Mid-Term Exam, ECE-137B

Tuesday, April 28, 2015

Closed-Book Exam

There are 2 problems on this exam , and you have 75 minutes.

1) show all work. Full credit will not be given for correct answers if supporting work is not shown.

2) please write answers in provided blanks

3) Don't Panic !

4) 137a, 137b crib sheets, and 2 pages personal sheets permitted.

Use any, all reasonable approximations. 5% accuracy is fine if the method is correct.

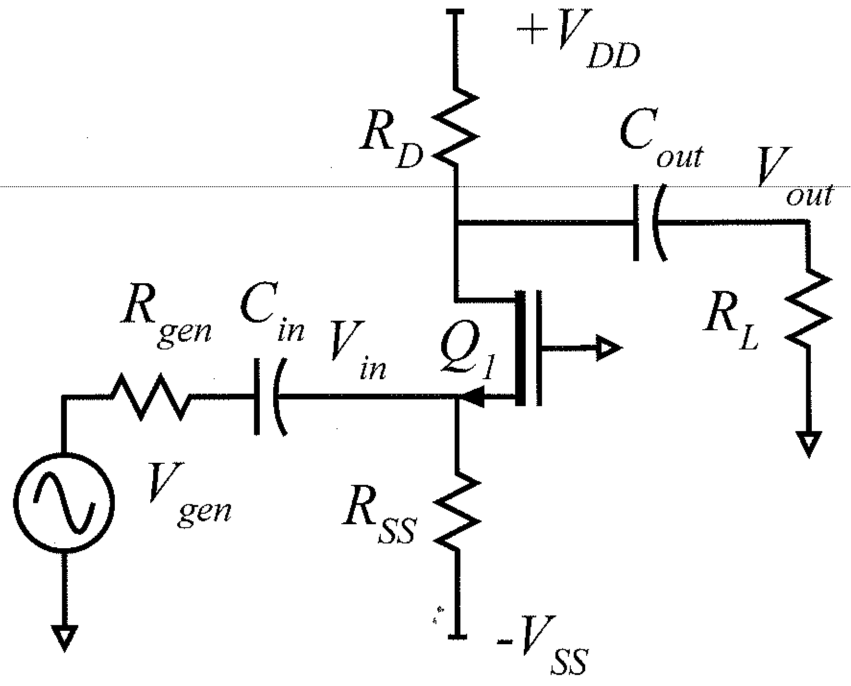
Do not turn over the cover page until requested to do so.

Name: Solution A

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

Problem	Points Received	Points Possible
1a		6
1b		8
1c		8
1d		14
1e		14
1f		10
2a		10
2b		10
2c		10
2d		10
total		100

Problem 1, 60 points



Q1 has 1.0 nm oxide thickness, ε_r=3.8, 22 nm gate length, and a 0.2 V threshold. Mobility is 400 cm^2/(V-s), saturation drift velocity is 1E7 cm/s, $\lambda = 0\ \text{Volts}^{-1}$, $C_{gs} = \varepsilon_r \varepsilon_{ox} L_g W_g / T_{ox} + (0.5\text{fF}/\mu\text{m}) \cdot W_g$ and $C_{gd} = (0.5\text{fF}/\mu\text{m}) \cdot W_g$.

Hints:

$\varepsilon_r \varepsilon_{ox} / T_{ox} = 3.36 \cdot 10^{-2}\ \text{F/m}^2$, $(\mu c_{ox} W_g / 2L_g) = (3.06 \cdot 10^{-2}\ \text{A/V}^2) \cdot (W_g / 1\mu\text{m})$

$(c_{ox} v_{sat} W_g) = (3.36 \cdot 10^{-3}\ \text{A/V}^1) \cdot (W_g / 1\mu\text{m})$, $(v_{sat} L_g / \mu) = 55\text{mV}$.

The power supplies are +2V and -2V. The drain currents of Q1 is 2 mA. V_{gs} of Q1 is 0.30 V. The drain of Q1 is at +1.0V.

