University of Toronto

Final Exam

Date - Dec 13, 2012 (9:30am to 12pm)

Duration: 2.5 hrs

ECE331 — Analog Electronics
Lecturer - D. Johns

ANSWER QUESTIONS ON THESE SHEETS **USING BACKS IF NECESSARY**

1. Equation sheet is on last page of test.
2. Unless otherwise stated, use transistor parameters on equation sheet.
3. Non-programmable calculator allowed; No other aids allowed
4. Grading indicated by [ ]. Attempt all questions since a blank answer will certainly get 0.

Question	Mark
1	
2	
3	
4	
5	
6	
Total	

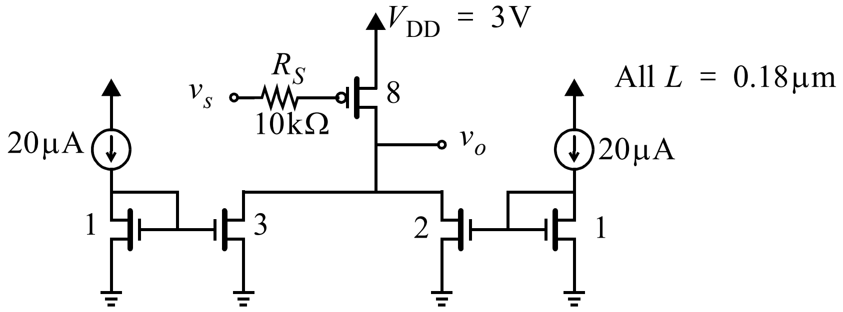
(max grade = 36)

Last Name: ________________________

First Name: ________________________

Student #: ________________________

[6] Question 1: Consider the circuit below where all transistors are in the active region. The numbers beside the transistors indicate the transistor width (in $\mu\mathrm{m}$).



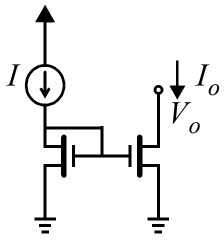
a) Find the small-signal gain v_o/v_s

$v_o/v_s =$

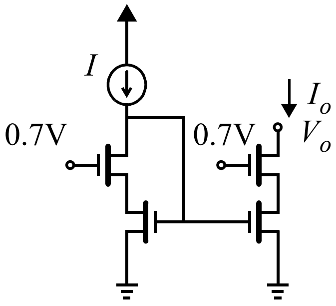
b) Estimate the 3db frequency cutoff, $f_{3\mathrm{dB}}$. For C_{db} values assume $V_{db} = 0$.

$f_{3\mathrm{dB}} =$

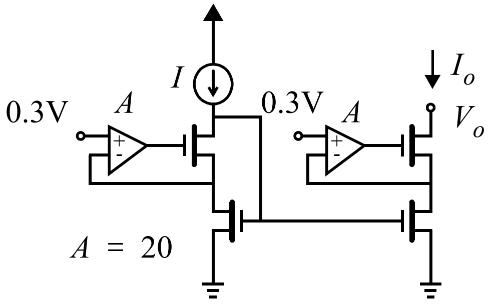
[6] Question 2: Consider the 3 current mirrors shown below. For all transistors, $L = 0.18\mu m$, $W = 3\mu m$. Also, $I = 100\mu A$.



(I)



(II)



(III)

a) For the current mirror in (I), estimate the **change** in the output current for an output voltage **change** of $0.5V$. Also, what is the minimum output voltage, $V_{o(\min)}$, while keeping transistors in the active region.

$\Delta I =$

$V_{o(\min)} =$

b) Repeat question a) for the mirror in (II)

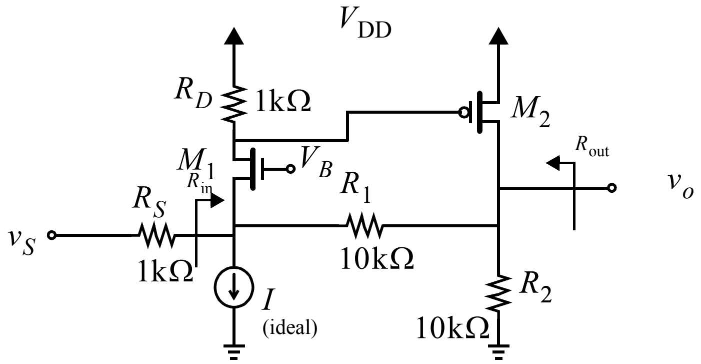
$\Delta I =$

$V_{o(\min)} =$

c) Repeat question a) for the mirror in (III)

$\Delta I\ =$
$V_{o(\min)}\ =$

[6] Question 3: Consider the circuit below.



$$g_{m1} = g_{m2} = 2\text{mA/V}$$

$$r_{o1} = r_{o2} \to \infty$$

a) Find L, A_∞ and d.

