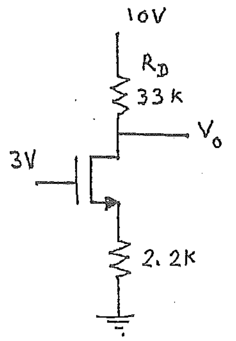
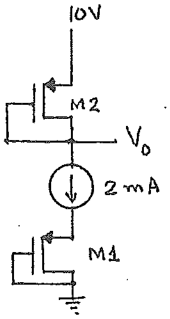
EE 381 ELECTRONICS I (Madhu)
REVIEW PROBLEMS FOR THE FINAL EXAM

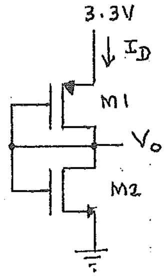
Problem 1: $k = 0.2$ mA/V^2 and $V_T = 1.5$ V.
(a) Find V_o.
(b) Find the maximum value that R_D can have before the transistor goes out of saturation. Find V_o for this condition.



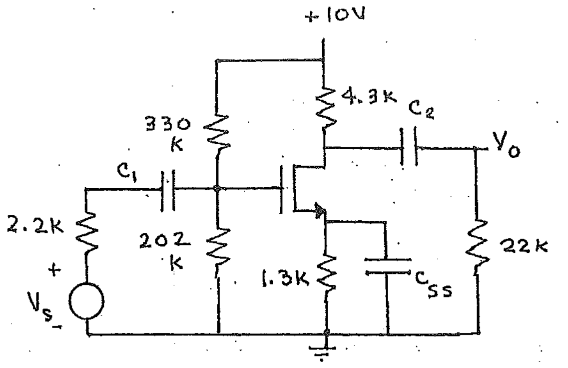
Problem 2: $k_1 = 1.25$ mA/V^2, $k_2 = 2.5$ mA/V^2. $|V_T| = 0.8$ V for both.
(a) Find V_o.
(b) Replace the current source by a resistor R_1. What is the value of R_1?



Problem 3: $\mu_n C_{ox} = 0.050$ mA/V^2 and $\mu_p C_{ox} = 0.025$ mA/V^2. $|V_T| = 0.9$ V for both.
(a) If $(W/L) = 10$ for both transistors, find I_D and V_o.
(b) Repeat the calculations of Part (a) if (W/L) of the NMOS is changed to 4, keeping (W/L) of the PMOS at 10.

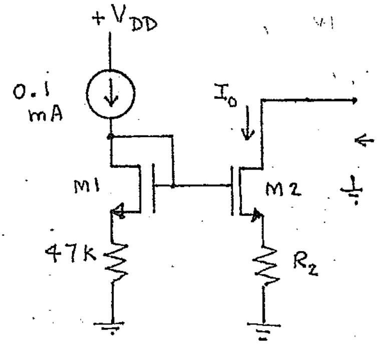


Problem 4: $k = 0.9$ mA/V^2 and $V_T = 0.5$ V. $C_{gs} = 12$ pF. $C_{gd} = 4$ pF. $C_{ds} = 6$ pF. Determine the midband gain and the upper cutoff frequency.



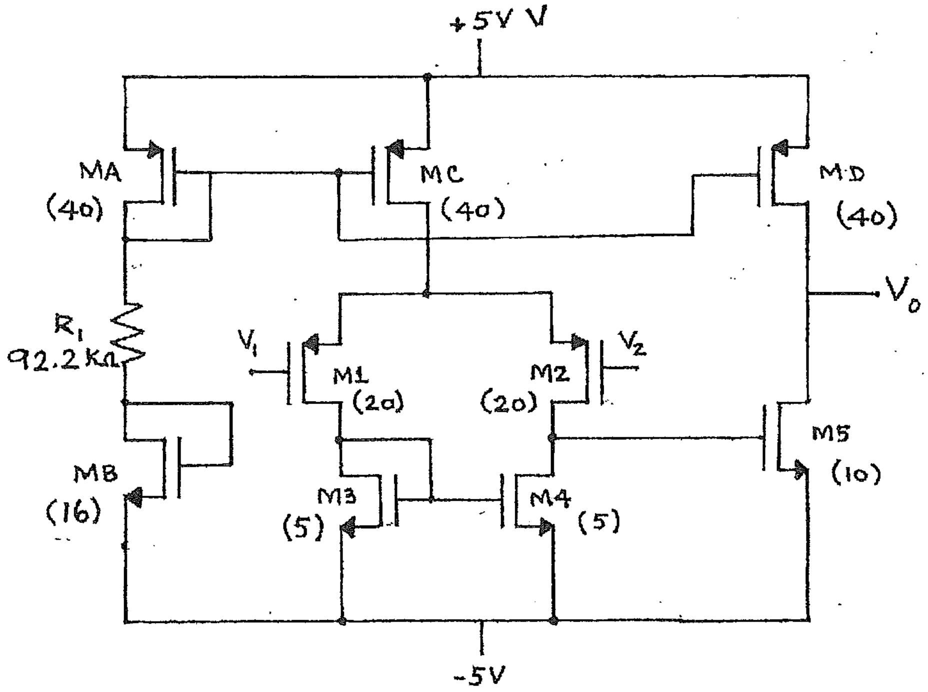
Problem 5: The amplifier of the previous problem is required to have a lower cutoff frequency of 30 Hz. (Note the units!) Select the value of C_{SS} so that it results in a pole at the specified lower cutoff frequency. Select the value of C_1 so that the pole due to it cancels the zero caused by C_{SS} and select the value of C2 so that the pole due to it is at 3 Hz.

