ECE 2C Mid-Term Exam

May 5, 2011

Do not open exam until instructed to.

Closed book: Crib sheet and 1 page personal notes permitted

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

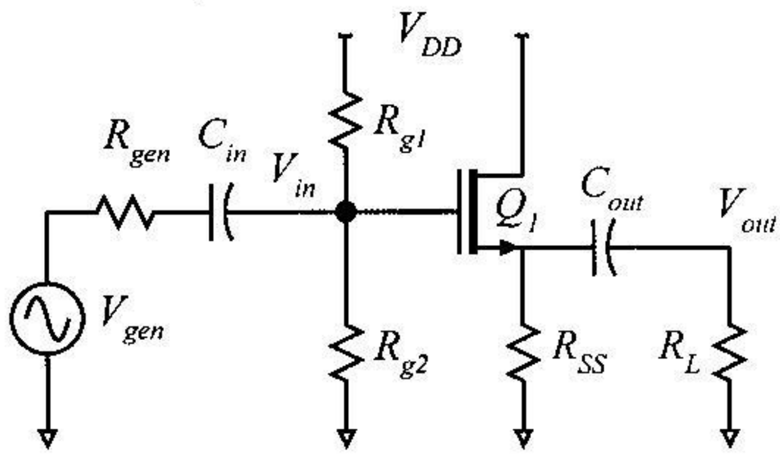
Use any and all reasonable approximations (5% accuracy is fine.), ***AFTER STATING and approximately Justifying them.***

Name: Solution "A"

Problem	Points Received	Points Possible
1a		10
1b		10
1c		10
1d		15
1e		10
1f		10
1g		15
2a		15
2b		5
total		100

Problem 1, 85 points

You will be working on the circuit below:



Q1 is a velocity-limited FET, i.e. $I_d = (v_{sat}c_{ox}W_g)(V_{gs} - V_{th})(1 + \lambda V_{ds})$
where $v_{sat}c_{ox}W_g$ =2 mA / V , $\lambda = 0.1\ \text{V}^{-1}$, and V_{th} =0.3 V.

V_{DD} = +2.0 volts.
C_{in} and C_{out} are very big and have negligible AC impedance.
RL=5 kOhm
Rgen=100kOhm

Part a, 10 points

DC bias.

Q1 is to be biased with 0.5 mA drain current.

The source of Q1 is to be biased at 1.0 Volts

The DC current in Rg1 is 2 μA

Ignore λ while solving this part.

Find: Rg1= 225 kΩ Rg2= 775 kΩ Rss= 2 kΩ

2.5

$I_d \cong 2\,mA/V \, (V_{gs} - V_{th})$

$0.5\,mA = 2\,mA/V \cdot (V_{gs} - 0.3V)$

$0.25V + 0.3V = V_{gs} = 0.55V$

$V_s = 1V \longrightarrow V_g = 1.0V + V_{gs} = 1.55V$

Current in R_{g1} = current in R_{g2} = 2 µA.

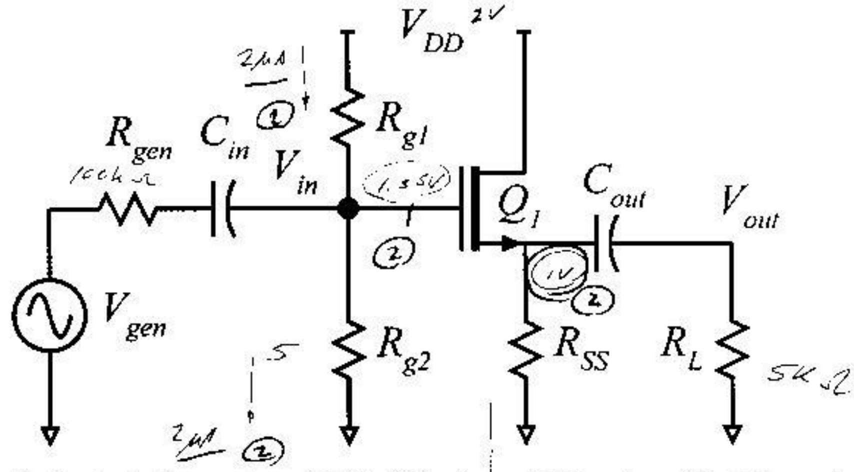
2.5 $R_{g2} = \dfrac{1.55V}{2\mu A} = 775\,k\Omega$

2.5 $R_{g1} = \dfrac{2V - 1.55V}{2\mu A} = 225\,k\Omega$

2.5 $R_{ss} = 1V/(0.5\,mA) = 2\,k\Omega$

Part b, 10 points

DC bias



On the circuit diagram above, label the DC voltages at **ALL nodes** and the DC currents through **ALL resistors**

1/2 mA

②

2pts ea.

Part c, 10 points

Find the small signal parameters of Q1. Use the constant-velocity model.

gm= 2 mS
Rds= 10 kΩ.

5

$g_m = 2\ mA/V\ (1+\lambda) = 2.2\ mA/V$

or

$= 2\ mA/V$ (ignoring λ) Either answer acceptable.

