7.1 For I = 10 μA:

$$g_m = \frac{I}{V_T} = \frac{10\ \mu A}{25\ mV} = 0.4\ mA/V$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.4\ mA/V} = 250\ k\Omega$$

$$r_o = \frac{V_A}{I} = \frac{10\ V}{10\ \mu A} = 1\ M\Omega$$

$$A_o = g_m r_o = \frac{V_A}{V_r} = \frac{10\ V}{0.025\ V} = 400\ V/V$$

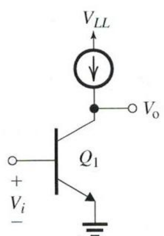
For I = 100 μA:

$$g_m = \frac{100\ \mu A}{25\ mV} = 4\ mA/V$$

$$r_\pi = \frac{100}{4\ mA/V} = 25\ k\Omega$$

$$r_o = \frac{10\ V}{100\ \mu A} = 100\ k\Omega$$

$$A_o = 4 mA/V(100\ k\Omega) = 400$$



For I = 1 mA:

$$g_m = \frac{1\ mA}{25\ mV} = 40\ mA/V$$

$$r_\pi = \frac{100}{40\ mA/V} = 2.5\ k\Omega$$

$$r_o = \frac{10\ V}{1\ mA} = 10\ k\Omega$$

$$A_o = 40\ mA/V\ (10\ K) = 400$$

I	g_m	r_π	r_o	A_o
10 μA	0.4 mA/V	250 kΩ	1 MΩ	400
100 μA	4.0 mA/V	25 kΩ	100 kΩ	400
1 mA	40 mA/V	2.5 kΩ	10 kΩ	400

7.3 $g_m = \dfrac{I_D}{\frac{V_{OV}}{2}}$, so

$$I_D = \frac{g_m V_{OV}}{2} = \frac{2\ mA/V(0.25\ V)}{2} = 0.25\ mA$$

From chapt. 5, $k_n' = \mu_n C_{OX}$

since $g_m = \sqrt{2\mu_n C_{ox}(W/L)}\sqrt{I_D}$,

$$2\ mA/V = \sqrt{2(200\ \mu A/V^2)(W/L)(250\ \mu A)}$$

yielding

$W/L = 40$

so that

$W = 40(0.5\ \mu m) = 20\ \mu m$

7.4 Assuming that the MOSFET is operating above V_t,

$$A_o = \frac{V_A'\sqrt{2(\mu_n C_{ox})(WL)}}{\sqrt{I_D}}$$

If I_D is decreased to 25 μA,

A_o is increased by $\dfrac{1}{\sqrt{1/4}} = 2$

$g_m = \sqrt{2(\mu_n C_{ox})(W/L)} \cdot \sqrt{I_D}$

so, g_m is decreased by

$\sqrt{1/4} = 1/2$

If I_D is increased to 400 μA,

A_o is decreased by $\dfrac{1}{\sqrt{4}} = \dfrac{1}{2}$

g_m increases by $\sqrt{4} = 2$

7.5 In this problem, we have two relevant equations, but three unknowns. so, one parameter can be choosen.

If we multiply the equations for A_o and g_m, we can eliminate I_D and L:

$$A_O \cdot g_m = \frac{V_A' \sqrt{2(\mu_n C_{ox})(WL)}}{\sqrt{I_D}}.$$

$\sqrt{2(\mu_n C_{ox})(WL)} \cdot \sqrt{I_D}$ so that,

$$A_O \cdot g_m = V_A'(2\mu_n C_{ox})W \text{, and}$$

$$W = \frac{A_O \cdot g_m}{V_A'(2\mu_n C_{ox})} = \frac{25(1 \text{ mA/V})}{5 \text{ V}/\mu\text{m}(2)(387\ \mu\text{A/V}^2)}$$

$$= 6.46\ \mu\text{m}$$

Since L must be $\geq 0.18\ \mu\text{m}$, arbitrarily choose $L = 0.3\ \mu\text{m}$

Then, $\frac{W}{L} = \frac{6.46\ \mu\text{m}}{0.3\ \mu\text{m}} = 21.5$

To find I_D:

$$g_m^2 = 2\ \mu\text{m}C_{ox}(W/L)I_D$$

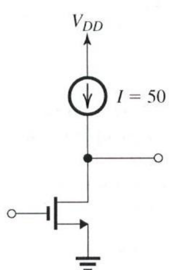
so,

$$I_D = \frac{g_m^2}{2\ \mu\text{m}C_{ox}(W/L)}$$

$$= \frac{(1 \text{ mA/V})^2}{2\ (387\mu\text{A/V}^2)(21.5)} = 60\ \mu\text{A}$$

Note that many answers are possible.

