UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering
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Midterm 2
- closed book, one 5.5"x 8.5" summary ok -

EECS 140
Fall 1999

Device Parameters (except where otherwise noted):

Parameter	Unit	NMOS	PMOS
Threshold voltage, V_{TH}	V	1	-1
Gate capacitance, C_{ox}	fF/μm²	5	5
Transconductance coefficient, $k_p=\mu C_{ox}$	μA/V²	200	100
Channel length modulation, λ(L), L in μm	V^{-1}	0.1/L	0.1/L
Overlap Capacitances	$C_{OL} = W\cdot 0.5fF/\mu m$		

- Show your calculations on exam sheets (no credit for numerical result only) -

Name: Solution (2 points)

Student-ID: ______ (3 points)

Result summary: ______ (5 points)

a) V_{omin} = 894mV ______ (10 points)
V_{omax} = 4.106V

b) W_{17} = 25μm ______ (10 points)
V_{omax}' = 4.434V

c) G_m = 1mS ______ (10 points)

d) R_o = 10 MΩ ______ (10 points)

e) A_{dm} = 80.0dB ______ (10 points)

f) f_u = 31.83 MHz ______ (10 points)

g) f_{p2} = 478 MHz ______ (10 points)

h) f_{pm} = 119 MHz ______ (10 points)
f_{zm} = 238 MHz

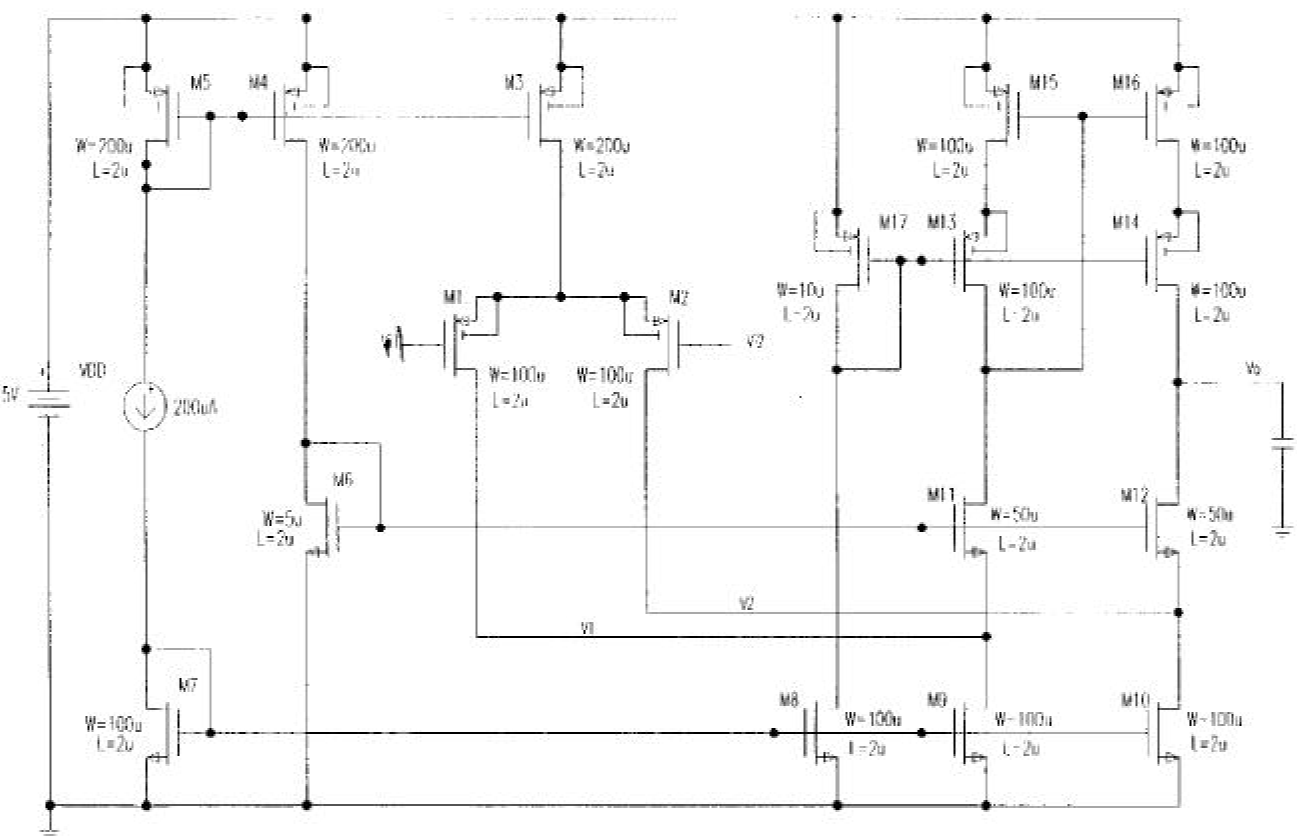
i) C_{i1} = 3.3pF ______ (10 points)

