University of Toronto

Term Test 2

Date - Nov 20, 2015 (1:10pm to 2:00pm)

Duration: 50 min

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 and assume $g_m r_o \gg 1$.
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	
Total	

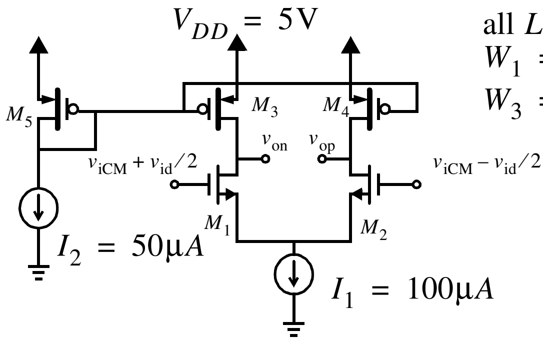
Last Name: ______________________

First Name: ______________________

Student #: ______________________

(max grade = 24)

[6] Question 1: Consider the circuit below where $v_{iCM} = 3V$.



all $L = 0.2\mu m$
$W_1 = W_2 = 5\mu m$
$W_3 = W_4 = W_5 = 5\mu m$

a) What is the max and min for v_{op}? (assume $v_{id} = 0$)

$v_{op\_min} =$
$v_{op\_max} =$

b) Find the gain, v_o/v_{id}. ($v_o = v_{op} - v_{on}$)

$v_o/v_{id} =$

[6] Question 2:

a) Write the transfer-function for an amplifier having an approximate gain of -100 at 100 rad/s and zeros at 1 and 10 rad/s (on the negative real axis) and poles at 5 and 1000 rad/s.

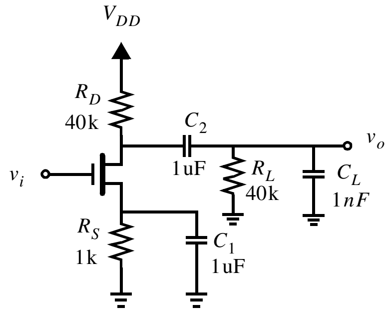
b) What is the dc gain of the amplifier in a)?

dc gain =

c) An amplifier has 2 poles at 50 Mrad/s and 100 Mrad/s. Using the open circuit time-constant approach, estimate the 3dB frequency for this amplifier in MHz.

f_{3dB} =

[6] Question 3: Consider the amplifier circuit shown below and only the shown capacitors.

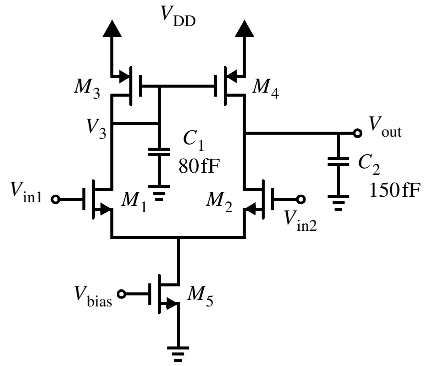


$g_m = 5\text{mA/V}$

ignore r_0

Given that a zero for this amplifier occurs at $\omega_z = 1/(R_S C_1) = 1\text{k rad/s}$ and a zero occurs dc, draw the Bode plot for this amplifier showing pole locations (in rad/s) and approximate gain values at 100 rad/s and 25k rad/s.

[6] Question 4: Consider the differential amp shown below and only consider the capacitances shown.



$g_{m1} = 1.5\text{mA/V}$	$r_{o1} = 26.7k\Omega$
$g_{m2} = 1.5\text{mA/V}$	$r_{o2} = 26.7k\Omega$
$g_{m3} = 1.5\text{mA/V}$	$r_{o3} = 26.7k\Omega$
$g_{m4} = 1.5\text{mA/V}$	$r_{o4} = 26.7k\Omega$
$g_{m5} = 3\text{mA/V}$	$r_{o5} = 13.3k\Omega$

a) Find the locations of the pole frequencies in this circuit (for the diff gain of the circuit).

b) Find the common-mode gain v_o / v_{icm} (in V/V). (Hint, v_o follows v_3 when a common-mode input signal is applied)

Last Name: ________________

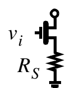
Analog Electronics Equation Sheet

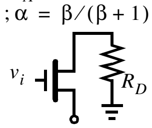
Constants: $k = 1.38 \times 10^{-23}\ \mathrm{JK}^{-1}$; $q = 1.602 \times 10^{-19}$ C ; $V_T = kT/q \approx 26\mathrm{mV}$ at 300 °K ;
$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m ; $k_{ox} = 3.9$; $C_{ox} = (k_{ox}\varepsilon_0)/t_{ox}$

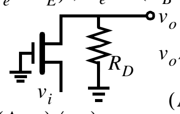
NMOS: $k_n = \mu_n C_{ox}(W/L)$; $V_{tn} > 0$; $v_{DS} \geq 0$; $v_{ov} = v_{GS} - V_{tn}$
(triode) $v_{DS} \leq v_{ov}$ (or $v_D < v_G - V_{tn}$) ; $i_D = k_n((v_{ov})v_{DS} - (v_{DS}^2/2))$
(active) $v_{DS} \geq v_{ov}$; $i_D = 0.5 k_n v_{ov}^2(1 + \lambda v_{DS})$; $g_m = k_n V_{ov} = 2I_D/V_{ov}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

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

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

Cascode:


$R_x \approx (1 + g_m R_S) r_o$
$i_{sc} \approx -(1/g_m + R_S)^{-1} v_i$


$R_x \approx 1/g_m + R_D/(g_m r_o)$
$v_{oc} \approx v_i$


$v_o/v_i \approx g_m(r_o \parallel R_D)$
(Approx due to $g_m r_o \gg 1$)

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 $T(s) = \dfrac{A_M}{1 + s/\omega_{3dB}}$ $f_t \approx |A_M|\omega_{3dB}$ 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 $f_H = 1/(2\pi\tau_{max})$

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 $L \equiv -s_r/s_t$; $A_f = A_\infty(L/(1 + L)) + d/(1 + L)$; $Z_{port} = Z_{p^0}((1 + L_S)/(1 + L_O))$
$\mathrm{PM} = \angle L(j\omega_1) + 180$; $\mathrm{GM} = -|L(j\omega_{180})|_{dB}$
Pole Splitting $\omega_{p1}' \cong 1/(g_m R_2 C_f R_1)$; $\omega_{p2}' \cong (g_m C_f)/(C_1 C_2 + C_f(C_1 + C_2))$

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

Power Amps: Class A: $\eta = (1/4)(\hat{V}_o/(IR_L))(\hat{V}_o/V_{CC})$ Class B: $\eta = (\pi/4)(\hat{V}_o/V_{CC})$; $P_{DN\_max} = V_{CC}^2/(\pi^2 R_L)$
Class AB: $i_n i_p = I_Q^2$

2-stage cmos opamp: $\omega_{p1} \approx (1/(R_1 G_{m2} R_2 C_c))$; $\omega_{p2} \approx (G_{m2}/C_2)$; $\omega_z \approx (1/(C_c((1/G_{m2}) - R)))$
$SR = I/C_c = \omega_t V_{ov1}$; will not SR limit if $\omega_t \hat{V}_o < SR$

<u>MOS Transistor;</u> 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} (μm)	$\frac{C_{db0}}{W}$ $\left(\frac{fF}{\mu m}\right)$
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