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.

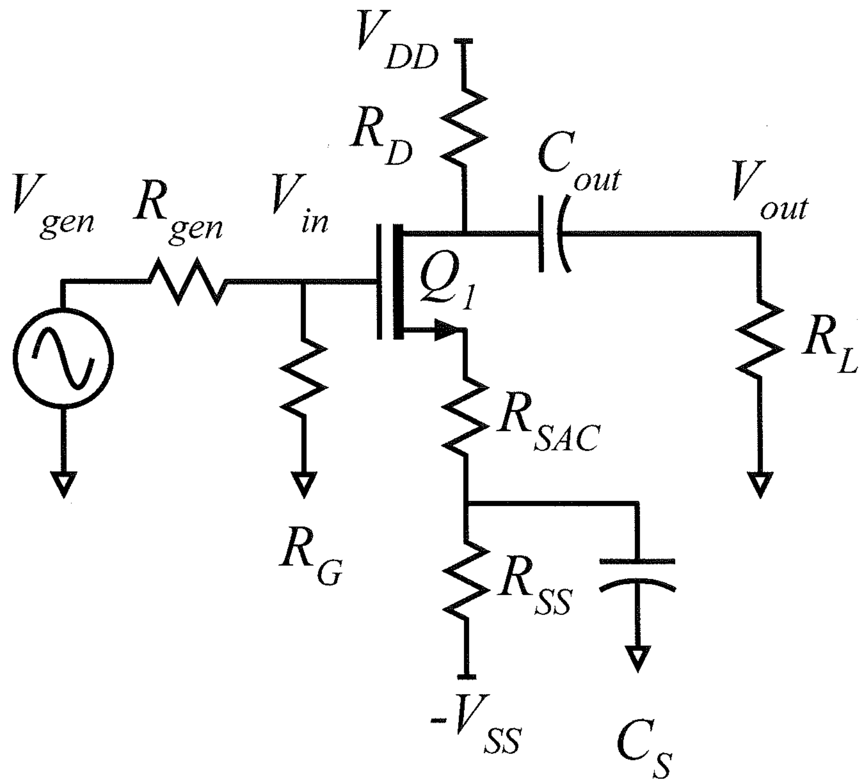
Use any and all reasonable approximations (5% accuracy is fine.) ,
AFTER STATING and approximately Justifying them.

Name: Solution B.

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 1mA drain current,
with 0.5V DC drain voltage, and with -0.35 V DC source voltage.
R_{SAC}=10 Ω, R_G=1 MΩ, R_{gen}=100 kΩ, R_L = 10 kΩ.

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= 15.3μm   Rss= 640Ω.   RD= 500Ω.

FET. $V_g = 0V$ so $V_{gs} = 0.35V$ 1

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

1 [so, we are mobility-limited.

2 [$I_D = \frac{15mA}{V^2 \cdot \mu m} \cdot W_g \cdot (V_{gs} - V_{th})^2$

0.35V − 0.284V.

1 [$\rightarrow W_g = \frac{I_D}{\frac{15mA}{V^2 \cdot \mu m} (V_{gs} - V_{th})^2} = 15.3\mu m.$

