ECE137B Final Exam

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

There are7 problems on this exam and you have 3 hours
There are pages 1-32 in the exam: please make sure all are there.

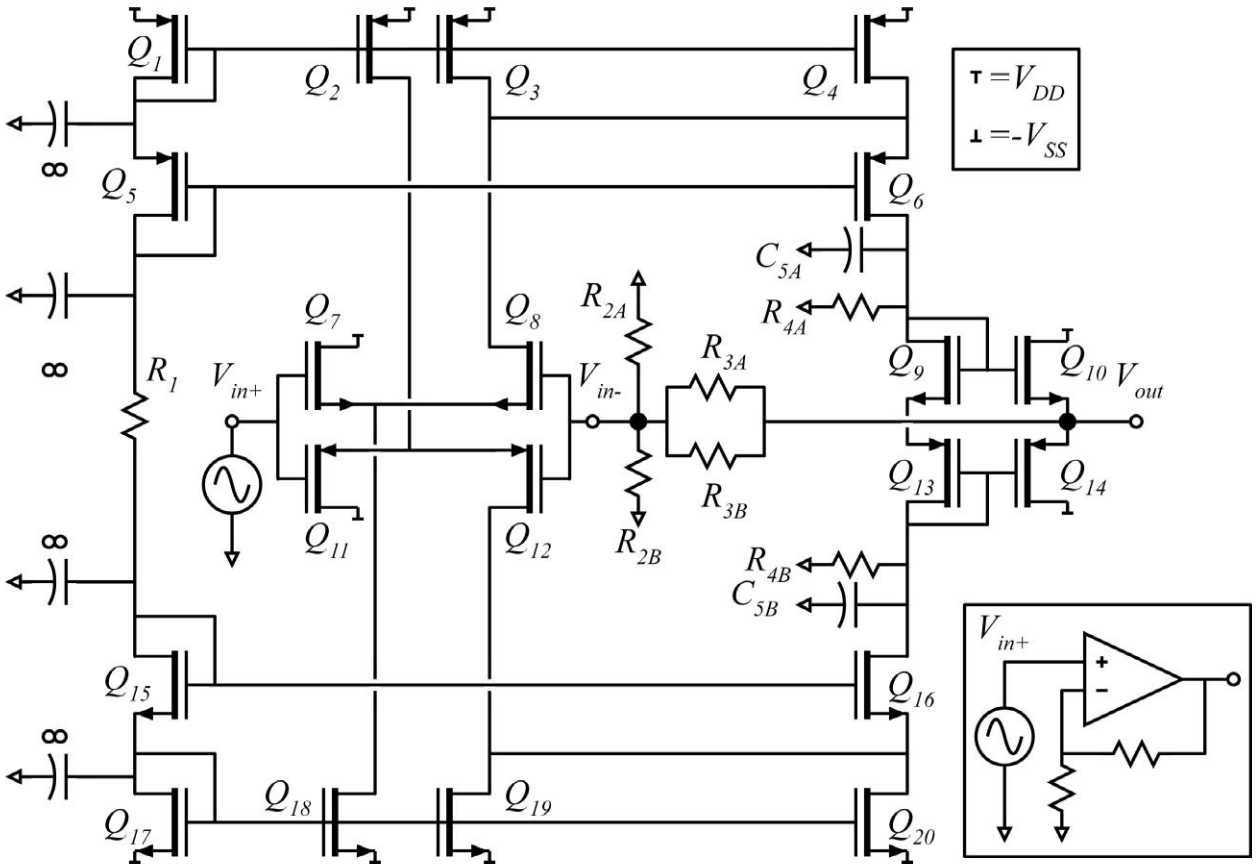
Do not open this exam until told to do so.
Show all work.
Credit will not be given for correct answers if supporting work is not shown.
Class Crib sheets and 3 pages (front and back→ 6 surfaces) of your own notes permitted.
Don't panic.

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

Name: ___________________________________

Problem	points	possible	Problem	points	possible
1a		5	5a		10
1b		3	5b		2
1c		10	6a		10
1d		15	6b		10
2		10	6c		3
3		10	7		10
4		10	total		108

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 = 45nm

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

All FETs have λ=0 V^{-1}, all have W_g=1 micrometers,

except Q2 and Q18, which have λ=0 V^{-1}, and W_g=2 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 fF.

