Microelectronic Devices and Circuits- EECS105

Second Midterm Exam

Wendesday, November 17, 1999

Costas J. Spanos

University of California at Berkeley
College of Engineering
Department of Electrical Engineering and Computer Sciences

Your Name: OFFICIAL SOLUTIONS
(last) *(first)*

Your Signature: [signature]

1. *Print and sign your name on this page before you start.*
2. *You are allowed two, 8.5"x11" handwritten sheets with formulas. No books or notes!*
3. *Do everything on this exam, and make your methods as clear as possible.*

Problem 1	________	*/ 30*
Problem 2	________	*/ 35*
Problem 3	________	*/ 35*
TOTAL	59.1	*/ 100* AVERAGE (67 students)

14.6 STANDARD DEVIATION

Problem 1 of 3 Answer each question briefly and clearly. (30 points)

Explain briefly why BJT performance depends so much on the diffusivity of minority carriers (5pts)

It is the diffusion of minority carriers that brings them to the reverse-biased collector junction that makes the transistor work

How does the small signal output resistance of a BJT depend on its size (emitter-to-base junction area), when V_{BE} is held constant? (5pts)

$I_C = I_S \cdot e^{V_{BE}/V_{th}}$ $\quad r_o = \frac{V_A}{I_C}$

I_C is proportional to I_S, and I_S is proportional to A_E.

So: $A_E \uparrow \Rightarrow I_S \uparrow \Rightarrow I_C \uparrow \Rightarrow r_o \downarrow$

Why is it desirable for V_{BS} = 0V in MOS Common Gate applications? (5pts)

The current buffer dc gain is -1 in general

but $R_{in} = \frac{1}{g_m + g_{mb}}$. The lower R_{in} (due to g_{mb}) is desirable,

but the added capacitance is not!

What happens to the overall (loaded) |Av| when Ic increases in a CE amplifier? (Assume that R_L is initially equal to ro, Rs<<rπ and r_{oc} = infinity)(5 pts)

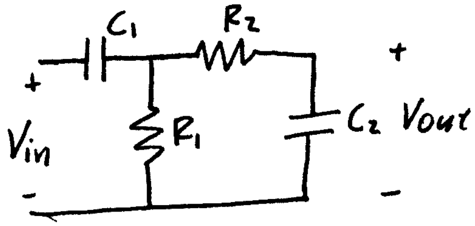
$$g_m = \frac{I_c}{V_{th}} \qquad r_o = \frac{V_A}{I_c}$$

$$|A_v| = g_m (r_o // R_L) = \frac{I_c}{V_{th}} \frac{r_o R_L}{r_o + R_L} = \frac{I_c}{V_{th}} \frac{\frac{V_A}{I_c} R_L}{\frac{V_A}{I_c} + R_L} =$$

$$\Rightarrow |A_v| = \frac{V_A}{V_{th}} \frac{R_L}{\frac{V_A}{I_c} + R_L}$$

so, if $I_c \uparrow$ then $|A_v| \uparrow$.

How many poles and how many zeros does this circuit have? What is its function, assuming that $R_1C_1 << R_2C_2$? (5pts)



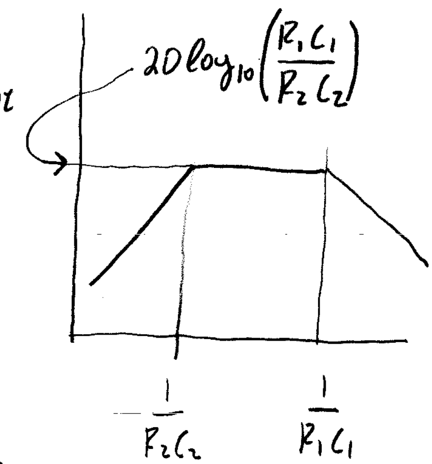
this is a band pass filter, with one $j\omega R_1 C_1$ mult. a pole at $\frac{1}{R_2 C_2}$ and one pole at $\frac{1}{R_1 C_1}$ (notice that you have two cascaded voltage dividers).

Assuming "no loading"

$$\frac{V_{out}}{V_{in}} = \underbrace{\frac{R_1}{R_1 + \frac{1}{j\omega C_1}}}_{\frac{V_{R1}}{V_{in}}} \cdot \underbrace{\frac{\frac{1}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}}}_{\frac{V_{out}}{V_{R1}}} = \frac{j\omega R_1 C_1}{(1 + j\omega R_1 C_1)(1 + j\omega R_2 C_2)}$$

dominant: $(1 + j\omega R_2 C_2)$

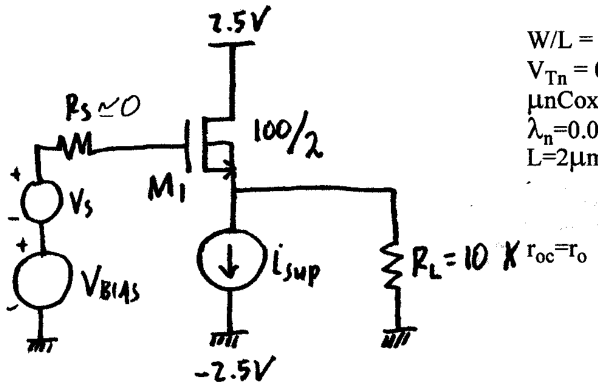
$$\omega_{p1} = \frac{1}{R_1 C_1} \qquad \omega_{p2} = \frac{1}{R_2 C_2}$$



