ECE 137 A Mid-Term Exam

Thursday February 5, 2015

Do not open exam until instructed to.

Closed book: Crib sheet and 1 page personal notes permitted

There are 3 problems on this exam, and you have 75 minutes.

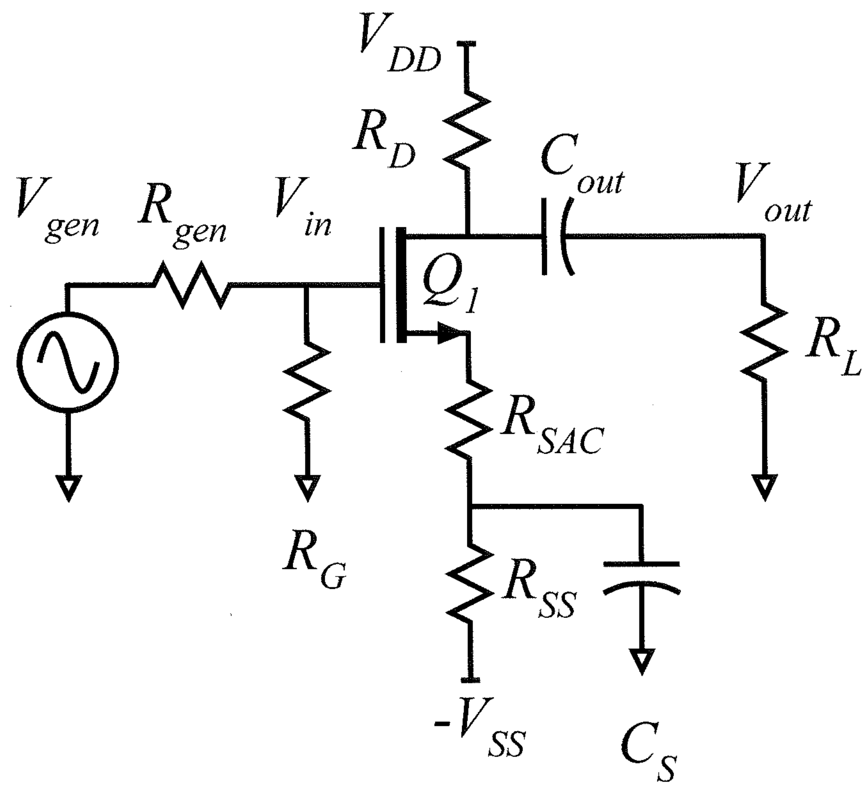
Use any and all reasonable approximations (5% accuracy is fine.) ,
AFTER STATING and approximately Justifying them.

Name: Solution A.

Part	Points Received	Points Possible	Part	Points Received	Points Possible
1a		10	2f		15
1b		5	3a		8
1c		5	3b		8
1d		10	3c		4
1e		15			
2a		10			
2b		5			
2c		5			
2d		10			
2e		5			
TOTAL					100

Problem 1, 30 points

You will be working on the circuit below:



The transistor has
L_g=45nm, μ=400 cm^2/V-s, $\varepsilon_{r,ox}$=3.8, T_{ox}=1nm, v_{sat}=10^{7}cm/s, $V_{th}=0.284V$, $1/\lambda=10$V,
From which we calculate:
$c_{ox}v_{sat}$=3.36 mA/V/μm, $\mu c_{ox}/2L_g$=15 mA/V^2/μm, $\Delta V = L_g v_{th}/\mu$=0.113V,

The supplies are +1V and -1 V
You are to bias the transistor at 2mA drain current,
with 0.6V DC drain voltage, and with -0.45 V DC source voltage.
R_{SAC}=20Ω, R_G=1 MΩ, R_{gen}=75 kΩ, R_L=10kΩ

C_S and C_{out} are very large (AC short-circuit)

Part a, 10 points

DC bias.

Use this approximation: Ignore (i.e. set to zero) the FET λ parameter in the DC bias calculation.