Problem 6: $\mu_n C_{ox} = 0.092$ mA/V^2. $|V_T| = 0.9$ V. $(W/L) = 62.5$. $\lambda = 0.025$ V^{-1} for both.
(a) Find the value of R_2 so as to make $I_o = 0.05$ mA.
(b) Find the output resistance R_o.



Problem 7: In the 2-stage CMOS op amp shown below, the sizing ratios of the different transistors are shown in parenthesis. $\mu_n C_{ox} = 0.160$ mA/V^2 and $\mu_p C_{ox} = 0.064$ mA/V^2.

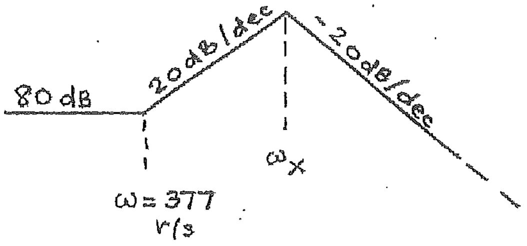
$|V_T| = 0.7$ V for all transistors. $\lambda = 0.025$ V^{-1} for NMOS and 0.05 V^{-1} for the PMOS devices.



(a) Determine the Q point values of the drain and gate voltages. Assume that $V_o = 0$ at the Q point.

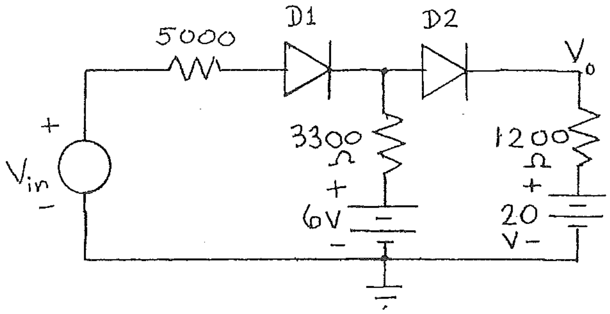
(b) Determine the diff mode gain.

Problem 8: The asymptotic value of the gain at ω_x is given as 97 dB.onstz
(a) Write the expression of the gain function. Be sure to evaluate the constant *K*.
(b) Draw the phase plot. Be sure to include all relevant numerical information in the diagram.



Problem 9: A two stage op amp has an equivalent circuit with parameters and element values as follows: $g_{m2} = 1.5$ mS; $R_{o1} = 40$ kΩ; $C_1 = 13.5$ pF; $g_{m5} = 0.8$ mS; $R_{o2} = 62.5$ kΩ; $C_2 = 1.2$ pF.
(a) Sketch the Bode magnitude and phase plots.
(b) Determine the value of the Miller compensation capacitor C_C needed to introduce a phase margin of 60°.

PROBLEM 10: Assume ideal diodes. Find the range of values of V_{in} for each of the following two states:
(a) both diodes are ON.
(b) D1 ON and D2 OFF.



REVIEW PROBLEMS FOR FINAL EXAM

12/5/2018

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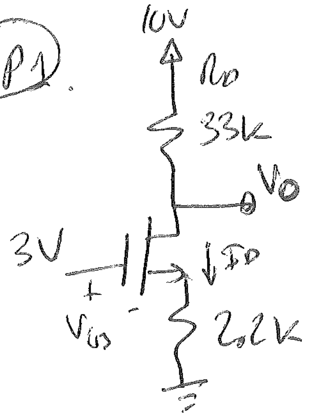
(P1).



$k = 0.2\,mA/V^2$

$V_T = 1.5V$

a) Find V_O.

b) Find max value of R_D for saturation and V_O for this condition.

(a) $$3 - 2.2\left(\frac{1}{2}\,0.2\,(V_{GS} - \overset{1.5V}{V_T})^2\right) = V_{GS}$$

$$3 - 0.22V_{GS}^2 + 0.66V_{GS} - 0.495 = V_{GS}$$

$$2.505 - 0.34V_{GS} - 0.22V_{GS}^2 = 0$$

$V_{GS} = -4.23V$

$= 2.689V$

$V_{GS} = 2.689V$

$I_D = 0.1414\,mA$.

