$$r_{DS} = \frac{v_{DS}}{i_D} = \frac{1}{k'_n \frac{W}{L} V_{OV}} = \frac{1}{126.5\times10^{-6}\times\frac{16}{0.8}V_{OV}} = 1000$$

$$\Rightarrow V_{OV} = 0.4V$$

$$V_{GS} = V_{OV} + V_t = 0.4 + 0.7 = 1.1V$$

4.7

$$k'_n = \mu_n C_{ox} = \mu_n \frac{\varepsilon_{ox}}{t_{ox}} = 650\times10^{-4}\times\frac{3.45\times10^{-11}}{20\times10^{-9}} = 112.1\,\mu A/V^2$$

a) triode region: $v_{DS} < V_{GS} - V_t$

$$i_D = k'_n \frac{W}{L}\left[(v_{GS}-V_t)v_{DS} - \frac{1}{2}v_{DS}^2\right]$$

$$i_D = 112.1\times10^{-6}\times10\times\left[(5-0.8)\times1 - \frac{1}{2}\times1^2\right] = 4.15\,mA$$

b) edge of saturation region: $v_{DS} = V_{GS} - V_t$

$$i_D = \frac{1}{2}k'_n\frac{W}{L}(V_{GS}-V_t)^2 = \frac{1}{2}\times112.1\times10^{-6}\times10\times(1.2)^2 = 0.8\,mA$$

c) triode region: $v_{DS} < V_{GS} - V_t$

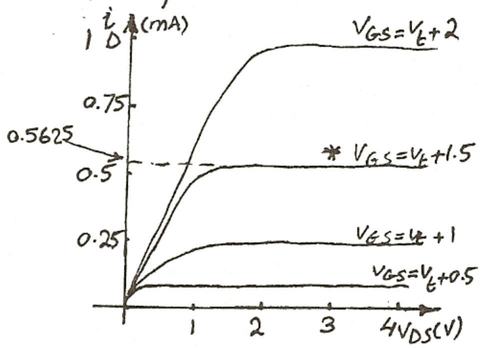
$$i_D = 112.1\times10^{-6}\times10\left[(5-0.8)\times0.2 - \frac{1}{2}\times0.2^2\right] = 0.92\,mA$$

d) Saturation region: $v_{DS} > V_{GS} - V_t$

$$i_D = \frac{1}{2}\times112.1\times10^{-6}\times10\times(5-0.8)^2 = 9.9\,mA$$

4.8

Refer to Fig. 4.11b, $i_D \propto \frac{W}{L}$ so if W is halved, then i_D would also be halved. The vertical axis, i_D, has to be divided by 2:



For $V_{OV} = 1.5^V$, by looking at the corresponding curve, $V_{GS} = V_t + 1.5$, we observe that:
$i_D = 0.5625$ mA

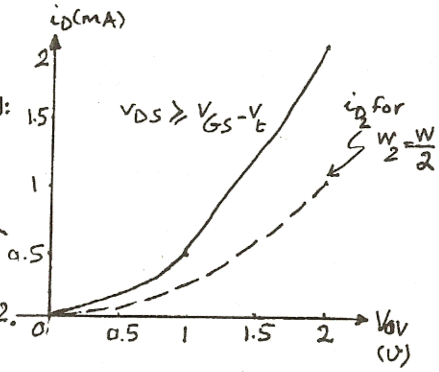
4.9

4.10

$$i_D = \frac{1}{2}k'_n\frac{W}{L}V_{OV}^2$$

assuming $k'_n \frac{W}{L} = 1$: $i_D = \frac{1}{2}V_{OV}^2$

For a device with half the width, i_D is divided by 2.



This graph is not dependent on V_t, while Fig. 4.12 is dependent on V_t.

4.11

Eq. 4.13: $r_{DS} = \left[k'_n\frac{W}{L}(V_{GS}-V_t)\right]^{-1}$ therefore:

$$\frac{r_{DS1}}{r_{DS2}} = \frac{V_{GS2}-V_t}{V_{GS1}-V_t} \Rightarrow \frac{1000}{200} = \frac{V_{GS2}-1}{1.5-1} \Rightarrow V_{GS2} = 3.5^V$$

Now for a device with twice the width:

Cont.

$$\frac{r_{DS1}}{r_{DS2}} = \frac{W_2(V_{GS2}-V_t)}{W_1(V_{GS2}-V_t)}$$

for $V_{GS}=1.5^V$ $\quad \frac{r_{DS1}}{r_{DS2}} = 2 \Rightarrow r_{DS2} = \frac{1000}{2} = 500^{\Omega}$

for $V_{GS}=3.5^V$ $\quad r_{DS2} = \frac{200}{2} = 100\,\Omega$

4.12

$i_D = \frac{1}{2}K_n'\frac{W}{L}(V_{GS}-V_t)^2 \Rightarrow 0.2\times10^{-3} = \frac{1}{2}\times0.1\times10^{-3}(V_{GS}-1)^2$

$V_{GS}-1 = 2 \Rightarrow V_{GS} = 3V$

$V_{DSmin} = V_{GS}-V_t = 3-1 = 2V$

for $i_D=0.8mA$: $\quad 0.8 = \frac{1}{2}\times0.1(V_{GS}-1)^2$ $\quad \times10^{-3}$

$V_{GS}-1 = 4 \Rightarrow V_{GS} = 5V$

$V_{DSmin} = V_{GS}-V_t = 5-1 = 4V$

4.13

$V_{GS}=V_{DS}$ indicates operation in saturation mode: $\quad i_D = \frac{1}{2}K_n'\frac{W}{L}(V_{GS}-V_t)^2$

$$\left.\begin{array}{l} 4 = \frac{1}{2}K_n'\frac{W}{L}(5-V_t)^2 \\ 1 = \frac{1}{2}K_n'\frac{W}{L}(3-V_t)^2 \end{array}\right\} \Rightarrow 4 = \frac{(5-V_t)^2}{(3-V_t)^2} \Rightarrow$$

$(5-V_t) = 2(3-V_t) \Rightarrow V_t = 1V$ $\quad , K_n'\frac{W}{L} = 0.5\,mA/V^2$

4.14

$i_D = \frac{1}{2}K_n'\frac{W}{L}(V_{GS}-V_t)^2 \Rightarrow 0.8 = \frac{1}{2}\times50\times10^{-3}\frac{W}{L}(5-1)^2$

$\frac{W}{L} = 2 \Rightarrow W = 2\times2 = 4\mu m$

4.15

In triode region: $\quad i_D = K_n'\frac{W}{L}\left[(V_{GS}-V_t)V_{DS}-\frac{V_{DS}^2}{2}\right]$

$\frac{i_{D1}}{i_{D2}} = \frac{60\mu A}{160\mu A} = \frac{(2-V_t)0.1-0.01/2}{(4-V_t)0.1-0.01/2} \Rightarrow V_t = 0.75V$

if $K_n' = 50\mu A/V^2$: $\quad 60 = 50\frac{W}{L}\left[(2-0.75)0.1-\frac{0.01}{2}\right]$

$\frac{W}{L} = 10$

If $V_{GS}=3V, V_{DS}=0.15^V$ then $i_D = 50\times10\times\left[2.25\times0.15-\frac{0.15^2}{2}\right]$

$i_D = 163.125\,\mu A$

IF $V_{GS}=3V$, the channel reach pinchoff at $V_{DS}=V_{GS}-V_t = 3-0.75 = 2.25^V$ for which:

$i_D = \frac{1}{2}\times K_n'\frac{W}{L}(V_{GS}-V_t)^2 = \frac{1}{2}\times50\times10\times2.25^2 = 1.3^{mA}$

$i_D = 1.3mA$

4.16

For the channel to remain continous:

$V_{DS}\le V_{GS}-V_t \Rightarrow V_{DSmax} = 1.5-0.8 = 0.7V$

4.17

Eq. 4.15: $\quad r_{DS} = \left[K_n'\frac{W}{L}V_{ov}\right]^{-1} = \frac{1}{50\times\frac{100}{5}(V_{GS}-1)}\,M\Omega$

$r_{DS} = \frac{1}{V_{GS}-1}\,K\Omega$

$V_{GS}=1.1V \Rightarrow r_{DS} = 10K\Omega$

$V_{GS}=11V \Rightarrow r_{DS} = 100\Omega$ $\quad \Rightarrow 100^{\Omega}\le r_{DS}\le 10^{K\Omega}$

a) $r_{DS}\propto\frac{1}{W}$ $\quad$ so if W is halved, r_{DS} is doubled:
$200^{\Omega}\le r_{DS}\le 20K\Omega$

b) $r_{DS}\propto L$ $\quad$ so if L is halved, r_{DS} is also halved: $\quad 50^{\Omega}\le r_{DS}\le 5^{K\Omega}$

c) $r_{DS}\propto\frac{L}{W}$ $\quad$ so if both W and L are halved, $\frac{W}{L}$ stays unchanged and so does r_{DS}.
$100^{\Omega}\le r_{DS}\le 10K\Omega$