Find the following:

FET gate width Wg=__________ Rss=________________ RD=____________

$V_g = 0V$ so $V_{gs} = 0.45V$. (1)

(1) [note $V_{th} + \Delta V = 0.284V + 0.113V = 0.397V$.

(1) [so we are velocity-limited.

(2) [$V_{th} + \Delta V/2 = 0.284V + 0.113V/2 = 0.340V$.

$I_D = \frac{3.36 mA}{V^2 \cdot \mu m} \cdot W_g (V_{gs} - 0.340V)$

(1) [$\Rightarrow W_g = \frac{2 mA}{3.36 \frac{mA}{V^2 \mu m}} \cdot \frac{1}{(0.45V - 0.340V)} = 5.41 \mu m$

(2) [$R_{SS} + R_{SAC} = \frac{1V - 0.45V}{2mA} = \frac{0.55V}{2mA} = 275\Omega$

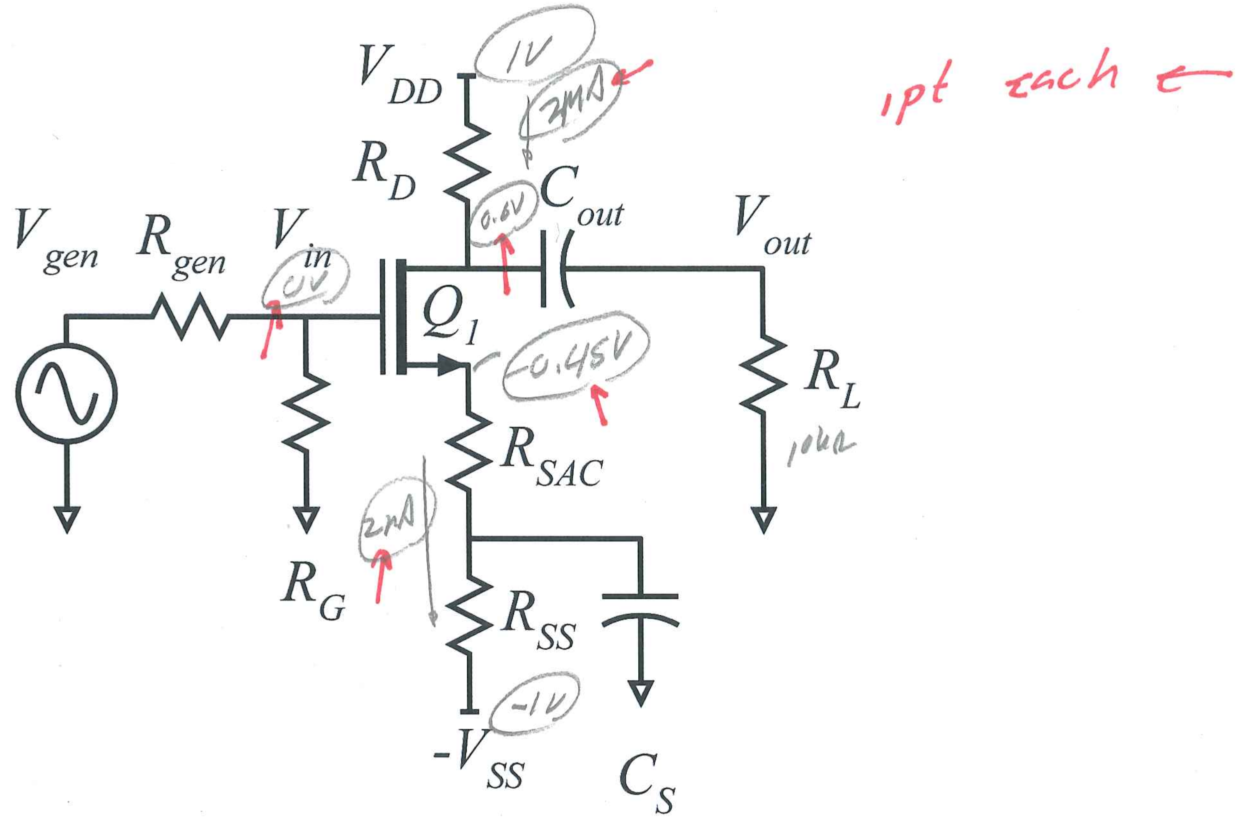
$R_{SS} = 275\Omega - 20\Omega = 255\Omega$.