2 [$R_{SS} + R_{SAC} = \frac{1V - 0.35V}{1mA} = \frac{0.65V}{1mA} = 650\Omega.$

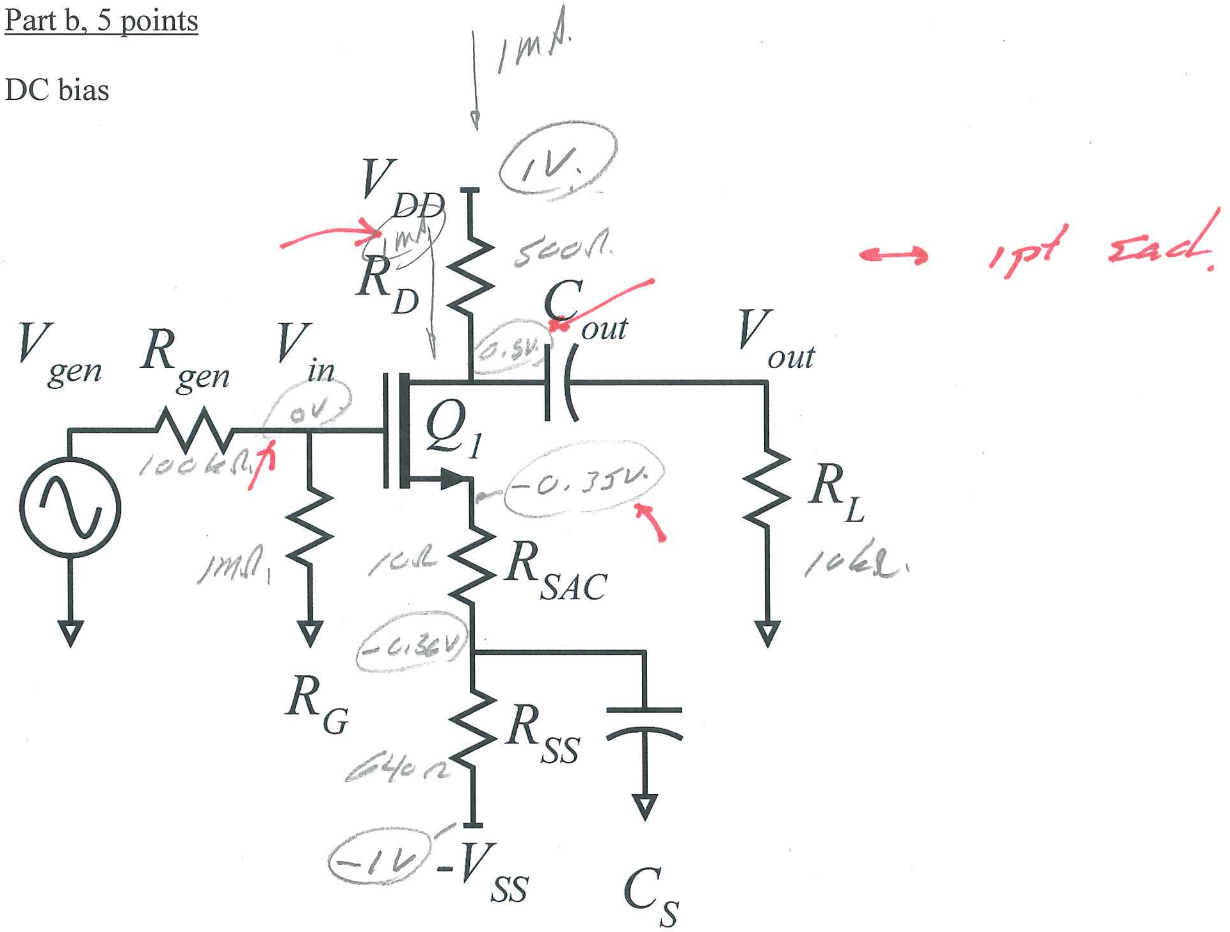
$R_{SS} = 650\Omega - R_{SAC} = 640\Omega$

2 [$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{1V - 0.5V}{1mA} = 500\Omega.$

b

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**

b

Part c, 5 points

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

we are mobility-limited, so

3

$$g_m = \frac{W_g}{L_g} \mu C_{ox} (V_{gs} - V_{th}) (1 + \lambda V_{DS})$$

$$= 2 \cdot \frac{15\,mA}{V^2 \cdot \mu m} \cdot 15.3\,\mu m \cdot (0.35V - 0.284V)\left(1 + \frac{0.85V}{10V}\right)$$

$$= 303\,mS \cdot (1 + \lambda V_{DS}) = 32.9\,mS$$

ok to omit $(1 + \lambda V_{DS}$ term)

$$= 1/30.4\,\Omega$$

2

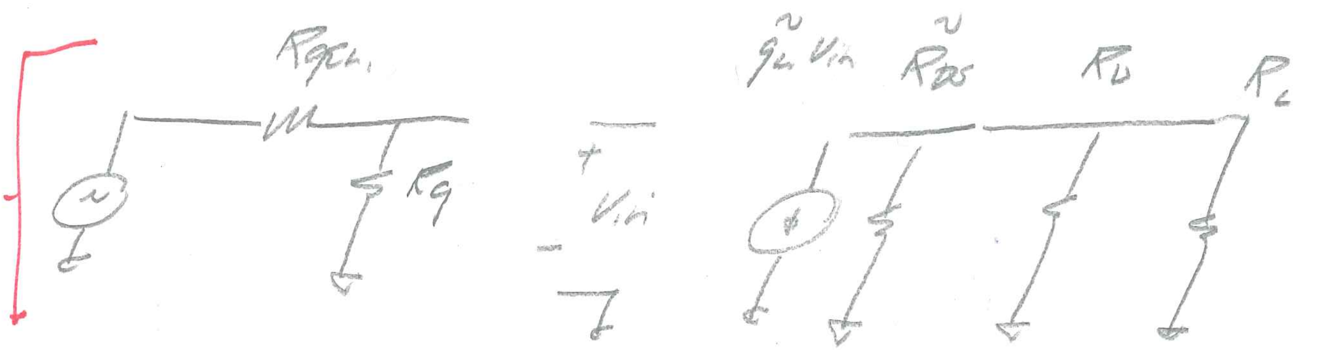
$$R_{ds} = \frac{V_{DS} + 1/\lambda}{I_D} \cong \frac{1}{\lambda I_D} = \frac{10V}{1mA} = 10k\Omega.$$