4.18

According to eq. 4.17: $V_{GD}\le V_t$ for saturation region. Since V_{GD} is zero in Fig. P4.18, then the device is always in saturation region:

$i_D = i = \frac{1}{2}K_n'\frac{W}{L}(V_{GS}-V_t)^2$

if we replace V_{GS} by v and $K' = \frac{1}{2}K_n'$

$i = K'\frac{W}{L}(V-|V_t|)^2$

$r = \left(\frac{\partial i}{\partial v}\right)^{-1} = \frac{1}{2K'\frac{W}{L}(V-|V_t|)} = \frac{1}{K_n'\frac{W}{L}V_{ov}}$ $\quad$ where $V=|V_t|+V_{ov}$

Now we calculate $R_{S\,max}$, assuming that the voltage drop across the current source is at least 2^V:

a) $V_1 = 8^V$ then $V_{GS} = 3^V \Rightarrow V_S = 8 - 3 = 5^V$

$R_{S\,Max} = \frac{5}{2} = 2.5\,K\Omega$

b) $V_2 = -9 + 2 = -7^V$, $V_S = 1 - |V_{GS}| = -2V$

$R_{S\,max} = \frac{-2-(-7)}{2} = 2.5\,K\Omega$

c) $V_3 = 10 - 2 = 8^V$, $V_S = 0 + |V_{GS}| = 3V$

$R_{S\,max} = \frac{8-3}{2} = 2.5\,K\Omega$

d) $V_4 = -5 + 2 = -3^V$; $V_S = -3 + |V_{GS}| = 0^V$

$R_{S\,max} = \frac{5}{2} = 2.5\,K\Omega$

4.34

$I_D = \frac{V_{DD} - V_D}{R_D} \Rightarrow \frac{5-0}{R_D} = 1\,mA \Rightarrow R_D = 5\,K\Omega$ ✓

$V_D = V_G \Rightarrow$ Saturation

therefore: $i_D = \frac{1}{2} K_n' \frac{W}{L} (V_{GS} - V_t)^2$

$1 = \frac{1}{2} \times 60 \times 10^{-3} \times \frac{100}{3} (V_{GS} - 1)^2$ ✓

$\Rightarrow V_{GS} = 2V \quad \Rightarrow V_S = -2^V$

$R_S = \frac{-2-(-5)}{1} = 3\,K\Omega$ ✓

4.35

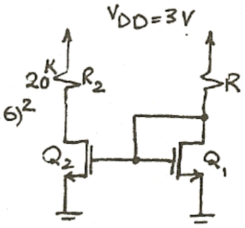
a) $i_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t)^2$

$i_{D_1} = 0.2^m = \frac{1}{2} \times 200 \times 10^{-6} \times \frac{8}{0.8} (V_{GS_1} - 0.6)^2$

$V_{GS_1} - 0.6 = \sqrt{0.2}$

$V_{GS_1} = 1.05\,V$

$R = \frac{3 - 1.05}{0.2} = 9.75\,K\Omega$



b) For Q_2 to conduct 0.5mA:

$R_2 = \frac{3-1}{0.5} = 4\,K\Omega$

Since the gates are connected together, both trasistors have the same V_{GS} and hence same i_D. In order to conduct 0.5MA or multiply i_D by 5: $\frac{W_2}{W_1} = 5 \Rightarrow W_2 = 5 \times 8$

$W_2 = 40\,\mu m$

4.36

Refer to Fig. P4.36.

$R = \frac{3.5}{0.115} = 3.04\,K\Omega$

$0.115\,mA = \frac{1}{2} \times 60 \times 10^{-3} \times \frac{W}{0.8} (-1.5 - (-0.7))^2 \Rightarrow W = 4.8\,\mu m$

4.37

Refer to Fig. P4.37

$V_{GS1} = 1.5V$, $120\,\mu A = \frac{1}{2} \times 120 \times \frac{W_1}{1} (1.5 - 1)^2$

$\Rightarrow W_1 = 8\,\mu m$

$V_{GS2} = 3.5 - 1.5 = 2^V$, $120 = \frac{1}{2} \times 120 \frac{W_2}{1} (2-1)^2$

$\Rightarrow W_2 = 2\,\mu m$

$R = \frac{5 - 3.5}{0.120} = 12.5\,K\Omega$

4.38

Refer to Fig. P4.38.

$V_{GS1} = 1.5^V$ $\quad 120\,\mu A = \frac{1}{2} \times 120 \times \frac{W_1}{1} (1.5 - 1)^2 \Rightarrow W_1 = 8\,\mu m$

$V_{GS2} = 2^V$ $\quad 120\,\mu A = \frac{1}{2} \times 120 \frac{W_2}{1} (2-1)^2 \Rightarrow W_2 = 2\,\mu m$

$V_{GS3} = 1.5^V$ $\quad W_3 = 8\,\mu m$

4.39

Refer to Fig. 4.23a. $V_{GS} = 5 - 6I_D \Rightarrow$

$I_D = \frac{1}{2} \times 2 \times (5 - 6I_D - 2)^2 \Rightarrow 36 I_D^2 - 37 I_D + 9 = 0$

$\Rightarrow I_D = 0.395^{mA}$ or $0.633\,mA$

$I_D = 0.633\,mA$ is not acceptable, because it results in $V_{GS} = 1.2^V$ which is lower than $V_t = 2^V$

Therefore $I_D = 0.395\,mA \cong 0.4\,mA$

$V_D = 10 - 6I_D = 7.6\,V$

These results show that although V_t and $K_n' \frac{W}{L}$ are doubled, I_D is only decreased by 20% and V_D is only increased by 8.5%. Therefore the conclusion is

Cont.

that the cir

device parar

4.40

$V_G = 6^V \Rightarrow$

$I_D = 0.5\,mA =$

$I_D = 0.5 = \frac{1}{2} \times 1$

$V_{GS} = -2.51$

$|V_{GS}| = 0.51$

$V_{GS} = -2.51$

4.41

Refer to

$V_t = V_{GS}$:

$r_{DS} = 50$

$R = \frac{V_{DD} -}{I_D}$

$V_{DS} < V_G$

$I_D = K_n' \frac{W}{L}$

$1 = 100 \times$

4.42

Refer to

In circu

assume

$\Rightarrow V_1 = -$

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In circu

In Circui

$V_{GS} = 1.61V \Rightarrow V_I = 1.61^V$ $\quad V_o = 1.61 - 1 = 0.61^V$

Point B: $\underline{V_{OB} = 0.61^V}$ $\quad \underline{V_{IB} = 1.61V}$

b) $I_Q = \frac{1}{2} \times 1 \times 0.5^2 = \underline{0.125mA}$

$V_{OQ} = 5 - 24\times0.125 = \underline{2^V}$

$V_{IQ} = V_{GS} = V_{OV} + V_t = 0.5+1 = \underline{1.5^V}$

Now to calculate the incremental gain A_v at this bias point, from equation 4.41, we have: $A_v = -2V_{RD}/V_{OV} = \frac{-2(V_{DD}-V_{OQ})}{V_{OV}}$

$$A_v = \frac{-2(5-2)}{0.5} = -12 V/V$$

c) $V_{IQ} = 1.5^V$, $V_t = 1^V$, $V_{IB} = 1.61^V$. Thus the largest amplitude of a sine wave that can be applied to the input while the transistor remain in saturation is: $1.61 - 1.5 = 0.11V$

The amplitude of the output voltage signal that results is approximately equal to $V_{OQ} - V_{OB} = 2 - 0.61 = 1.39^V$. The gain implied by this amplitudes is:

$$\text{gain} = \frac{-1.39}{0.11} = 12.64 V/V$$

This gain is 5.3% different from the incremental gain calculated in part (b). This difference is due to the fact that the segment of the voltage transfer curve considered here is not perfectly linear.