And $V_O = 5.335V = 10 - I_D R_D$

(b) $V_{GD} = V_T \leq 1.5V$

$V_{GDmax} = 1.5V$

$V_D = 1.5V$ (min)

$R_D = 60.11k$.

$$V_{DS} = V_{GS} - V_T = \overset{2.689}{3} - 1.5 = \overset{1.189V}{\cancel{1.5V}}$$

$$V_{DS} = \underbrace{\cancel{10-}I_D \cdot R_D}_{V_D} - \underbrace{I_D \cdot R_S}_{V_S}$$

~~$V_{DS} = 1.189 = \overset{10-}{(0.1414 \cdot R_D)} - 0.31108$~~

~~$R_D = \frac{1.189 + 0.311}{0.1414} = 3.33k$~~

$$V_{DS} = 1.189 = \overbrace{(10 - I_D R_D)}^{V_D} - \overbrace{I_D R_S}^{V_S}$$

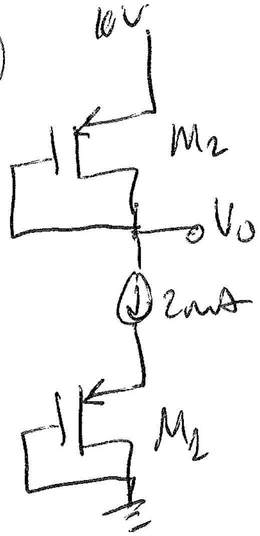
$$1.189 = 10 - 0.1414 \cdot R_D - 0.311$$

$$1.189 - 10 + 0.311 = -0.1414 R_D$$

$$R_D = \frac{8.5}{0.1414} = 60.11k.$$

$$\boxed{V_O = 10 - 8.5 = 1.5V}$$

#2



$k_1 = 1.25mA/V^2$ $|V_T| = 0.8V$

$k_2 = 2.5mA/V^2$

(a) V_o.

M2: $I_D = 2mA$

$2 = \frac{1}{2} \overset{2.5mA}{\cancel{25}} (V_{GS_2} - 0.8)^2$

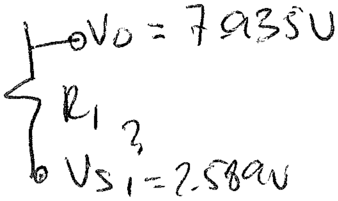
$V_{GS_2} = 2.065V \leftarrow$ $V_{ov} = \sqrt{\frac{4}{2.5}} = 1.26V$

$V_{GS} = V_{ov} + V_T$

$V_O = 7.935V$

$= (10 - 2.065V)$

(b) Replace current source by R_1. What is R_1?



$2mA = \frac{1}{2}(1.25mA/V^2)(V_{ov}^2)$

~~V_{GS_1}~~ $= \therefore V_{SG_1} = 2.589V$

$V_{S_1} = 2.589V$

$R = \frac{7.935 - 2.589}{2mA} = 2.673k$

②12/15/2016

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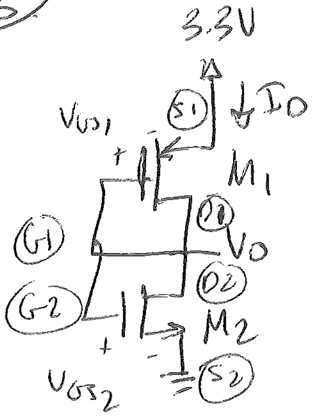
P3



$\mu_n C_{ox} = 0.05\ mA/V^2$

$\mu_p C_{ox} = 0.025\ mA/V^2$

$|V_T| = 0.9V$

(a) $\frac{W}{L} = 10$ for both. Find I_D + V_O

$K_n = 10 \cdot 0.05 mA/V^2 = 0.5 mA/V^2$

$K_p = 10 \cdot 0.025 mA/V^2 = 0.25 mA/V^2$

$I_{D_n} = I_{D_p}$

$$\frac{1}{2} 0.5 mA/V^2 (V_{GS_n} - V_T)^2 = \frac{1}{2} 0.25 mA/V^2 (V_{SG_p} - V_T)^2$$

$$\frac{V_{SG_1} - 0.9}{V_{GS_2} - 0.9} = \underbrace{\sqrt{\frac{0.25}{0.125}}}_{1.414}$$

$V_{SG_1} - 0.9 = 1.414 V_{SG_2} - 1.273$

2eq, 2unknowns

$$\begin{cases} V_{SG_1} = 1.414 V_{GS_2} - 0.3728 \\ V_{SG_1} + V_{GS_2} = 3.3 \end{cases}$$

