# 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.

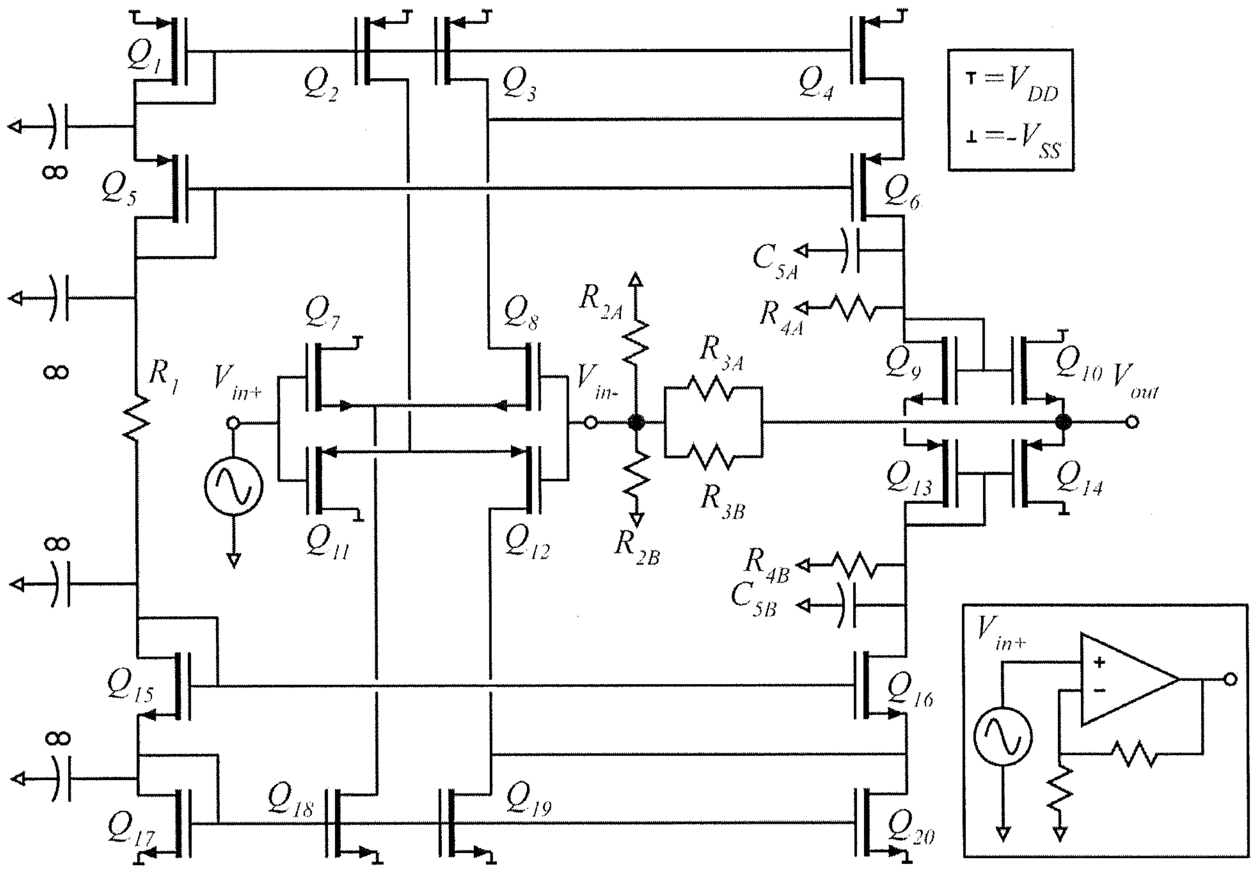
| Time function | LaPlace Transform |
|---|---|
| $\delta(t)$ | 1 |
| U(t) | 1/s |
| $e^{-\alpha t} \cdot U(t)$ | $\frac{1}{s+\alpha}$ or $\frac{1/\alpha}{1+s/\alpha}$ |
| $e^{-\alpha t}\cos(\omega_d t)\cdot U(t)$ | $\frac{s+\alpha}{(s+\alpha)^2+\omega_d^2}$ |
| $e^{-\alpha t}\sin(\omega_d t)\cdot U(t)$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

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 $L_g = 45$nm

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

All FETs have $\lambda$=0 V$^{-1}$, all have $W_g$=1 micrometers,

***except Q2 and Q18, which have $\lambda$=0 V$^{-1}$, and $W_g$=2 micrometers,***

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

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

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

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

The supplies are +1.5V and -1.5V.

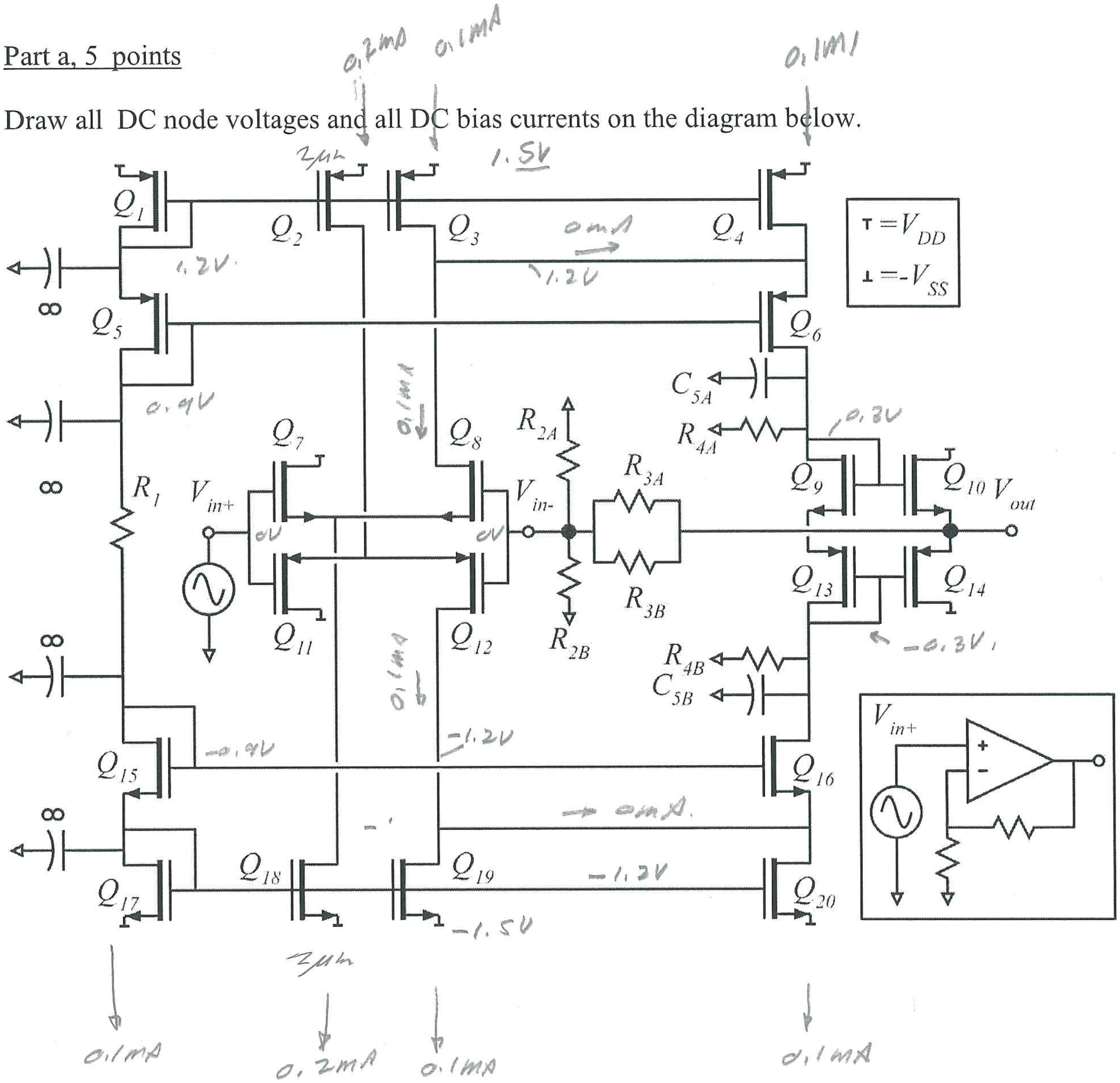


a

All FET: Wg = 1μm except Q2, Q18.