4.50

$V_{DS} = 1^V = V_{OQ} \Rightarrow I_D = \frac{V_{DD}-V_{OQ}}{R} = \frac{10-1}{18} = 0.5mA$

$I_D = 0.5 = \frac{1}{2}\times1\times V_{OV}^2 \Rightarrow V_{OV} = \sqrt{2I_D} = 1^V$

$V_{OV} = V_{GS} - V_t \Rightarrow V_{GS} = 2^V$

$A_v = \frac{-2V_{RD}}{V_{OV}} = -\frac{2\times18\times0.5}{1} = -18 V/V$

$v_o^+ = V_{DD} - V_{OQ} = 10 - 1 = 9^V$

$v_o^- = V_{OQ} - V_{OB}$

In order to find V_{OB} where $V_{DS} = V_{GS} - V_t$ or $V_{OB} = V_{IB} - V_t$: $v_o = v_{DD} - R_D I_D$

$v_{OB} = 10 - 18\times\frac{1}{2}\times1\ V_{OB}^2 \Rightarrow 9V_{OB}^2 + V_{OB} - 10 = 0 \Rightarrow V_{OB} = 1^V$

$v_o^- = V_{OQ} - V_{OB} = 1 - 1 = 0$

Using the same formulas we can calculate the rest of the values for $V_{DS} = 2, 3, \ldots, 10^V$

V_{DS} (V)	I_D (mA)	V_{OV} (V)	V_{GS} (V)	A_v (V/V)	v_o^+ (V)	v_o^- (V)
1	0.5	1	2	18	9	0
2	0.44	0.94	1.94	17.02	8	1
3	0.39	0.88	1.88	15.9	7	2
4	0.33	0.81	1.81	14.8	6	3
5	0.28	0.75	1.75	13.3	5	4
6	0.22	0.66	1.66	12.1	4	5
7	0.17	0.58	1.58	10.3	3	6
8	0.11	0.47	1.47	8.5	2	7
9	0.06	0.35	1.35	5.7	1	8
10	0	0	$\leq 1^V$	0	0	0

4.51

$R_D = 20k\Omega$, $V_{RD} = 2^V \Rightarrow I_D = 0.1mA$

$A_v = -\frac{2V_{RD}}{V_{OV}} \Rightarrow -10 = -\frac{2\times2}{V_{OV}} \Rightarrow V_{OV} = 0.4^V$

$V_{GS} = 1.2V \Rightarrow V_t = 1.2 - 0.4 = 0.8V$

$I_D = \frac{1}{2}k_n' \frac{W}{L} V_{OV}^2 \Rightarrow 0.1 = \frac{1}{2}\times50\times10^{-3}\ \frac{W}{L}\ 0.4^2$

$\Rightarrow \underline{\frac{W}{L} = 25}$

4.52

Eq. 4.41 : $A_v = -\frac{2(V_{DD}-V_{OQ})}{V_{OV}}$

a) $A_{v\,max} = -\frac{2(V_{DD}-0)}{V_{OV\,min}} = -\frac{2\times5}{0.2} = 50 V/V$

b)

Remove this problem from the assignment.

c)

4.53

From Figure 4.26(c) we have: $\hat{v}_o = V_{DS} - V_{OB}$

Assuming linear operation around the bias point:

$$A_v = -\frac{\hat{v}_o}{V_{IB}-V_{IQ}} = -\frac{\hat{v}_o}{V_{OB}+V_t-V_{IQ}} = -\frac{\hat{v}_o}{V_{OB}+V_t-(V_{ov}+V_t)}$$

$$A_v = -\frac{\hat{v}_o}{V_{OB}-V_{ov}} = -\frac{\hat{v}_o}{V_{OB}-V_{DS}+V_{DS}-V_{ov}} = -\frac{\hat{v}_o}{-\hat{v}_o+V_{DS}-V_{ov}}$$

$$-A_v\hat{v}_o + A_v(V_{DS}-V_{ov}) = -\hat{v}_o \Longrightarrow \hat{v}_o(1-A_v) = -A_v(V_{DS}-V_{ov})$$

$$\hat{v}_o = \frac{A_v(V_{DS}-V_{ov})}{A_v-1} \Longrightarrow \hat{v}_o = \frac{V_{DS}-V_{ov}}{1-\frac{1}{A_v}}$$

V_{DS} (V)	A_v (V/V)	$\hat{v}_o$ (V)	$\hat{v}_i$ (V)
1	-16	0.47	0.029
1.5	-14	0.93	0.066
2	-12	1.38	0.12
2.5	-10	1.81	0.18

$$I_D = \frac{1}{2}\times 1\times(0.5)^2 = 0.125\,mA$$

$$R_D = \frac{V_{DD}-V_{DS}}{I_D} = \frac{5-1}{0.125} = 32\,k\Omega$$

4.54

$$i_{D_1} = i_{D_2} \Rightarrow \frac{1}{2}k_n'\left(\frac{W}{L}\right)_1(V_{GS_1}-V_t)^2 = \frac{1}{2}k_n'\left(\frac{W}{L}\right)_2(V_{GS2}-V_t)^2$$

Note that $V_{GS1} = V_I$

$V_{GS2} = V_{DD} - V_O$

$$\Rightarrow \left(\frac{W}{L}\right)_1(V_I-V_t)^2 = \left(\frac{W}{L}\right)_2(V_{DD}-V_O-V_t)^2$$

$$\sqrt{\left(\frac{W}{L}\right)_1/\left(\frac{W}{L}\right)_2}\;(v_I - v_t) = v_{DD} - v_O - v_t$$

$$v_O = v_{DD} - v_t + \sqrt{\frac{(W/L)_1}{(W/L)_2}}\,v_t - \sqrt{\frac{(W/L)_1}{(W/L)_2}}\,v_I$$

If $\left(\frac{W}{L}\right)_1 = \frac{50}{0.5} = 100$ $\quad\left(\frac{W}{L}\right)_2 = \frac{5}{0.5} = 10$

then:

$$A_v = \frac{\partial v_O}{\partial v_I} = -\sqrt{\frac{100}{10}} = -3.16\,V/V$$

4.55

$$I_D = 2\,mA = \frac{1}{2}\times 80\times10^{-3}\times\frac{240}{6}\times(V_{GS}-1.2)^2 \Rightarrow$$

$V_{GS} = 2.32\,V$ ✓ Refer to Fig. 4.30C

$$R_D I_D = \frac{15}{3} = 5^V \Rightarrow R_D = \frac{5}{2^{mA}} = 2.5\,k\Omega ✓$$

$$R_S I_D = 5^V \Rightarrow R_S = \frac{5}{2} = 2.5\,k\Omega ✓$$

$V_G = 5 + V_{GS} = 7.32V$ ✓

$$\frac{15}{R_{G1}+R_{G2}}\times R_{G2} = 7.32 ✓ \qquad R_{G_1} = 22M\Omega \Rightarrow R_{G2} = 20.97\,M\Omega ✓$$

$V_{DS} = 5^V$

at the edge of saturation $V_{DS} = V_{GS} - V_t$ or

$V_{DS} = 2.32 - 1.2 = 1.12^V$ ✓. So V_{DS} is $5 - 1.12 = 3.88^V$

away from the edge of saturation. ✓

4.56

Refer to Fig. 4.30e

$$I_D = 2mA = \frac{1}{2}k_n'\frac{W}{L}V_{ov}^2 \Rightarrow 2 = \frac{1}{2}\times 50\times10^{-3}\times\frac{200}{4}V_{ov}^2$$

$V_{ov} = 1.26\,V$

$V_{DS} = V_{ov}$ edge of triode

Midway of cutoff ($V_{DS} = V_{DD}$) and beginning of triode operation ($V_{DS} = V_{ov}$) is when $V_{DS} = \frac{30+1.26}{2}$

$V_{DS} = 15.63V$

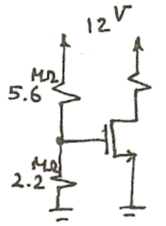
$V_{GS} = 2.32\,V \Rightarrow V_S = -2.32V \Rightarrow R_S = \frac{-2.32+15}{2}$

$R_S = 6.34\,k\Omega$

$V_D = V_S + V_{DS} = -2.32 + 15.63 = 13.31\,V \Rightarrow R_D = \frac{15-13.31}{2}$

$R_D = 0.85\,k\Omega$

4.57



$$V_G = 12\times\frac{2.2}{2.2+5.6} = 3.4^V$$

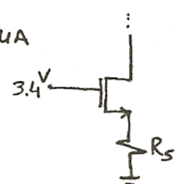
$k_n'\frac{W}{L} = 220$ to $380\,\mu A/V^2$

$V_t = 1.3$ to $2.4V$

$$I_D = \frac{1}{2}\times k_n'\frac{W}{L}(3.4-V_t)^2$$

$$I_{Dmin} = \frac{1}{2}\times 220\,(3.4-2.4)^2 = 110\,\mu A$$

$$I_{Dmax} = \frac{1}{2}\times 380(3.4-1.3)^2 = 838\,\mu A$$



to limit I_{Dmax} to $150\,\mu A$:

$$150 = \frac{1}{2}\times 380(3.4 - 0.15R_S - 1.3)^2$$

$R_S = 8.1\,k\Omega$

Select $R_S = 8.2\,k\Omega$

$$I_{Dmax} = \frac{1}{2}\times 380\times(3.4 - I_{Dmax}\times 8.2 - 1.3)^2$$

$I_{Dmax} = 0.15\,mA$ or $0.\cancel{44}\,mA$

The second answer results in negative V_{GS}

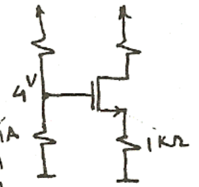
Cont.

and therefore it is not acceptable.

