### **ECE137B Final Exam**

There are 5 problems on this exam and you have 3 hours There are pages 1-19 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 2 pages (front and back→ 4 surfaces) of your own notes permitted. Don't panic.

Time function	LaPlace Transform
$\delta(t)$	1
U(t)	1/s
$e^{-\alpha t} \cdot U(t)$	$\frac{1}{s+\alpha}$ or $\frac{1/\alpha}{1+s/\alpha}$
$e^{-\alpha t}\cos(\omega_d t)\cdot U(t)$	$\frac{s+\alpha}{\left(s+\alpha\right)^2+\omega_d^2}$
$e^{-\alpha t}\sin(\omega_d t)\cdot U(t)$	$\frac{\omega_d}{\left(s+\alpha\right)^2+\omega_d^2}$

Name: \_\_\_\_\_\_

Problem	points	possible	Problem	points	possible
1a		3	2		10
1b		8	3a		7
1c		5	3b		13
1d		12	4a		10
1e		7	4b		5
1f		5	5a		5
			5b		5
			5c		5

### Problem 1, 40 points

method of first-order and second-order time constants, some feedback theory

The circuit below is an op-amp



Part a, 3 points DC analysis

Find all transistor DC emitter currents, find all node voltages. Make these on the circuit diagrm.

$\lambda = 1/20$ V for Q3 and Q9.	$\lambda = 0$ for all other transistors											
$ V_{th} =0.3$ V for all transistors, $g_m=1$ mS for all transistors.												
Q5 : $C_{gs} = 2$ fF, $C_{gd} = 0.5$ fF.	Q6 : $C_{gs} = 0$ fF, $C_{gd} = 0.5$ fF.											
All other transistors: $C_{gs} = C_{gd} = 0$ fF.												
The DC component of Vin is zero volts												
The supplies are +/- 2 Volts.												
Pick R3 so that the DC drain current of Q8 is 0.3 mA												
R1=1 MegOhm R2=100 kOhm												

Part b, 8 points mid-band analysis

Find the low-frequency loop transmission: T(f=0 Hz) =\_\_\_\_\_

To do this, you need to cut the feedback loop, thus, to find the loop transmission



Part c, 5 points feedback theory

At low frequencies, what is the closed-loop gain  $V_{out} / V_{in}$ ?

## Treat C<sub>infinite</sub> as an AC short (not a capacitor) in the MOTC analysis.

V<sub>out</sub> / V<sub>in</sub> =\_\_\_\_\_

Part d, 12 points

motc

Using MOTC, you will find the frequency, in Hz (not rad/sec), of the *two* major poles in the transfer function.

capacitor 1: Cgs of Q5	capacitor 2: Cgd of Q5	capacitor 3: Cgd of Q6
$R_{11}^0 =$	$R_{22}^0 =$	$R_{33}^0 =$
$R_{22}^1 =$	$R_{33}^1 =$	$R_{33}^2 =$
$f_{p1} =$	$f_{p2} =$	

Remember to treat C<sub>infinite</sub> as an AC short (not a capacitor) in the MOTC analysis.

Part e, 7 pointsMake accurate asymptotic plots of T. Find the phase margin and the loop bandwidth.Phase margin =Loop bandwidth =

# Draw the magnitude of T on this plot

Frequency, Hz

### Part f, 5 points

What is the gain and bandwidth of the closed-loop amplifier ?

low frequency Vout/Vgen=\_\_\_\_\_ bandwidth of Vout/Vgen=\_\_\_\_\_

### Problem 2: 10 points

method of time constants analysis



R1=1 KOhm, R2=2kOhm, R3=3kOhm, R4=4 kOhm, C1= 1 fF C2=2 fF Using MOTC, find the coefficients a1 and a2 of transfer function Vout(s)/Vgen(s), given a transfer function in the standard form  $\frac{V_{out}(s)}{V_{gen}(s)} = \frac{V_{out}}{V_{gen}} \bigg|_{DC} \frac{1+b_1s+b_2s^2+...}{1+a_1s+a_2s^2+...}$ 

 $V_{gen}(s) = V_{gen}\Big|_{DC} 1 + a_1 s + a_2 s^2 + \dots$ 

$$\begin{array}{c} R_{11}^{0} = \underline{\qquad} & R_{22}^{0} = \underline{\qquad} & R_{22}^{1} = \underline{\qquad} & a_{1} = \underline{\qquad} & a_{2} = \underline{\qquad} & a_{3} = \underline{\qquad} &$$

Problem 3: 20 points



Part a, 7 points

Draw an accurate small-signal equivalent circuit model of the circuit above.

# <u>Part b, 13 points</u> Using NODAL ANALYSIS, find the transfer function Vout(s)/Vin(s) The answer must be in standard form $\frac{V_{out}(s)}{V_{in}(s)} = \frac{V_{out}}{V_{in}}\Big|_{midband} \times \frac{1 + b_1 s + b_2 s^2 + \dots}{1 + a_1 s + a_2 s^2 + \dots}$ ,

Vout(s)/Vin(s)=\_\_\_\_\_

### Problem 4, 15 points

negative feedback

part a, 10 points



The amplifier has a differential gain of  $10^4$ . R1=9 kOhm, R2=1 kOhm. The op-amp has infinite differential input impedance and zero differential output impedance.

The differential amplifier has 2 poles in its openloop transfer function.

One, the dominant pole, is at a low frequency, and can be adjusted by appropriately adjusting a compensation capacitor internal to the op-amp. The second one is at 200 MHz

а

To repeat:

 $f_{p1}$  = dominant pole frequency= you must find the required value  $f_{p2}$  = second pole frequency= 200 MHz

### **PICK** $f_{p1}$ so that the phase margin is 161.6 degrees.

Using the Bode plot 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 ( $A_{CL}$ ). *Label all axes, slopes, pole/zero frequencies, etc.* Determine the following:

 $f_{p1}$ =\_\_\_\_\_ Loop bandwidth=\_\_\_\_\_

Vout/Vgen at DC=\_\_\_\_\_

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Frequency, Hz

part b, 5 points What is the gain and bandwidth of the closed-loop amplifier ?

low frequency Vout/Vgen=\_\_\_\_\_ bandwidth of Vout/Vgen=\_\_\_\_\_ Draw a plot of the closed loop gain, labeling all axes, slopes, pole/zero frequencies, etc.

# draw closed loop gain on this bode plot



Frequency, Hz

### **Problem 5: 15 points**

transfer functions

### Part a, 5 points

A transistor circuit has a step response (input is a 1-V step function) as shown.



Determine the frequency and damping factor of the dominant poles of the transfer function.

Part b, 5 points

Give the transfer function

Vout(s)/Vgen(s). Give the answer in standard form  $\frac{V_{out}(s)}{V_{gen}(s)} = \frac{V_{out}}{V_{gen}}\Big|_{DC} \frac{1+b_1s+b_2s^2+\dots}{1+a_1s+a_2s^2+\dots}$ 

Vout(s)/Vgen(s)=

### Part c, 5 points

Draw an accurate Bode plot of the transfer function. LABEL AXES precisely



Frequency, Hz