$L =$

$A_\infty =$

$d =$

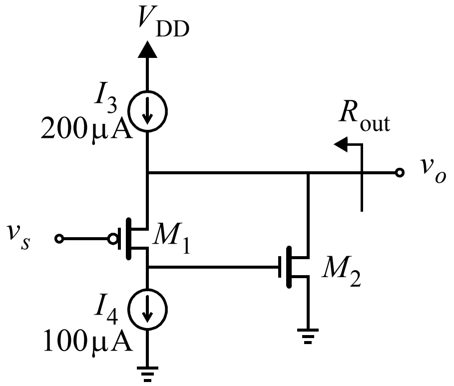
b) Find v_o/v_s, R_{in} and R_{out}.

$v_o/v_s =$

$R_{in} =$

$R_{out} =$

[6] Question 4: The circuit below is called a “super source follower”. Assume the current sources are realized using single transistors with $L = 0.18\mu\text{m}$ (include their output resistances r_{o3} and r_{o4}).

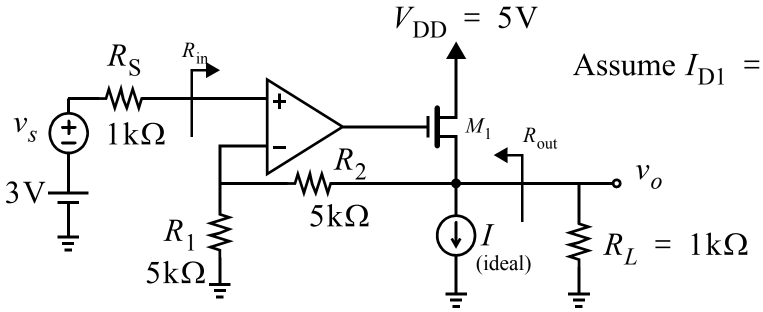


All $L = 0.18\mu\text{m}$
All $|V_{\text{ov}}| = 200\text{mV}$

Find the value for the output resistance, R_{out}, assuming $g_m r_o$ » 1 .

R_{out} =

[6] Question 5: Consider the circuit shown below. For the opamp, $A_o = 40$, $R_{\text{id}} = 10\text{k}\Omega$, $R_o = 1\text{k}\Omega$. For M_1, $V_{\text{ov}} = 200\text{mV}$ and $L = 0.18um$ (include r_o).



Assume $I_{\text{D1}} = 200\mu\text{A}$

a) Find L, A_∞ (assume d is about 0).

$L =$

$A_\infty =$

b) Find v_o / v_s, R_{in} and R_{out}.

v_o / v_s =
R_{in} =
R_{out} =

[6] Question 6: Assume an opamp is ideal but has the following open-loop gain and will be used in a non-inverting configuration with 2 resistors.

$$A(s) = \frac{10^4}{(1 + s/\omega_{p1})(1 + s/\omega_{p2})(1 + s/\omega_{p3})} \text{ where } \omega_{p1} = 10^5,\ \omega_{p2} = 10^7,\ \omega_{p3} = 10^8.$$

a) Draw the Bode plot for the above open-loop gain (both mag and phase)

Mag

Phase

b) Estimate the minimum closed-loop gain, $A_{\min}$, that can be realized while having a phase margin about $45°$

$A_{\min}$ =

c) If it is desired to have a closed-loop gain of 10 estimate the new value of ω_{p1} if it is moved to a lower freq and a phase margin of about $45°$ is desired.

ω_{p1}' =

Last Name: ______________

ECE331 Analog Electronics Equation Sheet

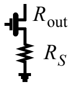
Constants: $k = 1.38 \times 10^{-23}\ \mathrm{JK}^{-1}$; $q = 1.602 \times 10^{-19}$ C ; $V_T = kT/q \approx 26\mathrm{mV}$ at 300 °K ;
$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m ; $k_{\mathrm{ox}} = 3.9$; $C_{\mathrm{ox}} = (k_{\mathrm{ox}}\varepsilon_0)/t_{\mathrm{ox}}$

NMOS: $k_n = \mu_n C_{\mathrm{ox}}(W/L)$; $V_{tn} > 0$; $v_{\mathrm{DS}} \geq 0$; $v_{ov} = v_{GS} - V_{tn}$
(triode) $v_{\mathrm{DS}} \leq v_{ov}$ (or $v_D < v_G - V_{tn}$) ; $i_D = k_n((v_{ov})v_{\mathrm{DS}} - (v_{\mathrm{DS}}^2/2))$
(active) $v_{\mathrm{DS}} \geq v_{ov}$; $i_D = 0.5k_n {v_{ov}}^2(1 + \lambda v_{DS})$; $g_m = k_n V_{ov} = 2I_D/V_{ov} = \sqrt{2k_n I_D}$; $r_s = 1/g_m$; $r_o = L/(|\lambda'|I_D)$