$I_{Dmin} = \frac{1}{2} \times 0.22 \times (3.4 - 8.2 I_{Dmin} - 2.4)^2$

$I_{Dmin} = 0.04\,mA$

4.58



$V_t = 2^V$, $k'_n \frac{W}{L} = 2\,mA/V^2$

$I_D = \frac{1}{2} \times 2 \times (4 - I_D \times 1 - 2)^2$

$I_D = 4 + I_D^2 - 4I_D \Rightarrow I_D = 1mA, \cancel{4mA}$

$I_D = 4^{mA}$ results in $V_{GS} = 0$ which is not acceptable, therefore $I_D = 1mA$.

For $k'\frac{W}{L}$ 50% larger, i.e. $k'\frac{W}{L} = 3mA/V^2$

$I_D = \frac{1}{2} \times 3(4 - I_D - 2)^2 \Rightarrow I_D = 1.13\,mA$

I_D increases by 13%.

4.59

Refer to Fig. 4.30.c

$V_{GS} = 5 - 2 = 3V$, $I_D = \frac{V_S}{R_S} = \frac{2}{1} = 2mA$

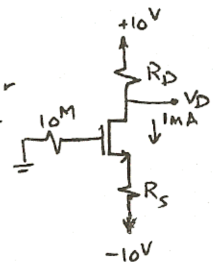
$I_D = 2 = \frac{1}{2} \times 2 \times (3 - V_t)^2 \Rightarrow \pm 1.41 = 3 - V_t \Rightarrow V_t = 1.59^V$

For a device with $V_t = 1.59 - 0.5 = 1.09^V$:

$I_D = \frac{1}{2} \times 2 \times (5 - I_D \times 1 - 1.09)^2 \Rightarrow I_D = 2.37^{mA}$

$V_S = 2.37V$

4.60



To maximize gain, we design for the lowest possible V_D consistant with allowing a 2V p-p signal swing. $V_{Dmin} = V_D - 1$ ✓

$V_{Dmin} = V_G - V_t = 0 - 2$ ✓

$V_D - 1 = -2 \Rightarrow V_D = -1V$ ✓ $\Rightarrow R_D = \frac{10 - (-1)}{1mA} = 11K\Omega$ ✓

$I_D = \frac{1}{2} \times 2\left[0 \underbrace{-(-10 + (1 \times R_S))}_{V_{GS}} - 2\right]^2 = 1 \Rightarrow 1 = (8 - R_S)^2$

$R_S = 7K\Omega$

4.61

For P-channel MOSFET to be 1V from the edge of saturation: $V_{DS} = V_{GS} - V_t - 1$. Since $V_D = 3V$ and $I_D = 1mA$: $R_D = \frac{3}{1} = 3K\Omega$, $R_1 + R_2 = \frac{10V}{10\mu A} = 1M\Omega$

a) $|V_t| = 1V$, $k'_p \frac{W}{L} = 0.5mA/V^2$

$I_D = 0.5 \times \frac{1}{2} \times (V_{GS} + 1)^2 = 1 \Rightarrow V_{GS} = -3V$

$V_{DS} = -3 + 1 - 1 = -3V$

$V_S = 6V$, $V_G = 3V$ $R_S = \frac{10 - 6}{1} = 4K\Omega$

$\frac{R_2}{R_1 + R_2} = \frac{3}{10} \Rightarrow R_1 = 0.7M\Omega$, $R_2 = 0.3M\Omega$

b) $|V_t| = 2V$, $k'_p \frac{W}{L} = 1.25\,mA/V^2$

$1 = \frac{1}{2} \times 1.25 (V_{GS} + 2)^2 \Rightarrow V_{GS} = -3.26^V$ or -0.74^V

the second answer is not acceptable $|V_{GS}| < |V_t|$

$V_{GS} = -3.26V$

$V_{DS} = -3.26 + 2 - 1 = -2.26V$

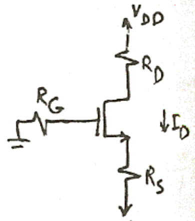
$V_S = 3 + 2.26 = 5.26V$

$V_G = 2V$

$R_S = \frac{10 - 5.26}{1} = 4.74K\Omega$, $R_D = 3K\Omega$

$\frac{R_2}{R_1 + R_2} = \frac{2}{10} \Rightarrow R_2 = 0.2M\Omega$ $R_1 = 0.8M\Omega$

4.62



$K = \frac{1}{2} k' \frac{W}{L}$

a) $I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$

$I_D = K(0 + V_{SS} - R_S I_D - V_t)^2$

$\frac{\partial I_D}{\partial K} = (V_{SS} - R_S I_D - V_t)^2 + 2K(V_{SS} - R_S I_D - V_t)(-R_S)\frac{\partial I_D}{\partial K}$

$\frac{\partial I_D}{\partial K} = \frac{I_D}{K} - 2R_S\sqrt{\frac{I_D}{K}}\, K \frac{\partial I_D}{\partial K}$

$\frac{\partial I_D}{\partial K}(1 + 2\sqrt{K I_D}\, R_S) = \frac{I_D}{K} \Rightarrow S_K^{I_D} = \frac{\partial I_D}{\partial K}\frac{K}{I_D} = \frac{1}{1 + 2\sqrt{K I_D}\, R_S}$

b) $K = 100\,\mu A/V^2$, $\frac{\Delta K}{K} = \pm 10\%$, $V_t = 1V$, $I_D = 100\mu A$

$\frac{\Delta I_D}{I_D} = \pm 1\%$

$S_K^{I_D} \simeq \frac{\partial I_D / I_D}{\partial K / K} = \frac{1}{10} = 0.1 = \frac{1}{1 + 2\sqrt{100 \times 10^{-3} \times 100 \times 10^{-3}}\, R_S}$

$\Rightarrow R_S = 45K\Omega$

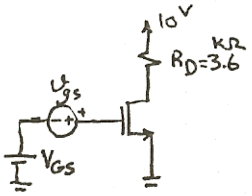
Cont.

4.69

a) $I_D = \frac{1}{2} \times 1 \times (4-2)^2 = 2\,mA$

$V_D = V_{DD} - R_D I_D = 10 - 2 \times 3.6$

$V_D = 2.8\,V$



b) $g_m = k'_n \frac{W}{L} V_{ov} = 1 \times (4-2) = 2\,mA/V$

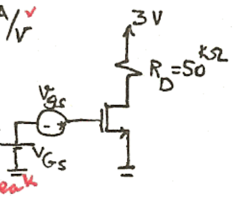
c) $A_v = \frac{v_d}{v_{gs}} = -g_m R_D = -2 \times 3.6 = -7.2\,V/V$

d) $r_o \simeq \frac{1}{\lambda I_D} = \frac{1}{0.01 \times 2} = 50\,k\Omega$

$A_v = \frac{v_d}{v_{gs}} = -g_m (R_D \| r_o) = -2(3.6 \| 50) = -6.7\,V/V$

4.70

$g_m R_D = 5 \Rightarrow g_m = \frac{5}{50K} = 0.1\,mA/V$



For 0.5V output signal and a gain of 5V/V, $v_{gs} = \frac{0.5}{5} = 0.1\,V$

neg peak

So we can write $V_{DS} - 0.5 \geq V_{GS} + 0.1 - V_t$

or $V_{DS} \geq V_{GS} + 0.6 - 0.8 \Rightarrow V_{DS} \geq V_{GS} - 0.2$

Also, from the other side: $V_{DS} + 0.5 \leq V_{DD}$

or $V_{DS} \leq 3 - 0.5 \Rightarrow V_{DS} \leq 2.5V$ pos peak

We design the circuit for lowest possible VDS that guarantees the device operation in saturation: $V_{DS} = V_{GS} - 0.2$