Total: ______ (100 points)

Problem: Consider the Folded Cascode Amplifier shown below.

- Neglect channel length modulation in DC calculations. (large signal)
- Neglect extrinsic parasitic capacitances in parts a) through h)
- Neglect body effect

a) Determine the minimum and maximum output voltages, V_{omin} and V_{omax}, that are required to operate the amplifier in its high gain regime.
b) Change W of M17 to *maximize* the output range while keeping all devices in the forward active region (assume maximum output current). Calculate the corresponding maximum output voltage V_{omax}'. Verify that M13 and M15 are indeed in saturation
c) Calculate the amplifier's differential mode transconductance G_m.
d) Calculate the amplifier's output resistance R_o.
e) Calculate the low frequency differential gain A_{dm} in dB.
f) Calculate the unity gain frequency f_u of the circuit for C_L=5pF. Assume that all non-dominant poles are at higher frequencies than f_u.
g) Estimate the pole frequency f_{p2} caused by the cascode device M11 (node V1).
h) Estimate the pole frequency f_{pm} and the zero frequency f_{zm} caused by the current mirror M13-M16.
i) Estimate the *low frequency* input capacitance C_{i2} looking into node V_{i2}. Include the gate to drain overlap capacitance of M2 in your analysis – neglect the parasitic junction capacitances. Hint: Include the Miller effect at node V2 and assume that C_L is an open circuit for the frequencies of interest. (C_{i1} at GND)



a) $Vdsat_6 = \sqrt{\frac{2 \cdot 200\mu}{200\mu \cdot 2.5}} = 894mV$

$Vdsat_{12} = \sqrt{\frac{2 \cdot 200\mu}{200\mu \cdot 25}} = 283\,mV$ (max.)

$\Rightarrow V_{omin} = Vdsat_6 - \cancel{Vdsat_{12}} + \cancel{Vdsat_{12}} = \underline{\underline{894\,mV}}$

$Vdsat_{17} = Vdsat_6 = 894\,mV$

$\Rightarrow V_{omax} = V_{DD} - Vdsat_{17} = \underline{\underline{4.106V}}$

b) for max output range: $\left(\frac{W}{L}\right)_{17} = \frac{1}{4}\left(\frac{W}{L}\right)_{13-16} = \frac{25\mu m}{2\mu m}$

$\Rightarrow W_{17} = \underline{\underline{25\mu m}}$

$\Rightarrow V_{omax}' = V_{DD} - 2Vdsat_{16} = V_{DD} - 2Vdsat_{17}$

$Vdsat_{17}' = \sqrt{\frac{2 \cdot 200\mu}{100\mu \cdot 12.5}} = 566\,mV$

$Vdsat_{16} = Vdsat_{12} = 282\,mV$

$V_{omax}' = 5V - 2 \cdot 283mV \overset{\checkmark}{=} 5V - 566\,mV = \underline{\underline{4.434V}}$

c) $G_m = g_{m1} = \sqrt{2 I_D k' \frac{W}{L}} = \sqrt{200\mu \cdot 100\mu \cdot 50} = \underline{\underline{1mS}}$

d) $R_o = g_{m14} r_{o14} r_{o16} \,||\, g_{m12} r_{o12} (r_{o10} || r_{o2})$

$r_{o14} = r_{o16} = \frac{1}{\lambda I_D} = \frac{1}{0.05 \cdot 100\mu A} = 200\,k\Omega = r_{o12} = r_{o2}$

