

University of Toronto

Final Exam

Date - Dec 16, 2013

Duration: 2.5 hrs

ECE331 — Electronic Circuits

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.
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Last Name: _____

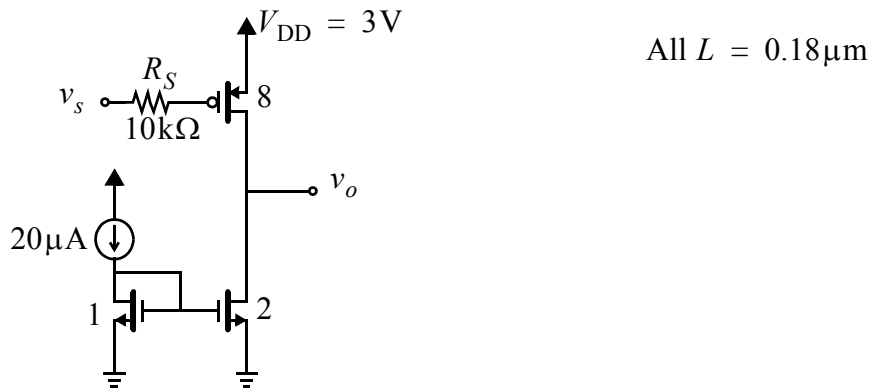
First Name: _____

Student #: _____

Question	Mark
1	
2	
3	
4	
5	
6	
Total	

(max grade = 36)

[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 μm).



a) Find the small-signal gain v_o/v_s

$v_o/v_s =$

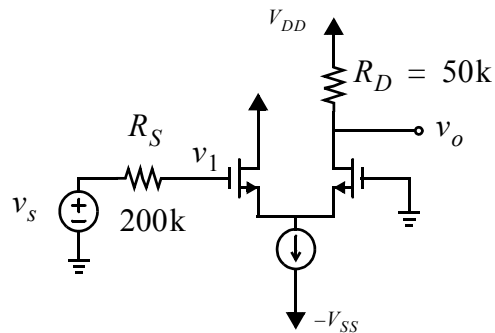
b) Estimate the 3db frequency cutoff, $f_{3\text{dB}}$. For C_{db} values assume $V_{db} = 0$.

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

[6] Question 2:

a) For a Mosfet transistor, show that $f_t \approx \frac{3\mu_n V_{ov}}{4\pi L^2}$ assuming $C_{gs} \gg C_{gd}$ and the overlap component of C_{gs} is negligibly small.

b) Consider the circuit below, only consider the capacitors C_{gs} and C_{gd} .

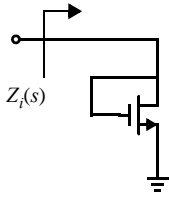


for each transistor
 $g_m = 1 \text{ mA/V}$
 $C_{gs} = C_{gd} = 1 \text{ pF}$
 $r_o \rightarrow \infty$

Find the pole due to the node v_1 and also find the pole due to the node v_o .

$\omega_{p1} =$
$\omega_{p2} =$

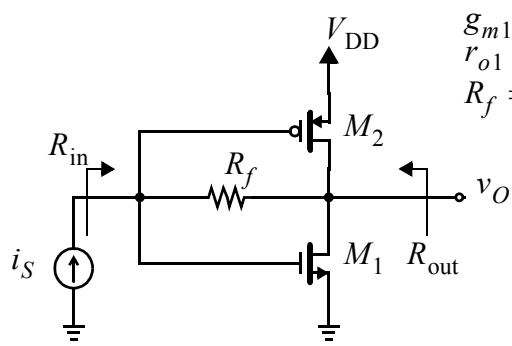
[6] Question 3: Consider the transistor below where it is biased such that $V_{ov} = 0.2\text{V}$. Including the effects of C_{gs} and C_{gd} , find the frequency, f_{45} , where the impedance has a phase angle of -45° (in Hz). Ignore r_o .



$$\begin{aligned} V_{ov} &= 0.2\text{V} \\ W &= 3\mu\text{m} \\ L &= 0.3\mu\text{m} \\ r_o &\rightarrow \infty \end{aligned}$$

$f_{45} =$

[6] Question 4: Consider the circuit shown below.



$$g_{m1} = g_{m2} = 100 \mu\text{A/V}$$

$$r_{o1} = r_{o2} = 100\text{k}$$

$$R_f = 100\text{k}$$

$$A_{cl} \equiv v_O / i_S$$

Hint: transconductance g_{m1} is parallel to g_{m2}

a) Find L , A_∞ and d .