$V_{DS} = V_{DD} - R_D I_D \Rightarrow V_{GS} - 0.2 = 3 - (50 \times I_D)$

$\Rightarrow I_D = \frac{3.2 - V_{GS}}{50}$

Also, from eq. 4.71: $g_m = \frac{2 I_D}{V_{GS} - V_t} = 0.1$

$g_m = 0.1 = \frac{2}{V_{GS} - 0.8} \times \frac{3.2 - V_{GS}}{50}$

$\Rightarrow V_{GS} = 1.49\,V$, $I_D = 0.034\,mA$

$V_{DS} = 1.49 - 0.2 = 1.29\,V$ $\quad V_{ov} = 1.49 - 0.8 = 0.69\,V$

$\frac{W}{L} = \frac{I_D}{\frac{1}{2} k'_n V_{ov}^2} = \frac{0.034 \times 10^3}{\frac{1}{2} \times 100 \times 0.69^2} = 1.43$

both num & denom $\times 10^6$

$\frac{W}{L} = 1.43$

4.71

$\left.\begin{array}{l} A_v = -g_m R_D, \\ g_m = \frac{2 I_D}{V_{ov}} \quad \text{eq. 4.71} \end{array}\right\} \Rightarrow A_v = -\frac{2 R_D I_D}{V_{ov}} = \frac{-2(V_{DD} - V_D)}{V_{ov}}$ ①

Minimum v_{DS} for edge of saturation:

$v_{DS} \geq v_{GS} - V_t \quad$ or $\quad v_{DSmin} = v_{GSmax} - V_t$

$V_{DS} - |A_v| \hat{v}_i = V_{GS} + \hat{v}_i - V_t$

IF we replace A_v with ①:

$V_D - \frac{2(V_{DD} - V_D)}{V_{ov}} \hat{v}_i = V_{ov} + \hat{v}_i$

$\Rightarrow V_D \left(1 + \frac{2\hat{v}_i}{V_{ov}}\right) = V_{ov} + \hat{v}_i + \frac{2 V_{DD} \hat{v}_i}{V_{ov}}$

$V_D = \frac{V_{ov} + \hat{v}_i + 2V_{DD}(\hat{v}_i / V_{ov})}{1 + 2(\hat{v}_i / V_{ov})}$

$V_{DD} = 3V$, $\hat{v}_i = 20\,mV$ $\quad m = 10 = \frac{V_{ov}}{\hat{v}_i} \Rightarrow V_{ov} = 0.2\,V$

$V_D = \frac{0.2 + 0.02 + 2 \times 3 \times 10^{-1}}{1 + 2 \times 0.1} = 0.68\,V$

$A_v = \frac{-2(3 - 0.68)}{0.2} = -23.2\,V/V$

IF $I_D = 100\,\mu A = 0.1\,mA$:

$A_v = -\frac{2 R_D I_D}{V_{ov}} \Rightarrow 23.2 = \frac{2 \times R_D \times 0.1}{0.2} \Rightarrow$

$R_D = 23.2\,k\Omega$

$I_D = \frac{1}{2} k'_n \frac{W}{L} V_{ov}^2 \Rightarrow 0.1 = \frac{1}{2} \times 100 \times 10^{-3} \frac{W}{L} 0.2^2$

$\Rightarrow \frac{W}{L} = 50$

4.72

$k'_n = \mu_n C_{ox} = 500 \times 10^8 \times 0.4 \times 10^{-15} = 20\,\mu A/V^2$, $k'_p = 10\,\mu A/V^2$

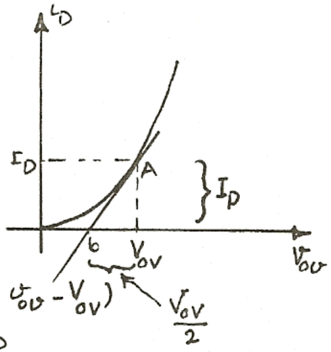
Case	Type	I_D (mA)	$\lvert V_{GS}\rvert$ (V)	$\lvert V_t\rvert$ (V)	V_{ov} (V)	W (μm)	L (μm)	$\frac{W}{L}$	$k'\frac{W}{L}$ (mA/V²)	g_m (mA/V)
a	N	1	3	2	1	100	1	100	2	2
b	N	1	1.2	0.7	0.5	50	$\frac{1}{8}$	400	8	4
c	N	10	?	?	2	250	1	250	5	10
d	N	0.5	?	?	0.5	?	?	200	4	2
e	N	0.1	?	?	1.41	10	2	5	0.1	0.14
f	N	0.1	1.8	0.8	1	40	4	10	0.2	0.2
g	P	1	?	?	2	?	?	25	0.25	1
h	P	1	3	1	2	?	?	50	0.5	1
i	P	10	?	?	1	4000	2	2000	20	20

Cont.

4.78

$$i_D = \frac{1}{2} k_n' \frac{W}{L} v_{OV}^2$$

The equation for the tangent line passing from point A (V_{OV}, I_D) can be written as:



$$(i_D - I_D) = \left.\frac{\partial i_D}{\partial v_{OV}}\right|_{\substack{i=I_D \\ v=V_{OV}}} (v_{OV} - V_{OV})$$

$$\left.\frac{\partial i_D}{\partial v_{OV}}\right|_{i_D=I_D} = k_n' \frac{W}{L} V_{OV}$$

$$\Rightarrow i_D - I_D = k_n' \frac{W}{L} V_{OV} (v_{OV} - V_{OV})$$

$$i_D - \frac{1}{2} k_n' \frac{W}{L} V_{OV}^2 = k_n' \frac{W}{L} V_{OV} (v_{OV} - V_{OV})$$

The tangent intersects the v_{OV} axis at $i_D = 0$

$$0 - \frac{1}{2} k_n' \frac{W}{L} V_{OV}^2 = k_n' \frac{W}{L} V_{OV} (v_{OV} - V_{OV})$$

$$-\frac{V_{OV}}{2} = v_{OV} - V_{OV} \Rightarrow v_{OV} = \frac{V_{OV}}{2}$$

The slope of the tangent is g_m and it is equal to: $g_m = \frac{\Delta i_D}{\Delta v_{OV}} = \frac{I_D}{V_{OV} - \frac{V_{OV}}{2}} = \frac{I_D}{\frac{V_{OV}}{2}} = \frac{2 I_D}{V_{OV}}$

4.79

For this common-source amplifier we have:

$g_m = 2\frac{mA}{V}$, $r_o = 50K\Omega$, $R_D = 10K\Omega$

$R_G = 10M\Omega$, $R_{sig} = 0.5M\Omega$ and $R_L = 20K\Omega$

From equation 4.82 we have:

$$G_v = -\frac{R_G}{R_G + R_{sig}} g_m (r_o \| R_D \| R_L) = -\frac{10 \times 2}{10 + 0.5} (50^K \| 10^K \| 20K) ✓$$

$$G_v = -11.2 \, V/V ✓$$

4.80

a) $A_{v_o} = -2 \frac{(V_{DD} - V_D)}{V_{OV}} = -2 \frac{(10 - 2.5)}{1} = -15 V/V$

b) if V_{OV} is halved ($V_{OV} = 0.5$) then I_D is divided by 4, i.e. $I_D = \frac{0.5}{4} = 0.125 mA$

Since V_D is kept unchanged at 2.5^V then:

$R_D = \frac{10 - 2.5}{0.125} = 60K\Omega$, $g_m = \frac{2 I_D}{V_{OV}} = 0.5 \frac{mA}{V}$

$r_o = \frac{V_A}{I_D} \Rightarrow r_o = 4 \times r_{o1} = 4 \times \frac{75}{0.5} = 600K\Omega$

$A_{v_o} = -15 \times 2 = -30 V/V$ (without r_o)

c) If we take r_o into account:

$$A_{v_o} = -g_m (r_o \| R_D) = -0.5 (600^K \| 60^K) = -27.3 V/V$$

$$R_{out} = R_D \| r_o = 600^K \| 60^K = 54.5K\Omega$$

d) $R_{in} = R_G = 4.7M\Omega$

$R_o = R_{out} = 54.5K\Omega$

$$G_v = \frac{R_{in}}{R_{in} + R_{sig}} A_{v_o} \frac{R_L}{R_L + R_o} = \frac{4.7}{4.7 + 0.1} \times 27.3 \times \frac{15}{15 + 54.5}$$

$$G_v = 5.77 V/V$$

e) As we can see by reducing V_{OV} to half of its value or equivalently multiplying drain current by 4, A_{v_o} is almost doubled, while R_{out} is multiplied by 4.

As a result G_v which is proportional to both A_{v_o} and $\frac{1}{R_{out}}$ is only slightly reduced.