(2) [$R_D = \frac{1V - 0.6V}{2mA} = \frac{0.4V}{2mA} = 200\Omega$.

a

Part b, 5 points

DC bias



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

Part c, 5 points

Using the actual (nonzero) FET λ parameter, find the FET small signal parameters
gm=_________ Rds=________

velocity limited.

3

$$g_m = v_{sat} C_{ox} W_g (1 + \lambda V_{DS})$$

$$= 3.36 \frac{mS}{\mu m} \cdot 5.41 \mu m \left(1 + \frac{1.05V}{10V}\right)$$

$$= 18.2 mS (1.105) = 20.1 mS.$$

2.

$$R_{DS} = \frac{V_{DS} + 1/\lambda}{I_d} \cong \frac{1}{\lambda I_D} = \frac{10V}{2mA} = \underline{5 k\Omega}$$

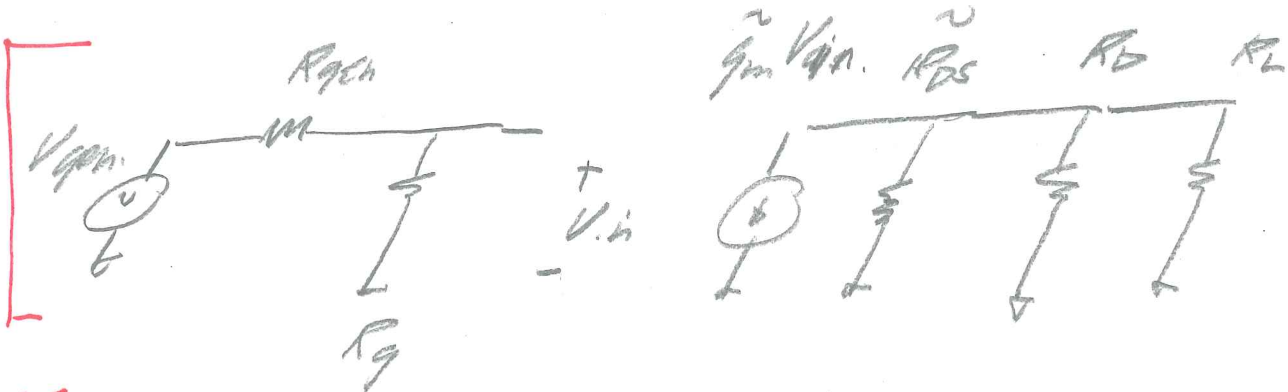
a

Part d, 10 points.

Find the small signal voltage gain Vout/Vin and the amplifier small-signal input resistance.

Vout/Vin=______________________________

Rin, amplfier = ______________________________

2 

2 $\tilde{g}_m = \frac{1}{1/g_m + R_{SAC}} = \frac{1}{49\Omega + 20\Omega} = \frac{1}{69\Omega}$.

2 $\tilde{R}_{DS} = R_{DS}(1+g_m R_{SAC}) = 5k\Omega\left(1+\frac{20\Omega}{49\Omega}\right) = 7.04k\Omega$