$L =$
$A_\infty =$
$d =$

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

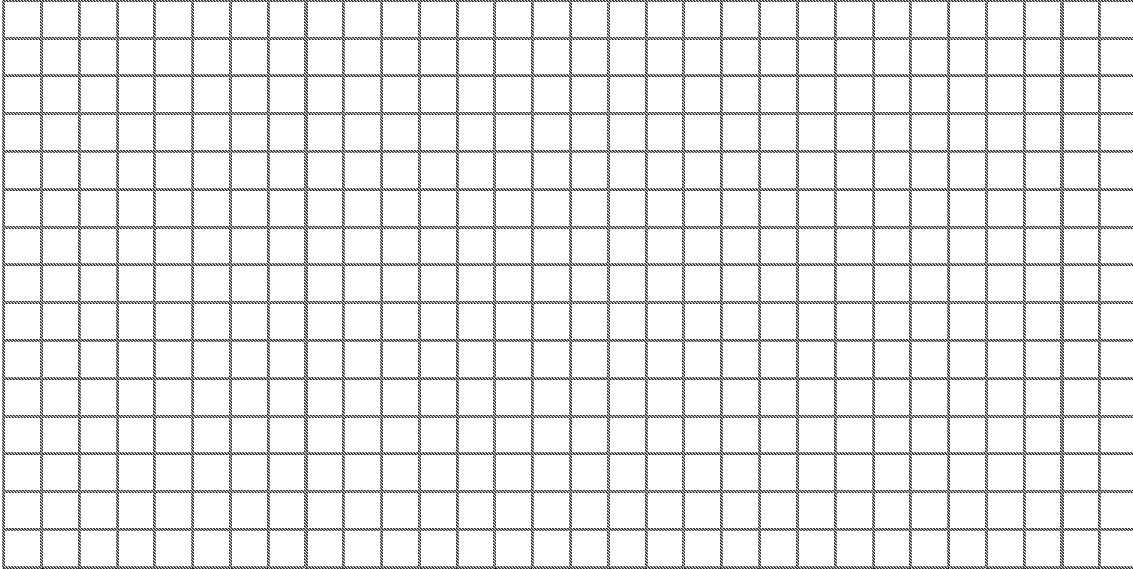
$v_o/i_s =$
$R_{in} =$
$R_{out} =$

[6] **Question 5:** Assume the loop gain for a feedback system is found to be the following.

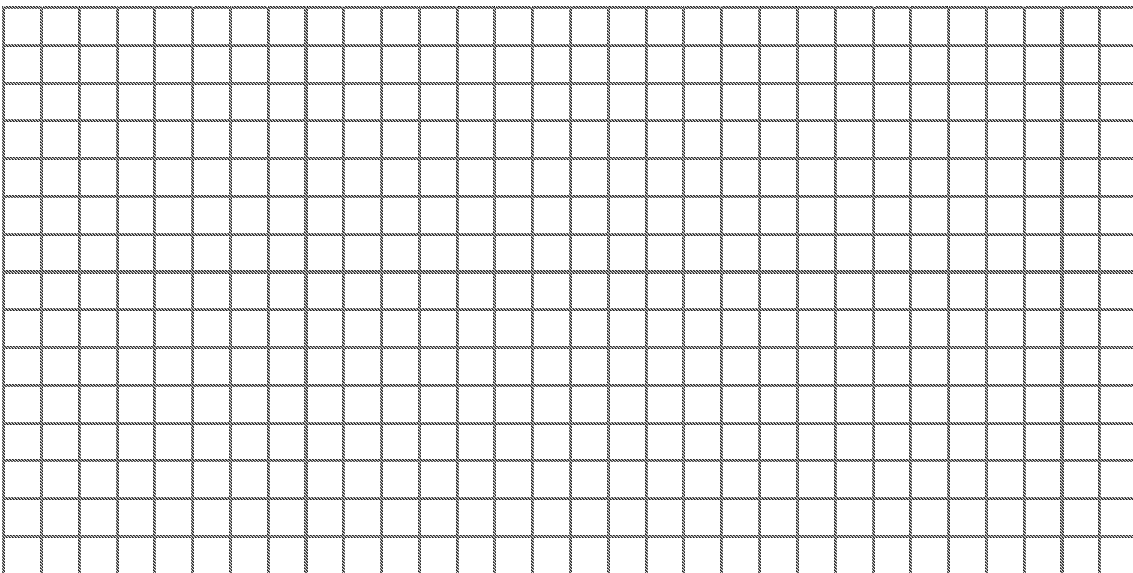
$$L(s) = \frac{5 \times 10^4}{(1 + s/\omega_{p1})(1 + s/\omega_{p2})(1 + s/\omega_{p3})} \text{ where } \omega_{p1} = 10^1, \omega_{p2} = 10^6, \omega_{p3} = 10^9.$$

a) Sketch the Bode plot for the above loop gain (both mag and phase)

