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.

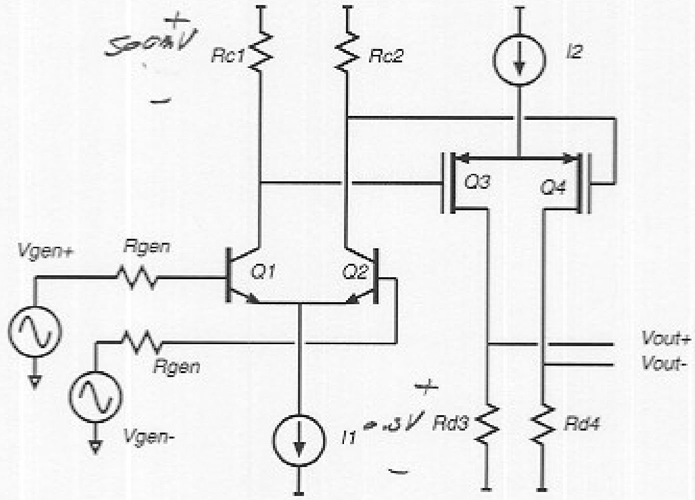
Time function	LaPlace Transform
$\delta(t)$	1
U(t)	1/s
$e^{-\alpha t}\cdot U(t)$	$\frac{1}{s+\alpha}$ or $\frac{1/\alpha}{1+s/\alpha}$
$e^{-\alpha t}\cos(\omega_d t)\cdot U(t)$	$\frac{s+\alpha}{(s+\alpha)^2+\omega_d^2}$
$e^{-\alpha t}\sin(\omega_d t)\cdot U(t)$	$\frac{\omega_d}{(s+\alpha)^2+\omega_d^2}$

Name: Solution B

Problem	points	possible	Problem	points	possible
1a		4	3a		10
1b		5	3b		20
1c		4	4		20
1d		12	5a		7
2		10	5b		8

Problem 1, 25 points

method of first-order and second-order time constants



Q1 and Q2 have β=infinity, Va=infinity, τ_f=1 ps, C_{je}=1 fF, C_{cb}=0 fF.

Q3 and Q4 have $v_{sat}c_{ox}W_g$ = 100 mS, $|V_t|$=0.25 volts, λ=0 V^{-1}, C_{gs}=160 fF, C_{gd}=16 fF

The supplies are +/- 3.3 Volts.
Rgen=100 Ohms

The input is fully differential, with $V_{gen+} = -1 * V_{gen-}$

Part a, 4 points

The DC voltage drops across Rc1 and Rc2 are both 500 mV.
Rc1, Rc2, are both 50 Ohms.
Rd3 and Rd4 are both 25 Ohms.
The DC voltage drops across Rd3 and Rd4 are both 0.5 V.

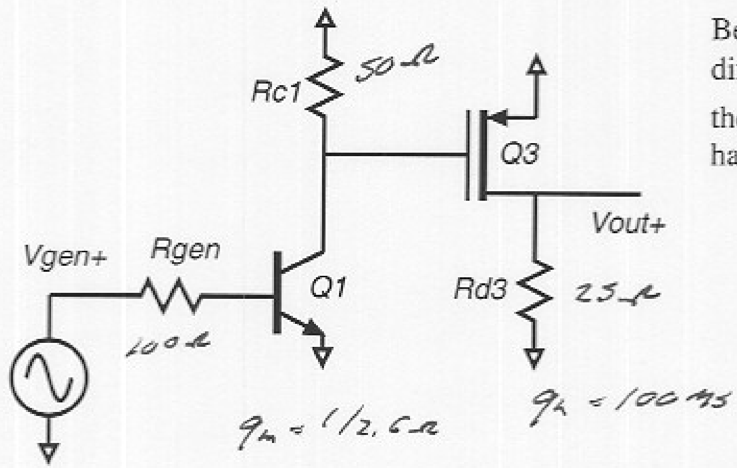
Find I1 and I2

~~Rd1~~ I_1= 20mA ~~Rd3~~ I_2= 40mA

$I_1 = 2 \cdot 500mV/50\Omega = 20mA$

$I_2 = 2 \cdot 500mV/25\Omega = 40mA.$

Part b. 5 points



Because the input is fully differential, with $V_{gen+} = -1 * V_{gen-}$, the circuit can be analyzed using a half-circuit equivalent.