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

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

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

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

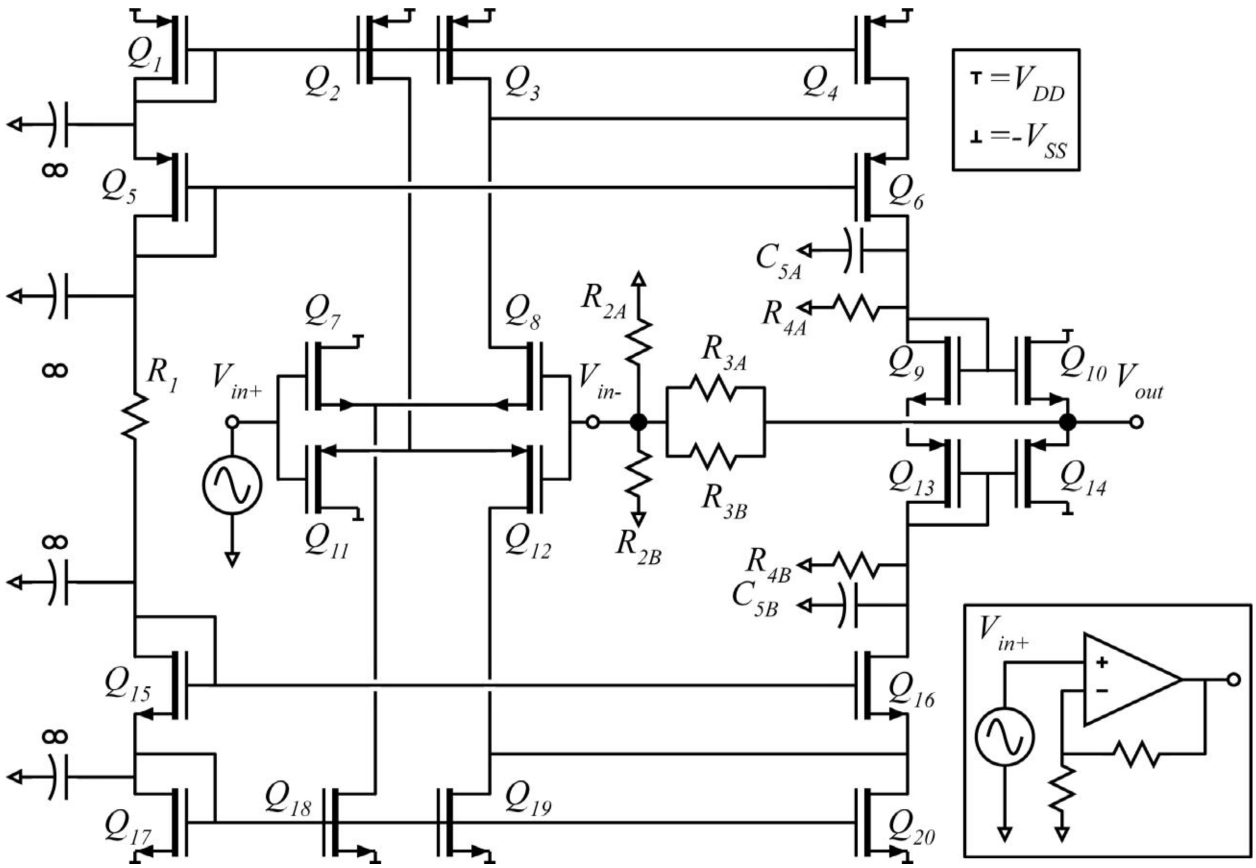
$R_{2a} = R_{2b} = 2\text{k}\Omega$, $R_{3a} = R_{3b} = 8\text{k}\Omega$

The supplies are +1.5V and -1.5V.

a

Part a, 5 points

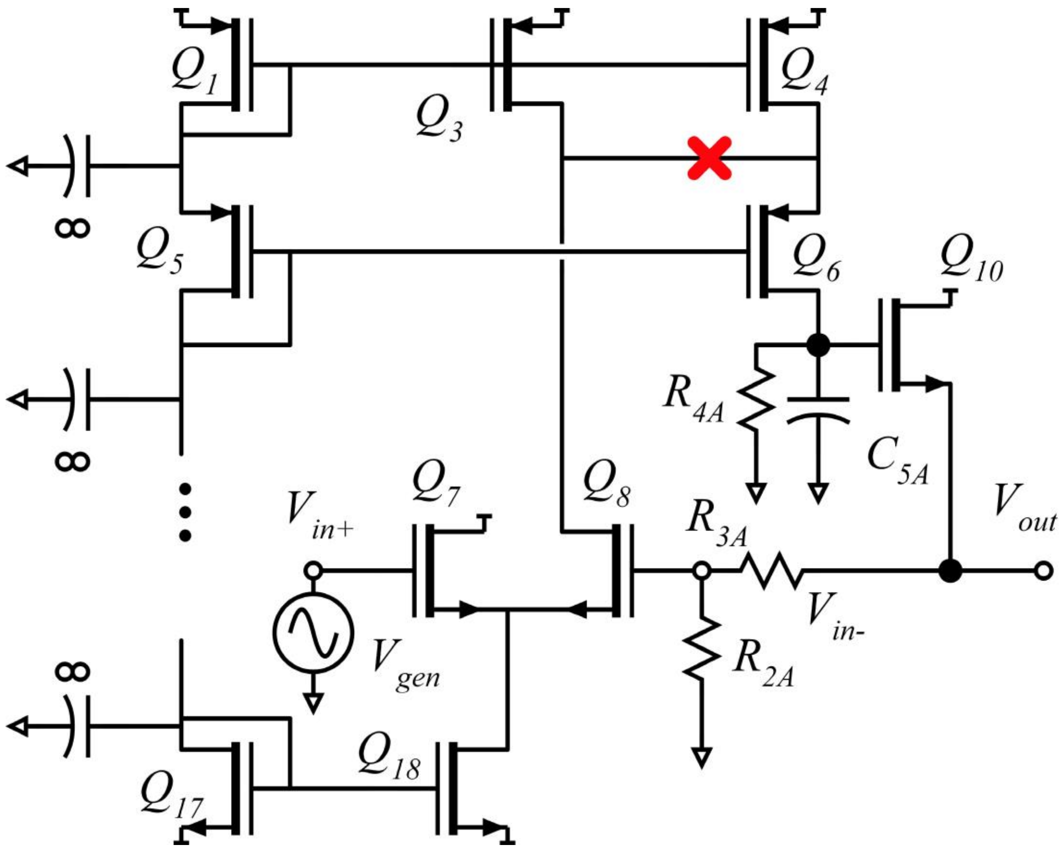
Draw all DC node voltages and all DC bias currents on the diagram below.