Part a, 5 points

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




All FET except Q2, Q18 $I_D = 1mS(V_{gs} - 0.2V) = 0.1mA$ 2

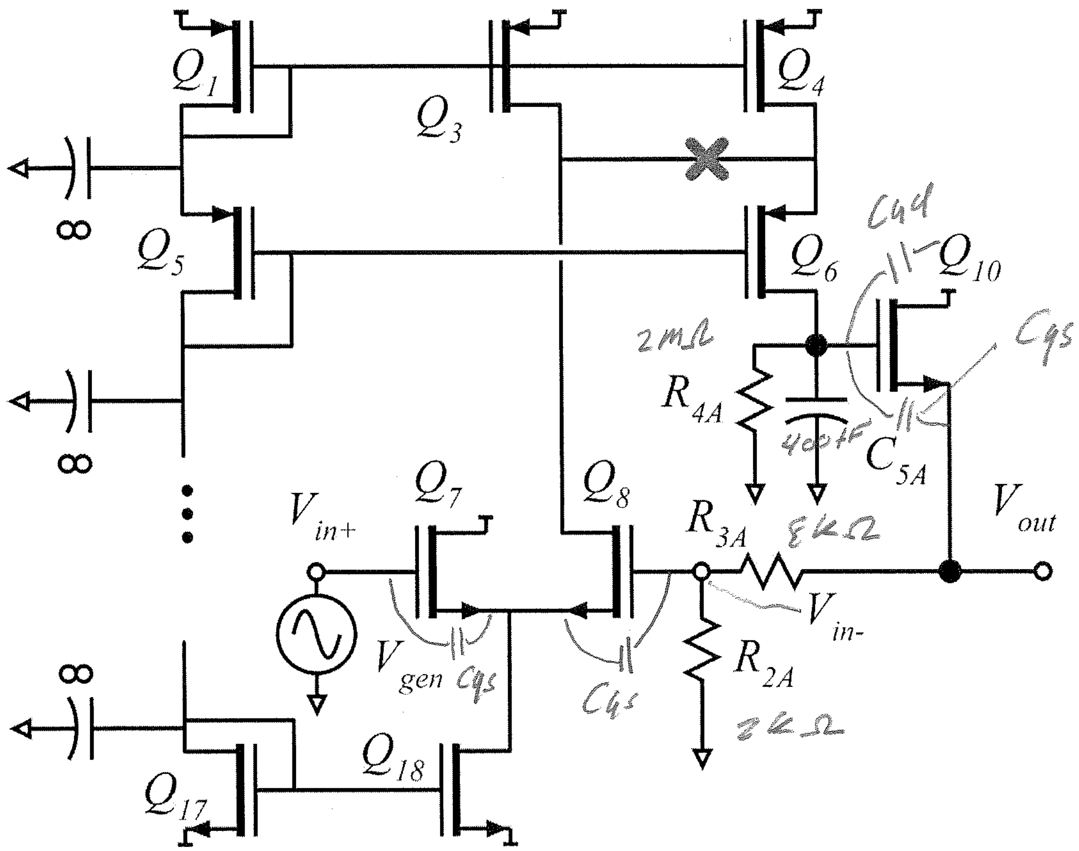
$\Rightarrow V_{gs} = 0.3V$ 1

Q2, Q18: same $V_{gs}$, but $W_g = 2\mu m \rightarrow I_d = 0.2mA$.

2.

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.

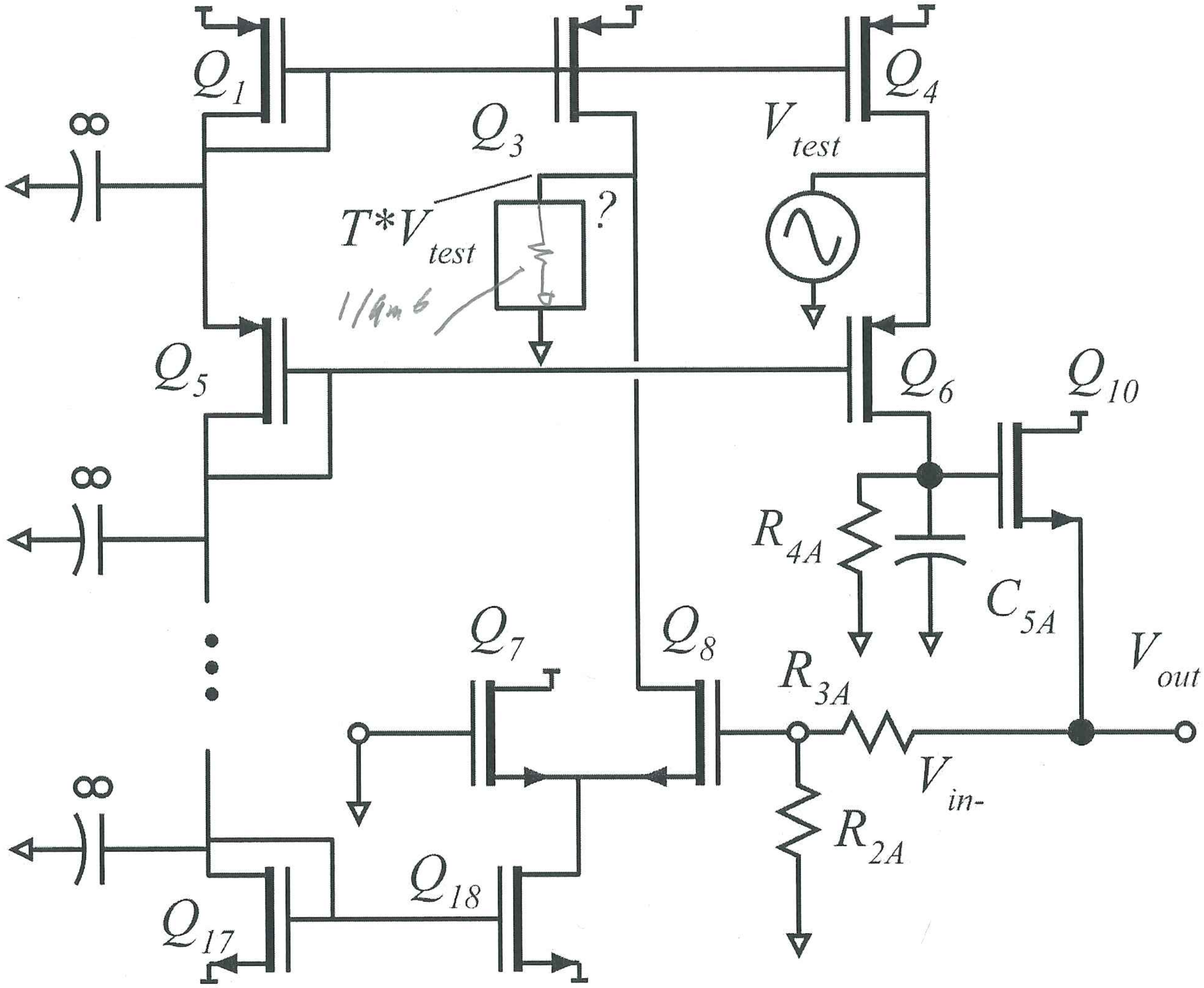
$C_{gs} = 33.6\ fF/\mu m^2\ W_g L_g + 0.5\ fF/\mu m \cdot W_g$

$= 1.51\ fF + 0.5\ fF \cong 2.0\ fF$

$C_{gd} = 0.5\ fF/\mu m \cdot W_g = 0.5\ fF$

$g_m = 1mS$ for all FETs (except Q18)

$g_{ds} = 0mS$ for all FETs



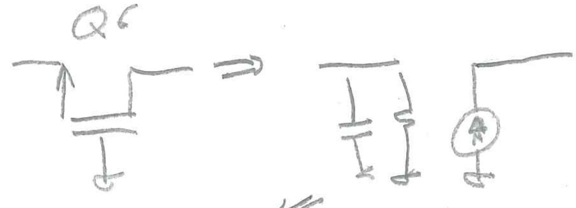

***Indicate on the drawing above what circuit element must be placed in the box labeled with a "?", and give the value of this element.***

3

resistor is $1/g_{m6} = r_{i6} = 1k\Omega$

[note: cut works only because we have set $C_{gs6} = 0$.

otherwise, cut loop as so:

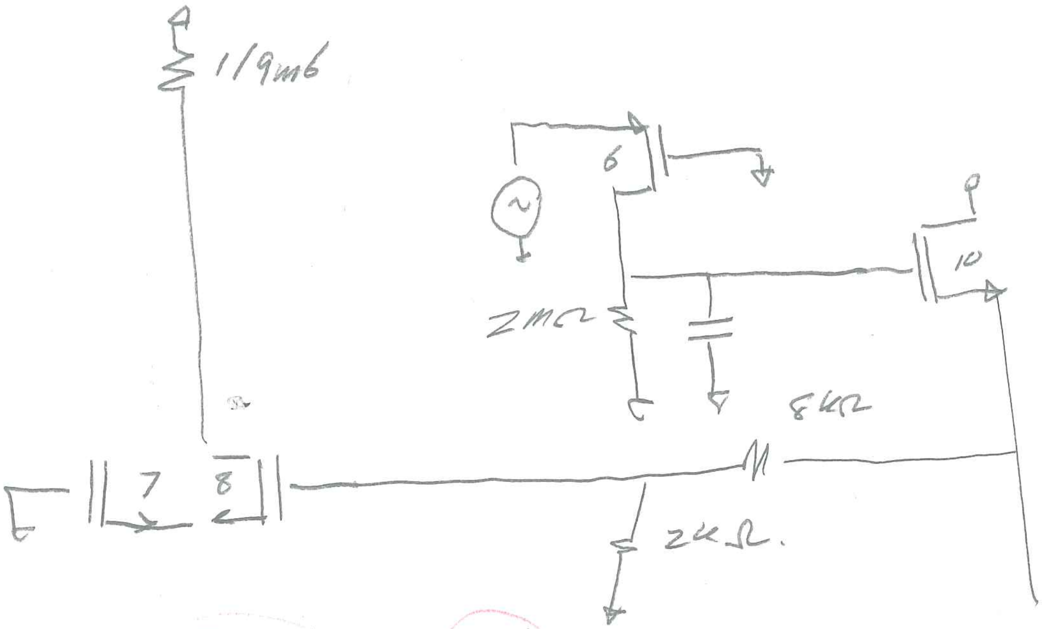



add RC loading at indicated point.

Part c, 10 points

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

$T_{DC}$= 182 2.