Find the following quantitites at mid-band
Vout/Vgen=__________________________

small-signal voltage gain of Q3 =___________________

small-signal voltage gain of Q1 =___________________

$I_{C1} = 10 mA \rightarrow g_{m1} = 1/2.6 \Omega$

Q3: CS: $A_v = -g_m R_{Leq} = -2.5$

Q1 CE: $A_v = -g_m R_{Leq} = -19.23$

$v_i / v_{gen} = 1$ because $R_{in} = \infty$

$v_o / v_{gen} = -192.3$

Part c, 4 points

Find the following:

Q1: f_T = 158 GHz   Q3: f_T = 90.3 GHz

C_{be1} = 386 fF

Q1 $C_{be} = C_{je} + g_m \tau_F = 386\,fF$

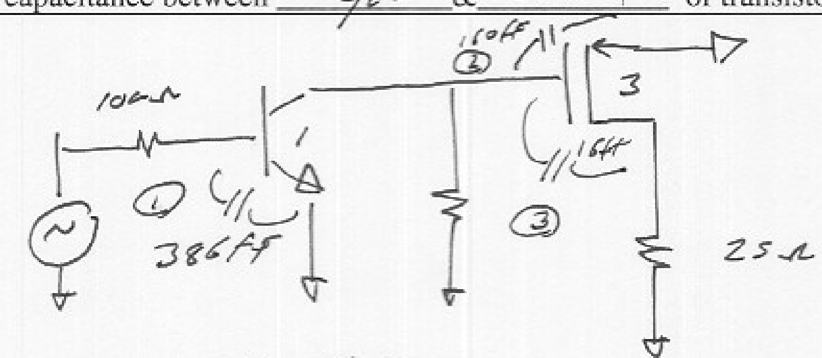
$f_T = \frac{g_m}{2\pi(C_{be} + C_{cs})} = 158\ GHz$

Q 3: $f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})} = 90.3\ GHz$

Part d, 12 points

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

capacitor 1:		capacitor 2:		capacitor 3:
$R_{11}^0 =$	100Ω	$R_{22}^0 =$	50Ω	$R_{33}^0 = 200\Omega$
$R_{22}^1 =$	50Ω	$R_{33}^1 =$	200Ω	$R_{33}^2 = 25\Omega$
$f_{p1} =$	4.14 GHz	$f_{p2} =$	13.4 GHz	
capacitor 1 is the capacitance between base & emitter of transistor Q 1				
capacitor 2 is the capacitance between gate & source of transistor Q 3				
capacitor 3 is the capacitance between gate & drain of transistor Q 3				



$g_m = 1/12.6\Omega$

$g_m = 100mS$

$R_{11}^0 = 100\Omega$ $\quad R_{11}^0 C_1 = 38.6\ ps$

$R_{22}^0 = 50\Omega$ $\quad R_{22}^0 C_2 = 50\Omega \cdot 160\ fF = 8ps.$

$R_{33}^0 = 50\Omega(1 + 25\Omega \cdot 100mS) + 25\Omega = 200\Omega.$

$R_{33}^0 C_3 = 200\Omega \cdot 16 fF = 3.2ps.$

$R_{22}^1 = R_{22}^0 = 50\Omega$ $\quad R_{11}^0 C_1 C_2 R_{22}^1 = 3.1(10^{-22}) sec^2$

$R_{33}^1 = R_{33}^0 = 200\Omega$ $\quad R_{11}^0 C_1 C_3 R_{33}^1 = 1.23(10^{-22}) sec^2$