(G_v was $-7 V/V$ before and it is $5.8 V/V$ now)

4.81

For an NMOS common-gate amplifier with $g_m = 5 mA/V$, $R_D = 5K\Omega$, $R_L = 2K\Omega$, $R_{sig} = 200\Omega$ we have:

$R_{in} = \frac{1}{g_m} = \frac{1}{5} = 0.2K\Omega = 200\Omega$

From Eq. 4.96b we know that the overall voltage gain of this amplifier is:

$$G_v = \frac{g_m (R_D \| R_L)}{1 + g_m R_{sig}} = \frac{5 (5K \| 2K)}{1 + 5 \times 0.2} = 3.57 V/V$$

If we increase the bias current by a factor of 4, while maintaining the other parameter constant (assuming linear operation), we have:

$$g_m = \sqrt{2 k_n \frac{W}{L} I_D} \Rightarrow \frac{g_{m2}}{g_{m1}} = \sqrt{\frac{I_{D2}}{I_{D1}}} = \sqrt{4} = 2$$

$g_m = 2 \times 5 = 10 \, mA/V$

$R_{in} = \frac{1}{g_m} = 0.1 K\Omega = 100\Omega$

$$G_v = g_m \frac{R_D \| R_L}{1 + g_m R_{sig}} = 10 \frac{(5^K \| 2^K)}{1 + 10 \times 0.2} = 4.76 V/V$$

4.82

Refer to Eq. 4.90: $G_v = \frac{R_G}{R_G+R_{sig}} \cdot \frac{g_m(R_D || R_L)}{1+g_m R_s}$

$G_{v1} = -16$ V/V reduced by factor of 4:

$\frac{G_{v2}}{G_{v1}} = \frac{1}{1+g_m R_s} \Rightarrow \frac{1}{4} = \frac{1}{1+2R_s} \Rightarrow \underline{R_s = 1.5K\Omega}$

4.83

Eq. 4.90: $G_v = \frac{R_G}{R_G+R_{sig}} \cdot \frac{g_m(R_D || R_L)}{1+g_m R_s}$

$G_v = -10$ V/V for $R_s = 1K\Omega$ and $G_v = -20$ V/V for $R_s = 0$

$\frac{G_{v1}}{G_{v2}} = \frac{1+g_m R_{s2}}{1+g_m R_{s1}} \Rightarrow \frac{10}{20} = \frac{1+g_m\times 0}{1+g_m\times 1} \Rightarrow 1+g_m = 2$

$g_m = 1$ mA/V

In order to have $G_v = -8$ V/V:

$\frac{G_{v1}}{G_{v3}} = \frac{20}{8} = \frac{1+g_m R_{s3}}{1+0} \Rightarrow 1+R_{s3} = 2.5 \Rightarrow \underline{R_{s3} = 3.5^{K\Omega}}$

4.84

$A_{vo} = 0.98$ V/V and $A_v = \frac{0.98}{2} = 0.49$ V/V for $R_L = 500\Omega$

Eq. 4.102a: $A_v \simeq \frac{R_L}{R_L+\frac{1}{g_m}} \Rightarrow 0.49 = \frac{0.5}{0.5+\frac{1}{g_m}} \Rightarrow$

$g_m = 1.92$ mA/V

Eq. 4.103: $A_{vo} = \frac{r_o}{r_o+\frac{1}{g_m}} \Rightarrow 0.98 = \frac{r_o}{r_o+0.52}$

$\Rightarrow \underline{r_o = 25.5 k\Omega}$

4.85

We have $g_m = 5$ mA/V and $r_o = 20K\Omega$. From Eq. 4.103 we know: $A_{vo} = \frac{r_o}{r_o+\frac{1}{g_m}} = \frac{20}{20+\frac{1}{5}} = 0.99$ V/V

$\underline{A_{vo} = 0.99 \text{ V/V}}$

From Eq. 4.105: $R_{out} = \frac{1}{g_m} || r_o = \frac{1}{5}^K || 20^K = 198\Omega$

$\underline{R_{out} \simeq 200\Omega}$

With $R_L = 1K\Omega$ we have:

$A_v = \frac{R_L || r_o}{(R_L || r_o)+\frac{1}{g_m}} = \frac{1^K || 20^K}{(1^K || 20^K)+\frac{1}{5}}$

$\Rightarrow \underline{A_v = 0.83 \text{ V/V}}$

4.86

$R_{i2} = \frac{1}{g_{m2}} = 50\Omega \Rightarrow g_{m2} = \frac{1}{0.05} = 20$ mA/V

if Q_1 is biased the same as Q_2, then $g_{m1} = g_{m2}$

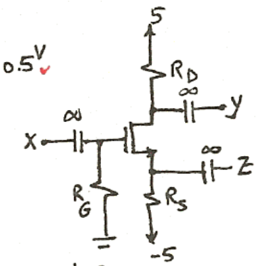
$i_{D1} = g_{m1} v_i = 20 \times 5^{mV} = 100\mu A = 0.1mA$

$v_{D1} = i_{D1} \times 50^{\Omega} = 0.5^V$

In order to have $v_{d2} = v_o = 1^V$:

$v_o = i_D R_D \Rightarrow 1 = 0.1 \times R_D \Rightarrow \underline{R_D = 10K\Omega}$

4.87



a) $I_D = 0.1 = \frac{1}{2} \times 0.8 \times V_{ov}^2 \Rightarrow V_{ov} = 0.5^V$

$\Rightarrow V_{GS} = 0.5 + 1 = 1.5^V$

$V_G = 0 \Rightarrow V_S = -1.5V$

$R_S = \frac{-1.5-(-5)}{0.1} = \underline{35K\Omega}$

$V_{DS} = 5 - R_D \times 0.1$

Largest possible R_D is achieved for V_{DSmin}

$V_{DS} \geq V_{GS} - V_t \Rightarrow V_{DSmin} = V_{ov} \Rightarrow V_{DS} - 1 = V_{ov}$

$\Rightarrow V_{DS} = 1 + 0.5 = 1.5V \Rightarrow R_D = \frac{5-1.5}{0.1} = \underline{35K\Omega}$

$\underline{R_G = 10M\Omega}$ ← arbitrary

V_o peak $= 1$

b) $g_m = \frac{2I_D}{V_{ov}} = \frac{2\times 0.1}{0.5} = 0.4$ mA/V

$r_o = \frac{V_A}{I_D} = \frac{40}{0.1} = 400K\Omega$

← not correct approach

c) If Z is grounded then the circuit becomes a common-source configuration. The overall voltage gain according to Eq. 4.82:

$G_v = -\frac{R_G}{R_G+R_{sig}} g_m (r_o || R_D || R_L)$

$G_v = \frac{10M}{10M+1M} \times 0.4 \times (400^K || 35^K || 40^K) = 6.5$ V/V

$\underline{G_v = 6.5 \text{ V/V}}$

d) If y is grounded, then the circuit becomes a source follower configuration.

Eq. 4.103: $A_{vo} = \frac{r_o}{r_o+\frac{1}{g_m}} = \frac{400}{400+\frac{1}{0.4}} = 0.99$ V/V

$R_{out} = \frac{1}{g_m} || r_o = \frac{1}{0.4} || 400$

$\underline{R_{out} = 2.48K\Omega}$ Correct if R_s considered to be the load. Otherwise

$R_{out} = \frac{1}{g_m} || r_o || R_s = \underline{2.31 k\Omega}$

Cont.

e) If x is grounded, the circuit becomes a common-gate configuration.

$R_{in} = \frac{1}{g_m} \| R_s = 35K \| \frac{1}{0.4} = 2.33K\Omega$ ✓ (Ignores r_o)

Eq. 4.98: $i_i = i_{sig} \frac{R_{sig}}{R_{sig}+R_{in}} \Rightarrow$

$$i_i = 10\mu A \frac{100^K}{100^K+2.33^K} = 9.77\mu A$$ ✓

$v_y = R_D \times i_i = 35 \times 9.77\mu A = 0.34V$ ✓

4.88

a) Fig. P4.88a is a source follower:

Eq. 4.103: $A_{v_o} = \frac{r_o}{r_o + \frac{1}{g_m}}$, $r_o \gg \frac{1}{g_m} \Rightarrow A_{v_o} \simeq 1 V/V$

$R_{out} = \frac{1}{g_m} = \frac{1}{5} = 0.2K\Omega$

b) Fig. P4.88b is a common-gate configuration:

$R_{in} = \frac{1}{g_m} = \frac{1}{5} = 0.2K\Omega$

Eq. 4.94: $A_v = g_m (R_D \| R_L) = 5(5^K \| 2^K) = 7.1 V/V$

c) If we connect both stages together, then:

for the first stage: $A_v = A_{v_o} \frac{R_L}{R_L + R_{out}}$

where R_L is in fact R_{in} of the second stage.