2 2 1 2. 1

$$T = 2M\Omega \cdot g_{m6} \cdot A_{v10} \cdot \frac{2k\Omega}{10k\Omega} \cdot \frac{g_{m8}}{2} \cdot \left(\frac{1}{g_{m6}}\right)$$

$$= \frac{g_{m8}}{2} \cdot 2M\Omega \cdot 0.2 \cdot A_{v10}$$

$$A_{v10} \rightarrow \frac{10k\Omega}{10k\Omega + 1/g_{m10}} = \frac{10}{11}$$

$$= \frac{1mS}{2} \cdot 2M\Omega \cdot 0.2 \cdot \frac{10}{11}$$

$$= 1000 \cdot 0.2 \cdot \frac{10}{11} = 200 \cdot \underbrace{\frac{10}{11}}_{\rightarrow 0.909\ldots} = 182$$

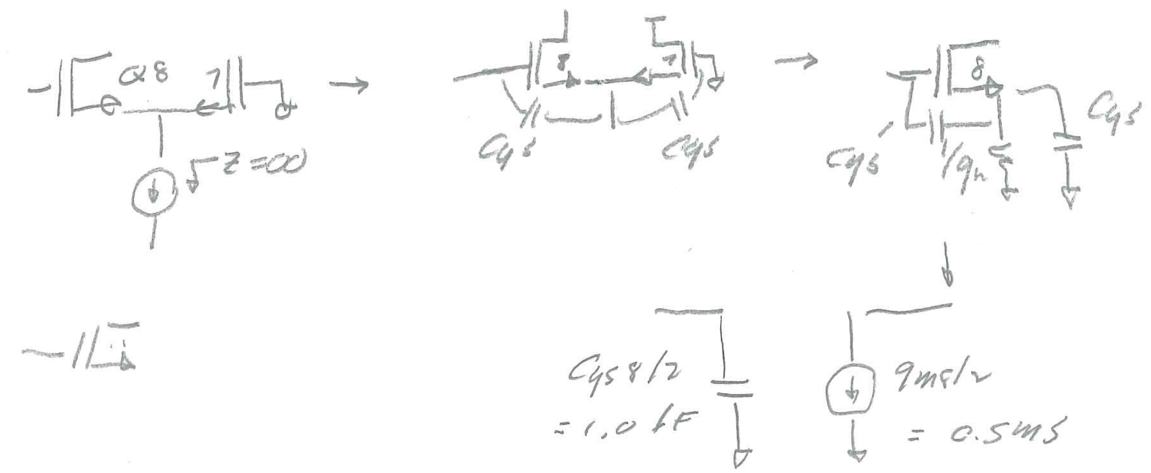
Part d, 15 points

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.

| | | |
|---|---|---|
| $C_1 = C_{5A} + C_{gd10}$ = 400 fF | $C_2 = C_{gs8}$: $\tilde{C}_2$ = 1 fF | $C_3 = C_{gs10}$ = 2 fF |
| $R_{11}^0 =$ 2 MΩ | $R_{22}^0 =$ 1.636 kΩ | $R_{33}^0 =$ 183 kΩ |
| $R_{22}^1 =$ 1.636 kΩ | $R_{33}^1 =$ 909 Ω | $R_{33}^2 =$ 223 kΩ |
| $f_{p1} =$ 200 kHz | $f_{p2} =$ 46 GHz. | |

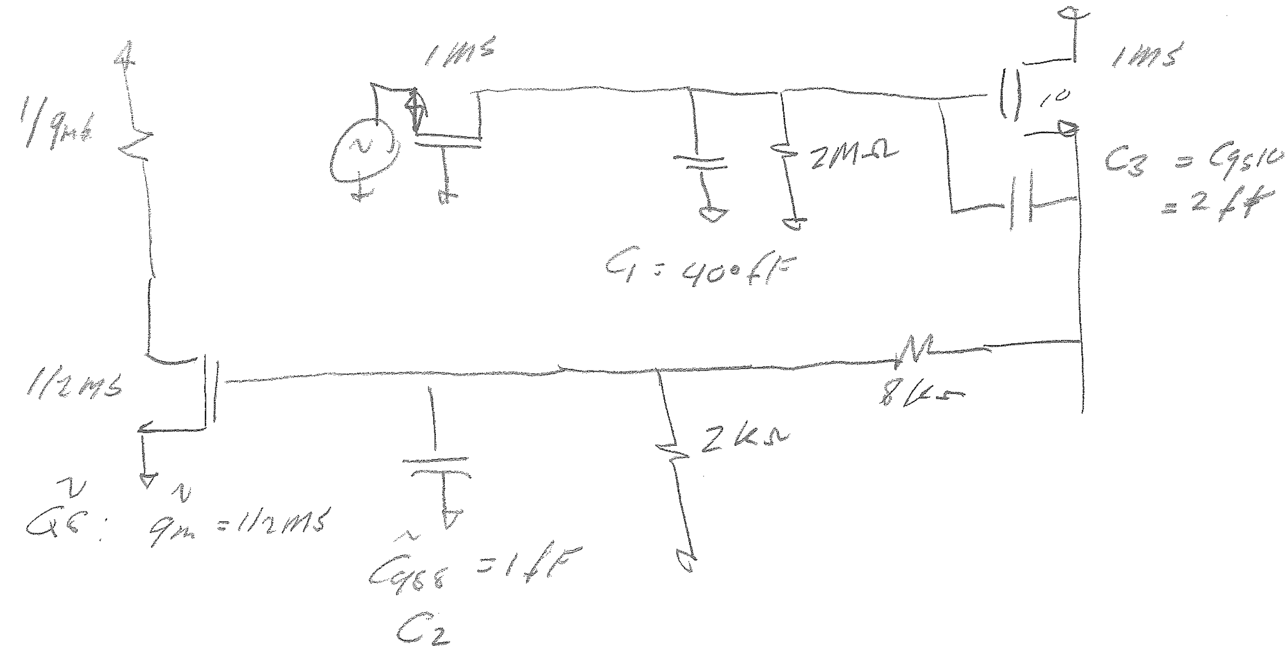
Q7–Q8:




$C_{gs}$ = 33.6 fF/μm² · $W_g L_g$ + 0.5 fF/μm · $W_g$ = 2.0 fF

$C_{gd}$ = 0.5 fF/μm · $W_g$ = 0.5 fF

$C_1 = C_{5A} + C_{gd10}$ = 400 fF + 1 fF = 401 fF ≅ 400 fF




$R_{11}^{\circ} = 2M\Omega$ by inspection

$R_{22}^{\circ} = 2k\Omega \,||\, (8k\Omega + 1/g_{m10}) = 2k\Omega \,||\, 9k\Omega = 1.636\,k\Omega$

$\underline{R_{33}^{\circ}:}$ recall $A_{v10} = \dfrac{10k\Omega}{10k\Omega + 1/g_{m10}} = \dfrac{10}{11}$

so $(1 - A_{v10}) = \dfrac{1}{11}$

$R_{33}^{\circ} \doteq 2M\Omega\,(1 - A_{v11}) + \dfrac{1}{g_{m10}} \,||\, (10k\Omega)$

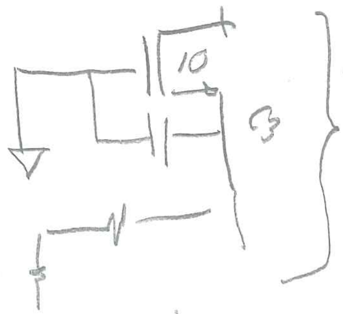
$= \dfrac{2M\Omega}{11} + 1k\Omega \,||\, 10k\Omega = 182k\Omega + 909\Omega$

$= 183k\Omega$

1 $R_{22}^1$ / : shorting $C_1$ does not change the Z seen by $C_2$.

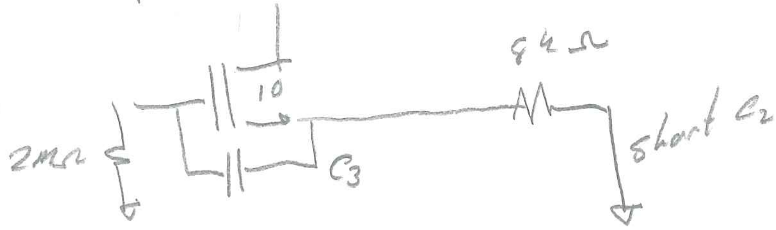
$R_{22}^1 = R_{22}^0 = 1.636\,k\Omega$

2 $R_{33}^1$ /




$R_{331} = \frac{1}{g_{m10}} \,||\, (10\,k\Omega)$
$= 909\,\Omega$

2 $R_{33}^2$ /




$A_{v10}$ has now changed! $A_{v10} = \frac{8\,k\Omega}{8\,k\Omega + 1/g_{m10}} = \frac{8}{9}$

2 $R_{33}^2 = 2M\Omega\left(1 - \frac{8}{9}\right) + \frac{1}{g_m} \,||\, 8\,k\Omega = \frac{2M\Omega}{9} + 884\,\Omega$

$= 222\,k\Omega + 888\,\Omega \cong 223\,k\Omega.$

(slightly larger than $R_{33}^0$; not much)

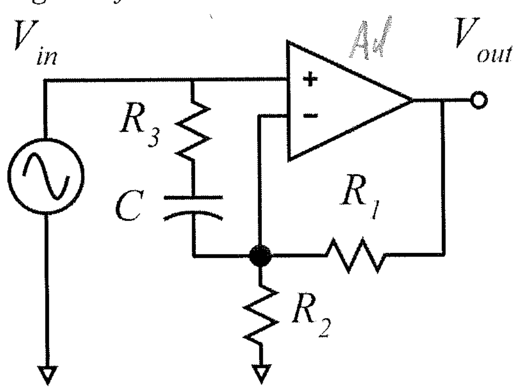
1 $a_1 = R_{11}^0 C_1 + R_{22}^0 C_2 + R_{33}^0 C_3 = 2M\Omega \cdot 400\,fF + 1.64\,k\Omega \cdot 1\,fF + 183\,k\Omega \cdot 2\,fF$
$= 800\,ns + 1.64\,ps + 363\,ps = 800.4\,ns$