Mag



Phase



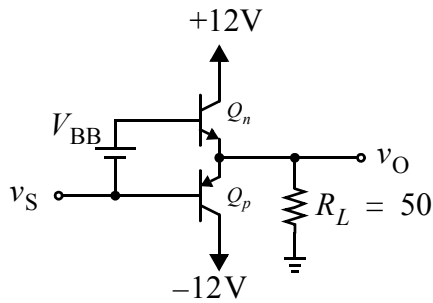
b) Estimate the phase-margin (PM) for the above loop gain. Hint, the unity gain freq is much greater than ω_{p1} and much less than ω_{p3} .

PM =

c) Estimate the time-constant for the settling behaviour of this feedback system (assuming it can be modeled as a first-order system).

τ =

[6] **Question 6:** Consider a class AB BJT output stage shown below. Assume transistors Q_n and Q_p are matched with $I_s = 10^{-13}$ A, β is large, and the output is sinusoidal with a maximum amplitude of 10V.



Assume $V_T = 25\text{mV}$

a) Find the value of V_{BB} such that the quiescent current is 5% of the maximum load current.

$V_{BB} =$

b) For an output voltage of -5V, estimate i_n , i_p , and v_S .

$i_n =$
$i_p =$
$v_S =$

Analog Electronics

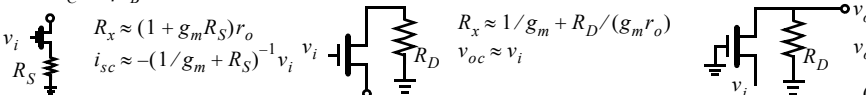
Equation Sheet

Constants: $k = 1.38 \times 10^{-23} \text{ JK}^{-1}$; $q = 1.602 \times 10^{-19} \text{ C}$; $V_T = kT/q \approx 26\text{mV}$ at $300 \text{ }^\circ\text{K}$;
 $\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$; $k_{ox} = 3.9$; $C_{ox} = (k_{ox}\epsilon_0)/t_{ox}$

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) $v_{DS} \geq v_{ov}$; $i_D = 0.5k_n v_{ov}^2(1 + \lambda v_{DS})$; $g_m = k_n V_{ov} = 2I_D/V_{ov} = \sqrt{2k_n I_D}$; $r_s = 1/g_m$; $r_o = L/(\lambda' I_D)$

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

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

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 $T(s) = \frac{A_M}{1 + s/\omega_{3dB}}$ $f_t \approx |A_M|\omega_{3dB}$ when $A_M \gg 1$

Freq: for real axis poles/zeros $T(s) = k_{dc} \frac{(1 + s/z_1)(1 + s/z_2) \dots (1 + s/z_m)}{(1 + s/\omega_1)(1 + s/\omega_2) \dots (1 + s/\omega_n)}$
 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 $L \equiv -s_r/s_f$; $A_f = A_\infty(L/(1 + L)) + d/(1 + L)$; $Z_{port} = Z_{p0}((1 + L_S)/(1 + L_O))$
 PM = $\angle L(j\omega_1) + 180$; GM = $-|L(j\omega_{180})|_{dB}$
 Pole Splitting $\omega_{p1}' \approx 1/(g_m R_2 C_f R_1)$; $\omega_{p2}' \approx (g_m C_f)/(C_1 C_2 + C_f(C_1 + C_2))$

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 $\omega_t \hat{V}_o < SR$

MOS Transistor: CMOS basic parameters. Channel length = $0.18 \mu\text{m}$

	V_t (V)	μC_{ox} ($\mu\text{A}/\text{V}^2$)	λ' ($\mu\text{m}/\text{V}$)	C_{ox} ($\text{fF}/\mu\text{m}^2$)	t_{ox} (nm)	L_{ov} (μm)	$\frac{C_{db0}}{W}$ ($\frac{\text{fF}}{\mu\text{m}}$)
NMOS	0.4	240	0.05	8.5	4	0.04	0.3
PMOS	-0.4	60	-0.05	8.5	4	0.02	0.3