

University of Toronto

Term Test 2

Date - Nov 18, 2013 (11:10am to 12pm)

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: Consider a first-order highpass circuit with input $v_s(t)$, output $v_o(t)$, time-constant $\tau = 1 \mu s$ and a high freq gain of 3.

a) Give an expression for the transfer-function, $T(s)$ for this circuit.

$$T(s) =$$

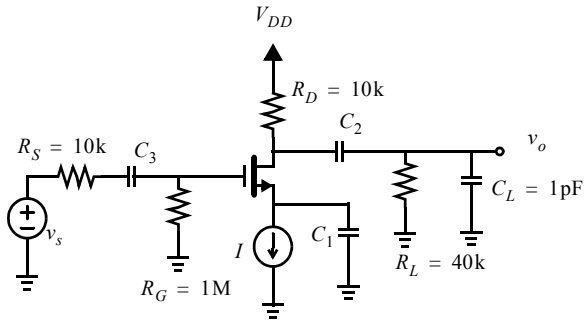
b) What is the f_{3dB} frequency for $T(s)$.

$$f_{3dB} =$$

c) Sketch the step response for a step input of 2V. In terms of τ , find the time, t_{set} , it takes for $v_o(t)$ to settle to within 1% of its final value.

$$t_{set} =$$

[6] Question 2: Consider the circuit shown below.



$$C_{gs} = 1\text{pF}$$

$$C_{gd} = 0.2\text{pF}$$

$$C_{db} = 0.2\text{pF}$$

$$g_m = 0.5\text{mA/V}$$

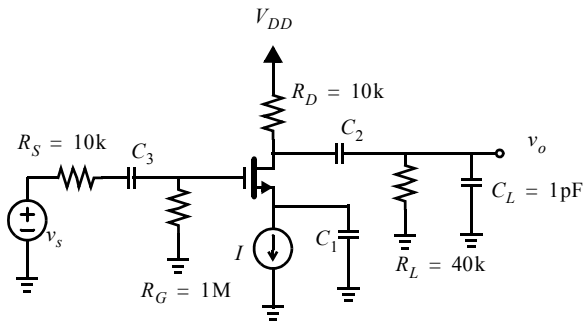
ignore r_0

current source output impedance = 10k

Given that the low frequency poles should occur at 1Hz, 10Hz and 100Hz, and it is desired to minimize capacitor sizes, find the value of C_1 (explain your reasoning).

$C_1 =$

[6] Question 3: Consider the circuit shown below.

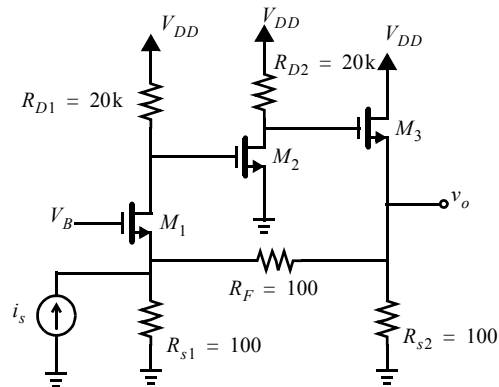


$C_{gs} = 1\text{pF}$
 $C_{gd} = 0.2\text{pF}$
 $C_{db} = 0.2\text{pF}$
 $g_m = 0.5\text{mA/V}$
 ignore r_0
 current source output impedance = 10k

Estimate the 2 high frequency poles for this circuit (in Hz), f_{p1} and f_{p2} .

$f_{p1} =$
$f_{p2} =$

[6] **Question 4:** Consider the feedback circuit below with input i_s and output v_o .
 Find the loop gain, L , asymptotic gain, A_∞ , and feedthrough gain, d .



$g_{m1} = g_{m2} = g_{m3} = 2\text{mA/V}$
 ignore r_0

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

ECE331

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

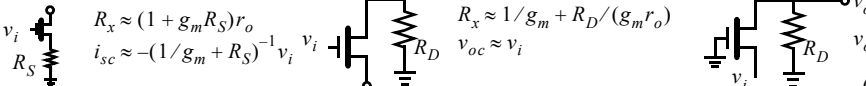
PMOS: $k_p = \mu_p C_{ox}(W/L)$; $V_{tp} < 0$; $v_{SD} \geq 0$; $v_{ov} = v_{SG} - |V_{tp}|$

(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 = $0.18 \mu m$

	V_t (V)	μC_{ox} ($\mu A/V^2$)	λ' ($\mu m/V$)	C_{ox} ($fF/\mu m^2$)	t_{ox} (nm)	L_{ov} (μm)	$\frac{C_{db0}}{W}$ ($\frac{fF}{\mu m}$)
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