_{DS1} = |I_{DS2}| = \frac{3mW}{1.8V}$$

$$= 1.67mA.$$

$$V_{OUT} = V_{G2} = \frac{V_{DD}}{2}$$

$$\therefore \; V_{GS2} = -0.9V$$

$$I_{DS2} = \frac{1}{2}(100\times 10^{-6})\left(\frac{W}{L}\right)_2 \times \left(|-0.9| - V_{TH}\right)^2 \times \left(1 + 0.1 \times \frac{V_{DD}}{2}\right)$$

$$\therefore \left(\frac{W}{L}\right)_2 \approx 122.$$

$$g_{m2} = \mu_p C_{ox} \left(\frac{W}{L}\right)_2 (V_{GS2} - V_{TH})$$

$$= 6.1 \, mS.$$

From (a), $|A_v| = \frac{1}{g_{m1}} \times (r_{o1} \,//\, r_{o2} \,//\, \frac{1}{g_{m2}})$

$$\because r_{o1} = \frac{1}{0.1 \times 1.67 \times 10^{-3}} = 6000 \, \Omega$$

$$r_{o2} = \frac{1}{0.2 \times 1.67 \times 10^{-3}} = 3000 \, \Omega$$

$$\therefore 15 = g_{m1} \left(6000 \,//\, 3000 \,//\, \frac{1}{6.1 mS}\right)$$

$$g_{m1} = 99 \, mS$$

$$g_{m1} = \sqrt{2\left(\frac{W}{L}\right)_1 \mu_n C_{ox} I_{DS1}}$$

$$\therefore \left(\frac{W}{L}\right)_1 = 14672$$

$$\therefore \left(\frac{W}{L}\right)_1 = 14672, \quad \left(\frac{W}{L}\right)_2 = 122, \quad I_{DS1} = |I_{DS2}| = 1.67 mA.$$

(65) a) Impedance looking into drain of M_2

$$= (1 + g_{m2} r_{o2}) R_s + r_{o2}$$

$$= 10\, r_{o1}$$

Assume $g_{m2} r_{o2} \gg 1$,

$\therefore g_{m2} r_{o2} R_s + r_{o2} \approx 10 r_{o1}$

$\because r_{o1} = r_{o2}$ $(\lambda_1 = \lambda_2$ and $I_{DS1} = |I_{DS2}|)$

$\therefore g_{m2} R_s + 1 = 10$

$g_{m2} R_s = 9$ ——— (1)

Given $V_B = 1V$,

set $|V_{GS2}| = 0.6\,V$ (ie. $V_{GS2} - V_{TH} = 0.2V$)

$\therefore V_{S2} = 1.6V$

$\therefore V_{R_S} = 1.8V - 1.6V = 0.2V$

$\because$ Power $= 2mW$

$I_{DS1} = |I_{DS2}| = \frac{2mW}{1.8V} = 1.11 mA$.

$\therefore R_s = \frac{V_{R_S}}{1.11 \times 10^{-3}} \approx 180\,\Omega$

From (1), $g_{m2} = \frac{9}{180} = 50\ mS$.

$\because g_{m2} = \left(\frac{W}{L}\right)_2 (100 \times 10^{-6}) (V_{GS2} - V_{TH})$

$\therefore \left(\frac{W}{L}\right)_2 = 2500$

b). $|\text{gain } (A_v)| = g_{m1} (r_{o1} \,//\, 10 r_{o1})$

$$30 = g_{m1} (0.909 \, r_{o1})$$

$$r_{o1} = \frac{1}{0.1 \times 1.11 \times 10^{-3}}$$

$$= 9009 \, \Omega$$

$$\therefore g_{m1} = 3.66 \text{ mS.}$$

$$\because g_{m1} = \sqrt{2 (\mu_n C_{ox}) \left(\frac{W}{L}\right)_1 \times I_{DS1}}$$

$$\therefore \left(\frac{W}{L}\right)_1 \approx 30.2$$

66.