$g_{m14} = g_{m1} = 1mS = g_{m12}$

$r_{o10} = \frac{1}{0.05 \cdot 200\mu A} = 100k\Omega$

$\Rightarrow R_o = 1mS \cdot 200k \cdot 200k \,||\, 1mS \cdot 200k\,(100k || 200k) = \underline{\underline{10M\Omega}}$

e) $A_{dm} = G_m R_o = 1mS \cdot 10M\Omega = 10\,000 \hat{=} \underline{\underline{80dB}}$

f) $f_U = \frac{1}{2\pi}\frac{G_m}{C_L} = \frac{1}{2\pi}\frac{1mS}{5pF} = \underline{\underline{31.83\ MHz}}$

g) $f_{p2} \cong \frac{1}{2\pi}\frac{g_{m11}}{C_{gs11}}$

$g_{m11} = g_{m1} = 1mS$

$C_{gs11} = \frac{2}{3}\cdot 50\cdot 2\cdot 5fF = 333fF$

$\Rightarrow \underline{\underline{f_{p2} = 478\ MHz}}$

h) $f_{pm} \cong \frac{g_{m15}}{C_{gs15}+C_{gs16}}$

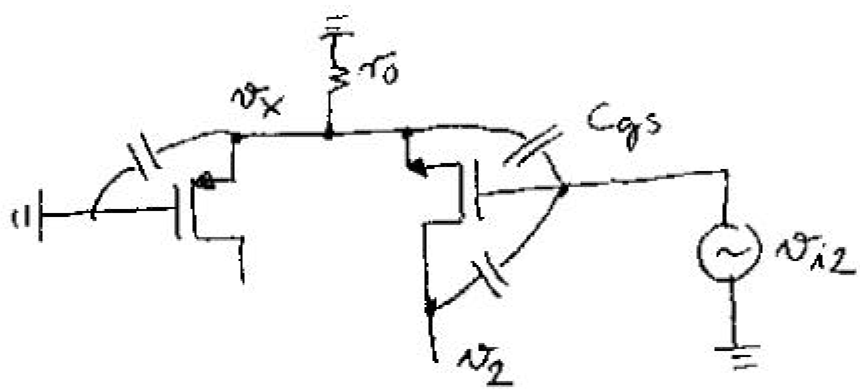
$C_{gs15} = C_{gs16} = 666fF$

$g_{m15} = g_{m1} = 1mS$

$\underline{\underline{f_{pm} = 119MHz}}$

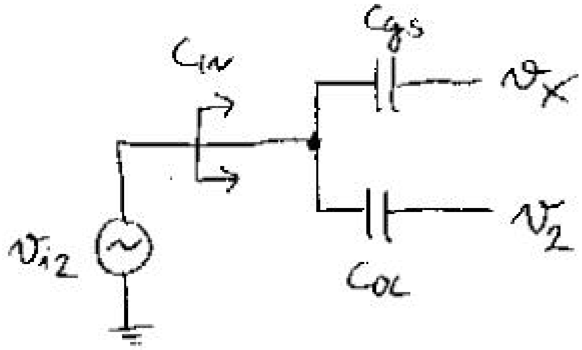
$f_{zm} = 2f_{pm} = \underline{\underline{238\ MHz}}$

i)



→ there is a common mode and diff mode iput component !