Problem 2 of 3 (35 points)

For each of the following questions, make sure that you show the expressions before you plug in the specific values. A correct expression is worth 70% of the credit, even if the numerical calculation is incorrect!

You are given the following nmos common drain amplifier.



W/L = 100/2
V_{Tn} = 0.7V
$\mu nCox=50\mu A/V^2$
$\lambda_n=0.05V^{-1}$ (for L=2μm)
$r_{oc}=r_o$

a) Assume V_{bs}=0v, and find V_{bias} so that I_{sup} = 500μA. (10pts) And Vout = 0V

$V_{GS} = \sqrt{\frac{2I_{DS}}{\frac{W}{L}\mu_n C_{ox}}} + V_{Tn} = 1.332V$. Since $V_s = 0V$, the $V_{GS} = V_{BIAS} = 1.332V$

b) Calculate the overall (loaded) voltage gain, with V_{bs}=0V. (10pts)

The unloaded voltage gain is

$A_V = \frac{g_m}{\frac{1}{r_o \| r_{oc}} + g_m} = 0.969$

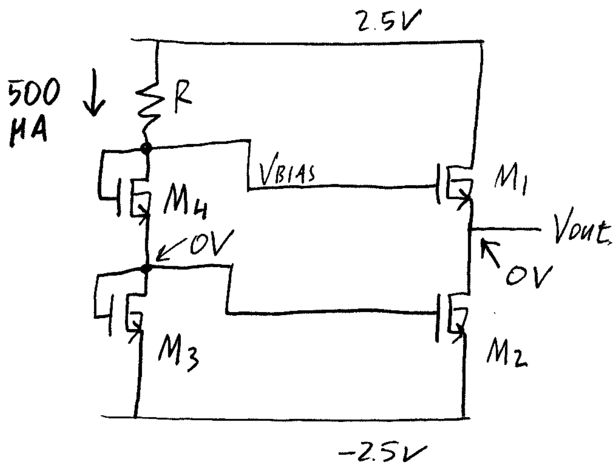
$g_m = \sqrt{2\frac{W}{L}\mu_n C_{ox} I_D} = 1.58mS$

$R_{out} = \frac{1}{\frac{1}{r_o \| r_{oc}} + g_m} = 613\Omega$

$r_o = (\lambda_n \cdot I_{DS})^{-1} = 40K = r_{oc} \Rightarrow r_o \| r_{oc} = 20K$

overall gain is $A_V \cdot \frac{R_L}{R_{out}+R_L} = \frac{10.000}{10.613} A_V = 0.913$

c) Size the biasing transistors and resistor in order to get the proper V_{bias} and proper supply current (10pts)



$V_{BIAS} = 1.332V. \Rightarrow R = \frac{2.5V - 1.332V}{500\mu A} = 2336\Omega$

M_4 must have 1.332 of V_{GS} $\Rightarrow$

$$\sqrt{\frac{2I_{DS}}{\left(\frac{W}{L}\right)_4 \mu_n C_{ox}}} + V_{tn} = 1.332 \Rightarrow \left(\frac{W}{L}\right)_4 = \frac{2I_{DS}/\mu_n C_{ox}}{(1.332 - V_{tn})^2} = 50 = \frac{100}{2}$$

$V_{GS_3} = 2.5V \Rightarrow$

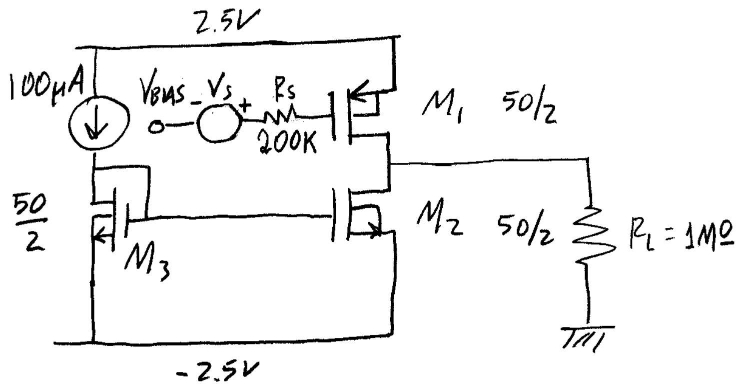
$$\sqrt{\frac{2I_{DS}}{\left(\frac{W}{L}\right)_3 \mu_n C_{ox}}} + V_{Tn} = 2.5 \Rightarrow \left(\frac{W}{L}\right)_3 = \frac{2I_{DS}/\mu_n C_{ox}}{(2.5 - V_{Tn})^2} = 6.17$$

also, $\left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_3 = 6.17. = \frac{12.30}{2}$