Power $= 1mW$

$\therefore I_{DS1} = I_{DS2} = \frac{1mW}{1.8V} = 0.556\,mA.$

Volt. gain $(A_v) = -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}$

$= -4$

set $V_{GS1} = V_{GS2} = \frac{V_{DD}}{3}$.

$\because I_{DS1} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS1} - V_{TH})^2$

$\therefore \left(\frac{W}{L}\right)_1 = 139$

$\therefore \left(\frac{W}{L}\right)_2 = \frac{139}{16}$

$\approx 8.69.$

and $V_{IN} = \frac{V_{DD}}{3} = 0.6V$

(67) $R_{in} = \frac{1}{g_{m1}} = 50\Omega$

$\therefore g_{m1} = 20\,mS$

Volt. gain $(A_v) = g_m R_D = 5$

$\therefore R_D = 250\Omega$

Power $= 3\,mW$

$\therefore I_{DS1} = \frac{3\,mW}{1.8\,V}$

$= 1.67\,mA$

$\because g_{m1} = \sqrt{2 \times \mu_n C_{ox} \times \left(\frac{W}{L}\right)_1 I_{DS1}}$

$\left(\frac{W}{L}\right)_1 = 600$

$\therefore R_D = 250\Omega, \quad \left(\frac{W}{L}\right)_1 = 600 \quad I_{DS} = 1.67\,mA.$

(68) Power $(P) = 2mW$

$$I_{DS_1} = \frac{2mW}{1.8V} = 1.11 mA.$$

$\because$ M_1 operates 100mV away from triode,

$$V_{DS} = V_{GS} - V_{TH} + 0.1$$

$$V_D = 1.8 - 0.4 + 0.1 = 1.5V$$

$$\therefore R_D = \frac{1.8 - 1.5}{1.11 \times 10^{-3}} \approx 270\,\Omega$$

Volt. gain $(A_v) = g_{m_1} R_D = 4$

$$\therefore g_{m_1} = 14.8 mS$$

$$\because I_{DS} = \frac{1}{2} g_{m_1} \times (V_{GS_1} - V_{TH})$$

$$V_{GS} \approx 0.550 V$$

Set $V_G = 0.9V$. $\therefore V_S = (0.9 - 0.55)V = 0.35V$

$$R_S = \frac{0.35}{1.11 \times 10^{-3}} \approx 315\,\Omega$$

To find $\left(\frac{W}{L}\right)_1$: $g_{m_1} = \mu_n C_{ox} \left(\frac{W}{L}\right)_1 (V_{GS_1} - V_{TH})$

$$\therefore \left(\frac{W}{L}\right)_1 \approx 135$$

$\therefore \left(\frac{W}{L}\right)_1 = 135$, $V_{IN} = 0.9V$. $R_S = 315\,\Omega$, $R_D = 270\,\Omega$

$I_{DS} = 1.11mA$

(69) Power $= 5\,mW$

$\therefore I_{DS_1} = \frac{5 \times 10^{-3}}{1.8} = 2.78\,mA$

gain $(A_v) = g_m R_D = 5$

$V_{G_1} = V_{OUT} = 1.8 - I R_D$

$V_{S_1} = I R_S$

Let $R_S = \frac{10}{g_{m_1}}$

$\therefore V_{S_1} = \frac{10 I}{g_{m_1}}$

$\therefore V_{GS_1} = 1.8 - I R_D - \frac{10 I}{g_{m_1}}$

$\because I_{DS} = \frac{1}{2} g_m (V_{GS} - V_{TH})$

$2.78 \times 10^{-3} = \frac{g_m}{2} \left(1.8 - 2.78 \times 10^{-3} R_D - \frac{2.78 \times 10^{-2}}{g_m} \right)$

$= 0.9\, g_m - 1.39 \times 10^{-3} g_m R_D - 1.39 \times 10^{-2}$

$\because g_m R_D = A_v = 5$

$2.78 \times 10^{-3} = 0.9\, g_m - 6.95 \times 10^{-3} - 1.39 \times 10^{-2}$

$\therefore g_m \approx 26.3\,mS$

and $R_D = \frac{5}{26.3 \times 10^{-3}} \approx 190\,\Omega$

$R_S = \frac{10}{26.3 \times 10^{-3}} = 380\,\Omega$

$\because g_m = \sqrt{2 \mu_n C_{ox} (\frac{W}{L}) I_{DS_1}} \Rightarrow (\frac{W}{L}) \approx 622$