Part d, 10 points.

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

Vout/Vin=______________________________

Rin, amplfier = ______________________________



$$\tilde{g}_m = \frac{g_m}{1 + g_m R_{SAC}} = \frac{1}{1/g_m + R_{SAC}} = \frac{1}{30.4\Omega + 10\Omega} = \frac{1}{40.4\Omega}$$

$$\tilde{R}_{DS} = R_{DS}(1 + g_m R_{SAC}) = 10k\Omega\left(1 + \frac{10\Omega}{40.4\Omega}\right) = 12.5k\Omega.$$

$$R_{Leq} = \tilde{R}_{DS} \parallel R_D \parallel R_L = 12.5k\Omega \parallel 500\Omega \parallel 10k\Omega. = 459\Omega.$$

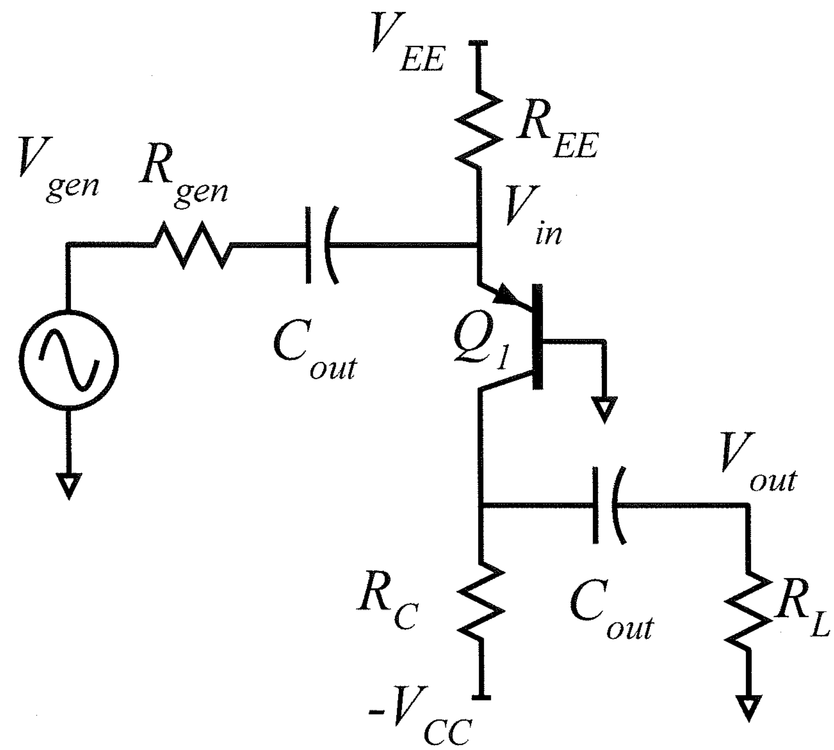
$$v_o/v_{in} = -\tilde{g}_m R_{Leq} = -\frac{459\Omega}{40.4} = -11.4.$$

$$R_{in,amp} = R_G = 1M\Omega.$$

b

Problem 2, 50 points

You will be working on the circuit below:



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

The supplies are +7.5V and -7.5 V.

You will bias the transistor with 1mA collector current.

The DC collector bias voltage is -4V.

R_L is $10\,\text{k}\Omega$, R_{gen} is 75 Ω

Part a, 10 points

DC bias.