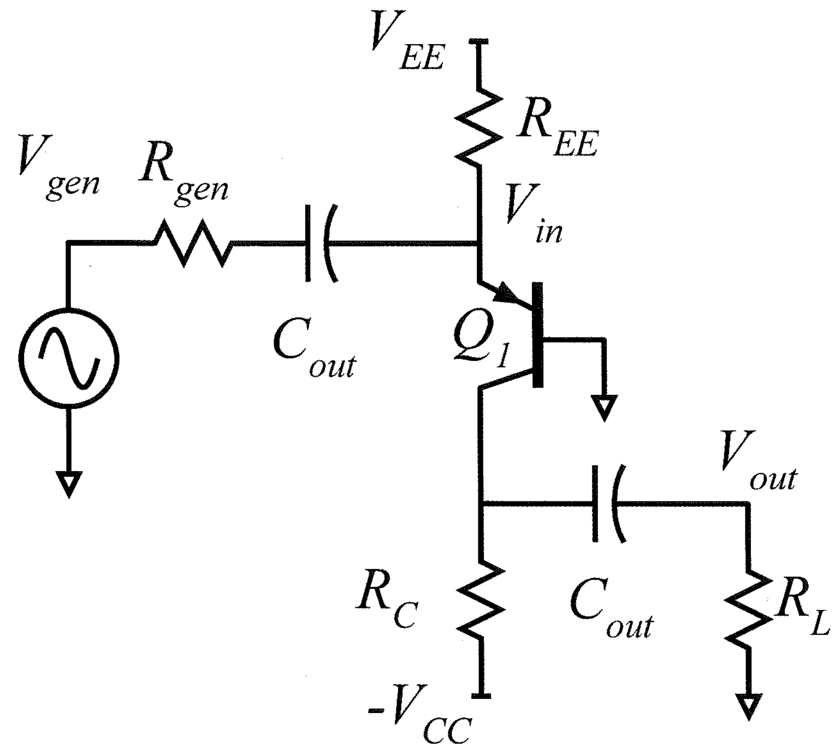
1 $R_{LEQ} = \tilde{R}_{DS} // R_D // R_L = 7.04k\Omega // 200\Omega // 10k\Omega = 191\Omega$

2 $v_o/v_{in} = -\tilde{g}_m R_{LEQ} = \frac{-191}{69\Omega} = -2.76$

1 $R_{in, Amp} = R_g = 1M\Omega$

Problem 2, 50 points

You will be working on the circuit below:



Q1: $\beta = 100$, V_A = infinity V

The supplies are +5V and -5 V.

You will bias the transistor with 2mA collector current.

The DC collector bias voltage is -2.5V.

R_L is $10\,\text{k}\Omega$, R_{gen} is 100 Ω

Part a, 10 points

DC bias.

Find the following:

R_{EE} =__________ R_C =________________

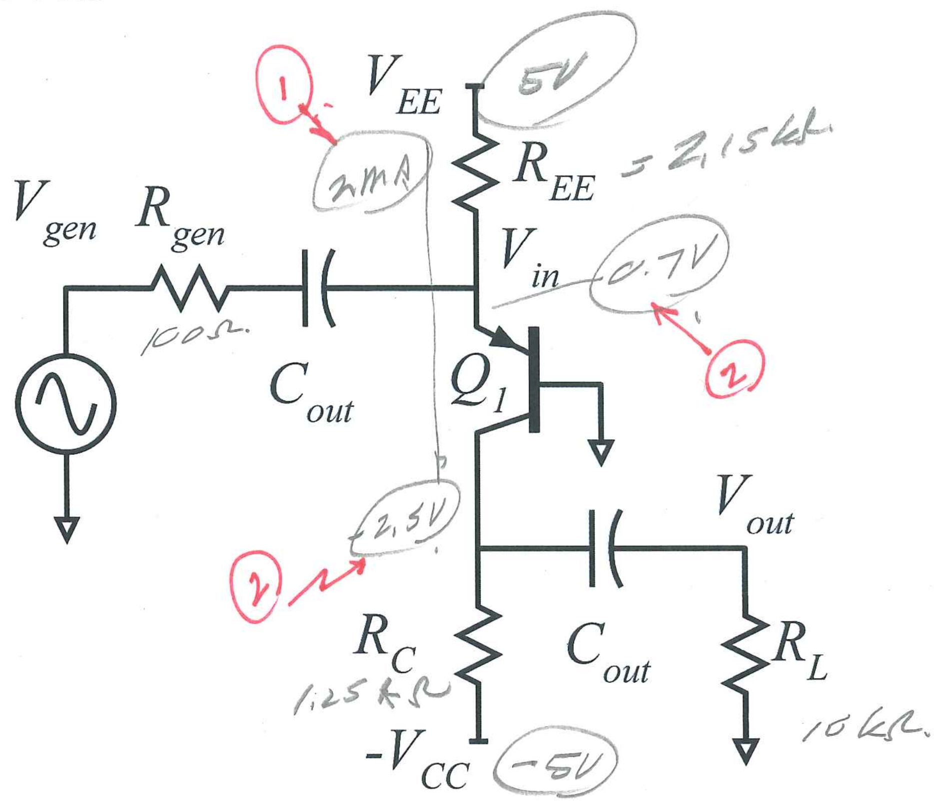
5 $R_{EE} = \frac{5V - 0.7V}{2mA} = \frac{4.3V}{2mA} = 2.15k\Omega$

