ECE137B Final Exam

Wednesday 6/8/2016, 7:30-10:30PM.

There are 7 problems on this exam and you have 3 hours
There are pages 1-32 in the exam: please make sure all are there.

Do not open this exam until told to do so.
Show all work.
Credit will not be given for correct answers if supporting work is not shown.
Class Crib sheets and 3 pages (front and back → 6 surfaces) of your own notes permitted.
Don’t panic.

<table>
<thead>
<tr>
<th>Time function</th>
<th>LaPlace Transform</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta(t)$</td>
<td>1</td>
</tr>
<tr>
<td>$U(t)$</td>
<td>$1/s$</td>
</tr>
<tr>
<td>$e^{-at} \cdot U(t)$</td>
<td>$\frac{1}{s + \alpha}$ or $\frac{1/\alpha}{1 + s/\alpha}$</td>
</tr>
<tr>
<td>$e^{-at} \cos(\omega_d t) \cdot U(t)$</td>
<td>$\frac{s + \alpha}{(s + \alpha)^2 + \omega_d^2}$</td>
</tr>
<tr>
<td>$e^{-at} \sin(\omega_d t) \cdot U(t)$</td>
<td>$\frac{\omega_d}{(s + \alpha)^2 + \omega_d^2}$</td>
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</tbody>
</table>

Name: _________________________________

<table>
<thead>
<tr>
<th>Problem</th>
<th>points</th>
<th>possible</th>
<th>Problem</th>
<th>points</th>
<th>possible</th>
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<tbody>
<tr>
<td>1a</td>
<td>5</td>
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<td>1b</td>
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<td>5b</td>
<td>5b</td>
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<tr>
<td>1c</td>
<td>10</td>
<td>6a</td>
<td>6a</td>
<td>10</td>
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<td>15</td>
<td>6b</td>
<td>6b</td>
<td>10</td>
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<tr>
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<td>10</td>
<td>6c</td>
<td>6c</td>
<td>3</td>
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<td>10</td>
<td>total</td>
<td>total</td>
<td>108</td>
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</table>
Problem 1, 33 points

*method of first-order and second-order time constants. Some negative feedback*

Above is a high-speed op-amp. It is connected, as the inset image suggests, as a positive voltage-gain stage.

All FETs are short-channel devices with $L_g = 45\text{nm}$

$I_d \simeq v_{sat} c_{ox} W_g (V_{gs} - V_{th} - \Delta V)$ where $v_{sat} c_{ox} = 1\text{mS/micrometer}$ and $(V_{th} + \Delta V) = 0.2 \text{ Volts}$.

All FETs have $\lambda = 0 \text{ V}^{-1}$, all have $W_g = 1 \text{ micrometers}$, except $Q_2$ and $Q_18$, which have $\lambda = 0 \text{ V}^{-1}$, and $W_g = 2 \text{ micrometers}$,

Q10,11,12,14 have $C_{gs} = 33.6 \text{ fF/}\mu\text{m}^2 \cdot L_g W_g + 0.5 \text{ fF/}\mu\text{m} \cdot W_g$ and $C_{gd} = 0.5 \text{ fF/}\mu\text{m} \cdot W_g$

Q7,8 have $C_{gs} = 33.6 \text{ fF/}\mu\text{m}^2 \cdot L_g W_g + 0.5 \text{ fF/}\mu\text{m} \cdot W_g$ and $C_{gd} = 0 \text{ fF}$.

Q1,2,3,4,5,6,9,13,15,16,17,18,19,20 have $C_{gs} = 0 \text{ fF}$ and $C_{gd} = 0 \text{ fF}$.

Note the indicated infinite bypass capacitors; these are AC grounds.

Pick $R_1$ so that the current through it is 0.1 mA.

$R_{4a} = R_{4b} = 2\Omega$, $C_{5a} = C_{5b} = 400\text{fF}$.