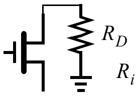
PMOS: $k_p = \mu_p C_{\mathrm{ox}}(W/L)$; $V_{tp} < 0$; $v_{SD} \geq 0$; $v_{ov} = v_{SG} - |V_{tp}|$
(triode) $v_{SD} \leq v_{ov}$ (or $(v_D > v_G + |V_{tp}|)$) ; $i_D = k_p((v_{ov})v_{SD} - (v_{SD}^2/2))$
(active) $v_{\mathrm{DS}} \geq v_{ov}$; $i_D = 0.5k_p {v_{ov}}^2(1 + |\lambda| v_{SD})$; $g_m = k_p V_{ov} = 2I_D/V_{ov} = \sqrt{2k_p I_D}$; $r_s = 1/g_m$; $r_o = L/(|\lambda'|I_D)$

BJT**:** (active) $i_C = I_S e^{(v_{BE}/V_T)}(1 + (v_{CE}/V_A))$; $g_m = \alpha/r_e = I_C/V_T$; $r_\pi = \beta/g_m$; $r_o = |V_A|/I_C$
$i_C = \beta i_B$; $i_E = (\beta + 1)i_B$; $\alpha = \beta/(\beta + 1)$; $i_C = \alpha i_E$; $R_b = (\beta + 1)(r_e + R_E)$; $R_e = (R_B + r_\pi)/(\beta + 1)$

Cascode:



$R_{\mathrm{out}} = R_S + r_o + g_m r_o R_S \approx (1 + g_m R_S)r_o$



$R_{in} = (R_D + r_o)/(1 + g_m r_o) \approx R_D/(g_m r_o) + 1/g_m$

Diff Pair: $A_d = g_m R_D$; $A_{CM} = -(R_D/(2R_{SS}))((\Delta R_D)/R_D)$; $A_{CM} = -(R_D/(2R_{SS}))((\Delta g_m)/g_m)$
$V_{os} = \Delta V_t$; $V_{os} = (V_{ov}/2)((\Delta R_D)/R_D)$; $V_{os} = (V_{ov}/2)((\Delta(W/L))/(W/L))$

1st order: step response $y(t) = Y_\infty - (Y_\infty - Y_{0+})e^{-t/\tau}$ unity gain freq for $T(s) = \dfrac{A_M}{1 + s/\omega_{3\mathrm{dB}}}$ $f_t \approx |A_M|\omega_{3\mathrm{dB}}$ when $A_M \gg 1$

Freq: for real axis poles/zeros $T(s) = k_{dc}\dfrac{(1 + s/z_1)(1 + s/z_2)\ldots(1 + s/z_m)}{(1 + s/\omega_1)(1 + s/\omega_2)\ldots(1 + s/\omega_n)}$
OTC estimate $f_H = 1/(2\pi\sum\tau_i)$; dominant pole estimate $f_H = 1/(2\pi\tau_{\mathrm{max}})$

Miller: $Z_1 = Z/(1 - K)$; $Z_2 = Z/(1 - 1/K)$

Mos caps: $C_{gs} = (2/3)WLC_{ox} + WL_{ov}C_{ox}$; $C_{gd} = WL_{ov}C_{ox}$; $C_{db} = C_{db0}/(\sqrt{1 + V_{db}/V_0})$
$f_t = g_m/(2\pi(C_{gs} + C_{gd}))$ assuming $C_{gd} \ll C_{gs}$ $f_t = (3\mu V_{ov})/(4\pi L^2)$

Feedback: $A_f = A/(1 + A\beta)$; $x_i = (1/(1 + A\beta))x_s$; $dA_f/A_f = (1/(1 + A\beta))dA/A$; $\omega_{Hf} = \omega_H(1 + A\beta)$; $\omega_{Lf} = \omega_L/(1 + A\beta)$
Loop Gain $L \equiv -s_r/s_t$; $A_f = A_\infty(L/(1 + L)) + d/(1 + L)$; $Z_{\mathrm{port}} = Z_{\mathrm{port(k=0)}}((1 + L_S)/(1 + L_O))$
PM $= \angle L(j\omega_1) + 180$; GM $= -|L(j\omega_{180})|_{\mathrm{dB}}$
Pole Splitting $\omega_{\mathrm{p1}}' \cong 1/(g_m R_2 C_f R_1)$; $\omega_{\mathrm{p2}}' \cong (g_m C_f)/(C_1 C_2 + C_f(C_1 + C_2))$

Pole Pair $s^2 + (\omega_o/Q)s + \omega_o^2 = 0$; $Q \leq 0.5 \Rightarrow$ real poles ; $Q > 1/\sqrt{2} \Rightarrow$ freq resp peaking

MOS Transistor; CMOS basic parameters. Channel length = $0.18\mu m$

	V_t (V)	μC_{ox} $(\mu A/V^2)$	λ' $(\mu\mathrm{m/V})$	C_{ox} $(\mathrm{fF}/\mu\mathrm{m}^2)$	t_{ox} $(n\mathrm{m})$	L_{ov} $(\mu\mathrm{m})$	$\dfrac{C_{db0}}{W}$ $\left(\dfrac{fF}{\mu\mathrm{m}}\right)$
NMOS	0.4	240	0.05	8.5	4	0.04	0.3
PMOS	-0.4	60	-0.05	8.5	4	0.04	0.3