5. $R_C = \frac{5V - 2.5V}{2mA} = \frac{2.5V}{2mA} = 1.25k\Omega$

a

Part b, 5 points

DC bias



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

Part c, 5 points

Find the small signal parameters of Q1.

gm=_________ Rce=____________ Rbe=_________

2 $\left[g_m = \frac{2mA}{26mV} = \frac{1}{13\Omega} = 76.9 mS. \right.$

1 $\left[R_{CE} = \frac{V_{CE} + V_A}{I_C} = \infty \right.$

2\. $\left[R_{BE} = \beta / g_m = 100 \cdot 13\Omega = 1.3 k\Omega. \right.$

a

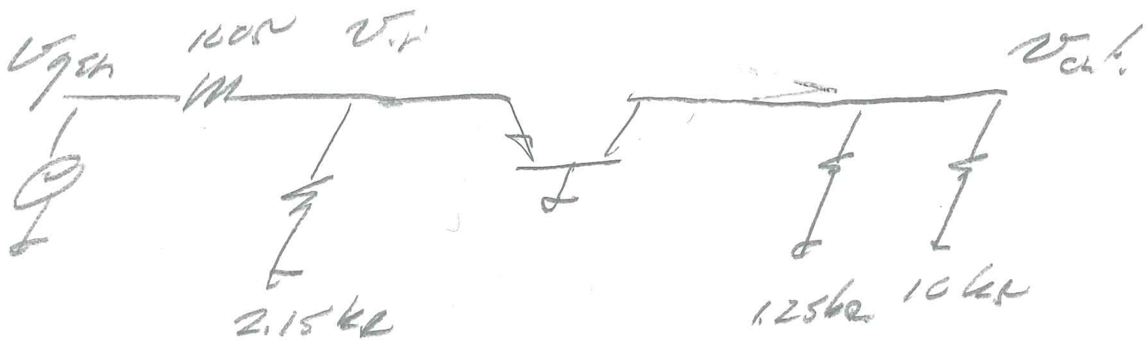
Part d, 10 points.

Find the small signal voltage gain (Vout/Vin) of Q1 and the amplifier small-signal input resistance.

Vout/Vin=____________________________

Rin,amp= ____________________________

2



2 $R_{Leq} = 10k\Omega \,\|\, 1.25k\Omega = 1.111\,k\Omega$

2 $R_{inT} = \left(\frac{1}{g_m} + \frac{R_B}{\beta}\right)\left(\frac{R_{CE} + R_{Leq}}{R_{CE}}\right) \approx \frac{1}{g_m} = 13\Omega$

2 $\frac{v_{out}}{v_{in}} = g_m R_{Leq} = \frac{1.11k\Omega}{13\Omega} = 85.5$

2. $R_{in\,Amp} = R_{inT} \,\|\, 2.15k\Omega = 13\Omega \,\|\, 2.15k\Omega \doteq 13\Omega$

a

Part e, 5 points

Find (Vin/Vgen) and (Vout/Vgen)