$R_{33}^2 = 25\Omega$ $\quad R_{11}^0 C_1 C_3 R_{33}^1 = 1.54(10^{-23}) sec^2$

$a_1 = 49.8\,ps$

$a_2 = 4.49(10^{-22})\,sec^2 = (21.2\,ps)^2$

SPA does not work because $\sqrt{a_2} \sim a_1$

$1 + a_1 s_p + a_2 s_p^2 = 0$

$$s_p = \frac{-a_1 \pm \sqrt{a_1^2 - 4 \cdot 1 \cdot a_2}}{2 \cdot a_2}$$

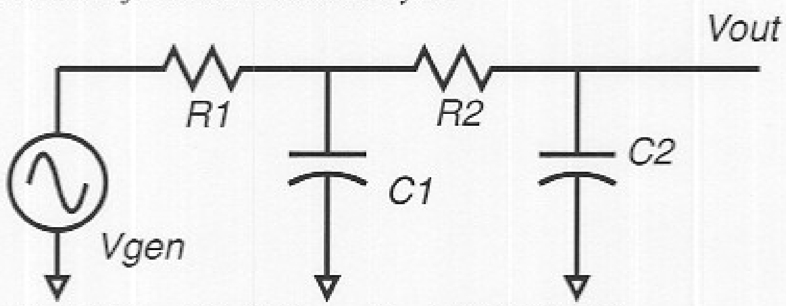
$= -8.456(10^{10})\,sec^{-1}$ and

$2.636(10^{10})\,sec^{-1}$

$f_p = 13.44\ GHz$ and $4.19\ GHz$.

Problem 2: 10 points

method of time constants analysis



R1=1 KOhm, R2=2kOhm C1= 1 fF C2=0.5 fF

Using MOTC, find the transfer function Vout(s)/Vgen(s). Give the answer in standard form

$$\frac{V_{out}(s)}{V_{gen}(s)} = \left.\frac{V_{out}}{V_{gen}}\right|_{DC} \frac{1+b_1 s + b_2 s^2 + \ldots}{1+a_1 s + a_2 s^2 + \ldots}$$

HINT: $b_1 = 0 = b_2 = b_3 = \cdots$

$R_{11}^0 =$ 1 kΩ $\qquad R_{22}^0 =$ 3 kΩ $\qquad R_{22}^1 =$ 2 kΩ

$\left.\frac{V_{out}}{V_{gen}}\right|_{DC} =$ 1 $\qquad a_1 =$ 2.5 ps $\qquad a_2 =$ 10^{-24} sec^2

$R_{11}^0 = R_1 = 1\,k\Omega$

$R_{22}^0 = R_1 + R_2 = 3\,k\Omega$

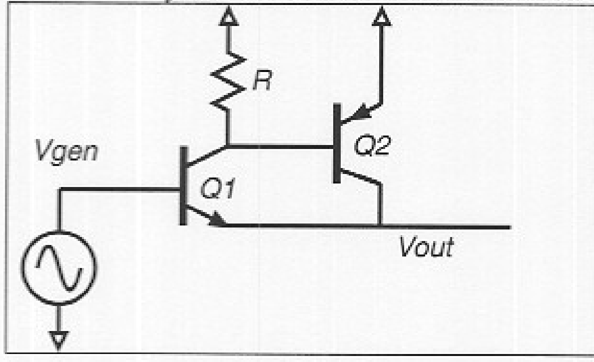
$R_{22}^1 = R_2 = 2\,k\Omega$

$a_1 = R_{11}^0 C_1 + R_{22}^0 C_2 = 2.5\,ps$

$a_2 = R_{11}^0 C_1 C_2 R_{22}^1 = 10^{-24}\,sec^2$

Problem 3 30 points

Nodal analysis and transistor circuit models



This circuit was used in 1960's audio power amplifiers.

Ignore DC bias; you don't need it.

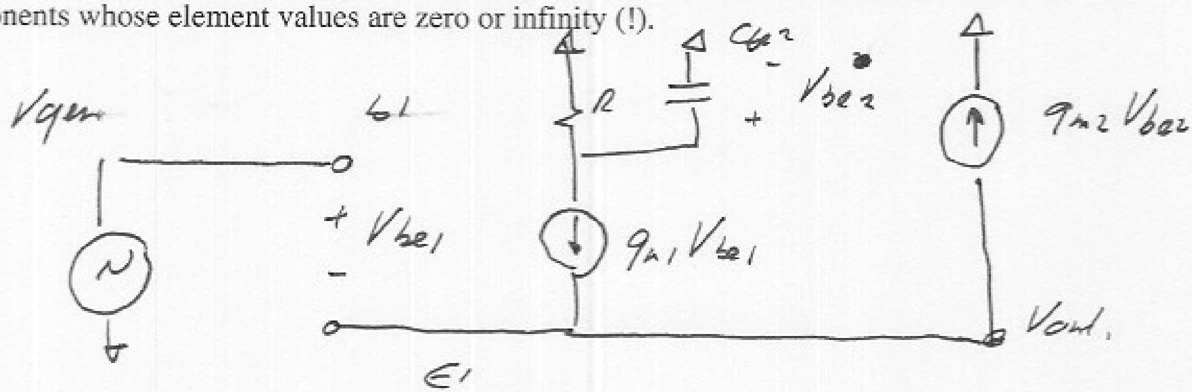
Q1: $C_{be}=C_{cb}=0$. R_{ds}=infinity.