(70) $\because \quad R_s \approx \frac{10}{g_m}$,

$\therefore \quad R_{in} \approx \frac{1}{g_m} = 50\,\Omega$

i.e. $\quad g_m = 20\,mS$ //

$$|\text{gain } (A_v)| = \frac{g_m R_D}{1 + g_m R_s} = 4$$

$$g_m R_D = 4 + 4 g_m R_s$$

$$R_D = \frac{4 + 0.08 R_s}{0.02} = 200 + 4 R_s \quad \text{——} (1)$$

$\because \quad R_s I_D + V_{GS} - V_{TH} + 0.25 = 1.8 - I_D R_D$ (given)

and $\quad I_D = \frac{1}{2} g_m (V_{GS} - V_{TH})$

i.e. $\quad V_{GS} - V_{TH} = 100\, I_D$

$\therefore \quad R_s I_D + 100\, I_D + 0.25 = 1.8 - I_D R_D$

From (1):

$$R_s I_D + 100 I_D + 0.25 = 1.8 - 200 I_D - 4 I_D R_s$$

$$5 R_s I_D + 300 I_D = 1.55$$

Set $\quad R_s = \frac{10}{g_m} = 500\,\Omega$

$\therefore \quad 2500 I_D + 300 I_D = 1.55$

$\therefore \quad I_D = 0.554\, mA$ //

$\because \quad I_D = \frac{1}{2} g_m (V_{GS} - V_{TH})$

$$0.554 \times 10^{-3} = \frac{1}{2} \times 20 \times 10^{-3} (V_{GS} - 0.4)$$

$\therefore \quad V_{GS} = 0.455\, V$

To find $\left(\frac{W}{L}\right)$:

$$g_m = \sqrt{2\left(\frac{W}{L}\right)\mu_n C_{ox}\ I_{DS}}$$

$$\therefore \left(\frac{W}{L}\right) \approx 1805$$

To find R_D:

$$\because\ R_D = 200 + 4R_S \qquad (\text{from } (1))$$

$$R_D = 2200$$

To find R_1 and R_2,

$$\because\ R_1 + R_2 = 20\,k\Omega$$

and $V_{GS} = V_G - I_D R_S = 0.455V$

i.e. $V_G = 0.732\,V$

$$V_G = \frac{R_1}{R_1 + R_2} \times V_{DD}$$

$$\therefore R_1 = 8133\,\Omega$$

$$R_2 \approx 11.9\,k\Omega.$$

$\therefore R_1 = 8133\,\Omega$, $R_2 = 11.9\,k\Omega$, $R_D = 2200\,\Omega$ $R_S = 500\,\Omega$

$\left(\frac{W}{L}\right) = 1805$ $I_{DS} = 0.554\,mA.$

(7)