7.9



Since $A_0 = \frac{2V_A' L}{V_{OV}}$, and the current source is ideal,

$$L = \frac{A_O V_{OV}}{2V_A'} = \frac{100(0.2 \text{ V})}{2(20 \text{ V}/\mu\text{m})} = 0.5\ \mu\text{m}$$

Since $I_D = \frac{1}{2}(\mu_n C_{ox})\left(\frac{W}{L}\right)Vov^2$,

$$\frac{W}{L} = \frac{2I_D}{(\mu_n C_{ox})V_{OV}^2}$$

$$= \frac{2\ (50\ \mu\text{A})}{(200\ \mu\text{A/V}^2)(0.2 \text{ V})^2} = 12.5$$

7.12 If both MOSFETs have the same current-source values, and $|V_{An}| = |V_{A_p}|$, all r_o values are equal.

The small-signal model shows all r_{os}':

$$V_o = -g_{m2}V_{gs_2}(r_{o_2} \parallel r_{o_2})$$

$$= -\frac{1}{2}g_{m2}V_{gs_2}r_o$$

$$V_{gs_2} = -g_{m1}V_{gs_1}(r_{o_1} \parallel r_{o_1})$$

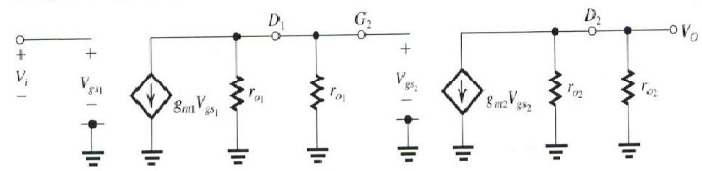
$$= -g_{m2}, V_{gs}, r_o$$

since $V_{gs_1} = V_i$,

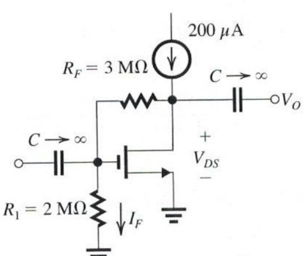
$$A_V = \frac{V_D}{V_i} = \left(-\frac{1}{2}g_{m2}r_o\right)\left(-\frac{1}{2}g_{m1}r_o\right)$$

$$A_V = \frac{1}{4}g_{m1}g_{m2}\ r_o^2$$

This figure belongs with 7.12



7.13



(a) If we neglect the current through R_F,

$$I_D = 200\ \mu\text{A} = \frac{1}{2}k_n'(W/L)V_{OV}^2$$

$$V_{OV} = \sqrt{\frac{2I_D}{k_n'(W/L)}} = \sqrt{\frac{2(200\ \mu\text{A})}{2 \text{ mA/V}^2}} = 0.45 \text{ V}$$

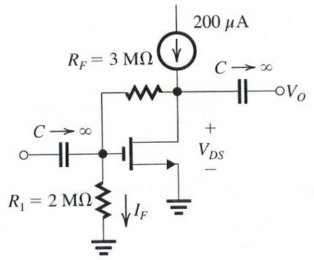
$$V_{GS} = V_t + V_{OV} = 0.5 + 0.45 = 0.95 \text{ V}$$

The current through the feedback network is

$$I_F = \frac{V_G}{R_1} = \frac{0.95 \text{ V}}{2\ \text{M}\Omega} = 0.475\ \mu\text{A}$$

This is << 200 μA, so this assumption is justified.

7.13



(a) If we neglect the current through R_F,

$$I_D = 200\ \mu A = \frac{1}{2}k_n'(W/L)V_{OV}^2$$

$$V_{OV} = \sqrt{\frac{2I_D}{k_n'(W/L)}} = \sqrt{\frac{2(200\ \mu A)}{2\ mA/V^2}} = 0.45\ V$$

$$V_{GS} = V_t + V_{OV} = 0.5 + 0.45 = 0.95\ V$$

The current through the feedback network is

$$I_F = \frac{V_G}{R_1} = \frac{0.95\ V}{2\ M\Omega} = 0.475\ \mu A$$

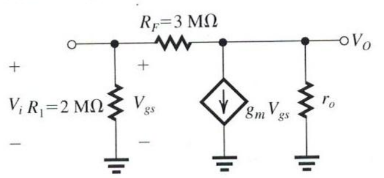
This is << 200 μA, so this assumption is justified.