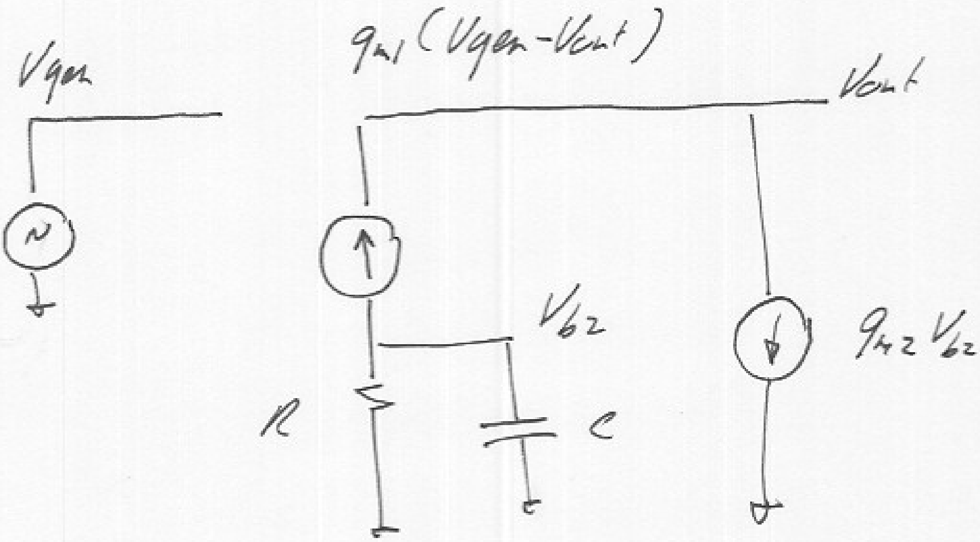
Q2: C_{be}= 1pF. C_{cb}=0. R_{ds}=infinity

gm1=20 mS. gm2=10 mS. R=1000 Ohms.

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 (!).





Part b, 20 points

Using NODAL ANALYSIS, find the transfer function Vout(s)/Vgen(s).

The answer must be in standard form $\frac{V_{out}(s)}{V_{gen}(s)} = \left.\frac{V_{out}}{V_{gen}}\right|_{DC} \frac{1 + b_1 s + b_2 s^2 + \ldots}{1 + a_1 s + a_2 s^2 + \ldots}$

$\left.\frac{V_{out}}{V_{gen}}\right|_{DC} =$ 1, $a_1 =$ 0, $a_2 =$ 0

$b_1 =$ 0, $b_2 =$ 0

(note that a3, a4, ..., b3,b4, ... are all zero)

$\Sigma I = 0$ @ V_{b2}

$g_{m1}(V_{gen} - V_{out}) + V_{b2}(1/R + sC) = 0$

$V_{out}(-g_{m1}) + V_{b2}(1/R + sC) = -g_{m1} V_{gen}$

$\Sigma I = 0$ @ V_{out}

$g_{m1}(V_{out} - V_{gen}) + V_{b2} \cdot g_{m2} = 0$

$V_{out}(g_{m1}) + V_{b2}\, g_{m2} = g_{m1} V_{gen}$

$$\begin{bmatrix} -g_{m1} & 1/R + sC \\ g_{m1} & g_{m2} \end{bmatrix} \begin{bmatrix} V_{out} \\ V_{b2} \end{bmatrix} = \begin{bmatrix} -g_{m1} \\ g_{m1} \end{bmatrix} V_{ga}$$

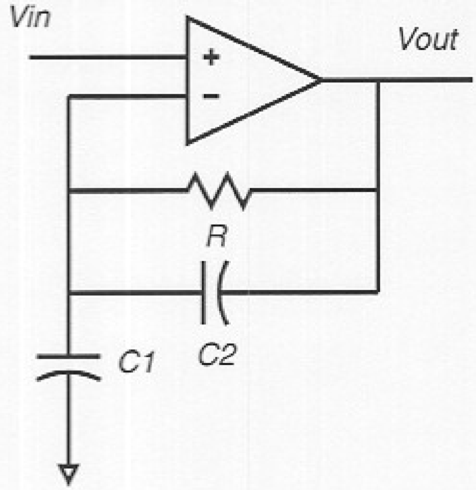
$V_o/V_{ga} = N/D$ where

$$N = \begin{vmatrix} -g_{m1} & 1/R + sC \\ g_{m1} & g_{m2} \end{vmatrix}$$

$$D = \begin{vmatrix} -g_{m1} & 1/R + sC \\ g_{m1} & g_{m2} \end{vmatrix}$$

$$V_{out}/V_{ga} = 1$$

Problem 4, 20 points
negative feedback



The amplifier has a differential gain of 10^5. R=1 kOhm, C2=100 pF, C1=25 pF . The op-amp has infinite differential input impedance and zero differential output impedance.

