

University of Toronto

Term Test 2

Date - Nov 16, 2012 (3:15pm to 4:45pm)

Duration: 1.5 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.
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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 a first-order lowpass circuit with input $v_s(t)$, output $v_o(t)$, time-constant $\tau = 1 \mu s$ and a dc gain of 2.

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) Assuming $v_s(t)$ is a step input of 2V, in terms of τ , find the time, t_{set} , it takes for $v_o(t)$ to settle to within 0.1% of its final value.

$$t_{set} =$$

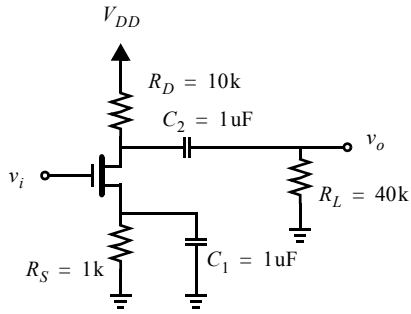
[6] **Question 2:** An amplifier has a voltage transfer-function of $T(s) = \frac{10^4 s}{(s + 10)(s + 10^3)}$.

a) Convert $T(s)$ to a form suitable for a Bode plot (i.e. the denominator should have factors in the form $(1 + s/a)$).

$T(s) =$

b) Draw a Bode plot for the magnitude response and use it to estimate the gain at frequency values of 1, 100, 10^4 rad/s.

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



$g_m = 5\text{mA/V}$
ignore r_0

a) Find the low-freq small-signal gain and the high-freq small-signal gain.

$\left. \frac{v_o}{v_i} \right _{s=0}$	=
$\left. \frac{v_o}{v_i} \right _{s \rightarrow \infty}$	=

b) Given that the zero for this amplifier occurs at $\omega_z = 1/(R_S C_1) = 1\text{k rad/s}$, sketch the bode plot for this amplifier using the dominant pole estimate for ω_L .

[6] **Question 4:** Using the transistor parameters on the equation sheet, consider a transistor of size $W = 2 \text{ } \mu\text{m}$, $L = 0.18 \text{ } \mu\text{m}$.

a) Assuming the transistor is biased in the active region and assuming $V_{db} = 0$, find the values of C_{gs} , C_{gd} and C_{db} for the transistor (all in units of fF).

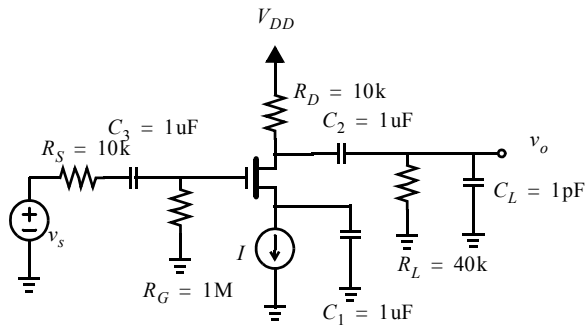
$C_{gs} =$
$C_{gd} =$
$C_{db} =$

b) If $V_{ov} = 0.2 \text{ V}$, find the unity-gain freq of the transistor (do not ignore C_{gd}).

$f_t =$

c) If the transistor width is doubled and the current through the transistor is also doubled, what is the new unity-gain frequency?

[6] Question 5: Consider the circuit shown below.

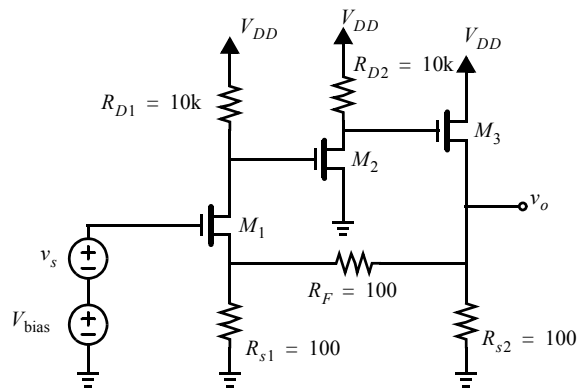


$C_{gs} = 1\text{pF}$
 $C_{gd} = 0.2\text{pF}$
 $C_{db} = 0.2\text{pF}$
 $g_m = 5\text{mA/V}$
 ignore r_0

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

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

[6] Question 6: Consider the feedback circuit below. Find the loop gain, L .



$g_{m1} = g_{m2} = g_{m3} = 5\text{mA/V}$
ignore r_0

$L =$

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

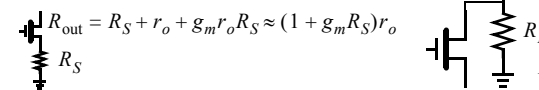
PMOS: $k_p = \mu_p C_{ox}(W/L)$; $V_{tp} < 0$; $v_{SD} \geq 0$; $v_{ov} = v_{SG} - |V_{tp}|$

(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) $i_C = I_S e^{(v_{BE}/V_T)}(1 + (v_{CE}/V_A))$; $g_m = \alpha/r_e = I_C/V_T$; $r_\pi = \beta/g_m$; $r_o = |V_A|/I_C$

$i_C = \beta i_B$; $i_E = (\beta + 1)i_B$; $\alpha = \beta/(\beta + 1)$; $i_C = \alpha i_E$; $R_b = (\beta + 1)(r_e + R_E)$; $R_e = (R_B + r_\pi)/(\beta + 1)$

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

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 $T(s) = \frac{A_M}{1 + s/\omega_{3dB}}$ $f_t \approx |A_M|\omega_{3dB}$ 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 $L \equiv -s_f/s_t$

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	0.04	0.3