$V_{DS} \simeq$

$I_F(R_F + R_1) = 0.475\ \mu A(3M\Omega + 2M\Omega)$

$= 2.38\ V \simeq 2.4\ V$

(b) small-signal model:



KCL at the output node yields

$$\frac{V_O}{r_O} + g_m V_{gs} + \frac{V_O - V_i}{R_F} = O$$

since $V_{gs} = V_i$

$$\frac{V_O}{r_O} + g_m V_i + \frac{v_O}{R_F} - \frac{V_i}{R_F} = O \text{ or}$$

$$\frac{V_O}{V_i} = \frac{\left(\frac{1}{R_F} - g_m\right)}{\left(\frac{1}{r_O} + \frac{1}{R_F}\right)}$$

$$g_m = \frac{2I_D}{V_{OV}} = \frac{2(200\ \mu A)}{0.45\ V} = 0.89\ mA/V$$

$$r_O = \frac{V_A}{I_D} = \frac{20\ V}{200\ \mu A} = 100\ k\Omega$$

so,

$$\frac{V_D}{V_i} = \frac{\frac{1}{3000\ K} - 0.89\ mA/V}{\frac{1}{100\ K} + \frac{1}{3000\ K}} = -86.1\ V/V$$

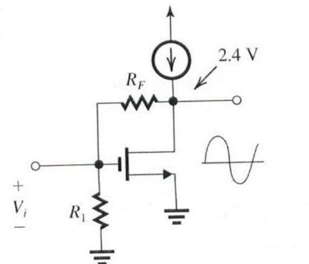
To find the peak of the maximum sinewave output possible, we note that the current source is assumed to be ideal. Therefore, sinewave amplitude will be limited by the negative excursion. Since this happens when

$V_{DS} = V_{OV} = 0.45\ V$,

the maximum peak amplitude will be

$2.4 - 0.45 = 1.95\ V$

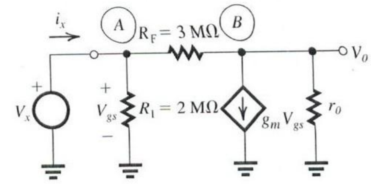
(That is, the output will vary between 0.45V and $2.4 + 1.95 = 4.35\ V$.)



The corresponding input voltage is

$$V_{i_{peak}} = \frac{V_{O_{peak}}}{|A_V|} = \frac{1.95\ V}{86.1\ V/V} = 23\ mV_{peak}$$

(c) To find R_{in}, we apply a test voltage V_X to the input



KCL at node A:

$$i_X = \frac{V_X}{R_1} + \frac{V_X - V_O}{R_F}$$

KCL at node B:

$$\frac{V_X - V_O}{R_F} = \frac{V_O}{r_O} + g_m V_X$$

$$\Rightarrow V_O = \frac{V_X\left(\frac{1}{R_F} - g_m\right)}{\frac{1}{r_O} + \frac{1}{R_F}}$$

Substituting into the first equation, we get

$$i_X = \frac{V_X}{R_1} + \frac{V_X}{R_F} - \frac{V_X}{R_F}\frac{\left(\frac{1}{R_F} - g_m\right)}{\left(\frac{1}{r_O} + \frac{1}{R_F}\right)}$$

so that

$$R_{in} = \frac{V_X}{i_X}$$

$$= \frac{1}{\frac{1}{R_1} + \frac{1}{R_F} - \frac{\frac{1}{R_F{}^2}}{1/r_O + 1/R_F} + \frac{g_m/R_F}{\frac{1}{r_O} + \frac{1}{R_F}}}$$

$$R_{in} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_F} - \frac{1}{\frac{(R_F)^2}{r_O} + R_F} + \frac{g_m}{\frac{R_F}{r_O} + 1}}$$

$$R_{in} = \frac{1}{\frac{1}{2\ m\Omega} + \frac{1}{3\ m\Omega} - \frac{1}{\frac{(3\ m\Omega)^2}{0.1\ m\Omega} + 3\ m\Omega} + \frac{0.89\ mA/V}{\frac{3\ m\Omega}{0.1\ m\Omega} + 1}}$$

$$R_{in} = 33.9\ k\Omega$$