$V_{SG_1} = 1.778V$

$V_{GS_2} = 1.521V$

(b) $\left(\frac{W}{L}\right)_n = 4$ $\left(\frac{W}{L}\right)_p = 10$

$K_n = 0.2 mA/V^2$

$K_p = 0.25 mA/V^2$

$0.1 (V_{GS_2} - 0.9)^2 = 0.125 (V_{SG_1} - 0.9)^2$

$$\frac{V_{GS_2} - 0.9}{V_{SG_1} - 0.9} = \sqrt{\frac{0.125}{0.1}}$$

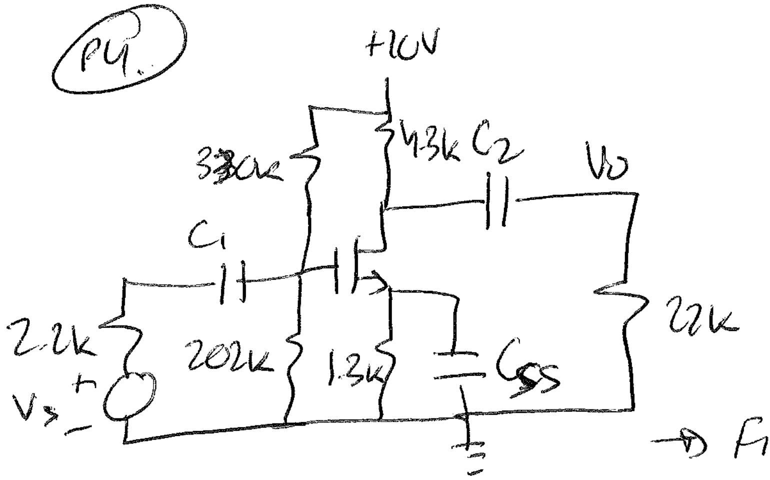
$V_{GS_2} - 0.9 = 1.118 V_{SG_1} - 1.006$

$$\left.\begin{aligned} 1.118 V_{SG_1} - V_{GS_2} &= 0.1062 \\ V_{SG_1} + V_{GS_2} &= 3.3 \end{aligned}\right\}$$ 2eq 2unknowns

$V_{SG_1} = 1.608V$

$V_{GS_2} =$ ~~1.592V~~ 1.692V ◁—

P4.



$k = 0.9\ mA/V^2$

$V_T = 0.5$

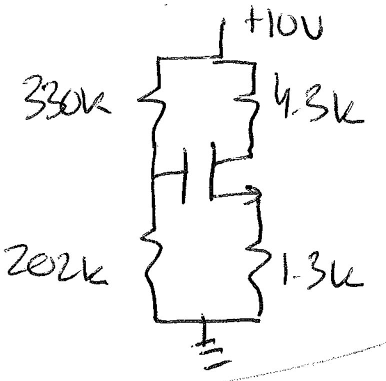
$C_{gs} = 12pF$

$C_{gd} = 4pF$

$C_{ds} = 16pF.$

→ Find midband gain and upper cutoff frequency.

D.C Analysis



Caps → open

$$V_G = 10V \cdot \frac{202K}{202K + 330K} = 3.797V$$

$$V_{GS} = 3.797 - \left(\frac{1}{2}0.9(V_{GS}-0.5)^2\right)(1.3K)$$

$$V_{GS} = 3.797 - 0.585(V_{GS}-0.5)^2$$

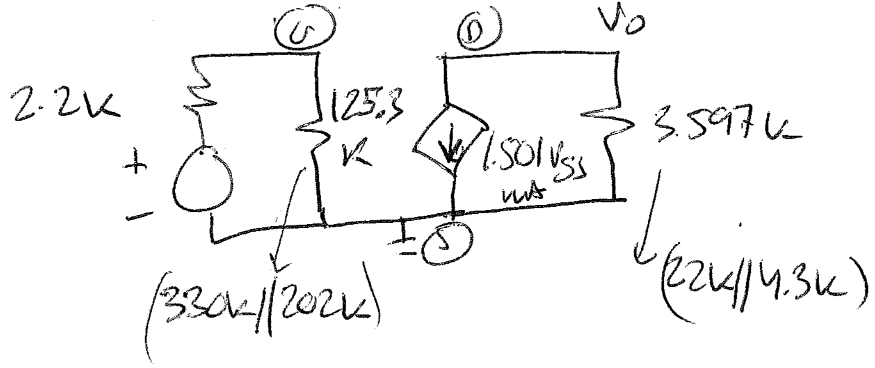
$$3.797 - 0.585V_{GS}^2 + 0.585V_{GS} - 0.14625 = V_{GS}$$

$V_{GS} = 2.168V$

$g_m = 1.501 mS$

$g_m = k(V_{GS} - V_T)$

Small signal midband:



$$\frac{V_o}{V_{gs}} = -5.399$$

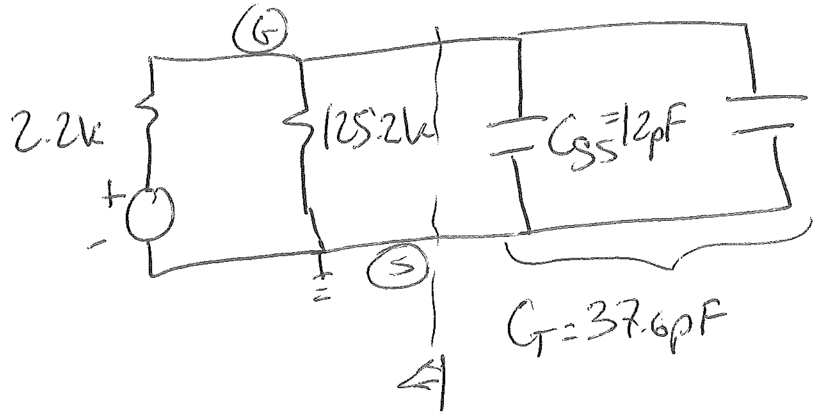
$$\frac{V_{gs}}{V_{sig}} = \frac{125.3}{125.3+2.2} = 0.9827$$