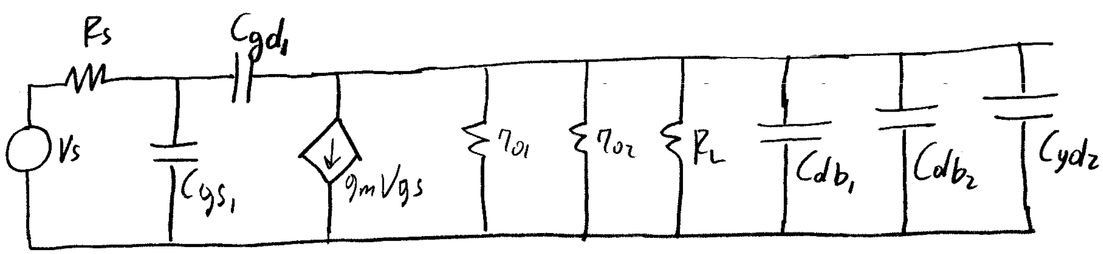
Problem 3 of 3 (35 points)

For each of the following questions, make sure that you show the expressions ***before*** *you plug in the specific values. A correct expression is worth 70% of the credit, even if the numerical calculation is incorrect!*

You are given the following p-channel common-source amplifier.



a) Draw the small signal model of the amplifier. Make sure that you include the entire small signal model of transistor M_1, along with all the relevant capacitances, including r_{o2}, C_{db2} and C_{gd2} from the current sink transisotr M_2. (10 points)



Notice that all the following small signal voltages are grounds: (0V)

v_{s_2} v_{g_2} v_{b_1} v_{b_2} ...

This is why all these caps are here

Also: $v_{gs_2} = 0V$ $v_{bs_2} = 0V$, that is why there are no dependent sources from M_2 in this model...

b) Apply the Miller approximation (ignore all capacitances when calculating the Miller gain), and derive a symbolic expression for the complete transfer function (hint: this function has two poles and no zeros) (7 points).

$$C_M = (1+|A_v|)\, C_{GD_1} \qquad A_v = -g_m (r_{o1} \| r_{o2} \| R_L)$$

$$V_{out} = -V_s \cdot \frac{\frac{1}{j\omega(C_{gs_1}+C_M)}}{R_s + \frac{1}{j\omega(C_{gs_1}+C_M)}} \cdot g_m \left(r_{o1} \| r_{o2} \| R_L \| \frac{1}{j\omega(C_{db_1}+C_{db_2}+C_{gd_2})} \right) \Rightarrow$$

$$\frac{V_{out}}{V_s} = -\underbrace{\frac{g_m}{\left[1+j\omega R_s (C_{gs_1}+C_M)\right]}}_{\text{pole}} \cdot \underbrace{\frac{r_{o1} \| r_{o2} \| R_L}{\left[1+R_L \| r_{o1} \| r_{o2} \cdot j\omega (C_{db_1}+C_{db_2}+C_{gd_2})\right]}}_{\text{pole}}$$

$$\omega = \frac{1}{R_s(C_{gs_1}+C_M)} \qquad \omega = \frac{1}{(R_L \| r_{o1} \| r_{o2}) \cdot (C_{db_1}+C_{db_2}+C_{gd_2})}$$

c) Calculate dc gain and the values of the two poles, given that C_{gs1}=78fF, C_{gd1}=25fF, C_{gd2}=25fF, C_{db1}=90fF, C_{db2}=30fF (8 points)

$$\text{dc gain} = -g_m \underbrace{(r_{o1} \| r_{o2} \| R_L)}_{91\,K\Omega} = \underline{-32.214}$$

$$g_m = \sqrt{2 \frac{W}{L} \mu_n C_{ox} I_D} = 0.354\,mS$$

$$r_{o1} = (\lambda_n \cdot I_D)^{-1} = 200K = r_{o2}$$

$$\text{pole 1 (dominant)} = \frac{1}{R_s(C_{gs_1}+C_{M_1})} \simeq \underline{5.5\,M\,rad/sec}$$

C_{M_1}: $25fF \times (1+32.214) = 805fF$

$$\text{pole}_2 = \frac{1}{(r_{o1} \| r_{o2} \| R_L) \cdot (C_{db_1}+C_{db_2}+C_{gd_2})} = \underline{75.7\,M\,rad/sec}$$

d) Draw the Bode plot for amplitude and phase of the gain of this amplifier (10 points).

$|A_v| = 32.214 = 30dB \quad (20\log_{10}(32.214))$