R_{gen}=50Ohm. $R_L = 3 \cdot R_D$

$C_{in} = 1\,\text{nF}$, $C_{out} = 2\,\text{nF}$

Part a, 6 points

Find the following:

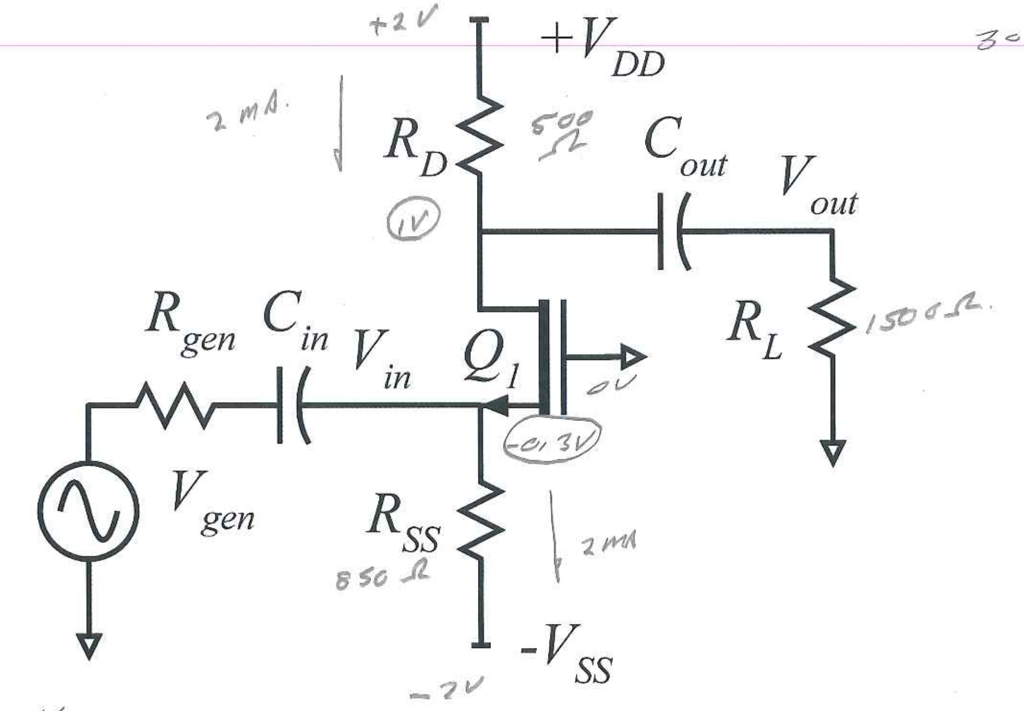
R_{ss} = 850 Ω.　　R_D = 500Ω.

W_g = 8.3μm　　R_L = 1500Ω.

$3.36 \frac{mA}{V} \cdot \frac{W_g}{1\mu m}$

$30.6 \frac{mA}{V^2} \cdot \frac{W_g}{1\mu m}$.

Draw all DC node voltages on the circuit diagram below.



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$V_{th} = 0.2V$, $V_{gs} = 0.5V \geq V_{gs} + \Delta V$

$\rightarrow$ velocity limited.

$\underset{\underset{2\,mA}{\uparrow}}{I_D} = 3.36\frac{mA}{V} \cdot \frac{W_g}{1\mu m} (\underset{\underset{0.3V}{\uparrow}}{V_{gs}} - 0.228V)$