$A_{mid} = -5.306$

③ 12/5/2016
Madlu

→ Upper cut-off frequency

ω_{hi} Input side:



$C_M = C_{gd}(1+g_m \cdot R_{eq})$

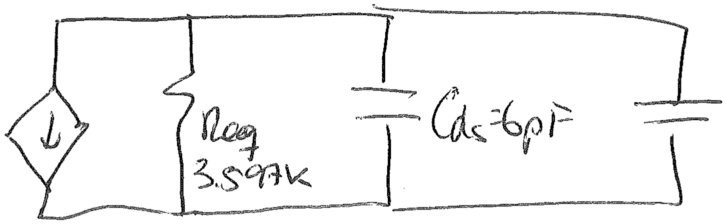
$= 4pF(1+1.501mS \cdot 3.597k)$

$C_M = 4(1+5.399) = 25.6pF$

$R_{TH} = 125.2k // 2.2k = 2.162k.$

$$\therefore \omega_{hi(in)} = \frac{1}{(2.162k)(37.6pF)} = 1.230\times10^7 \ r/s$$

ω_{hi} output side.



$C'_M = C_{gd}\left(1+\frac{1}{g_m R_{eq}}\right)$

$C'_M = 4pF\left(1+\frac{1}{5.399}\right) = 4.741 pF$

$$\omega_{hi(out)} = \frac{1}{(3.597\times10^3)(10.741\times10^{-12})} = 2.588\times10^7 \ r/s$$

No dominant pole

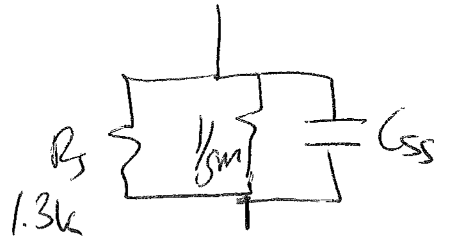
$$\left|\frac{(1.23\times10^7)(2.588\times10^7)}{(j\omega+1.23\times10^7)(j\omega+2.588\times10^7)}\right| = 0.707$$

← to find 3dB pole.

$$\therefore \boxed{\omega_{hi} = 1.044\times10^7 \ r/s}$$

(P5) → $f_{LO} = 30Hz \rightarrow \omega_{LO} = 188.5\ r/s$

Bypass capacitor $C_{SS} \rightarrow \omega_p = 188.5\ r/s$



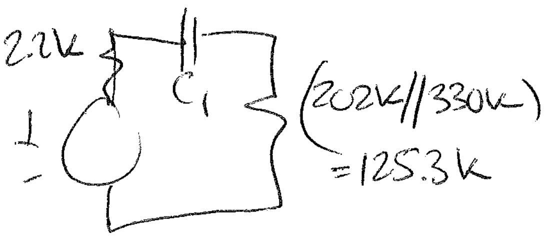
$$\frac{1}{1.801ms} = 0.662k$$

$$\omega_p = 188.5 r/s = \frac{1}{(1.3k//0.662k)\cdot C_{SS}}$$

$$C_{SS} = \frac{1}{(188.5 r/s)(0.4405\times10^3)} = 12.04\mu F$$

$$\omega_z \text{ due to } C_{SS} = \frac{1}{R_S\cdot C_{SS}} = \frac{1}{(1.3\times10^3\Omega)(12.04\times10^{-6}F)} = 63.89 r/s$$

→ Want C_1 to cancel that zero (ω_z of C_{SS})