2 $a_2 = R_{11}^0 C_1 C_2 R_{22}^1 + R_{11}^0 C_1 C_3 R_{33}^1 + R_{22}^0 C_2 C_3 R_{33}^2$
$= (800\,ns)\,1\,fF \cdot 1.636\,k\Omega + 800\,ns \cdot 2\,fF \cdot 909\,\Omega +$
$1.64\,ps \cdot 2\,fF \cdot 223\,k\Omega$
$= 1.31(10^{-18})\,sec^2 + 1.45(10^{-18})\,sec^2 + 7.31 \cdot 10^{-22}\,sec^2$
$= 2.76(10^{-18})\,sec^2$

1 SPA: $f_{p1} = \frac{0.159}{a_1} = 200\,kHz$ $\qquad f_{p2} = \frac{0.159}{a_2/a_1} = 46\,GHz$

SPA checks

**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 $A_\infty$ and plot the closed loop gain ($A_{CL}$=Vout/Vgen), and determine the following:

Loop bandwidth= 2.5 MHz , phase margin = 37.9°

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

[note: $A_{CL} = A_\infty \cdot \frac{T}{1+T}$ not $\frac{1}{\beta} \frac{A\beta}{1+A\beta}$ because $R_3$, C make $Z_{in}$ small

[$A_\infty = \frac{R_1 + R_2}{R_2} = 10$

In the loop transmission, C introduces a pole-zero pair.
@ $f \to DC$, $T = Ad \cdot \frac{R_2}{R_1+R_2} = Ad/10$.
@ $f \to \infty$ $T = Ad \frac{R_2 \| R_3}{R_1 + R_2 \| R_3} = Ad \cdot \frac{99\Omega}{9k\Omega + 99\Omega} = \frac{Ad}{101} \cong \frac{Ad}{100}$

so, $R_3$ & C give you a pole-zero pair with $f_z = (10) f_p$.

[what is $f_{pole}$ for feedback loop?]

use MOTC

Impedance seen by C is

$$R_3 + R_2 \| R_1 = 111\Omega + 1k\Omega \| 9k\Omega$$

$$= 111\Omega + 900 = 201\Omega \cong 200\Omega.$$

$$C_1 R_{11}^0 = 1.57nf \cdot 200\Omega = 0.314\mu s$$

$$f_p = \frac{0.159}{C_1 R_{11}^0} = 506\,kHz \cong 500\,kHz$$

$$f_z = 10 \cdot f_p = 5MHz.$$

4 pts

$$\Rightarrow T = \frac{10^7}{1+j\,f/10Hz} \frac{1+j\,f/5MHz}{1+j\,f/500kHz)} \frac{R_2}{R_1+R_2}$$

$$= \frac{10^6}{1+j f/10Hz} \frac{1+j\,f/5MHz}{1+j\,f/500kHz}.$$

From plot, $f_{loop} \cong 2.5MHz$

1 pt

$$\angle T @ f_{loop} \cong -90^\circ - \arctan(2.5MHz/500kHz) + \arctan(2.5MHz / 5MHz)$$