5

$R_{ds} = \frac{(V_{DS} + 1/\lambda)}{I_d} = \frac{1V + 10V}{1/2\ mA} = 22k\ \Omega$

or

$\cong \frac{1}{\lambda I_D} = 10k\ \Omega$ Either answer acceptable.

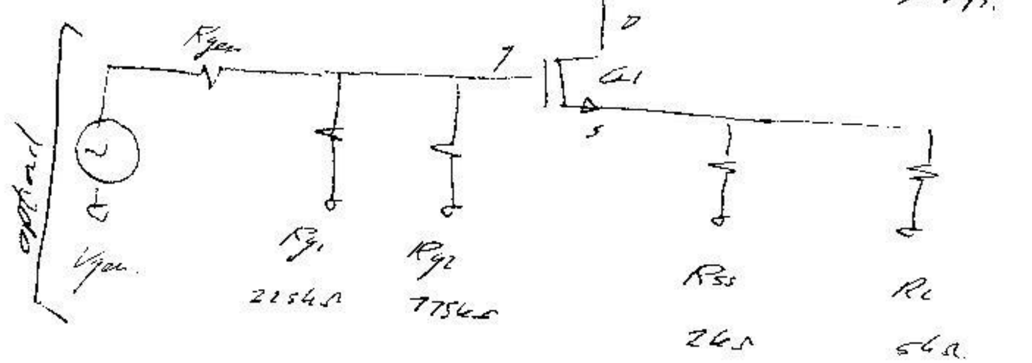
Part d, 15 points

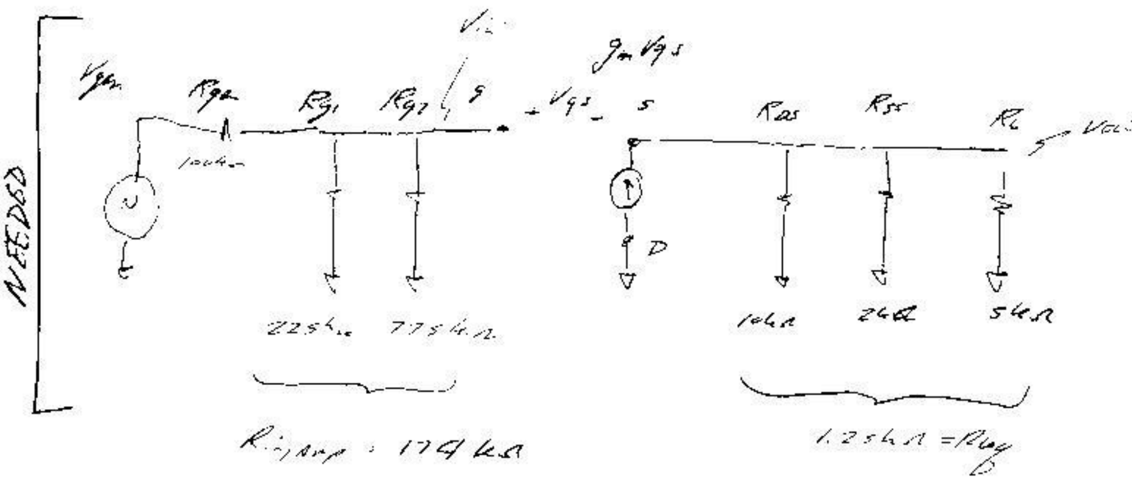
Replacing the transistor with its small-signal model, draw a small-signal equivalent circuit diagram for the amplifier. Give values for all elements on the diagram.

Points off if elements missing, including + − V_{gs} control of $g_m V_{gs}$.

$g_m = 2mS$

$R_{DS} = 10k\Omega$.





Part e, 10 points.

Find the small signal voltage gain (Vout/Vin) of Q1.

Vout/Vin= 0.714

5 [$R_{eq} = R_{OS} \parallel R_{SS} \parallel R_L = 10k\Omega \parallel 2k\Omega \parallel 5k\Omega$
$= 1.25k\Omega$

5 [$V_{out}/V_{in} = \dfrac{R_{eq}}{R_{eq} + 1/g_m} = \dfrac{g_m R_{eq}}{g_m R_{eq} + 1} = \dfrac{2.5}{1 + 2.5} = 0.71$

Part f. 10 points

Find the *** amplifier *** input resistance, Vin/Vgen, and Vout/Vgen

Rin,amplifier = 174kΩ

Vin/Vgen= 0.635

(Vout/Vgen) = 0.45.

4 $R_{in,Amp} = R_{g1} \| R_{g2} = 225k\Omega \| 775k\Omega$

$= 174k\Omega$

4 $V_{in}/V_{gen} = \frac{R_{inAmp}}{R_{inAmp} + R_{gen}} = \frac{174k\Omega}{175k\Omega + 100k\Omega} = 0.635$

2 $\frac{V_{out}}{V_{gen}} = \frac{V_{out}}{V_{in}} \frac{V_{in}}{V_{gen}} = 0.45$

Part g, 15 points

Now you must find the maximum signal swings. Find the output voltage due to the knee voltage and due to cutoff in Q1. Since this is a constant-velocity model, the knee voltage of the transistor must be specified: $V_{DS,knee} = V_{DS,minimum} = V_{DS,saturation}$=0.30 Volts, i.e. the FET must have a minimum 0.30 Volts between drain and source for linear operation.