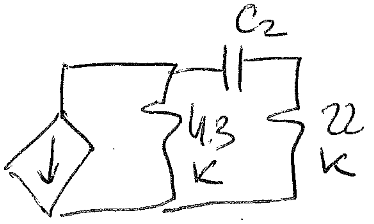


$$\omega_{PC_1} = \frac{1}{C_1\cdot(127.5\times10^3\Omega)} = 63.89 r/s$$

$$\therefore C_1 = \frac{1}{(63.89 r/s)(127.5\times10^3\Omega)}$$

$$C_1 = 122.8nF$$

→ Make C_2's pole at 0.1× flow. = 3Hz $\omega_{PC_2} = 6\pi\ r/s$

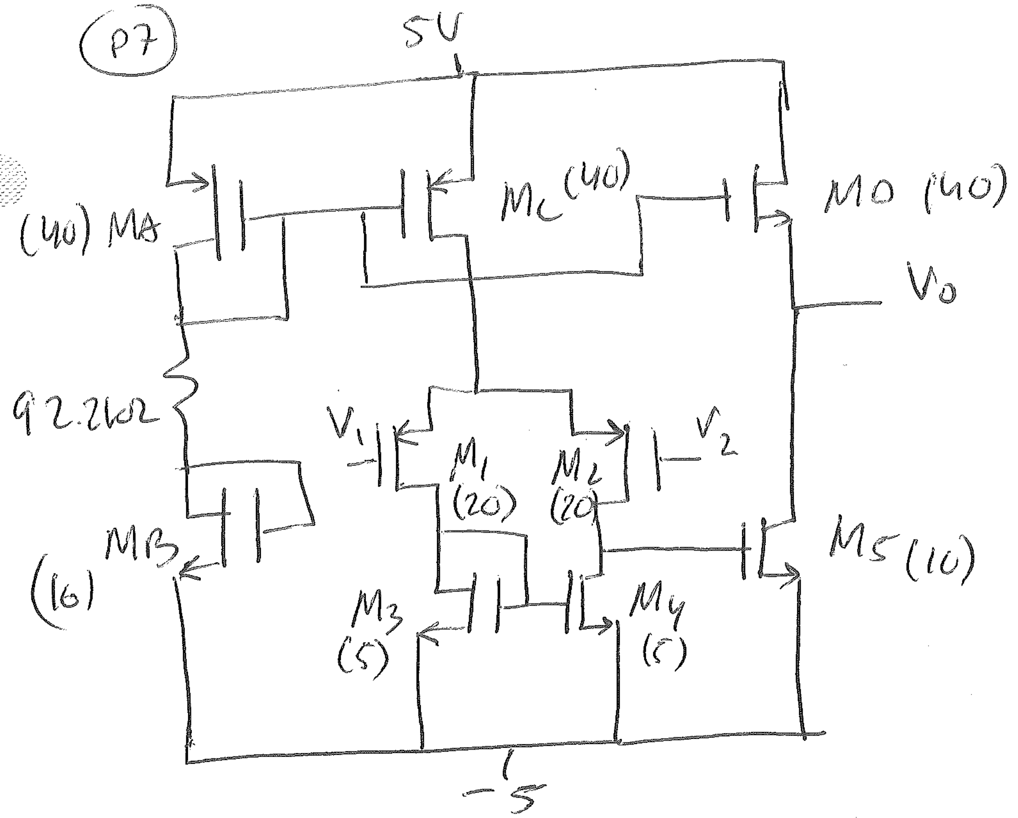


$$\omega_{PC_2} = \frac{1}{C_2\cdot(26.3k)} = 6\pi\ r/s$$

$$C_2 = \frac{1}{(26.3k)(6\pi r/s)} = 2.017\mu F$$

12/7/2016 ②

(P7)



$\mu_n C_{ox} = 0.16\ mA/V^2$

$\mu_p C_{ox} = 0.064\ mA/V^2$

$K_A = 0.064 \times 40 = 2.56\ mA/V^2$

$K_B = 0.16 \times 16 = 2.56\ mA/V^2$

$\therefore V_{SGA} = V_{GSB}$

$5 - V_{SGA} - 92.2k\left(\frac{1}{2}\right)(2.56)^{mA/V^2}(V_{SGA} - 0.7)^2 - V_{SGA} = -5$

$5 - V_{SGA} - 118V_{SGA}^2 + 165.2V_{SGA} - 57.82 - V_{SGA} = -5$

~~$-118V_{SGA}^2 \quad {}^2 + 10$~~

$V_{SGA} = 0.9616V \quad \left[-118V_{SGA}^2 + 163.2V_{SGA} - 47.82 = 0 \right]$

$I_{REF} = 0.0876\ mA$

$\underline{M_A}:\ V_G = V_D = 4.038V$

$\underline{M_B} =\ V_G = V_D = -4.038V$

→ M1: $\left\{ \begin{array}{l} I_D = 0.0438\ mA \\ \text{PMOS} \quad K_1 = \cancel{0.16\times}\ 0.064 \times 20 = 1.28\ mA/V^2 \end{array} \right.$

$0.0438\ mA = \frac{1}{2}\ 1.28\ mA/V^2 \underbrace{(V_{SG_1} - V_t)^2}_{V_{ov}^2}$

$V_{OV} = \sqrt{\frac{2-0.0438}{1.28}} = 0.2616$

$V_{SG_1} = 0.9616V = 0.2616+0.7$

M3: $k_3 = 0.8 mA/V^2$

NMOS $I_{D3} = 0.0438 mA$

$0.0438 mA = \frac{1}{2} 0.8 mA/V^2 (V_{OV})^2$

$V_{OV} = 0.331 V$

$V_{GS3} = 1.031V$

$M_3: V_{G3} = V_{D3} = -3.969V$

→ M2 same as M1

→ M4 same as M3 → what is V_{D4}?

Mc: $k_C = 2.5 mA/V^2$

V_G of Mc = V_G of MA = 4.038V

MD: same as Mc.