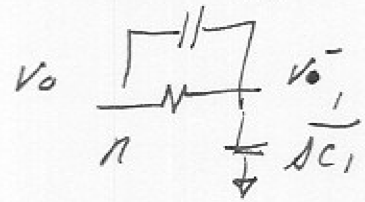
25 pF 100 pF

The differential amplifier has 1 pole in its open-loop transfer function at 1000 Hz, and one pole at 50 MHz.

C= 1nF

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}), and determine the following:

Loop bandwidth= 20 MHz phase margin= 54°
Vout/Vgen at DC= 1



$V_o^-(sC_2 + sC_1 + G) + V_o(-G - sC_2) = 0$

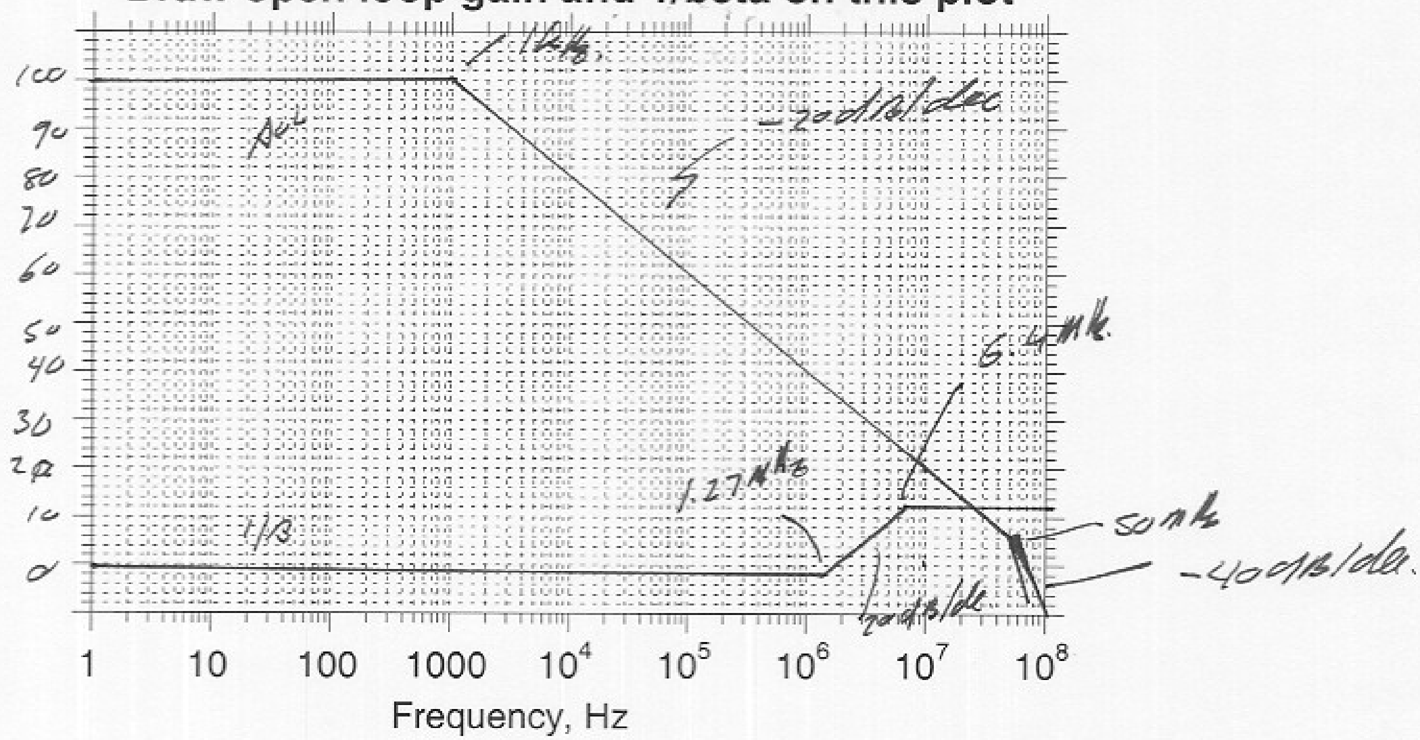
$$\rightarrow \beta(s) = \frac{V_o}{V^-} = \frac{G + sC_2}{G + sC_1 + sC_2} = \frac{1 + sC_2R}{1 + sR(C_1 + C_2)}$$