Therefore: $A_{v_1} = 1 \times \frac{0.2K}{0.2+0.2} = 0.5 V/V$

For the second stage: $A_{v_2} = 7.1 V/V$

Overall gain $A_v = A_{v_1} A_{v_2} = 7.1 \times 0.5 = 3.55 V/V$

4.89

[illegible]

$\frac{\epsilon_{ox}}{t_{ox}} = \frac{3.45\times10^{-11}}{8\times10^{-9}} = 4.3\times10^{-3}\,F/m^2 = 4.3\,fF/\mu m^2$

$\mu_n C_{ox} = 450\times10^{-4}\times4.3\times10^{-3} = 193.5\,\mu A/V^2$

$100\,\mu A = \frac{1}{2}\times193.5\times\frac{20}{1}V_{ov}^2 \Rightarrow \underline{V_{ov} = 0.23\,V}$

$0.5^V > V_{ov} \Rightarrow$ Saturation

$\frac{2I_D}{V_{ov}} = \underline{880\,\mu A/V}$, $r_o = \frac{1}{\lambda I_D} = \frac{1}{0.05\times0.1} = \underline{200^{k\Omega}}$

$\frac{\gamma}{2\sqrt{2\phi_f + V_{SB}}} = \frac{0.5}{2\sqrt{0.65+1}} = 0.19$

$\chi g_m = \underline{167.2\,\mu A/V}$

$W L_{ov} C_{ox} = 20\times0.05\times4.3 = 4.3\,fF$

$\frac{2}{3}WLC_{ox} + C_{ov} = \frac{2}{3}\times20\times1\times4.3 + 4.3 = \underline{61.6\,fF}$

$C_{ov} = \underline{4.3\,fF}$

$\frac{C_{sbo}}{\sqrt{1+\frac{V_{SB}}{V_0}}} = \frac{15}{\sqrt{1+\frac{1}{0.7}}} = \underline{9.6\,fF}$

$\frac{C_{dbo}}{\sqrt{1+\frac{V_{DB}}{V_0}}} = \frac{15}{\sqrt{1+\frac{(1+1.5)}{0.7}}} = \underline{7\,fF}$

91

$\frac{2I_D}{V_{ov}} = \frac{2\times0.1}{0.25} = 0.8\,mA/V$

$\frac{g_m}{2\pi(C_{gs}+C_{gd})} = \frac{0.8\times10^{-3}}{2\pi(20+5)\times10^{-15}} = 5.1\,GHz$

92

$\frac{g_m}{2\pi(C_{gs}+C_{gd})}$, $g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D}$

$C_{gs} \simeq \frac{2}{3}WLC_{ox}$, if $C_{gs} \gg C_{gd}$ then [illegible] ignore C_{gd}. If we replace for [illegible] and C_{gs} in the f_T formula, we have:

$\frac{\sqrt{2\mu_n C_{ox} W/L\, I_D}}{2\pi\times\frac{2}{3}WLC_{ox}} = \frac{1.5}{\pi L}\sqrt{\frac{\mu_n I_D}{2C_{ox}WL}}$

[illegible] we can see that the higher the [illegible] I_D, then the higher is the f_T. Also [illegible] frequency is reverse proportional to the [illegible] of the device, i.e. higher frequencies [illegible] achievable for smaller devices.

4.93

$$f_T = \frac{g_m}{2\pi(C_{gs}+C_{gd})} \quad ①$$

for $C_{gs} \gg C_{gd}$ and the overlap capacitance of C_{gs} neglicibly small: $C_{gs} \simeq \frac{2}{3}WLC_{ox}$

Also $g_m = \frac{2I_D}{V_{ov}} = k'_n \frac{W}{L} V_{ov}$

If we substitude g_m and C_{gs} in ① from the above formulas: $f_T = k'_n \frac{W}{L} V_{ov} \frac{1}{2\pi\times\frac{2}{3}WLC_{ox}}$

$\Rightarrow f_T = \frac{3\mu_n V_{ov}}{4\pi L^2}$

Therefore, for a given device f_T is proportional to V_{ov}. $f_T \propto V_{ov}$

For $L = 1\,\mu m$, $V_{ov} = 0.25$:

$f_T = \frac{3\times450\times10^{-4}\times0.25}{4\times\pi\times1\times10^{-12}} = \underline{2.7\,GHz}$

For $V_{ov} = 0.5V$: $\frac{f_{T1}}{f_{T2}} = \frac{V_{ov1}}{V_{ov2}} \Rightarrow f_{T_2} = 2.7\times\frac{0.5}{0.25}$

$\underline{f_T = 5.4\,GHz}$

4.94

$A_M = -27\,V/V$, $C_{gs} = 0.3\,pF$, $C_{gd} = 0.1\,pF$

Common - Source configuration.

Eq. 4.127: $C_{in} = C_{gs} + C_{gd}(1 + g_m R'_L)$.

Also $A_M = -g_m R'_L$, therefore:

$C_{in} = 0.3 + 0.1\times(1+27) = 3.1\,pF$

Now to find the range of R_{sig} that results in 3-db frequencies over 10MHZ, we use eq. 4.132: $f_H = \frac{1}{2\pi C_{in} R'_{sig}}$

If we neglect R_G effect then $R'_{sig} \simeq R_{sig}$.

$f_H \geqslant 10^{MHZ} \Rightarrow \frac{1}{2\pi\times3.1\times10^{-12}\times R_{sig}} \geqslant 10^{MHZ}$

$\Rightarrow \underline{R_{sig} \leqslant 5.1^{k\Omega}}$

4.95

$R_{sig} = 100^{k\Omega}$, $R_{in} = 100\,k\Omega$, $C_{gs} = 1\,pF$, $C_{gd} = 0.2\,pF$ ✓

Cont.

$$A_M = -\frac{R_G}{R_G + R_{sig}} g_m (r_o \| R_D \| R_L) \quad \text{(Eq. 4.119)}$$

Also $R_{in} = 100k\Omega = R_G$

$$A_M = \frac{-100}{100+100} 3(50^k \| 8^k \| 10^k) = \underline{-6.1 \, V/V}$$

$$f_H = \frac{1}{2\pi C_{in} R'_{sig}} \quad \text{(Eq. 4.132)}$$

$R'_{sig} = R_{sig} \| R_G = 100 \| 100 = 50k\Omega$

$C_{in} = C_{gs} + C_{gd}(1 + g_m R'_L)$

$R'_L = r_o \| R_D \| R_L = 4.1k\Omega$

$C_{in} = 1 + 0.2(1 + 3 \times 4.1) = 3.66pF$

Now we can calculate f_H:

$$f_H = \frac{1}{2\pi \times 3.66 \times 10^{-12} \times 50 \times 10^3} = \underline{870^{KHz}}$$

In order to double f_H, we have to either decrease C_{in} (by reducing R_{out}) or reduce R'_{sig} by reducing R_{in}.

If we reduce $R_{out} = R_D \| r_o$:

$$\frac{f_{H2}}{f_{H1}} = \frac{C_{in1}}{C_{in2}} \Rightarrow 2 = \frac{3.66\,pF}{1 + 0.2(1 + 3 \times R'_L)}$$

$\Rightarrow R'_L = 1.27k\Omega \qquad R'_L = R_{out} \| R_L = R_{out} \| 10^k$

$\Rightarrow \underline{R_{out} = 1.45k\Omega}$

Therefore in order to double f_H to $870 \times 2 = 1.74^{MHz}$, we have to reduce $R_{out} = r_o \| R_D$ to $1.45^{k\Omega}$ or equivalently reducing R_D to $1.5^{k\Omega}$. The new midband gain would be:

$$\frac{A_{M2}}{A_{M1}} = \frac{R'_{L2}}{R'_{L1}} \Rightarrow A_{M2} = -6.1 \times \frac{1.27}{4.1} = \underline{-1.9 \, V/V}$$

Gain is almost reduced by a factor of $\underline{3}$.

If we reduce $R_{in} = R_G$:

$$\frac{f_{H2}}{f_{H1}} = \frac{R'_{sig1}}{R'_{sig2}} \Rightarrow 2 = \frac{50^k}{R'_{sig2}} \Rightarrow R'_{sig2} = 25^{k\Omega}$$

$$\Rightarrow 25k\Omega = 100k \| R_G \Rightarrow \underline{R_G = 33^{k\Omega} = R_{in}}$$

Therefore in order to double f_H, R_{in} is reduced by a factor of 3, from $100k\Omega$ to $33k\Omega$.