M5: $I_{D5} = 0.0876 mA$

$k_5 = 1.6 mA/V^2 = 10 \times 0.16 mA/V^2$

$0.0876 mA = \frac{1}{2} 1.6 mA/V^2 (V_{OV})^2$

$V_{OV} =$ ~~0.468V~~ ~~1.0464 V~~ 0.331V

$V_{GS5} =$ ~~1.16V~~ 1.031V

$V_{G5} =$ ~~-3.84~~ $= V_{D5}$

$-3.969V$

12/7/2016

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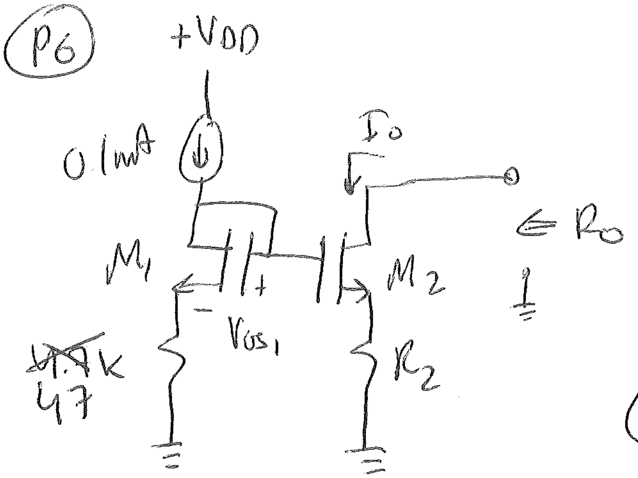
(P6)



$\mu_n C_{ox} = 0.092\,mA/V^2$

$|V_T| = 0.9V$

$\frac{W}{L} = 62.5$, $\lambda = 0.025V^{-1}$ (for both)

(a) Find R_2 to make $I_O = 0.05mA$

(b) Find output resistance Ro.

(a) $I_{D_1} = 1mA = \frac{1}{2}(0.092mA/V^2)(62.5)\cdot(\underbrace{V_{GS_1} - \overset{0.9V}{V_T}}_{V_{OV}})^2$

$V_{OV_1} = 0.186$

$V_{GS_1} = 1.086V$

$V_{G_1} = (47k)(0.1mA) + 1086V = 5.786V$

Also $V_{G_2} = 5.786V$

For $I_{D_2} = 0.05mA = \frac{1}{2}(0.092mA/V^2)(62.5)(V_{OV})^2$

$V_{OV_2} = \cancel{0.186}\ 0.132$

$V_{GS_2} = 1.032V$

$\therefore\ V_{GS_2} = V_{G_2} - V_{S_2}$

$1.032V = 5.786 - V_{S_2}$

$V_{S_2} = 4.754 = R_2\cdot(0.05)$

$R_2 = 95.08k\Omega$.

OR: $1.032 = 5.786 - R_2\cdot(0.05)$

$R_2 = 95.08k\Omega$

1.086−0.9
$\uparrow$=0.186

b) Find output resistance R_o:

Draw small signal circuit, need $gm_1 = 0.092 \times 62.5 (V_{ov_1})$

$gm_1 = 1.07\ mS$

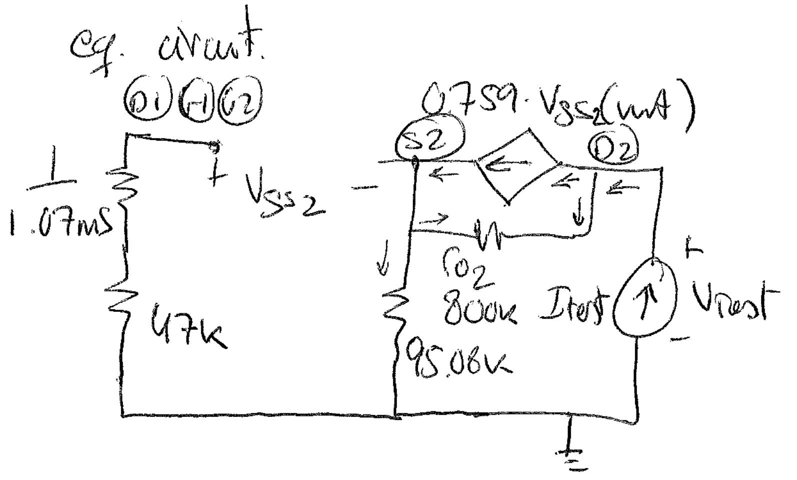
1.032−0.9
=0.132

and $gm_2 = 0.092 \times 62.5 (V_{ov_2})$

$gm_2 = 0.759 mS$

and $r_{o_2} = \dfrac{1}{\lambda \cdot I_{D_2}} = \dfrac{1}{0.025 \times 0.05}$

$r_{o_2} = 800k\Omega$



$V_{gs_2} = -V_{s_2}$ since $V_{g_2} = 0V$ (no current flowing)

Node S_2: $\dfrac{V_{s_2}}{95.08k} + \dfrac{V_{s_2} - V_{test}}{800k} = 0.759(-V_{s2})$