a

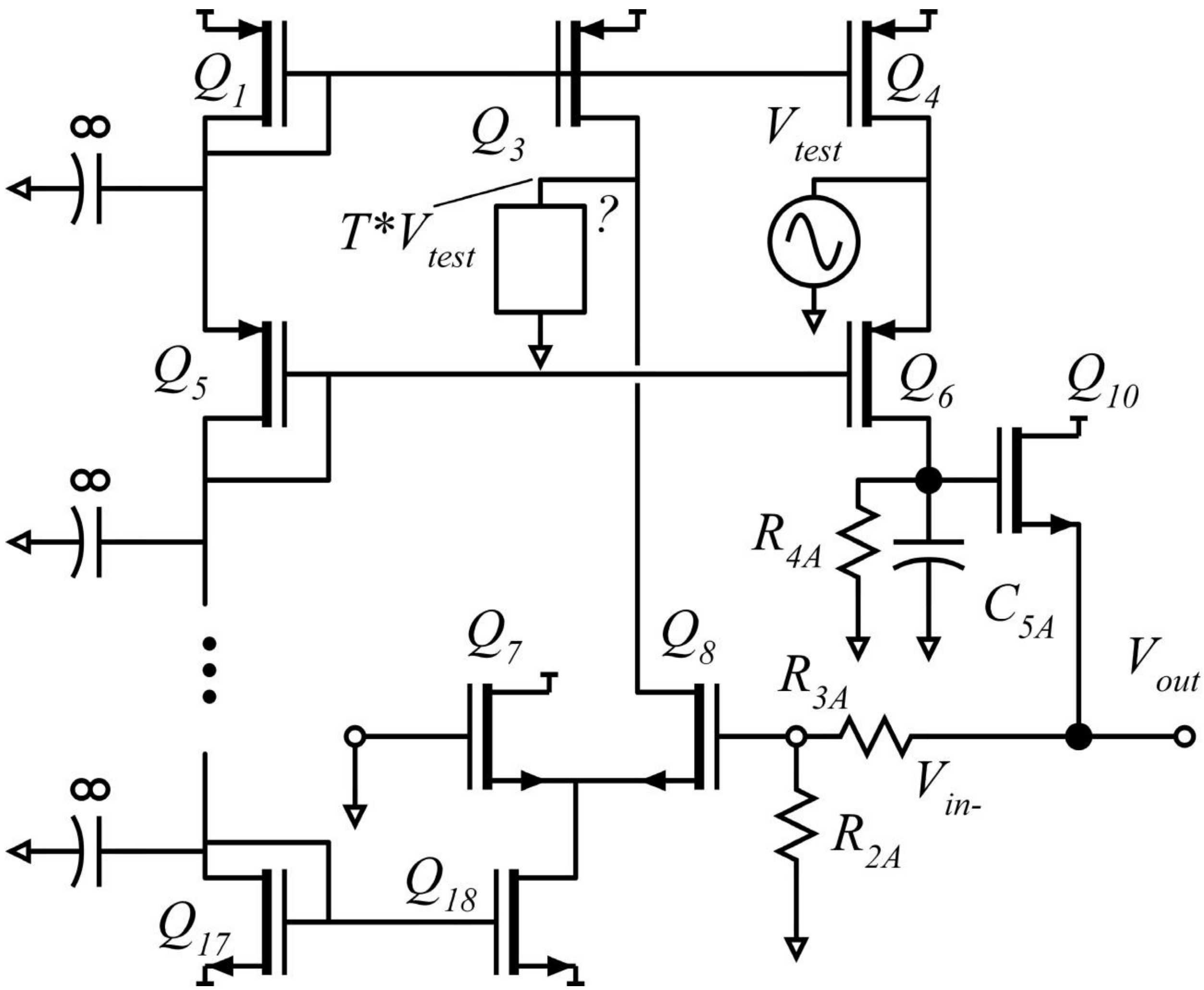
Part b, 3 points

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



To compute the loop transmission you must (1) set Vgen 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.

a



Indicate on the drawing above what circuit element must be placed in the box labeled with a "?", and give the value of this element.

a

Part c, 10 points

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

T_{DC}=____________

a

a

Part d, 15 points

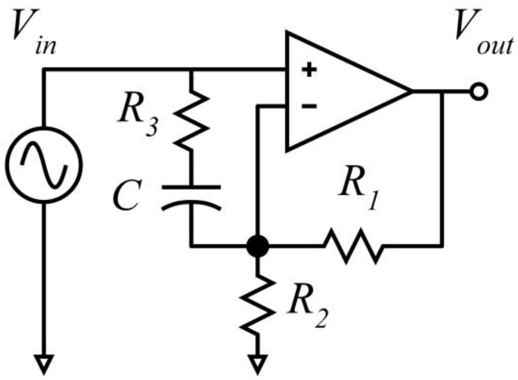
Using MOTC, you will find the frequency, in Hz (not rad/sec), of the ***two*** major poles in the ***loop transmission T***. Hint: you can use the source degeneration model for Q7-Q8.

Find all the following.

$C_1 = C_{5A} + C_{gd10}$	$C_2 = C_{gs8}$:	$C_3 = C_{gs10}$
$R_{11}^0 =$	$R_{22}^0 =$	$R_{33}^0 =$
$R_{22}^1 =$	$R_{33}^1 =$	$R_{33}^2 =$
$f_{p1} =$	$f_{p2} =$	

a

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=1.57nF.