The new midband gain would be:

$$\frac{A_{M2}}{A_{M1}} = \frac{R_{G2}}{R_{G1}} \cdot \frac{R_{G1} + R_{sig}}{R_{G2} + R_{sig}} \Rightarrow A_{M2} = -6.1 \times \frac{1}{3} \times \frac{100+100}{33+100}$$

$$\underline{A_{M2} = -3.06 \, V/V}$$

Gain is almost reduced by a factor of $\underline{2}$.

4.96

$R_{in} = 2M\Omega$, $g_m = 4\,mA/V$, $r_o = 100k\Omega$, ...

$C_{gs} = 2pF$, $C_{gd} = 0.5pF$, $R_{sig} = 500k\Omega$, ...

a) using Eq. 4.119 and noting that ... we have:

$$A_M = -\frac{R_G}{R_G + R_{sig}} g_m (r_o \| R_D \| R_L) = ...$$

$$\underline{A_M = -15.2 \, V/V}$$

b) Eq. 4.132: $f_H = \frac{1}{2\pi C_{in} R'_{sig}}$ where

$C_{in} = C_{gs} + C_{gd}(1 + g_m(r_o \| R_D \| R_L))$, R'_{sig} ...

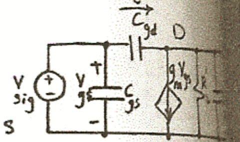
$C_{in} = 2 + 0.5(1 + 4 \times (100^k \| 10^k \| 10^k)) = 12...$

$R'_{sig} = 0.5^M \| 2^{M\Omega} = 0.4M\Omega = 400k\Omega$

$$f_H = \frac{1}{2\pi \times 12.02 \times 10^{-12} \times 400 \times 10^3} = \underline{33.1^{KHz}}$$

4.97

If we write KCL at node D:



$$i = g_m V_{gs} + \frac{V_o}{R'_L} + V_o C_L s$$

then: $V_{sig} = i \times \frac{1}{C_{gd} s} + v_o$

$$V_{sig} = \left(g_m V_{gs} + \frac{V_o}{R'_L} + V_o C_L s\right) \frac{1}{C_{gd} s} + v_o,$$

$$v_{sig}\left(1 - \frac{g_m}{C_{gd} s}\right) = v_o\left(1 + \frac{1}{R'_L C_{gd} s} + \frac{C_L s}{C_{gd} s}\right)$$

$$\frac{v_o}{v_{sig}} = -g_m R'_L \frac{(1 - s(C_{gd}/g_m))}{R'_L C_{gd} s + 1 + R'_L C_L s}$$

$$\frac{v_o}{v_{sig}} = -g_m R'_L \frac{1 - s\, C_{gd}/g_m}{1 + s(C_L + C_{gd}) R'_L}$$

$$\text{If } (g_m/C_{gd}) \gg \omega \Rightarrow \frac{v_o}{v_{sig}} = \frac{-g_m R'_L}{1 + s(C_L + C_{gd}) R'_L}$$

For $C_{gd} = 0.5pF$, $C_L = 2pF$, $g_m = 4mA/V$, ...

$$\frac{V_o}{V_{sig}} = \frac{A_M}{1 + s/\omega_H} \Rightarrow \begin{cases} A_M = -g_m R'_L = -4 \times 5 = ... \\ f_H = \frac{1}{2\pi (C_L + C_{gd}) R'_L} \end{cases}$$

$$\Rightarrow f_H = \frac{10^{12}}{2\pi \times (2 + 0.5) \times 5 \times 10^3}$$

$$\underline{f_H = 12.7MHz}$$

$g_m / C_{gd} = \frac{4}{0.5} = 8^{Grad/s}$

4.98

Eq. 4.134 ...

For $f_P = 1$...

To ensur...

C_1 has t...

$C_1 = 8n$...

To lowe...

possibl...

used, ...

To cal...

$\frac{f_{P2}}{f_{P1}}$ ...

f_P is ...

4.103

$$A_M = -\frac{R_G}{R_G+R_{sig}}\, g_m (r_o \| R_D \| R_L) = -\frac{2\times3}{2+0.5}(20^K \| 10^K)$$

$(r_o=\infty)$

$A_M = -16\, V/V$

Using equations 4.134, 4.136 and 4.138 we have:

$$f_{P1} = \frac{1}{2\pi C_{C1}(R_G+R_{sig})} \Rightarrow 3^{Hz} = \frac{1}{2\pi\times C_{C1}(2+0.5)\times10^6}$$

$\Rightarrow C_{C1} = 21.2\, nF$

$$f_{P2} = \frac{g_m}{2\pi C_S} \Rightarrow 50^{Hz} = \frac{3\times10^{-3}}{2\pi\times C_S} \Rightarrow C_S = 9.6\,\mu F$$

$$f_{P3} = \frac{1}{2\pi C_{C2}(R_D+R_L)} \Rightarrow 10^{Hz} = \frac{1}{2\pi C_{C2}(10^K+20^K)}$$

$\Rightarrow C_{C2} = 0.5\,\mu F$

$f_L = 50^{Hz}$ (Highest of the 3 poles)

4.104

Refer to Fig. P4.104.

$$f_{P1} = \frac{1}{2\pi C_{C1} R_{in}} = 1^{Hz}$$ (a decade lower than 10^{Hz})

$$f_{P2} = \frac{1}{2\pi C_{C2}(R_L + R_D \| R_o)} = 10^{Hz}$$

$$f_{P1} = 1^{Hz} = \frac{1}{2\pi C_{C1}\times 2.33\times10^6} \Rightarrow C_{C1} = 68.3\, nF$$

$$f_{P2} = 10^{Hz} = \frac{1}{2\pi C_{C2}(10^K + 10^K \| 47^K)} \Rightarrow C_{C2} = 873\, nF$$

4.105

Note that $k_n' \frac{W_n}{L} = k_p' \frac{W_p}{L}$ (matched)

a) when V_o is low: (eq. 4.140)

$$r_{DSN} = \frac{1}{k_n'(\frac{W}{L})_n(V_{DD}-V_{tn})} = \frac{1}{120\times10^{-6}\times\frac{1.2}{0.8}\times(3-0.7)}$$

$r_{DSN} = 2.4\, k\Omega$

when V_o is high (V_{OH}): (eq. 4.141)

$$r_{DSP} = \frac{1}{k_p'(\frac{W}{L})_p(V_{DD}-|V_{tp}|)} = \frac{1}{60\times10^{-6}\times\frac{2.4}{0.8}\times(3-0.7)}$$

$r_{DSP} = 2.4\, k\Omega$

b) $I_{max} = k_n'(\frac{W}{L})_n\,(V_{DD}-V_{tn})$

$I_{max} = 120\times10^{-6}\times\frac{1.2}{0.8}\times(3-$

c) Eq. 4.148: $V_{IH} = \frac{1}{8}(5V_D$

$V_{IH} = \frac{1}{8}(5\times3 - 2\times0.7) = 1.7V$

Eq. 4.149: $V_{IL} = \frac{1}{8}(3V_{DD}$

$N_{MH} = V_{OH} - V_{IH}$

$N_{ML} = V_{IL} - V_{OL}$

4.106

From the formula given in E

have: $V_{th} = \frac{r(V_{DD}-|V_{tp}|)+V}{1+r}$

where $r = \sqrt{\frac{k_p'(\frac{W}{L})_p}{k_n'(\frac{W}{L})_n}}$

We have $V_{tn} = |V_{tp}| = 0.7V$, $V_{DD} =$

$k_p' = 60\,\mu A/V^2$. Thus: for $(\frac{W}{L}$

$r = \sqrt{\frac{60}{120}} = 0.71$

$V_{th} = \frac{0.71(3-0.7)+0.7}{1+0.71} = 1.3$

For $(\frac{W}{L})_p = 2(\frac{W}{L})_n$ (the m

we have: $r = \sqrt{\frac{60}{120}\times2} = 1$

$V_{th} = \frac{1\times(3-0.7)+0.7}{1+1} = 1.5^V$

For $(\frac{W}{L})_p = 4(\frac{W}{L})_n$ we have:

$V_{th} = \frac{1.41\times(3-0.7)+0.7}{1+1.41} = 1.6$

The results are summarized

table:

$(\frac{W}{L})_p = (\frac{W}{L})_n$	$V_{th} = 1.36^V$
$(\frac{W}{L})_p = 2(\frac{W}{L})_n$	$V_{th} = 1.5^V$
$(\frac{W}{L})_p = 4(\frac{W}{L})_n$	$V_{th} = 1.64^V$