(Vin/Vgen) = ______________________________

(Vout/Vgen) = ____________________________

3 $$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}} = \frac{13\Omega}{13\Omega + 100\Omega} = 0.115$$

2 $$\frac{V_o}{V_{gen}} = 0.115 \cdot 85.5 = 9.84$$

a

Part f, 15 points

Now you must find the maximum signal swings. Find the output voltage due to saturation and cutoff in Q2. ***Give the sign (+ or -) in your answers below.***

Cutoff of Q1; Maximum ΔVout resulting = ______________________

Saturation of Q1; Maximum ΔVout resulting = ____________________

Cutoff

$I_{CQ} = 2mA$, $I_{min} = 0 mA$

$\Delta I_C/_{max} = 2mA$, decrease. 4

$\Delta V_{out} = 2mA \cdot R_{Leq} = 2mA \cdot 1.11 k\Omega$

$= 2.22$ Volts, negative 4

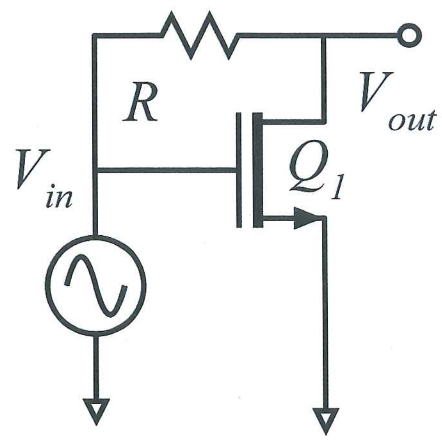
Saturation

3 [$V_{CEQ} = 3.2V$

3 [$V_{CEsat} \cong 0.5V$

1 [$\Delta V_{out} = 2.7V.$ positive

Problem 3, 20 points
nodal analysis



You will be working on the circuit to the left.

Ignore DC bias analysis. You don't need it.

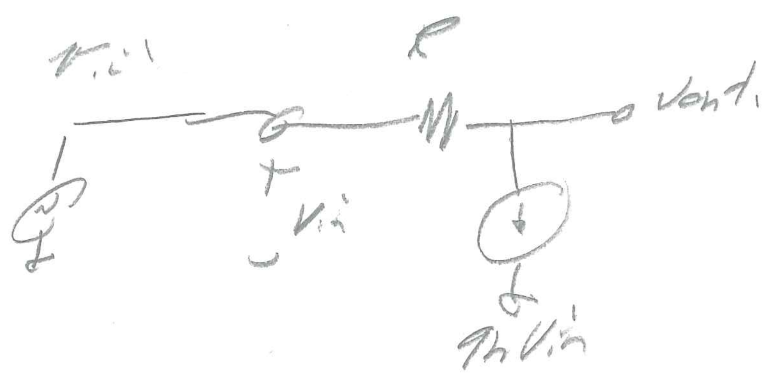
Transistor 1 has transconductance gm1.

The drain-source resistances Rds of the transistor is infinity (so you don't need to draw it!)

Part a, 8 points

Draw the small-signal equivalent circuit

8



takes off 3 pts if controlling voltage not shown.

Part b, 8 points

Find, by nodal analysis, a small-signal expression for Vout/Vin.

Vout/Vin= ___________________

4pts. [$\Sigma I = 0$ @ v_{out}.

$$g_m V_{in} + \frac{V_{out} - V_{in}}{R} = 0.$$

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

$$\frac{V_{out}}{V_{in}} = \frac{-(g_m - 1/R)}{1/R} = -g_m R + 1$$

4pts.

$$\boxed{\frac{V_{out}}{V_{in}} = 1 - g_m R}$$

a

Part c, 4 points

gm1= 1 mS , R=~~4~~ 3 kOhm

Give a numerical value for Vout/Vin.

Vout/Vin= ___________________

4.

$$\frac{v_o}{v_i} = 1 - g_m R$$

$$= 1 - 1mS\,(3k\Omega)$$

$$= -2.$$