$$= \frac{1 + jf/f_{z\beta}}{1 + jf/f_{p\beta}}, \quad f_{z\beta} = 6.36\text{ MHz}, \quad f_{p\beta} = 1.27\text{ MHz}.$$

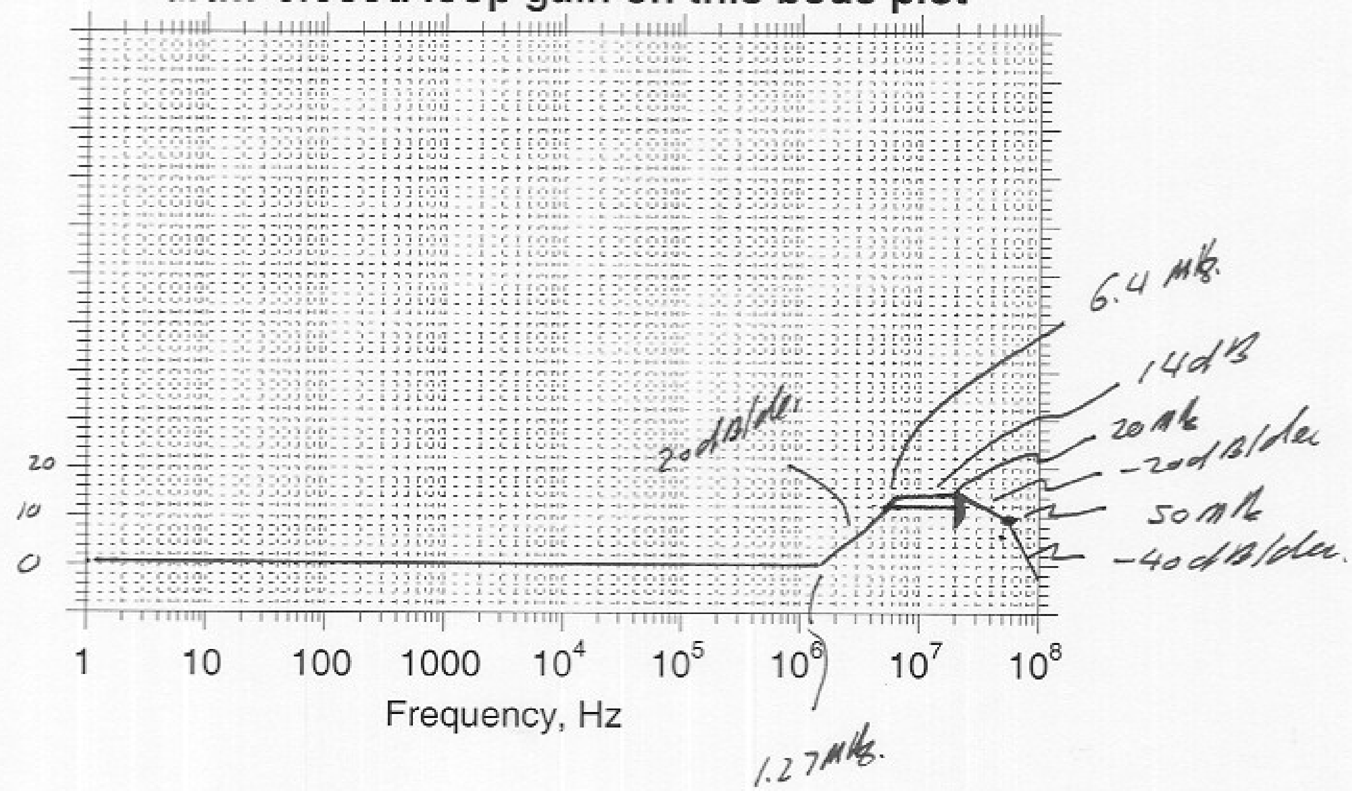
$$PM = 180 - \arctan(20\text{ MHz}/1\text{ KHz}) - \arctan(20\text{ MHz}/1.27\text{ MHz}) + \arctan(20\text{ MHz}/6.36\text{ MHz}) - \arctan(20\text{ MHz}/50\text{ MHz})$$