$v_x \neq$ AC ground

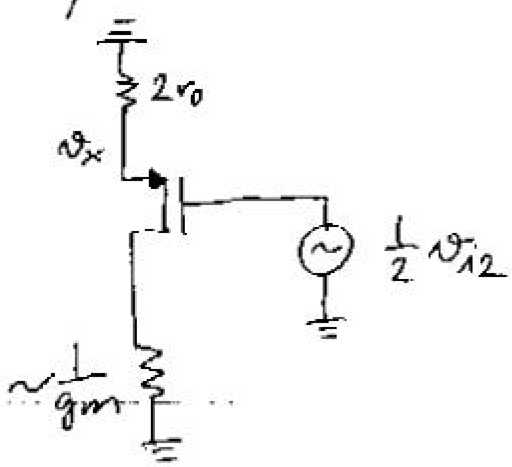


$$C_{IN} = C_{gs}\left(1 - \frac{v_x}{v_{i2}}\right) + C_{OL}\left(1 - \frac{v_2}{v_{i1}}\right)$$

→ find $\frac{v_x}{v_{i2}}$:

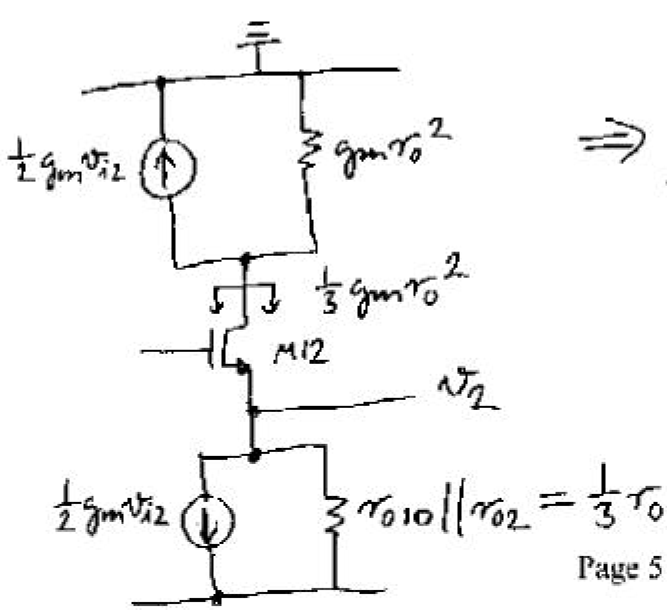
$$v_{iCM} = \frac{1}{2}\left(\cancel{v_{i1}}^{\,0} + v_{i2}\right) = \frac{1}{2} v_{i2}$$

CM half circuit:

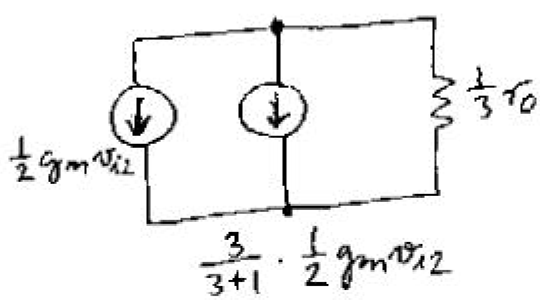


$$\Rightarrow \frac{v_x}{v_{i2}} \simeq \frac{1}{2}$$

→ find $\frac{v_2}{v_{i2}}$:



$\Rightarrow$



$$\Rightarrow \frac{v_2}{v_{x2}} = -\left(\frac{1}{2} + \frac{3}{8}\right) g_m \cdot \frac{1}{3} r_o = -\frac{7}{24} g_m r_o$$

$$= -\frac{7}{24} \cdot 1mS \cdot 200k = \underline{\underline{-58.3}}$$

$$\Rightarrow C_{IN} = C_{gs}\left(1 - \frac{v_x}{v_{x2}}\right) + C_{OL}\left(1 - \frac{v_2}{v_{x1}}\right)$$

$$C_{IN} = 666fF\left(1 - \frac{1}{2}\right) + 50fF\left(1 - (-58.3)\right)$$

$$\underline{\underline{C_{IN} = 3.3pF}}$$