$\Rightarrow W_g = 8.27\mu m.$

$\Rightarrow I_D = 27.8 \frac{mA}{V} \cdot (V_{gs} - 0.228V)$

$R_D = 1V/2mA = 500Ω$

$R_{SS} = \frac{1.7V}{2mA} = 850Ω$

$R_L = 3 \cdot R_D = 1500Ω$

Part b, 8 points

small-signal parameters

Find the following

C_{gs} = 66.1 fF C_{gd} = 4.15 fF

g_m = 27.8 mS f_τ = ~~63 GHz~~ 305 GHz

$$C_{gs} = 3.36\cdot10^{-2}\,\frac{fF}{nm^2}\cdot \underset{\underset{22\,nm}{\uparrow}}{L_g}\cdot \underset{\underset{8.3\,\mu m}{\uparrow}}{W_g} + 0.5\,fF/\mu m\cdot \underset{\underset{8.3\,\mu m}{\uparrow}}{W_g}$$

$$= 6.19\,fF + 4.15\,fF$$

$$\approx \cancel{66.1\,fF}\ 10.34\,fF$$

$$C_{gd} = 0.5\,fF/\mu m\cdot \underset{\underset{8.3\,\mu m}{\uparrow}}{W_g} = 4.15\,fF$$

$$I_D = 27{,}8\,\frac{mA}{V}\cdot(V_{gs} - 0.228V) \Rightarrow g_m = \underline{27.8\,mS}$$

$$f_T = \frac{1}{2\pi}\,\frac{g_m}{(C_{gs}+C_{gd})} = 0.159\,\frac{27.8\,\cancel{fF}\,mS}{\cancel{70.2\,fF}\ 14.49\,fF}$$

$$= \cancel{65.0\,GHz}\ 305.35\,GHz$$

Part c: 8 points

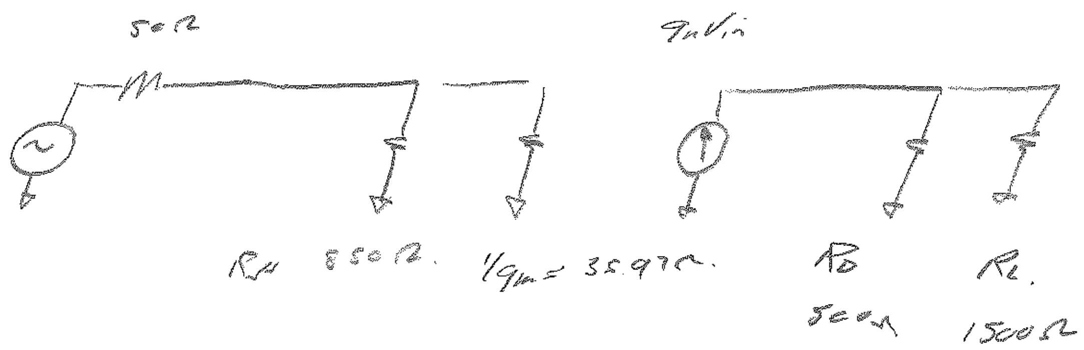
Mid Band Analysis:

Find the following:

$R_{in,Amplifier}$ = 34.5Ω. $R_{L,eq}$ = 375Ω.

V_{out}/V_{in} = 10.42 V_{in}/V_{gen} = 0.408

$v_o/v_{gen} = \underline{4.25}$



$R_{in,Amp} = 35.97Ω \| 850Ω$
$= 34.50Ω$

$R_{eq} = R_D \| R_L = 500Ω \| 1500Ω = 325Ω.$

$R_T = R_{in,Amp} \| R_{gen} = 20.4Ω.$

$$v_{in}/v_{gen} = \frac{R_{in A}}{R_{in A} + R_{gen}} = \frac{34.5Ω}{34.5Ω + 50Ω} = 0.408$$

$$v_o/v_i = + g_m R_{eq} = \frac{375Ω}{35.97Ω} = 10.42.$$

Part d: 14 points

High-Frequency Analysis:

Find the frequencies, in Hz, of the two poles limiting the high-frequency response of the amplifier. Show your analysis (do not simply state that the input pole of a common-gate amplifier is approximately at f_τ)

$f_{p1,HF}$ = 754 ~~118~~ GHz $f_{p2,HF}$ = 102 GHz.