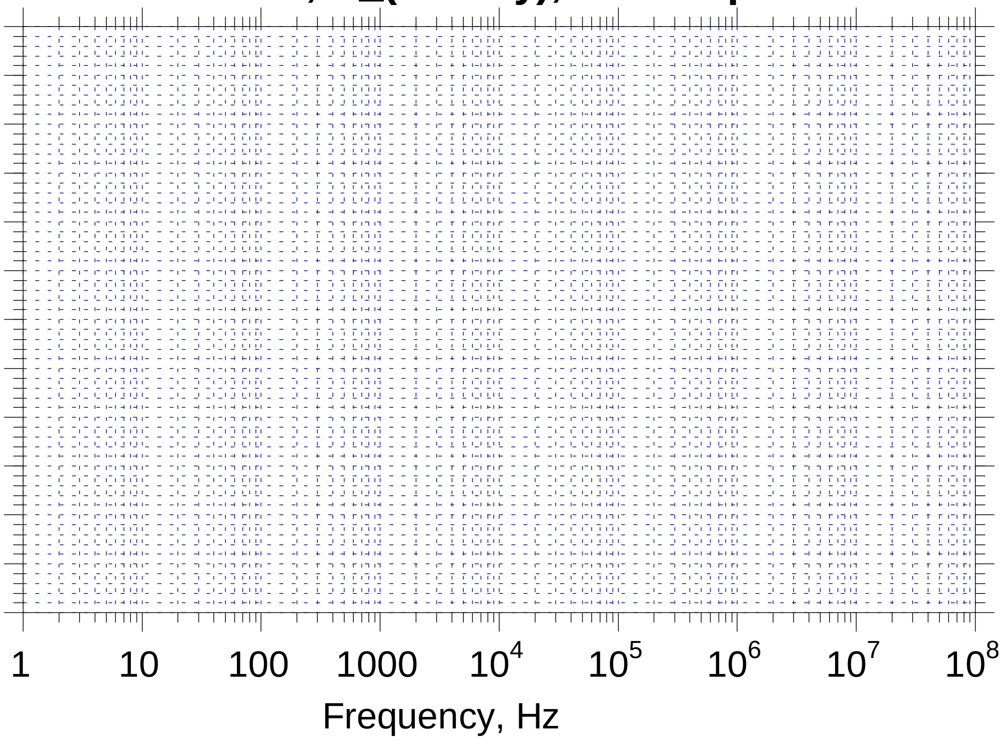
Using the Bode plots on the next page, plot the loop transmission (T), plot A_∞ and plot the closed loop gain (A_{CL} =Vout/Vgen), and determine the following:

Loop bandwidth=________________ , phase margin = ____________________

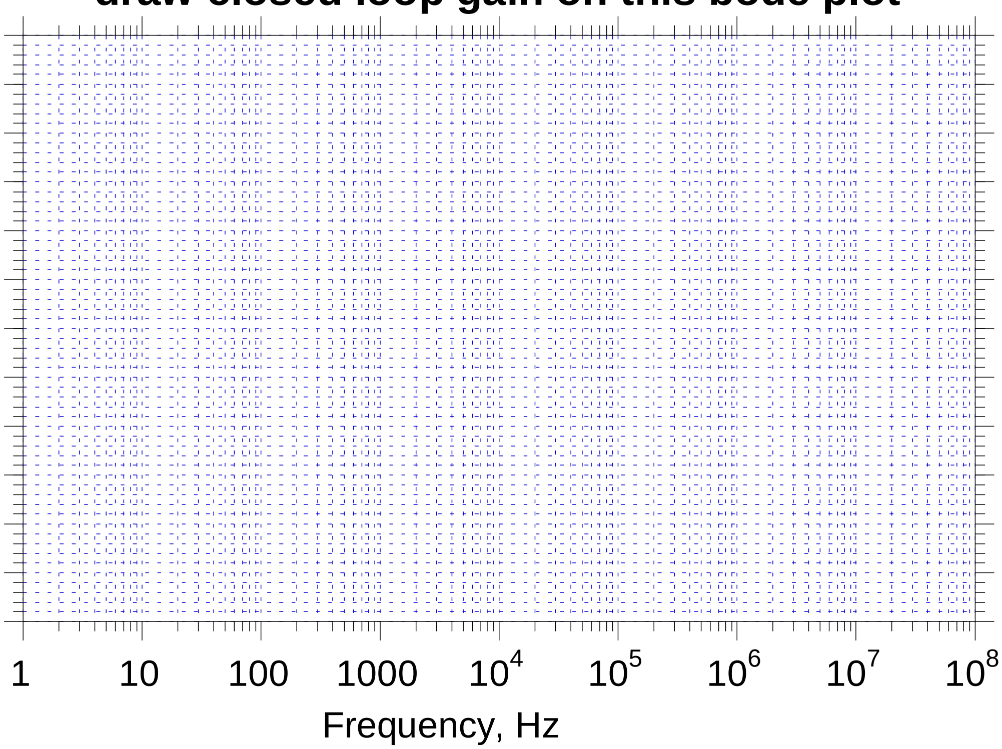
Be SURE to ***label*** and ***dimension*** all ***axes*** clearly, and to make clear and ***accurate asymptotic*** plots.