$R_{2a} = R_{2b} = 2\kappa\Omega$, $R_{3a} = R_{3b} = 8\kappa\Omega$

The supplies are +1.5V and -1.5V.
Part a, 5 points

Draw all DC node voltages and all DC bias currents on the diagram below.
Part b, 3 points

Symmetry allows us to analyze bandwidth and gain with the half-circuit below:

To compute the loop transmission you must (1) set $V_{\text{gen}}$ to zero, (2) cut the feedback loop as shown (3) restore the stage loading which has been removed by making the cut, (4) insert an AC voltage generator at the cut point, and (5) compute the voltage gain once around the loop.
Indicate on the drawing above what circuit element must be placed in the box labeled with a "?", and give the value of this element.
Part c, 10 points

Working with the circuit diagram of the previous page, determine the DC value of the loop transmission.

\[ T_{DC} = \]
Part d, 15 points
Using MOTC, you will find the frequency, in Hz (not rad/sec), of the two major poles in the loop transmission \( T \). Hint: you can use the source degeneration model for Q7-Q8.

Find all the following.

<table>
<thead>
<tr>
<th>( C_1 = C_{5A} + C_{gd10} )</th>
<th>( C_2 = C_{gd8} )</th>
<th>( C_3 = C_{gri10} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{11}^0 = )</td>
<td>( R_{22}^0 = )</td>
<td>( R_{33}^0 = )</td>
</tr>
<tr>
<td>( R_{22}^1 = )</td>
<td>( R_{33}^1 = )</td>
<td>( R_{33}^2 = )</td>
</tr>
<tr>
<td>( f_{p1} = )</td>
<td>( f_{p2} = )</td>
<td></td>
</tr>
</tbody>
</table>
Problem 2, 10 points

negative feedback

The amplifier has a differential gain of $10^7$.

The op-amp has infinite differential input impedance and zero differential output impedance.

The differential amplifier has pole in its open-loop transfer function at 10 Hz.

$R_1=9$ kOhm, $R_2=1$ kOhm, $R_3=111$ Ohm.

$C=1.57$ nF.

Using the Bode plots on the next page, plot the loop transmission ($T$), plot $A_\infty$ and plot the closed loop gain ($A_{CL}=V_{out}/V_{gen}$), and determine the following:

Loop bandwidth=_________________, phase margin =_________________

Be SURE to label and dimension all axes clearly, and to make clear and accurate asymptotic plots.
Plot $T, A_{(\infty)}$, on this plot

Draw closed loop gain on this bode plot
Problem 3, 10 points

negative feedback

![Circuit Diagram]

The op-amps are ideal: infinite gain, infinite differential input impedance and zero output impedance.

\[ R_1 = 100 \text{ Ohm}, \quad R_2 = 1 \text{ kOhm}, \quad C_1 = 15.9pF, \quad R_3 = 333\text{Ohms}, \quad R_4 = 1\text{kOhm}, \quad C_2 = 159pF. \]

Using the Bode plots on the next page, plot the loop transmission (T) of the overall feedback loop around the two op-amps, plot \( A_x \) and plot the closed loop gain (\( A_{cl} = V_{out}/V_{gen} \)), and determine the following:

Loop bandwidth = _______________, phase margin = ________________

Be SURE to label and dimension all axes clearly, and to make clear and accurate asymptotic plots.
Plot $T$, $A_{\infty}$, on this plot.

draw closed loop gain on this bode plot.
Problem 4, 10 points
negative feedback

The amplifier has a differential gain of $10^7$.

The op-amp has infinite differential input impedance and zero differential output impedance.

The differential amplifier has one pole in its open-loop transfer function at 1 Hz.

$$R_1 = 9 \text{kOhm}, \quad R_2 = 1 \text{kOhm}, \quad C = 88.3 \text{pF}$$

Using the Bode plots on the next page, plot the open-loop gain ($A_d$ or $A_{ol}$), the inverse of the feedback factor ($1/\beta$), closed loop gain ($A_{cl}$), and determine the following:

Loop bandwidth=$\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$   Amplifier 3dB bandwidth=$\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$

Be SURE to label and dimension all axes clearly, and to make clear and accurate asymptotic plots.
Draw open loop gain ($A_d$) and $1/\beta$ on this plot