$\tau_{in} = R_S \cdot C_{gs}$

$= 20.4\Omega \cdot$ ~~66.1 fF~~ 10.34 fF

$=$ ~~1.35 ps~~ 21.1 pS

$f_{p1,HF} = \frac{0.159}{\tau} =$ ~~118 GHz~~ 754.5 GHz

$\tau_{out} = R_{Leq}\, C_{gd}$

$= 375\Omega \cdot 4.15\text{ fF}$

$= 1.56\text{ pS}$

$f_{p2,HF} = \frac{0.159}{\tau} = 102\text{ GHz}$

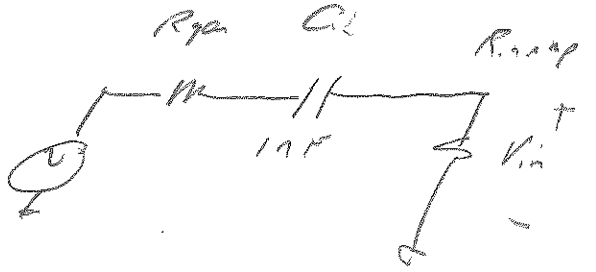
a

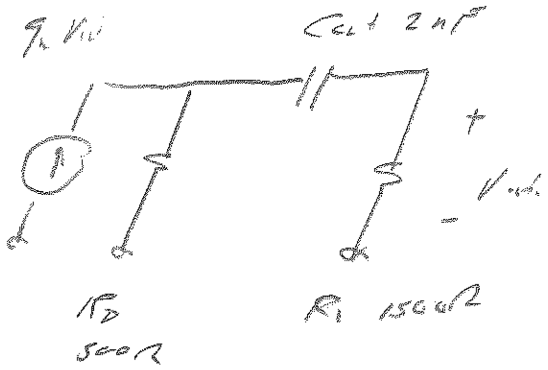
Part e: 14 points

Low-Frequency Analysis:

Find the frequencies, in Hz, of the two poles limiting the low-frequency response of the amplifier. Show your analysis.

$f_{p1,LF}$ = 1.88 MHz $f_{p2,LF}$ = 39.8 KHz.