$0.77076 V_{s_2} - 1.25 \times 10^{-3} V_{test} = 0 \longrightarrow ①$

Node D_2: $\dfrac{V_{test} - V_{s_2}}{800} = I_{test} - 0.759(-V_{s_2})$

$-0.76025 V_{s_2} + 1.25 \times 10^{-3} V_{test} = I_T$

set $I_T = 1mA$

$-0.76025 V_{s_2} + 1.25 \times 10^{-3} V_{test} = 1mA \rightarrow ②$

$V_{s_2} = 95.15V$

$V_{test} = 5.867 \times 10^4$

$\therefore R_o = \dfrac{5.867 \times 10^4}{1 \times 10^{-3}} = 58.67 M\Omega$

12/9/2016

Diff. mode gain

→ Need g_{m2}, r_{o2}, r_{o4}
g_{m5}, r_{o5}, r_{oD}

→ $g_{m2} = 20 \times 0.064\,\text{mA/V}^2\,(0.261)^{*} = \overset{0.3341\text{ mS}}{\cancel{0.0872\text{ mS}}}$

$r_{o2} = \dfrac{1}{0.05 \times 0.0438} = 456.6\text{k}\Omega$

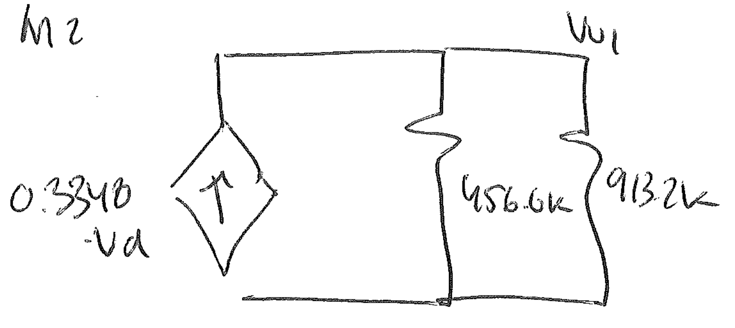
$r_{o2} = \dfrac{1}{0.025 \times 0.0438} = 913.2\text{ k}\Omega$

→ $g_{m5} = 10 \times 0.16\,\text{mA/V}^2\,(\overset{0.331}{\cancel{0.468}})^{*} = 0.528\text{mS}$

$r_{o5} = \dfrac{1}{0.025 \times 0.0876} = 456.6\text{k}$

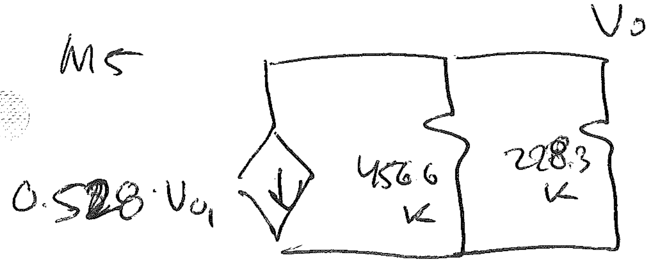
$r_{oD} = \dfrac{1}{0.05 \times 0.0876} = 228.3\text{k}.$

M2



$\dfrac{V_{o1}}{V_d} = 101.9 = (0.3348\text{mS})(304.4\text{k}\Omega)$

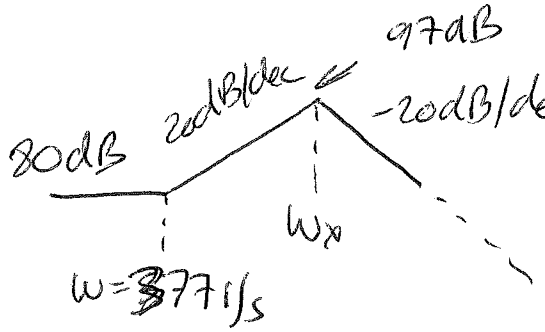
M5



$\dfrac{V_o}{V_{o1}} = -80.36 = -(0.528\text{mS})(152.2\text{k}\Omega)$

$A_d = -8189$ V/V

P8



a) Write expression for gain function.

$$\omega_x ? \rightarrow \quad 80 + 20\,\text{dB/dec} \log\left(\frac{\omega_x}{377}\right) = 97$$

$$\omega_x = 2669\ r/s$$

$$\therefore \quad H(s) = K\frac{(s+377)}{(s+2669)^2}$$

$$20 \cdot \log H(0) = 80$$

$$H(0) = 10^{80/20}$$

$$\rightarrow \text{Find } K \text{ if } H(0) = 10^4 \longleftarrow$$

$$10^4 = K\frac{377}{(2669)^2}$$

$$K = \frac{10^4 \cdot (2669)^2}{377} = 1.889 \times 10^8$$

$$\rightarrow \quad H(s) = 1.889 \times 10^8 \frac{(s+377)}{(s+2669)^2}$$

$\downarrow$ cont's

↳ Cont'd

② 12/9/2006

→ Phase plot.

ω = 377 (zero)

(0, 37.7) level 0°

(37.7, 3770) +45°/dec slope

(3770, ∞) level +90° level

ω = 2669 (pole)

(0, 266.9) level 0° level

(266.9, 26690) -~~90°~~/dec -90°/dec (double pole) slope

(26690, ∞) level -180° level

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combined.

(0, 37.7) level 0°

(37.7, 266.9) +45°/dec slope

(266.9, 3770) -45°/dec slope

(3770, 26690) -90°/dec slope

(266690, ∞) level -90°