$$= -90^\circ - 78.7^\circ + 26.6^\circ = -142^\circ$$

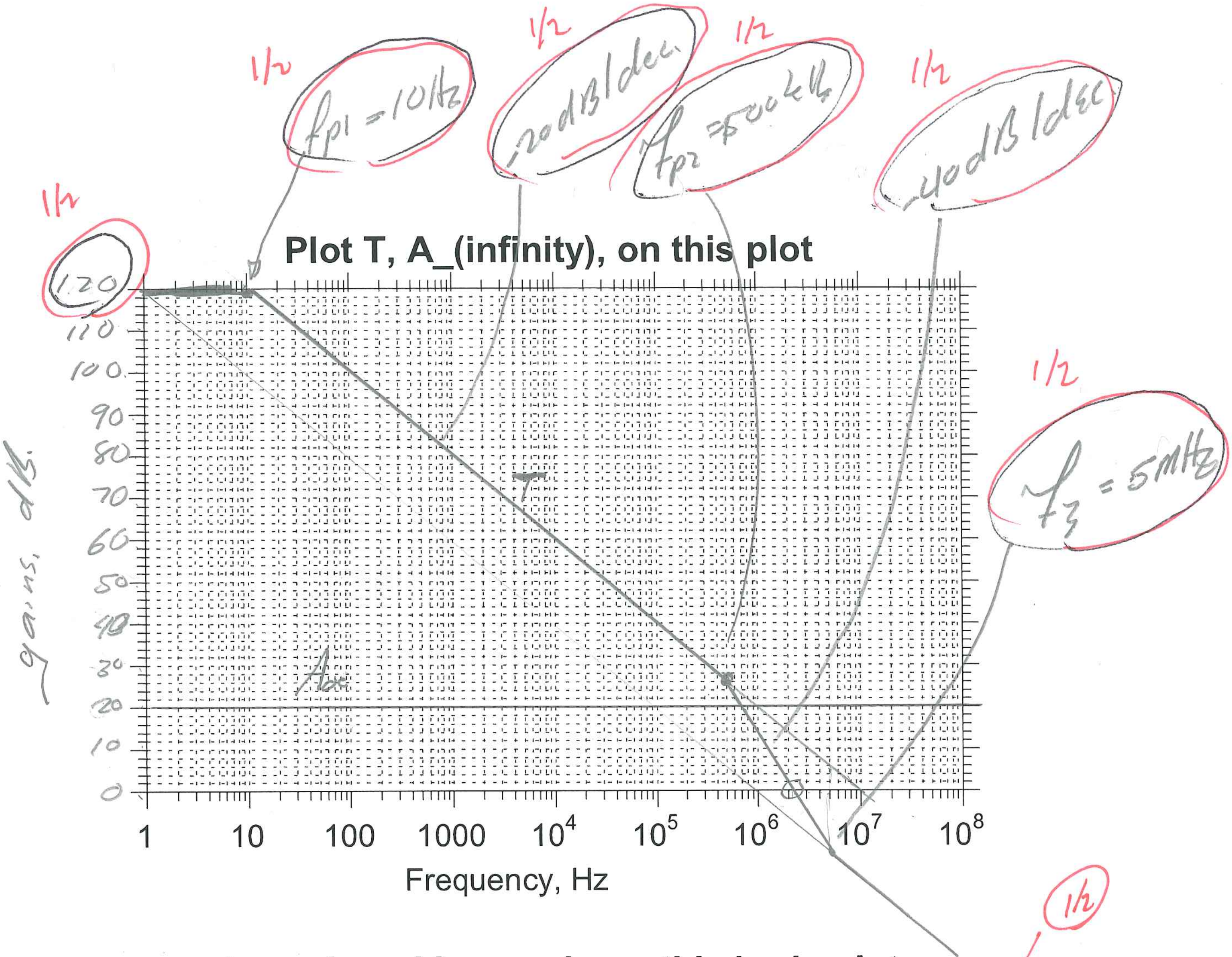
$$PM = 37.9^\circ$$

12 A

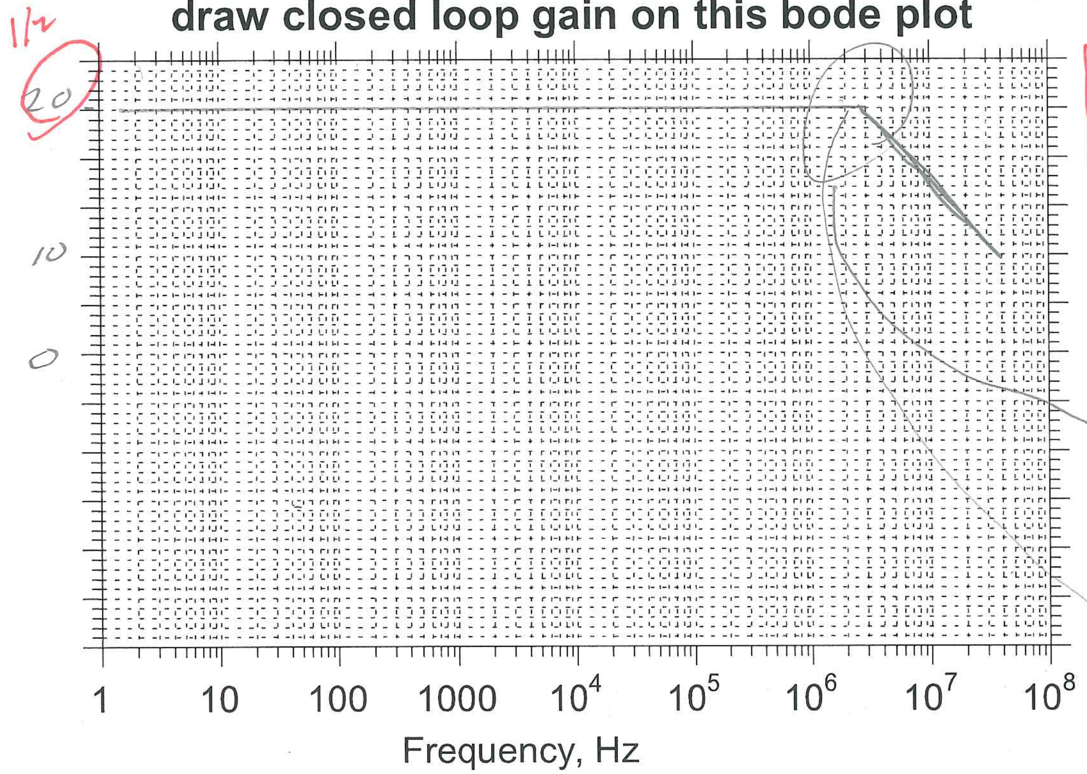


a

## Plot T, A_(infinity), on this plot




## draw closed loop gain on this bode plot




1/2

$A_{CL} = A_{\infty} \frac{T}{1+T}$

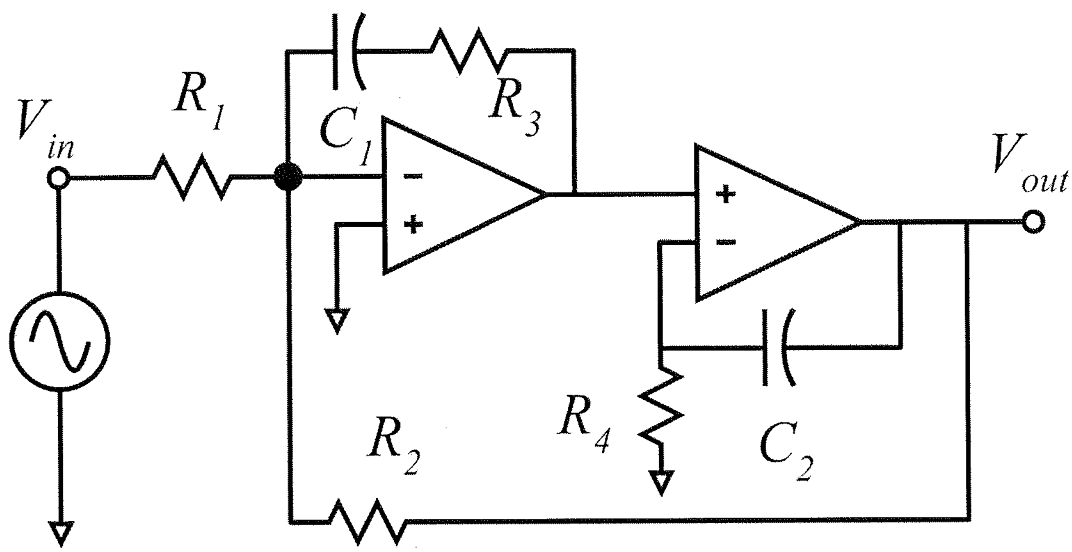
$\cong \begin{cases} A_{\infty} & \text{if } T \ll 1 \\ \frac{A_{\infty}}{T} & \text{if } T \ll 1 \end{cases}$

only estimate of BW needed.

$f_{3dB} \cong 2.5MHz$

1/2

**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 $A_\infty$ and plot the closed loop gain ($A_{CL}$=Vout/Vgen), and determine the following:

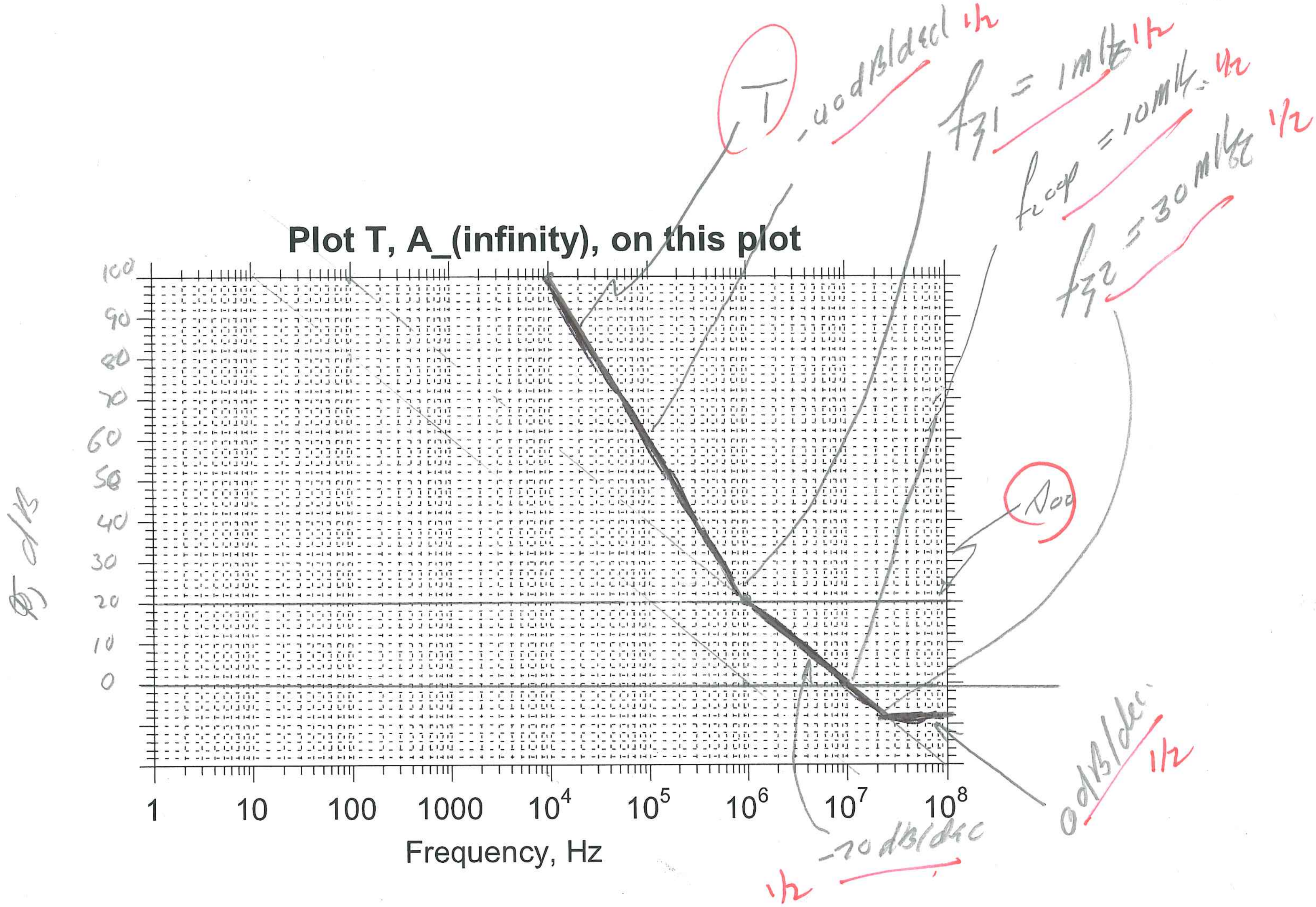
Loop bandwidth= 10 MHz , phase margin = 103°