$\tau_{in} = RC$

$= (R_{sig} + R_{in,amp}) C_{in}$

$= 84.5\Omega \cdot 1nF$

$= 84.5ns$

$f_{p1,LF} = 1.88$ MHz. $= \frac{0.159}{\tau}$

$\tau_{out} = (R_D + R_L) C_{out}$

$= 2000\Omega \cdot 2nF$

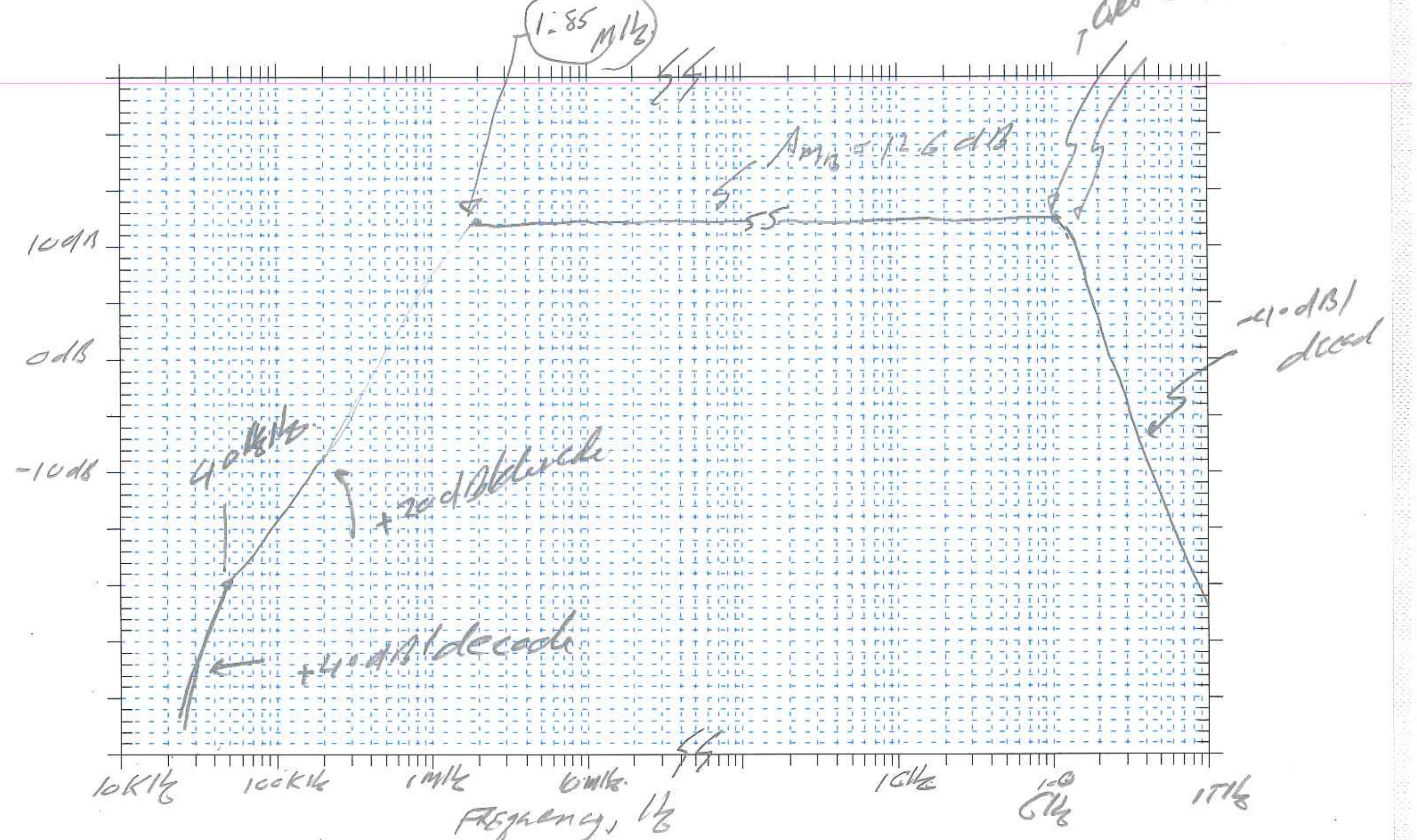
$= 4\mu s$

$f_{p2,LF} = \frac{0.159}{4\mu s} = 39.8$ kHz

a

Part f: 10 points

Draw a clean asymptotic Bode Magnitude plot of V_{out}/V_{gen} as a function of frequency in Hz. Be sure to label and dimension the axes clearly, label pole and zero frequencies and gain slopes. Be sure to use the semi-log paper correctly



$v_o/v_{in}|_{MB}$ = 4.25 = 12.6 dB

LF: 1.85MHz, 37.8kHz

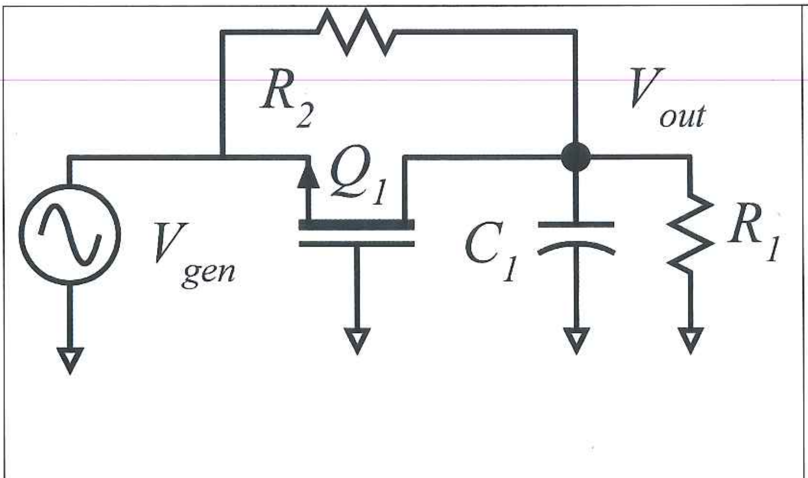
HF: 118GHz, 102.6GHz

(plot has too small a range, I've had to split scales.

