University of Toronto

Term Test 1

Date - Oct 21, 2013 (11:10am to 12:00pm)

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.
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)

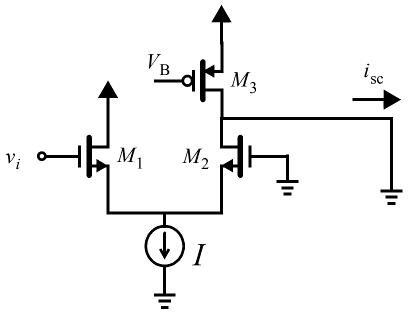
[6] Question 1: Assume an nmos transistor (based on the 0.18um parameters given on the equation sheet) with $W = 4\mu m$, $L = 0.5\mu m$ is biased with $V_{ov} = 0.4V$ and $V_{\mathrm{DS}} = 1V$.

a) Find the r_o for this device.

b) If V_{DS} is increased by 0.5V, what is the corresponding change in I_D?

[6] Question 2: Given 2 current sources from V_{DD} where each are $10\mu A$, design a wide-swing cascode current-mirror circuit (including bias voltage generation) that gives an nmos output of $40\mu A$. Assume all transistor lengths are $0.18\mu m$ and the nmos current mirror output transistors have $W = 4\mu m$. Show the widths of all transistors on your schematic. (Hint: there should be 5 nmos transistors and 2 current sources on your schematic).

[6] Question 3: Consider the circuit below.

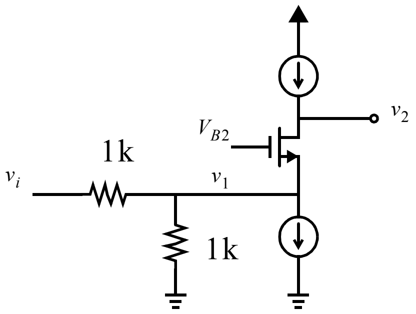


$$g_{m1} = 1\text{mA/V}$$
$$g_{m2} = 0.5\text{mA/V}$$
$$g_{m3} = 1\text{mA/V}$$

a) Find the small-signal short-circuit current gain, i_{sc}/v_i assuming all $r_o \to \infty$.

b) Find the small-signal gain, i_{sc}/v_i assuming $r_o = 20\text{k}$ for all transistors (current source is still ideal) and make no approximations. Compare this result with that found in part a) in terms of percentage error.

[6] Question 4: Consider the circuit shown below. All current sources and the transistors have the same output impedance of $r_o = 40\text{k}$. Also the transistors has $g_m = 1\text{mA/V}$. Estimate the small-signal gains, v_1/v_i, and v_2/v_1. Make the assumption that $g_m r_o$ » 1 .



v_1/v_i =	
v_2/v_1 =	

Last Name: ________________

Analog Electronics Equation Sheet

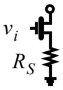
Constants: $k = 1.38 \times 10^{-23}\ \mathrm{JK}^{-1}$; $q = 1.602 \times 10^{-19}$ C ; $V_T = kT/q \approx 26\mathrm{mV}$ at 300 °K ;
$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m ; $k_{\mathrm{ox}} = 3.9$; $C_{\mathrm{ox}} = (k_{\mathrm{ox}}\varepsilon_0)/t_{\mathrm{ox}}$

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

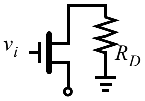
PMOS: $k_p = \mu_p C_{\mathrm{ox}}(W/L)$; $V_{tp} < 0$; $v_{SD} \geq 0$; $v_{ov} = v_{SG} - |V_{tp}|$
(triode) $v_{SD} \leq v_{ov}$ (or $(v_D > v_G + |V_{tp}|)$) ; $i_D = k_p((v_{ov})v_{SD} - (v_{SD}^2/2))$
(active) $v_{\mathrm{DS}} \geq v_{ov}$; $i_D = 0.5k_p v_{ov}^2(1 + |\lambda| v_{SD})$; $g_m =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

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

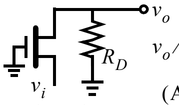
Cascode:



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



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



$v_o/v_i \approx g_m(r_o \parallel R_D)$
(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 $T(s) = \dfrac{A_M}{1 + s/\omega_{3\mathrm{dB}}}$ $f_t \approx |A_M|\omega_{3\mathrm{dB}}$ 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 $L \equiv -s_r/s_t$; $A_f = A_\infty(L/(1 + L)) + d/(1 + L)$; $Z_{\mathrm{port}} = Z_{p^0}((1 + L_S)/(1 + L_O))$
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

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

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

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

	V_t (V)	μC_{ox} ($\mu A/V^2$)	λ' (μm/V)	C_{ox} (fF/μm^2)	t_{ox} (nm)
NMOS	0.4	240	0.05	8.5	4
PMOS	-0.4	60	-0.05	8.5	4