Cutoff of Q1; Maximum ΔVout resulting = -0.3V

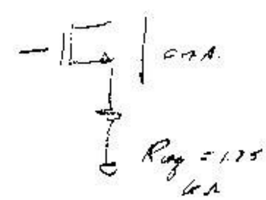
Knee voltage of Q1; Maximum ΔVout resulting = +0.7V

7.5

cutoff

BIAS

cutoff



$$\Delta V_{out} = \overbrace{1/2\,mA}^{4} \cdot \overbrace{1.25\,k\Omega}^{3.5} = 0.625\,V$$

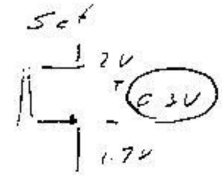
negative excursion.

7.5

knee voltage / "saturation"

BIAS

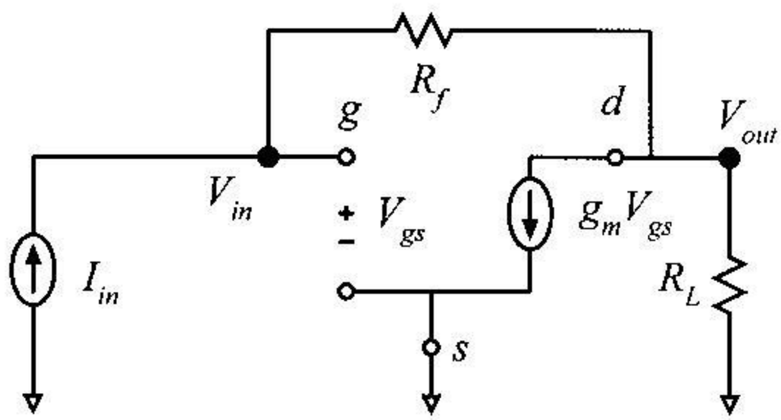
Sat



$\Delta V_{out} = 1.7V - 1V = 0.7V$ positive excursion

Problem 2, 20 points
Nodal analysis

Part a, 15 points



Using nodal analysis, determine V_{out} / I_{in}

5 [Nodal equation at V_{in}: $V_{in}/R_f - V_{out}/R_f = I_{in}$

5 [Nodal equation at V_{out}: $V_{in}(g_m - 1/R_f) + V_{out}(1/R_f + 1/R_L) = 0.$

5. [$V_{out}/I_{in} =$ $(1 - g_m R_f)/(g_m + 1/R_L)$

$\Sigma I = 0$ @ V_{in}:

f $(V_{in} - V_{out})/R_f = I_{in} \longrightarrow V_{in}/R_f + V_{out}(-1/R_f) = I_{in}$

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

$V_{out}/R_L + (V_{out} - V_{in})/R_f + g_m V_{in} = 0$

$V_{in}(g_m - 1/R_f) + V_{out}(1/R_f + 1/R_L) = 0$

$$\begin{bmatrix} G_f & -G_f \\ g_m - G_f & G_f + G_L \end{bmatrix} \begin{bmatrix} V_{in} \\ V_{out} \end{bmatrix} = \begin{bmatrix} I_{in} \\ 0 \end{bmatrix}$$

$$V_{out} = \frac{N}{D} \quad \text{where}$$

$$N = \begin{vmatrix} G_f & I_{in} \\ g_m - G_f & 0 \end{vmatrix} = I_{in} (G_f - g_m)$$

$$D = \begin{vmatrix} G_f & -G_f \\ g_m - G_f & G_f + G_L \end{vmatrix} = \cancel{G_f G_f} + G_f G_L + g_m G_f - \cancel{G_f G_f}$$

$$= (g_m + G_L) G_f$$

$$\frac{V_{out}}{I_{in}} = \frac{G_f - g_m}{(g_m + G_L) G_f} = \frac{(1/R_f - g_m) R_f}{g_m + 1/R_L}$$

$$= \frac{1 - g_m R_f}{g_m + 1/R_L}$$

Part b, 5 points

$R_L = 1$ kOhm, $R_f = 10$ kOhm, $g_m = 100$ mS.

Find the numerical value of V_{out}/I_{in}:

$V_{out}/I_{in} =$ $-9.83\ k\Omega$

$$\frac{V_{out}}{I_{in}} = \frac{1 - g_m R_f}{g_m + 1/R_L} =$$

5

$$= \frac{1 - 100\,mS \cdot 10\,k\Omega}{100\,mS + 1\,mS}$$

$$= \frac{-999}{101\,mS}$$

$$= \underline{\underline{-9.83\,k\Omega}}$$