a

Problem 2, 40 points

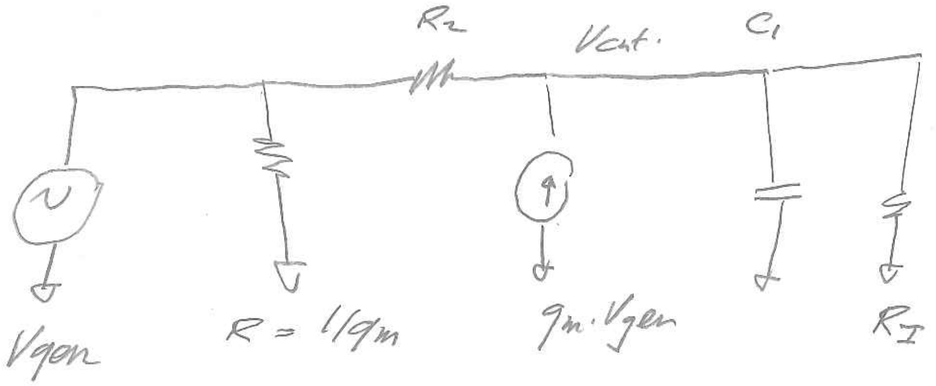
Part a 10 points



Small signal analysis. Ignore the DC bias; you don't need it.

The FET has lambda=0 hence Gds=0. Also, Cgs =Cgd=0 fF

Replacing the transistor with its high frequency small-signal model, draw a small-signal equivalent circuit diagram.



Part b, 10 points

USING NODAL ANALYSIS, compute Vout(s)/Vgen(s) in ratio-of-polynomials form:

$$\frac{V_{out}(s)}{V_{gen}(s)} = \left.\frac{V_{out}}{V_{gen}}\right|_{mid-band} \times (s\tau)^m \times \frac{1+b_1 s + b_2 s^2 + \ldots}{1+a_1 s + a_2 s^2 + \ldots} = \underline{\hspace{8cm}}$$

here m, an integer, can be positive or negative or zero

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

$$V_{out}[G_2 + G_1 + sC_1] + V_{gen}[-G_2 - g_m] = 0.$$

$$\frac{V_{out}}{V_{gen}} = \frac{G_2 + g_m}{G_1 + G_2 + sC_1}$$

$$= \frac{G_2 + g_m}{G_1 + G_2} \; \frac{1}{1 + s\,C_1(G_1 + G_2)^{-1}}$$

$$\boxed{\frac{V_{out}}{V_{gen}} = (g_m + 1/R_2)\,R_1//R_2 \cdot \frac{1}{1 + s\,C_1\,(R_1//R_2)}}$$

Part c, 10 points

g_m=10 mS. R_1=1 kOhm, R_2=3 kOhm, C_1 = 1pF

Find the frequencies of any zeros (there may be zero, one or two present) in the transfer function:

f_{z1}=__________, f_{z2}=__________, ...

There may be either 1 or 2 poles of the transfer function.

If the poles are real, give the 1 or 2 pole frequencies in Hz:

f_{p1}= 212 MHz, f_{p2}=__________

If there are 2 poles, and they are complex, give $f_n = \omega_n / 2\pi$ and the damping factor ζ :