a

Plot T, A_(infinity), on this plot



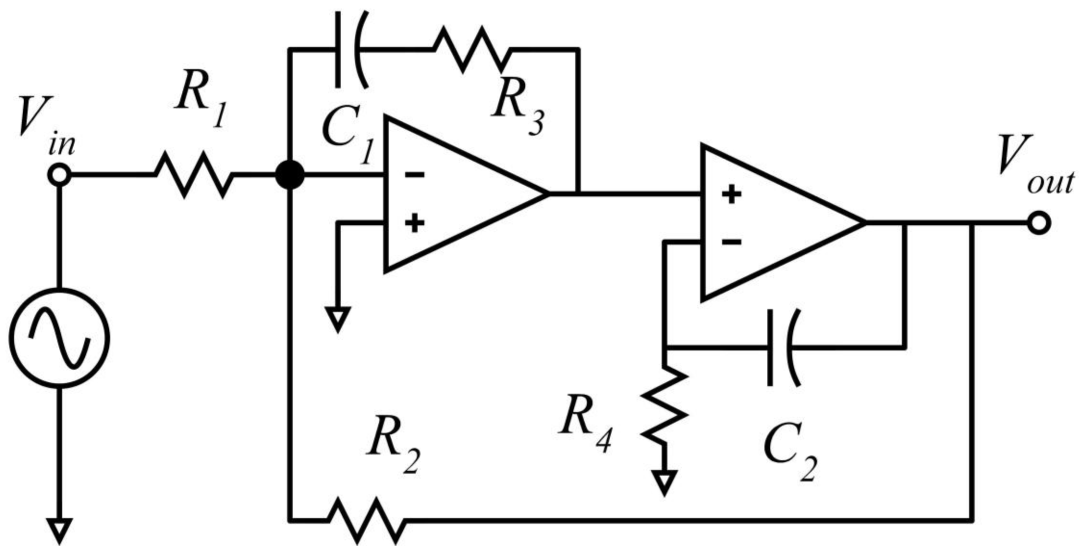
draw closed loop gain on this bode plot



a

a

Problem 3, 10 points
negative feedback



The op-amps are ideal: infinite gain, infinite differential input impedance and zero output impedance.
R_1=100 Ohm, R_2=1 kOhm, C1=15.9pF, R3=333Ohms, R4=1kOhm, C2=159pF.

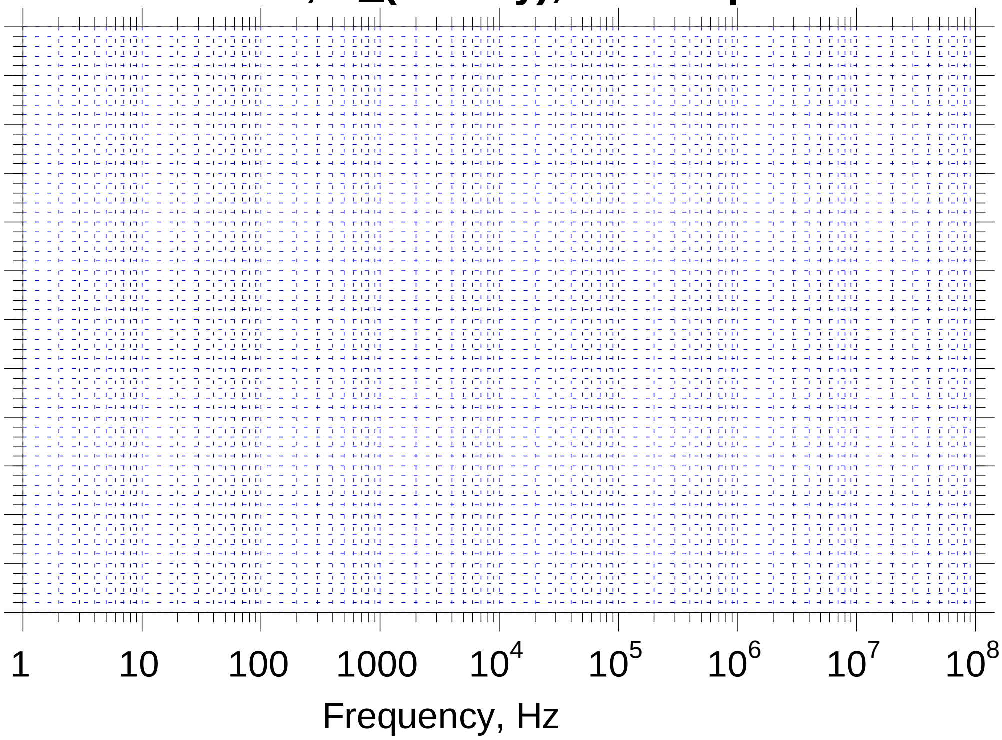
Using the Bode plots on the next page, plot the loop transmission (T) of the overall feedback loop around the two op-amps, plot A_∞ and plot the closed loop gain (A_{CL}=Vout/Vgen), and determine the following:

Loop bandwidth=________________ , phase margin = ____________________

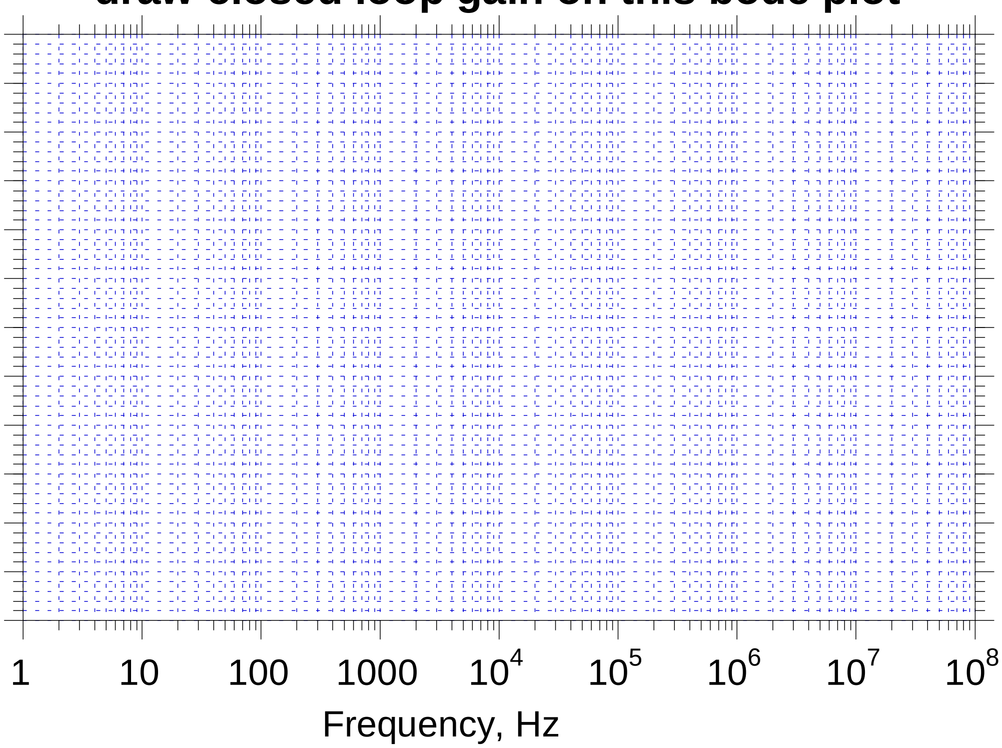
Be SURE to ***label*** and ***dimension*** all ***axes*** clearly, and to make clear and ***accurate asymptotic*** plots.