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

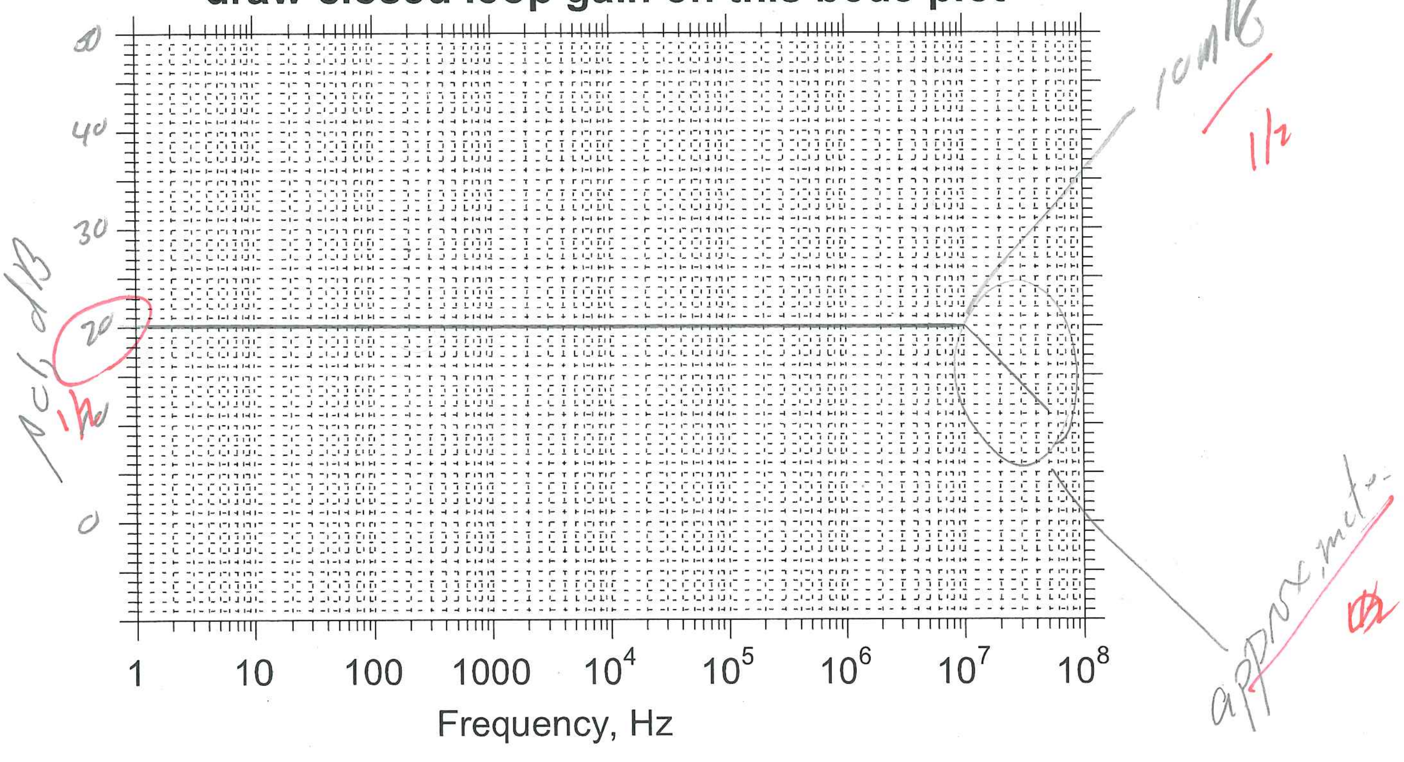


a

## Plot T, A_(infinity), on this plot




## draw closed loop gain on this bode plot



HENCE: $A_\infty = \frac{-R_2}{R_1} = -10.$

$$T = \frac{R_3 + 1/sC_1}{R_2} \cdot \left(1 + \frac{1}{sC_2R_4}\right)$$

$$= \frac{1}{sC_1R_2}(1+sC_1R_3)\left[\frac{1}{sC_2R_4}\right](1+sC_2R_4)$$

$$= \frac{1}{sC_1R_2}\,\frac{1}{sC_2R_4}\,(1+sC_1R_3)(1+sC_2R_4)$$

$$= \frac{1/2\pi C_1R_2}{jf}\,\frac{1/2\pi C_2R_4}{jf}\,(1+jf/(1/2\pi C_1R_3)) \cdot (1+jf/(1/2\pi C_2R_4))$$

standard form

4

$$T = \frac{10\,\mathrm{mHz}}{jf}\,\frac{1\,\mathrm{mHz}}{jf}\left(1+\frac{jf}{30\,\mathrm{mHz}}\right)(1+jf/1\,\mathrm{mHz})$$

$$T = \frac{10\,\mathrm{mHz}}{jf}\left(1+\frac{jf}{30\,\mathrm{MHz}}\right)\cdot\left[1+\frac{1\,\mathrm{mHz}}{jf}\right]$$ ← easier to plot from this.

2

$pm = 180 - 180$ (2 poles @ DC) $+ \arctan(10\,\mathrm{mHz}/1\,\mathrm{mHz}) + \arctan(10\,\mathrm{mHz}/30\,\mathrm{mHz})$

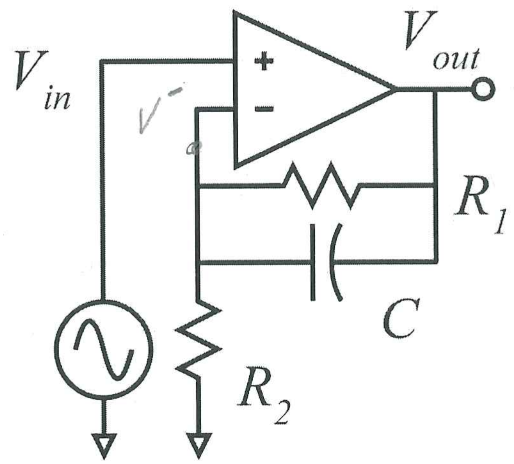
$= 84.3^\circ + 18.4^\circ = 103.2^\circ$



a

**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= 10 MHz . Amplifier 3dB bandwidth= 200 kHz

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

we can use $A_{CL} = 1/\beta \dfrac{T}{1+T}$

$\beta = \dfrac{V^-}{V_{out}} = ?$ use nodal analysis:

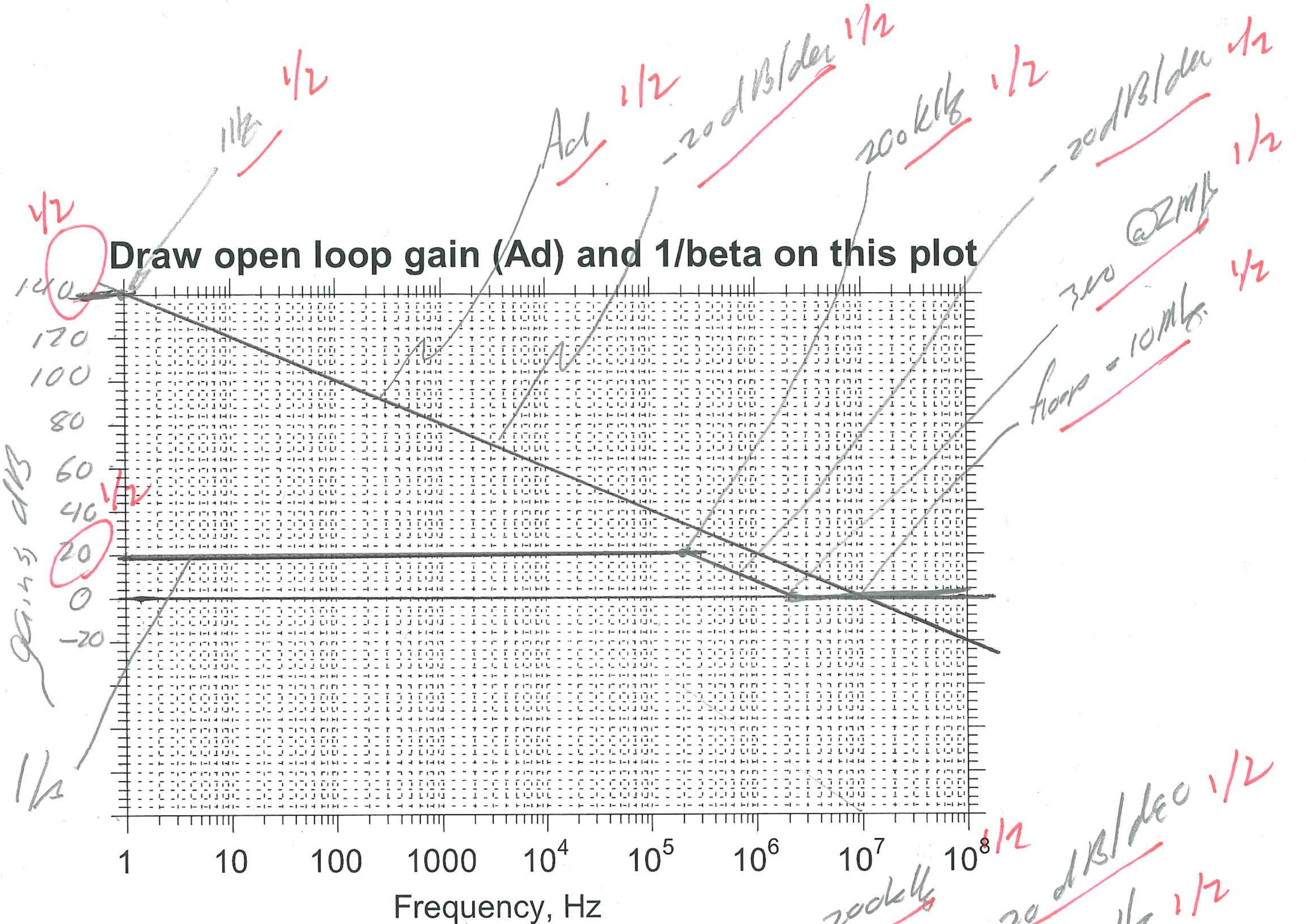
$$V^-(G_1 + G_2 + sC) = V_{out}(G_1 + sC)$$

$$V^-/V_{out} = \frac{G_1 + sC}{G_1 + G_2 + sC} = \frac{R_2}{R_1 + R_2} \frac{1 + sC R_1}{1 + sC(R_1 // R_2)}$$