$f_n = \omega_n / 2\pi$ =__________, ζ =__________

there is a single, σ- axis pole in the transfer function

$\tau_1 = (R_1 // R_2) C_1$

$= 750\Omega \cdot 1pF$

$= 750ps$

$f_{p1} = \frac{0.159}{\tau} = 212$ MHz

Low-frequency gain

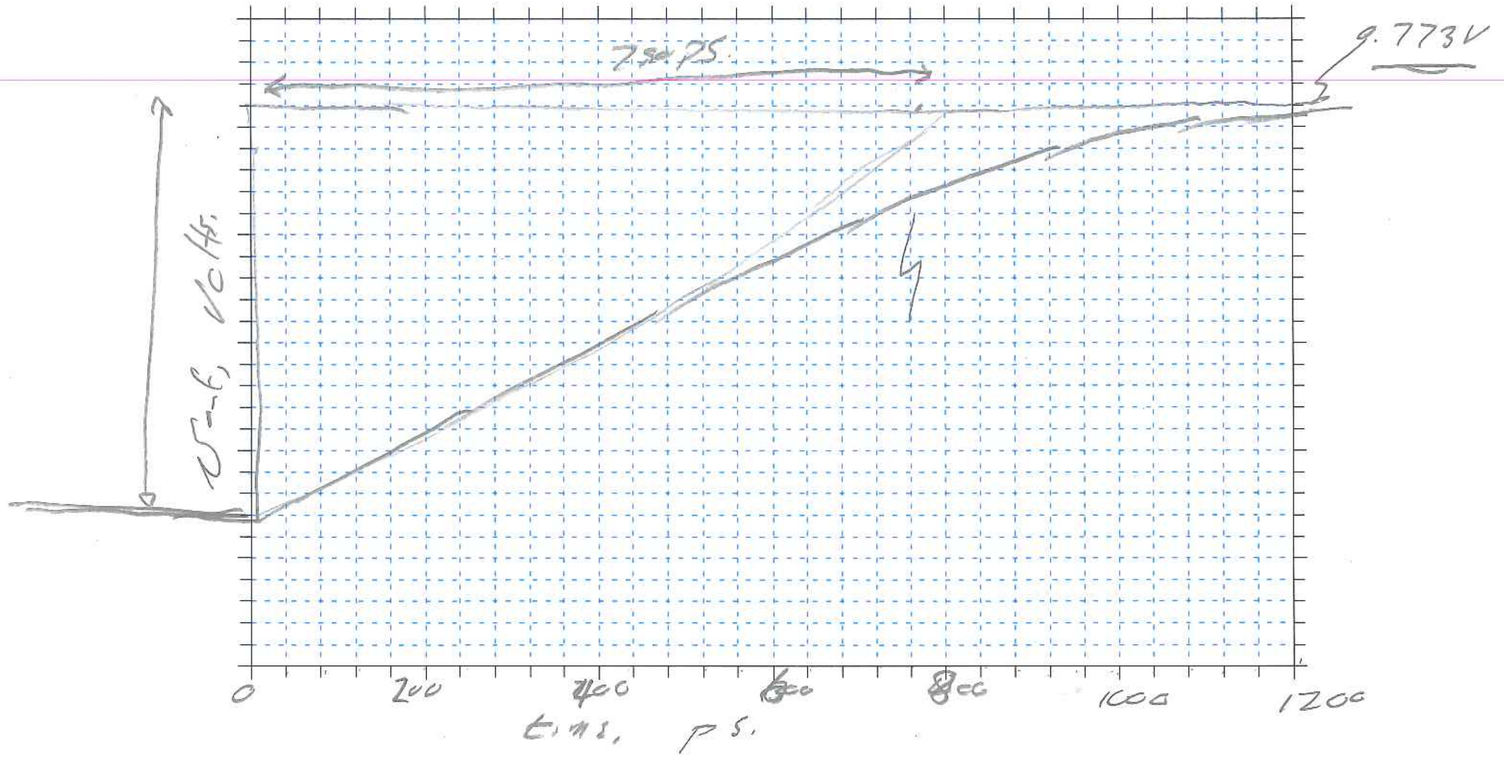
$= (g_m + 1/R_2)(R_1//R_2)$

$= 10.333$ mS (750Ω)

$= 7.73$

Part d, 10 points

If Vin(t) is a 100mV step-function, find and plot Vout(t). Be sure to label and dimension the axes clearly, and to clearly label key features of the time waveform.



by inspection,

$$v_o(t) = 0.1 \cdot 7.73 \cdot u(t)\left[1 - e^{-t/\tau}\right]$$

$$= 0.773 \cdot u(t)\left[1 - e^{-t/750ps}\right]$$