a

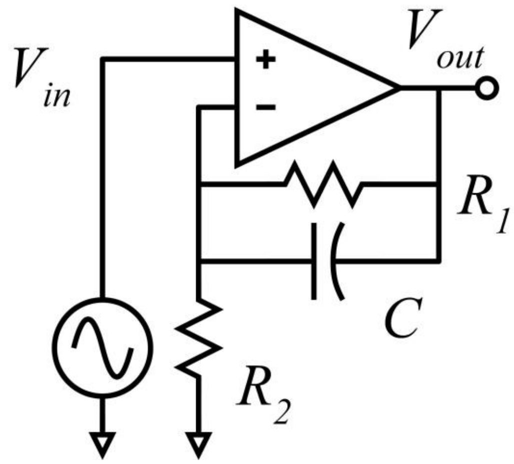
Plot T, A_(infinity), on this plot



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 kOhm, R_2 =1 kOhm, C=88.3pF

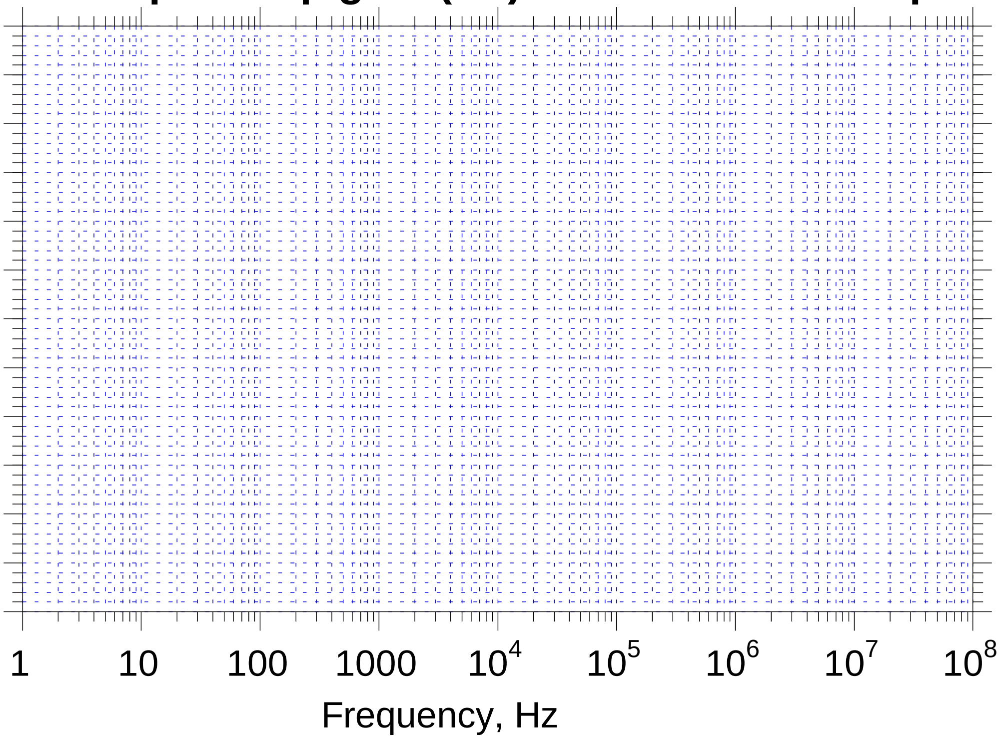
Using the Bode plots on the next page, plot the open-loop gain (A_d or A_{ol}), the inverse of the feedback factor ($1/\beta$) , closed loop gain (A_{CL}), and determine the following:

Loop bandwidth=_______________ . Amplifier 3dB bandwidth=_______________

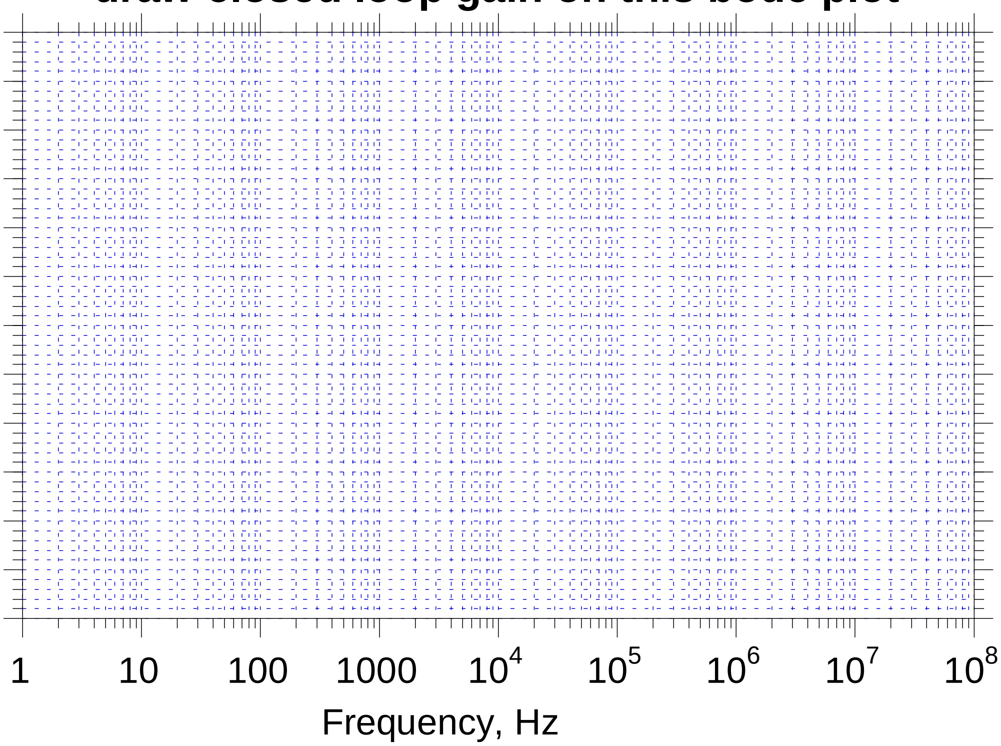
Be SURE to ***label*** and ***dimension*** all ***axes*** clearly, and to make clear and ***accurate asymptotic*** plots.

a

Draw open loop gain (Ad) and 1/beta on this plot



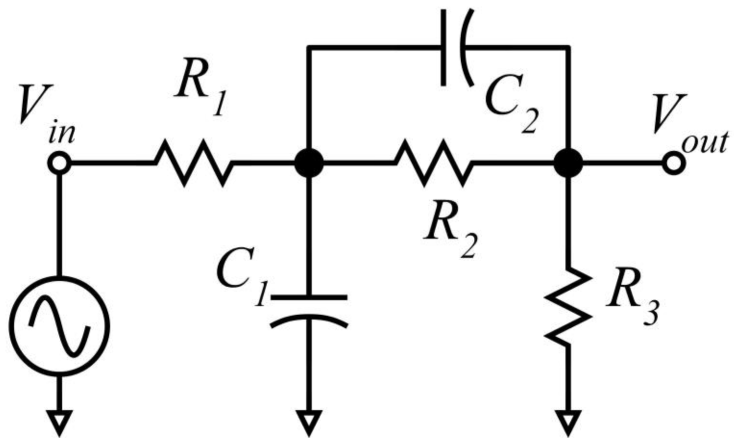
draw closed loop gain on this bode plot



a

Problem 5: 12 points
method of time constants analysis

<u>part a, 10 points</u>



Using MOTC, find the transfer function Vout(s)/Vgen(s). Working with the transfer function in standard form, i.e. $\frac{V_{out}(s)}{V_{gen}(s)} = \left.\frac{V_{out}}{V_{gen}}\right|_{DC} \frac{1+b_1 s + b_2 s^2 + ...}{1+a_1 s + a_2 s^2 + ...}$ give algebraic answers in the blanks below

$\left.\frac{V_{out}}{V_{gen}}\right|_{DC} =$ ______________________ $a_1 =$ ______________________ $a_2 =$ ______________________

$b_1 =$ ______________________

You need some method other than MOTC to get the zero time constant b1. Nodal analysis, solving only for the numerator, would do this, but is hard work. Hint: What would happen to Vout if the impedance of the parallel R2||C2 network were infinite ? Does that tell you the zero frequency ?

a

a

part b, 2 points

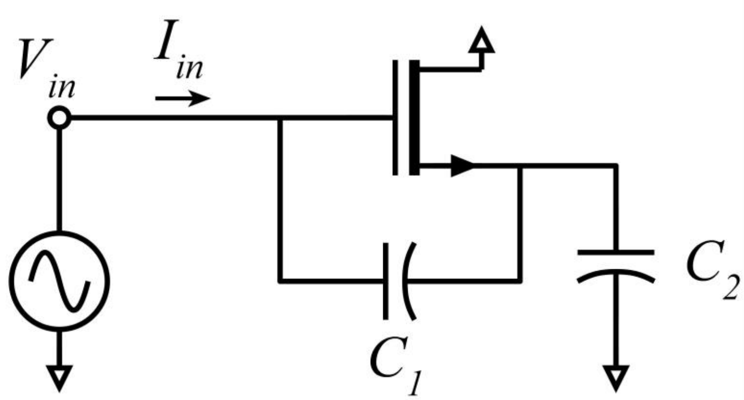
Now, R1=1 kΩ, R2=2 kΩ, R3=3 kΩ, C1=1 μF, C2=2 μF. Again find a1 and a2 and Vout/Vgen at DC.