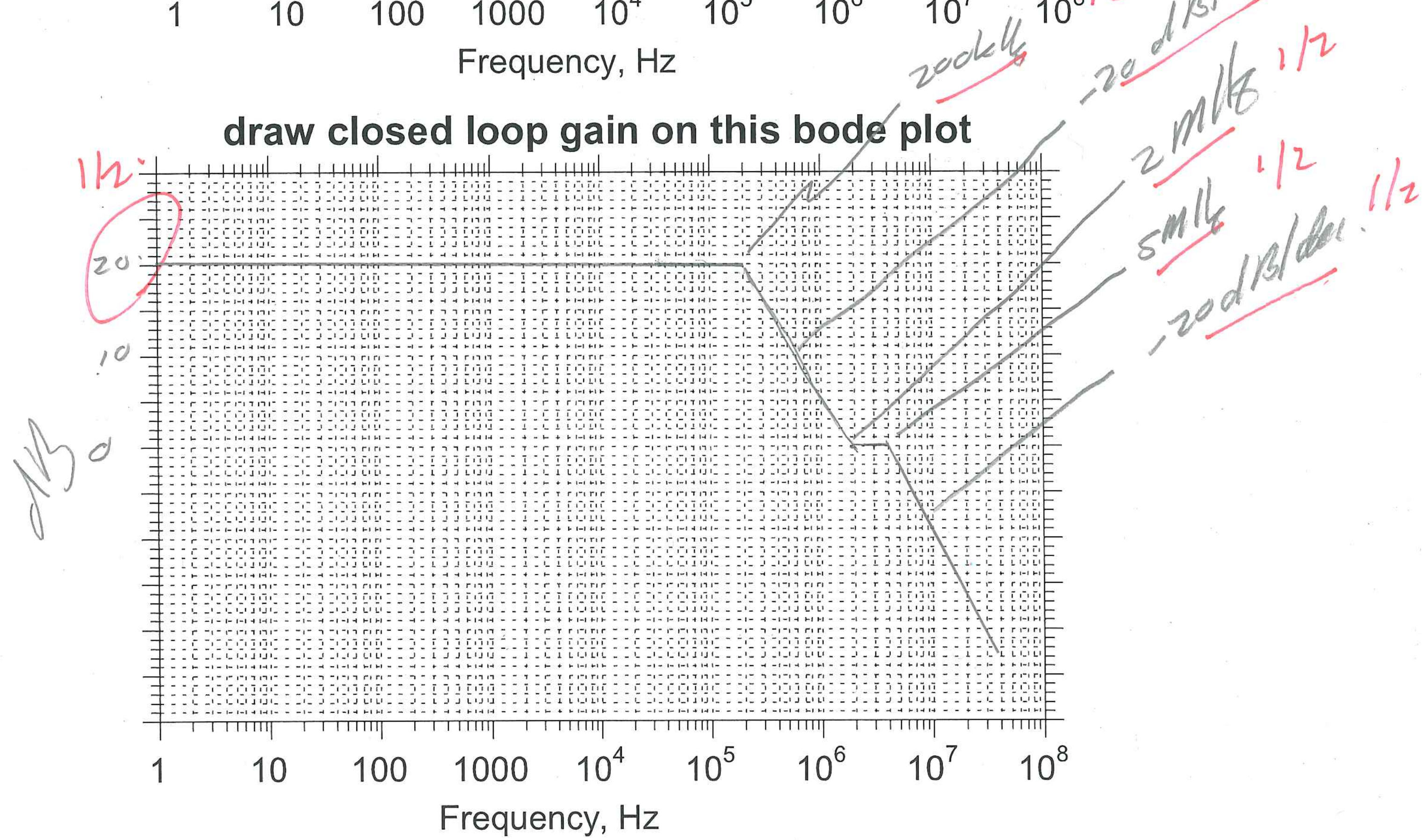
2.5

$$\frac{1}{\beta} = \frac{R_1 + R_2}{R_2} \frac{1 + sC(R_1 // R_2)}{1 + sC R_1} = 10 \cdot \frac{1 + j f/2\,\text{MHz}}{1 + j f/200\,\text{kHz}}$$

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

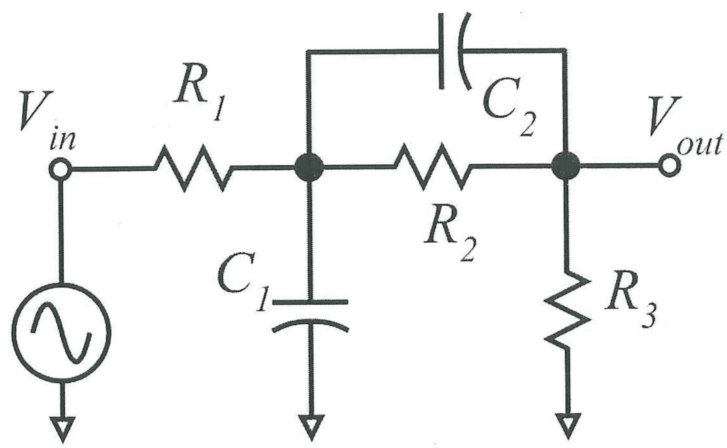



## draw closed loop gain on this bode plot



**Problem 5: 12 points**
*method of time constants analysis*

part a, 10 points




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

$\left.\frac{V_{out}}{V_{gen}}\right|_{DC} = \frac{R_3}{R_1+R_2+R_3}$

$a_1 = C_1 \cdot [R_1 \| (R_2+R_3)] + C_2[R_2 \| (R_1+R_3)]$

$a_2 =$ See page 22.

$b_1 = R_2 C_2$

**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 ?**

3

if $R_2 \| 1/sC = \infty \Rightarrow V_{out} = 0$

$G_2 + s_{zero} C_2 = 0 \Rightarrow s_{zero} = -\frac{1}{R_2 C_2}$ LHP zero.

so $b_1 = +R_2 C_2$ (!) easy!

For poles, use MOTC.

1 $R_{11}^{0} = R_1 \| (R_2 + R_3) =$

1 $R_{22}^{0} = R_2 \| (R_1 + R_3)$

2 $R_{22}^{1} = R_2 \| R_3$

1 $a_1 = C_1 [R_1 \| (R_2 + R_3)] + C_2 [R_2 \| (R_1 + R_3)]$

$\cancel{a_2} =$

2 $a_2 = C_1 C_2 R_{11}^{0} R_{22}^{1} = C_1 C_2 [R_1 \| (R_2 + R_3)][R_2 \| R_3]$



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.

$\left.\frac{V_{out}}{V_{gen}}\right|_{DC} =$ 1/2 $\qquad a_1 =$ 3.5ms $\qquad a_2 =$ $1.99 \cdot 10^{-6}\ sec^2$

note: $1k\Omega \cdot \mu F = 1ms$

1/3

$$a_1 = C_1[R_1 \| (R_2+R_3)] + C_2[R_2 \| (R_1+R_3)]$$
$$= 1ms \cdot [1 \cdot (1 \| (2+3)) + 2 \cdot (2 \| (1+3))]$$
$$= 1ms[0.83 + 2(1.33)] = 3.49ms$$

1/3

$$\left.\frac{V_c}{V_{gen}}\right|_{DC} = \frac{3k\Omega}{3k\Omega + 1k\Omega + 2k\Omega} = 1/2$$

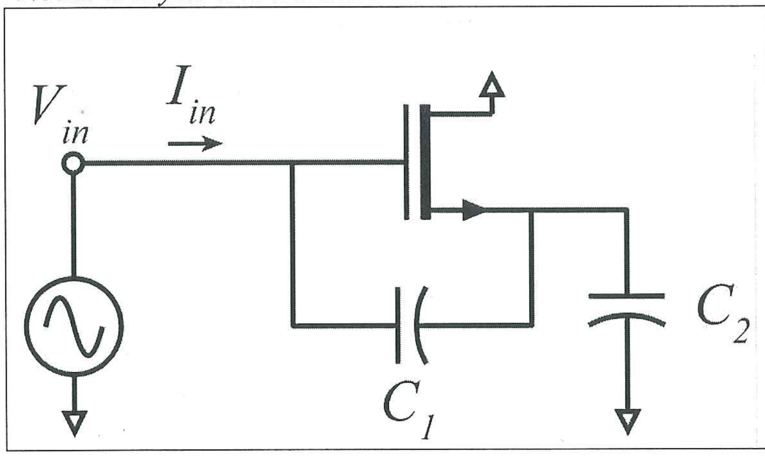
1/3.

$$a_2 = 1ms \cdot 1ms \cdot [1 \cdot 2][1 \| (2+3)] \cdot [2 \| 3]$$
$$= 1ms \cdot 1ms \cdot 2 \cdot 0.83 \cdot 1.2$$
$$= 1.99(ms)^2 = 1.99 \cdot 10^{-6}\ sec^2 = (1.41ms)^2$$



a

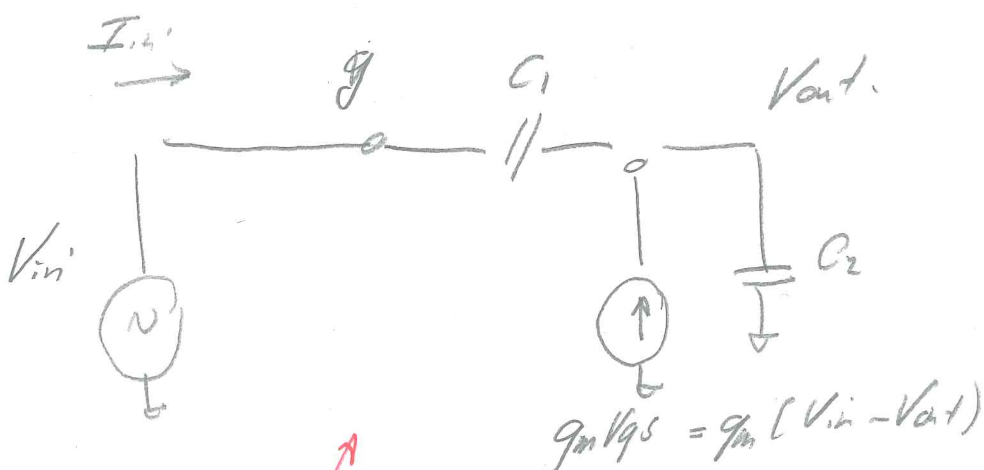
**Problem 6: 23 points**
*Nodal analysis and transistor circuit models*




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***




hard to give partial credit
value of generator; $g_m V_{gs}$, is only correct if $V_{gs}$ is somehow indicated on diagram as $V_g$ and $V_s$, or as $V_{in} - V_{out}$

Part b, 10 points

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

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

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

$Y_x =$ $gm$ , $\tau =$ $\sqrt{C_1 C_2}\,/\,gm$ , $n =$ $2$ ,
$a_1 =$ $[C_1 + C_2]/gm$ , $a_2 =$ N/A $b_1 =$ N/A ,
$b_2 =$ N/A.

[ KEY: first find Vout, then find Iin.

[ $\Sigma I$ @ Vout = 0.

3 [ $-gm(V_{in} - V_{out}) + (V_{out} - V_{in})\,sC_1 + V_{out}\,sC_2 = 0$.