Draw closed loop gain on this bode plot
Problem 5: 12 points

method of time constants analysis

part a, 10 points

Using MOTC, find the transfer function \( \frac{V_{out}(s)}{V_{gen}(s)} \). Working with the transfer function in standard form, i.e.

\[
\frac{V_{out}(s)}{V_{gen}(s)} = \frac{V_{out}}{V_{gen}} \left|_{DC} \right. \frac{1+b_1s+b_2s^2+...}{1+a_1s+a_2s^2+...}
\]

give algebraic answers in the blanks below

\[
\frac{V_{out}}{V_{gen}} \left|_{DC} \right. = \frac{1}{a_1} \quad a_1 = \frac{1}{a_2} \quad a_2 = \frac{1}{b_1} \\

b_1 = \frac{1}{a_2}
\]

You need some method other than MOTC to get the zero time constant \( b_1 \). Nodal analysis, solving only for the numerator, would do this, but is hard work. Hint: What would happen to \( V_{out} \) if the impedance of the parallel \( R_2 || C_2 \) network were infinite? Does that tell you the zero frequency?
part b, 2 points

Now, $R_1=1 \text{k}\Omega$, $R_2=2 \text{k}\Omega$, $R_3=3 \text{k}\Omega$, $C_1=1 \text{\mu F}$, $C_2=2 \text{\mu F}$. Again find $a_1$ and $a_2$ and $\frac{V_{out}}{V_{gen}}$ at DC.

$$\frac{V_{out}}{V_{gen,DC}} = \frac{a_1}{a_2}$$

$a_1 = \text{______________________} \quad a_2 = \text{______________________}$
Problem 6: 23 points
Nodal analysis and transistor circuit models

Part a, 10 points
Draw an accurate small-signal equivalent circuit model of the circuit above. Do not show components whose element values are zero or infinity (!).
Important hint:
(1) use a hybrid-pi model, not a T-model, for the FET
Part b, 10 points

Using NODAL ANALYSIS, find the input admittance \( Y_{in}(s) = I_{in}(s)/V_{in}(s) \)

The answer must be in the form \( Y_{in}(s) = Y_x \cdot (s \tau)^n \frac{1 + b_1 s + b_2 s^2 + \ldots}{1 + a_1 s + a_2 s^2 + \ldots} \),

where \( Y_x \) has units of (Amps/Volt), \( n \) might be any positive or negative integer (or \( n \) might be zero), and \( \tau \) has units of time.

\[
Y_x = \quad \_\_\_\_\_\_\_\_\_\_\_\_, \quad \tau = \quad \_\_\_\_\_\_\_\_\_\_\_\_, \quad n = \quad \_\_\_\_\_\_\_\_\_\_\_,
\]
\[
a_1 = \quad \_\_\_\_\_\_\_\_\_\_\_\_, \quad a_2 = \quad \_\_\_\_\_\_\_\_\_\_\_\_\_, \quad b_1 = \quad \_\_\_\_\_\_\_\_\_\_\_\_,
\]
\[
b_2 = \quad \_\_\_\_\_\_\_\_\_\_\_\_.
\]
Part c, 3 points

Now set: $g_m = 1 \text{mS}$, $C_1 = 1 \text{pF}$, $C_2 = 2 \text{pF}$. Find the numeric value (real and imaginary part) for $Y_{in}$ at 10 MHz. Do not be surprised if the answer appears to be an unexpected value.

$Y_{in}(10 \text{MHz}) =$ _______________
Problem 7, 10 points

mental Fourier Transforms

An amplifier has 3dB gain, is non-inverting, has a low-frequency cutoff, at the -3dB point, of 100kHz, and a high-frequency cutoff, at the -3dB point, of 1 MHz. Below the low-frequency 3dB point, the gain varies as 20dB/decade. Above the high-frequency 3dB point, the gain varies as -20dB/decade.

Plot below an accurate Bode plot of Vout/Vgen and an accurate plot of its step response with a 1 V step-function input. Label and dimension axes.

Bode Magnitude plot-please label axes
output voltage with $V_{in}(t) = 1$ Volt step function