$\left.\frac{V_{out}}{V_{gen}}\right|_{DC} =$ ______________________ $a_1 =$ ______________________ $a_2 =$ ______________________

a

Problem 6: 23 points

Nodal analysis and transistor circuit models

	Ignore DC bias; you don't need it. FET: C_{gs} =0fF, C_{gd} =0 fF, R_{ds} =infinity. ** g_m is nonzero**

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

a

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 $Y_{in}(s) = Y_x \cdot (s\tau)^n \dfrac{1+b_1 s+b_2 s^2+...}{1+a_1 s+a_2 s^2+...}$,

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

Y_x =____________________ , τ =____________________ , n =____________________ ,

a_1 =____________________ , a_2 =____________________ b_1 =____________________ ,

b_2 =____________________

a

Part c, 3 points

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

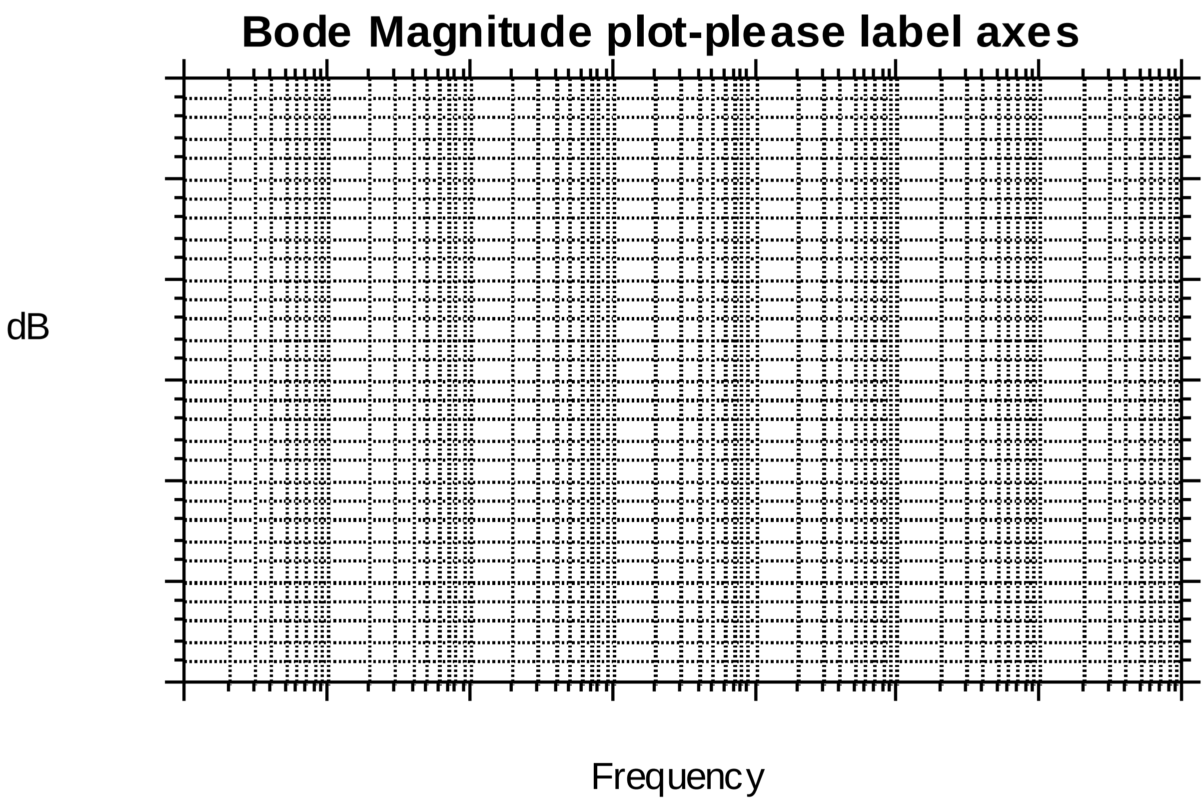
$Y_{in}(10MHz) =$________________

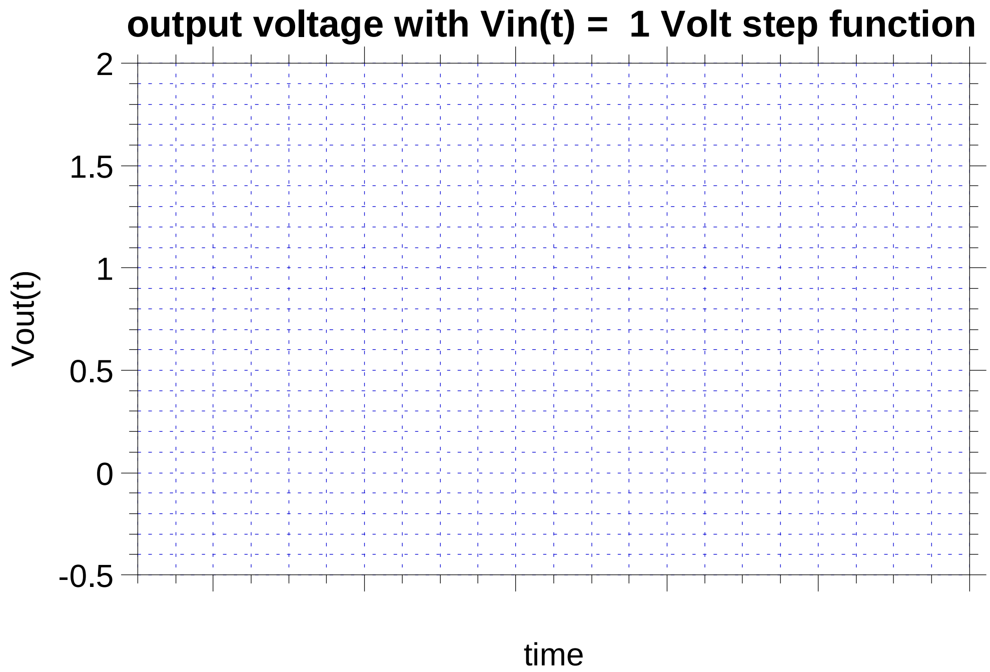
a

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.




output voltage with Vin(t) = 1 Volt step function
Vout(t)
2
1.5
1
0.5
0
-0.5
time

a