$V_{out}(gm + sC_1 + sC_2) = V_{in}(gm + sC_1)$

1 [ $\dfrac{V_{out}}{V_{in}} = \dfrac{gm + sC_1}{gm + sC_1 + sC_2} = \dfrac{1 + sC_1/gm}{1 + s(C_1 + C_2)/gm}$

Now find Iin

4 [ $Y_{in} = \dfrac{I_{in}}{V_{in}} = \dfrac{1}{V_{in}} \cdot (V_{in} - V_{out})\,sC_1 = \left[1 - \dfrac{V_{out}}{V_{in}}\right] \cdot sC_1$

$Y_{in} = sC_1 \left[\dfrac{sC_2/gm}{1 + s(C_1 + C_2)/gm}\right]$ Now, put in standard form:

1 [ $Y_{in} = gm \cdot \dfrac{sC_1}{gm} \cdot \dfrac{sC_2}{gm} \; \dfrac{1}{1 + s(C_1 + C_2)/gm}$

1 [ $= gm\left(s\,\dfrac{1}{gm}\sqrt{C_1 C_2}\right)^2 \dfrac{1}{1 + s(C_1 + C_2)/gm}$



a

Part c, 3 points

Now set: $g_m = 1\text{mS}$, $C_1 = 1$ 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.

$Y_{in}(10MHz) =$ $-7.8\mu S + j\,1.45\mu S$

$Y_{in} =$

1

$g_m = 1mS$

$\tau = \frac{1}{g_m}\sqrt{C_1 C_2} = 1k\Omega \cdot \sqrt{2}\,pF = \sqrt{2}\,ns$

$a_1 = (C_1 + C_2)/g_m = 3pF \cdot 1k\Omega = 3ns$

1

$$Y_{in} = 1mS\,(j2\pi f \cdot \sqrt{2}\,ns)^2 \frac{1}{1 + j2\pi f \cdot 3ns}$$

note: $j^2 = -1$ (!)

$$= \frac{-1mS \cdot 7.9 \cdot 10^{-3}}{1 + j(0.188)} = \frac{-7.9(10^{-6})S}{1 + j(0.188)}$$

$$= -7.76(10^{-6})S\,(1 - j0.188)$$

1

$$= \underbrace{-7.76 \cdot 10^{-6} S}_{\text{negative input conductance}} + j\,1.45 \cdot 10^{-6} S.$$

this is a classic case — loading a SF with a capacitor can produce negative input conductance.

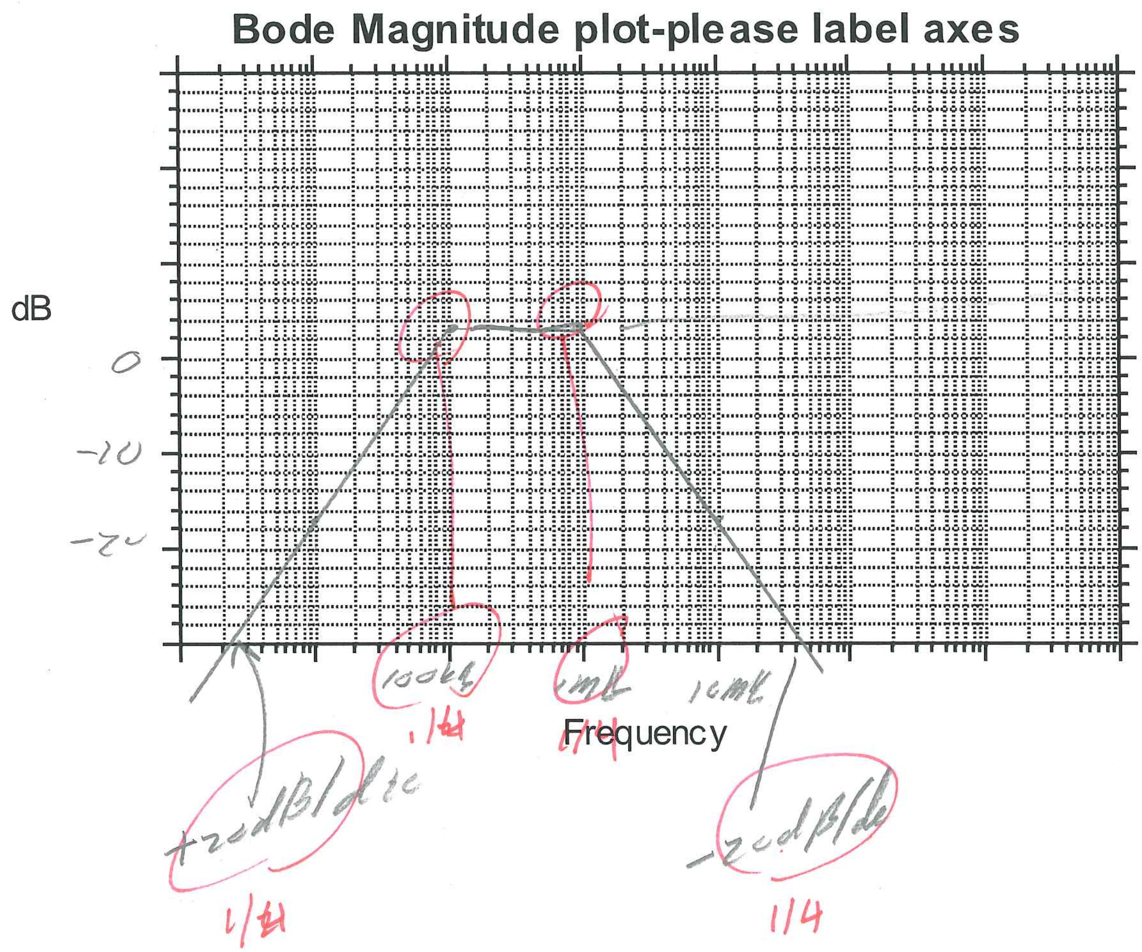


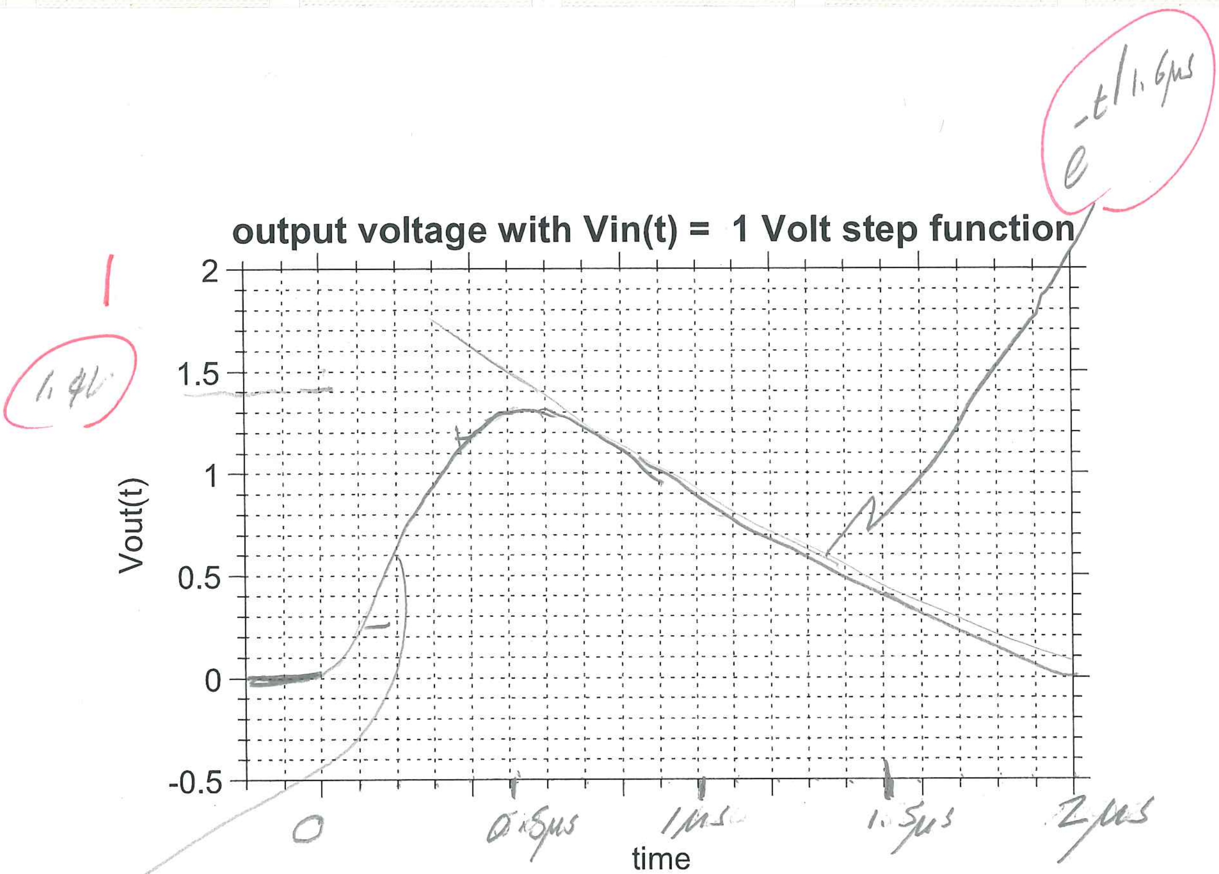
a

**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.






the step-response, approximately, is

$$V_{out}(t) = \sqrt{2} \cdot u(t) \cdot e^{-t/\tau_{Low}} \left(1 - e^{-t/\tau_{High}}\right)$$ 4

where $\tau_{Low} = \frac{1}{2\pi(100kHz)} = 1.6\mu s.$ 1

$$\tau_{High} = \frac{1}{2\pi(1MHz)} = 0.16\mu s$$ 1

$$T_{10-90} = 2.2\tau = 0.35\mu s. = 350ns.$$

rise as $\left(1-e^{-t/0.16\mu s}\right)$ 1



a