$R_{in} = R_G = 10\,k\Omega$

$Power = 2\,mW$

$\therefore I_{DS} = \dfrac{2\,mW}{1.8\,V} = 1.11\,mA$

$A_v = \dfrac{R_S}{\frac{1}{g_m} + R_S} = 0.8$

$\therefore R_S = \dfrac{4}{g_m}$ ——— ①

$\because V_{OUT} = \dfrac{V_{DD}}{2} = I_{DS} R_S$

$I_{DS} R_S = 0.9$ ——— ②

$\because V_G = 1.8\,V$ and $V_S = 0.9$

$\therefore V_{GS} = 0.9\,V$

From ②, $\because I_{DS} = 1.11\,mA$

$R_S = \dfrac{0.9\,V}{1.11\,mA} \approx 810\,\Omega$

From ①, $g_m = \dfrac{4}{810\,\Omega} \approx 4.94\,mS$

$\because g_m = \left(\frac{W}{L}\right)(\mu_n C_{ox})(V_{GS} - V_{TH})$

$\frac{W}{L} \approx 49.4$

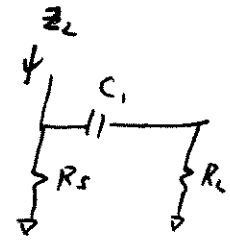
(72) $R_{in} = R_G = 20k\Omega$

$\because$ Power $= 3mW$

$\therefore I_{DS} = \dfrac{3mW}{1.8V} = 1.67mA$

$V_{x,\,at\,DC} = I_{DS}\, R_S = 0.9V$

$\therefore R_S = 540\Omega$



Load impedance, $Z_L = R_S // (\frac{1}{SC_1} + R_L)$
(at 100 MHz)

$= 540 // (\frac{1}{2\pi\times10^8 C_1} + 50)$

Voltage gain $(A_v) = \dfrac{Z_L}{\frac{1}{g_m} + Z_L}$

$g_m = \dfrac{2 I_{DS}}{V_{GS} - V_{TH}}$

$= \dfrac{2\times 1.67\times10^{-3}}{(1.8-0.9) - 0.4}$

$= 6.67\,mS.$

$\therefore A_v = \dfrac{Z_L}{+Z_L} = 0.8$

$Z_L = 120 + Z_L(0.8)$

$\therefore Z_L = 150$

$$\therefore 150 = 540 \,//\, \left(\frac{1}{2\pi \times 10^8 C_1} + 50\right)$$

$$= 540 \,//\, \left[\frac{1 + 50(2\pi \times 10^8 C_1)}{2\pi \times 10^8 C_1}\right]$$

$$= \frac{540 \times \frac{1 + 50(2\pi \times 10^8 C_1)}{2\pi \times 10^8 C_1}}{540 + \frac{1 + 50(2\pi \times 10^8 C_1)}{2\pi \times 10^8 C_1}}$$

$$\therefore \frac{1 + 50(2\pi \times 10^8 C_1)}{2\pi \times 10^8 C_1} \approx 208$$

$$\therefore C_1 \approx 10.1\,pF$$

To find $(\frac{W}{L})$:

$$\because g_m = \left(\frac{W}{L}\right) \mu_n C_{ox} (V_{GS} - V_{TH})$$

$$\frac{W}{L} = 66.7$$

$$\therefore \frac{W}{L} = 66.7, \quad C_1 = 10.1\,pF, \quad R_s = 540\,\Omega.$$

(73) Power $= 3mW$

$$\therefore I_{DS_{1,2}} = \frac{3mW}{1.8V} = 1.67mA.$$

$$r_{o2} = \frac{1}{\lambda I_{DS2}}$$

$$= \frac{1}{0.1 \times 1.67 \times 10^{-3}} \approx 5990\,\Omega.$$

$$= r_{o1}$$

$$\because A_v = \frac{r_{o2} // r_{o1}}{\frac{1}{g_{m1}} + r_{o2} // r_{o1}} = 0.9$$

$$\therefore \quad 0.9 = \frac{2995}{\frac{1}{g_{m1}} + 2995}$$

$$g_{m1} \approx 3mS$$

$\because \quad V_{DS2} \geq 0.3V$ (for M_2 to be in saturation).

set V_{out} (ie. V_{DS2}, nominal) $= 0.3V$

$$\because \quad g_{m1} = \frac{2 I_{DS1}}{V_{GS1} - V_{TH}}$$

$$3 \times 10^{-3} = \frac{2 \times 1.67 \times 10^{-3}}{V_G - 0.3 - 0.4}$$

$$\therefore V_{IN} = V_G \approx 1.81V$$

$$g_m = \sqrt{2\left(\frac{W}{L}\right)\mu_n C_{ox} \quad I_{DS}}$$

$$\therefore \frac{W}{L} \approx 13.5$$

$$\therefore \frac{W}{L} = 13.5, \qquad V_{IN} = 1.81V, \qquad I_{DS} = 1.67mA.$$