$$= 54.2°.$$

Draw open loop gain and 1/beta on this plot



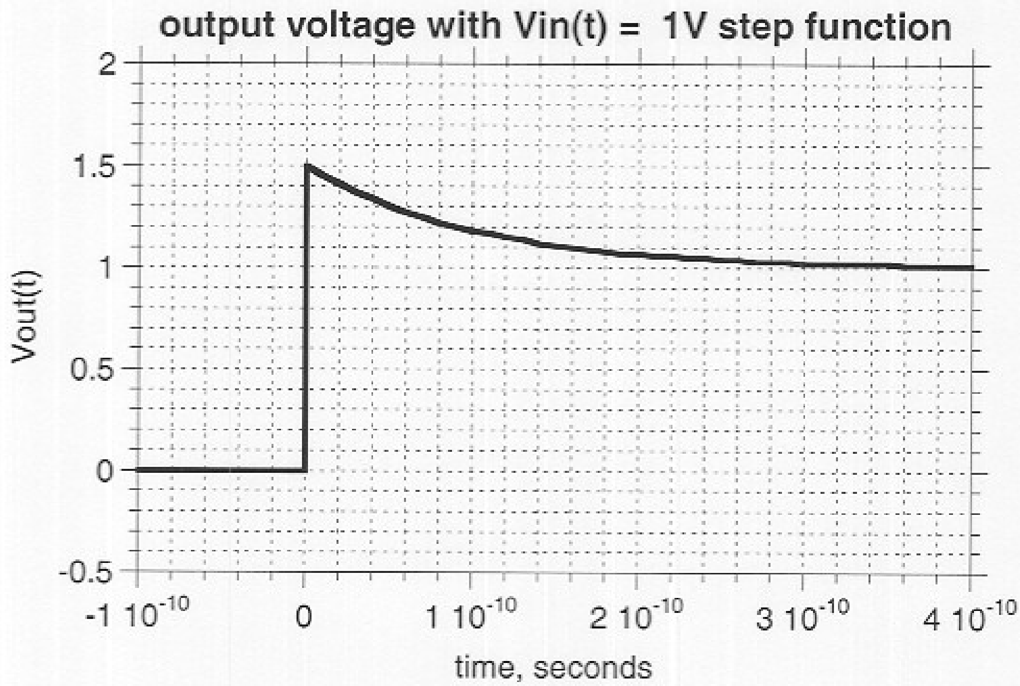
draw closed loop gain on this bode plot



Problem 5: 15 points
transfer functions

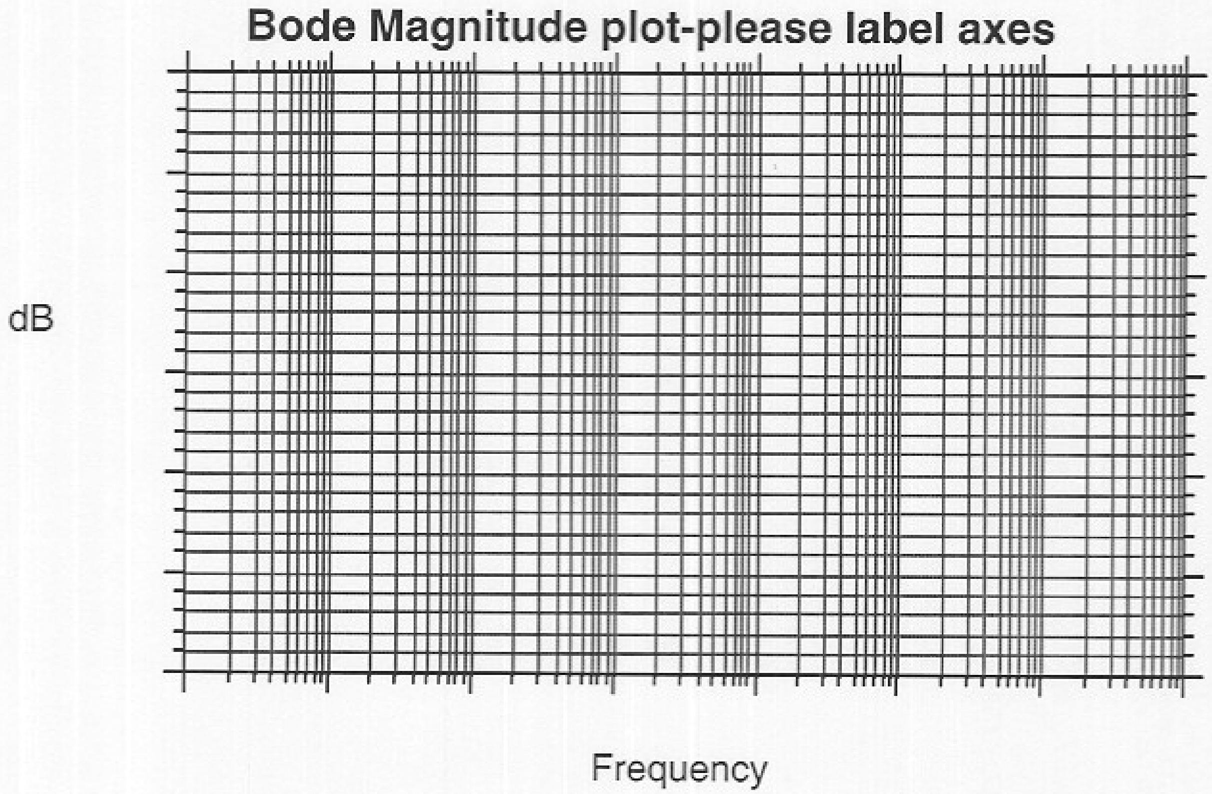
Part a. 7 points

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



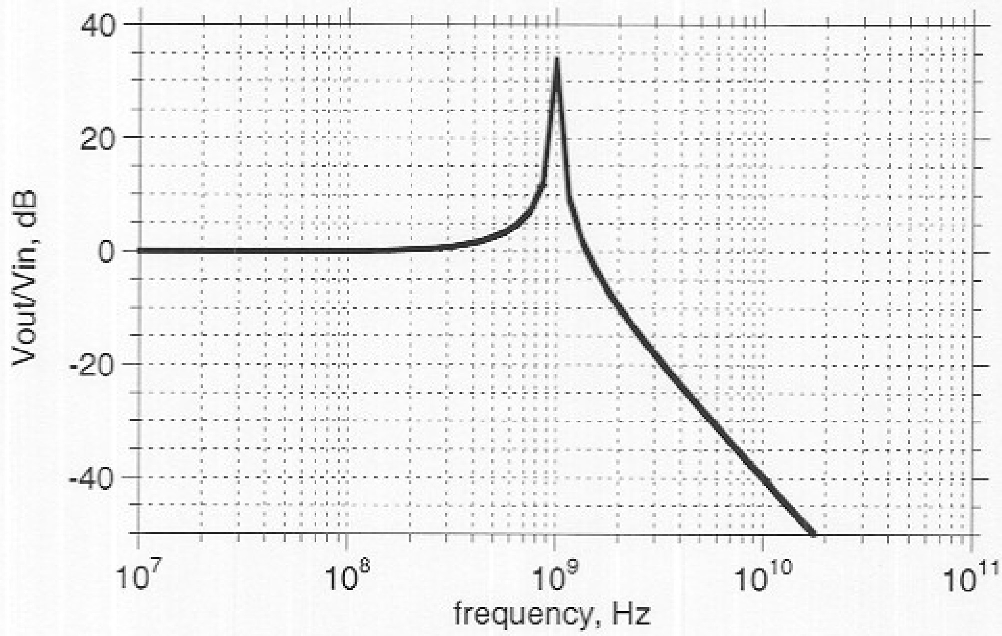
identify all pole and zero frequencies in the transfer function

Draw a Bode Plot (Straight-line asymptotes) of the circuit transfer function Vout/Vgen, labeling all pole and zero frequencies and labeling the slopes of all asymptotes.



Part b, 8 points

Another transistor circuit has a frequency response as shown.



Identify the frequency of all significant poles in the transfer function.

___________ Hz, ____________Hz, (etc)

If the poles are complex, please give the dampling factor __________________

Draw the output voltage given that the input is a 1-V step function. Clearly label and dimension the axes, and show and lable clearly all key features of the waveform.