Find the following:

R_{EE} =__________ R_C =________________

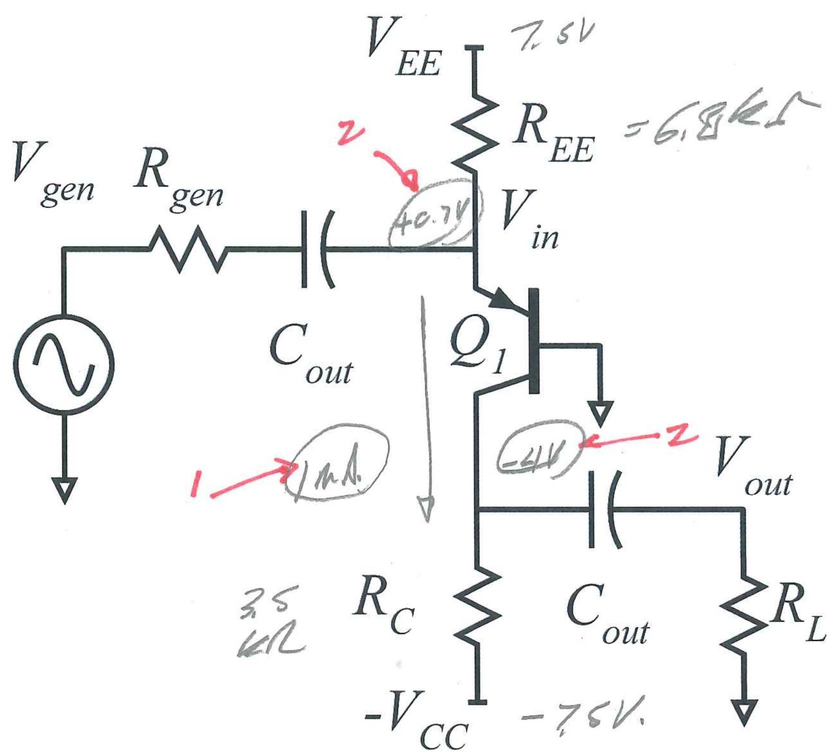
5 [$R_{EE} = \frac{7.5V - 0.7V}{1mA} = \frac{6.8V}{1mA} = 6.8k\Omega$

5 [$R_C = \frac{3.5V}{1mA} = 3.5 k\Omega$

b

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 $\left[g_m = \frac{1mA}{26mV} = \frac{1}{26\Omega} = 38mS. \right.$

1 $\left[R_{be} = \beta / g_m = 100 \cdot 26\Omega = 2.6\,k\Omega \right.$

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

b

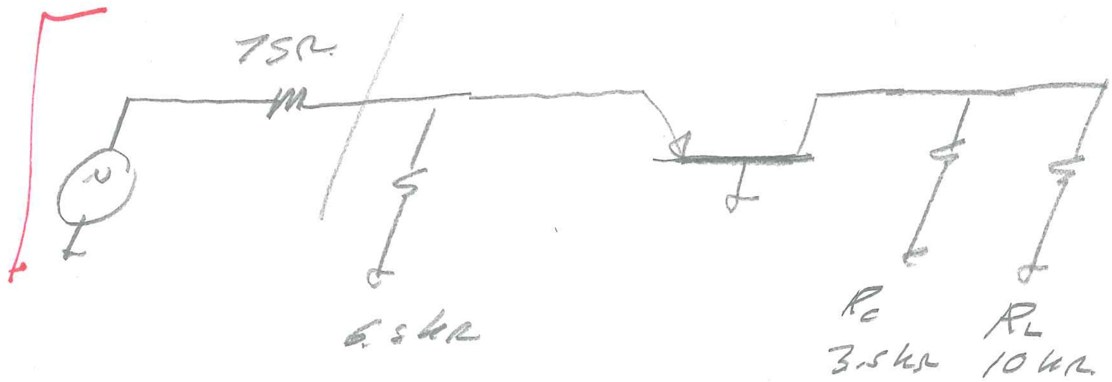
Part d, 10 points.

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

Vout/Vin=______________________________

Rin,amp= ______________________________

2



2 $R_{Leq} = 10k\Omega \| 3.5k\Omega = 2.6k\Omega$.

2 $R_{in,T} = \left(\frac{1}{g_m} + \frac{R_s}{\beta}\right)\left(\frac{R_{CE} + R_{Leq}}{R_{ce}}\right) \approx \frac{1}{g_m} = 26\Omega$.

2 $v_o/v_{in} = g_m R_{Leq} = \frac{2.6k\Omega}{26\Omega} = 100$.

2 $R_{in,Amp} = R_{in,T} \| 6.8k\Omega = 26\Omega \| 6.8k\Omega$

$= 25.9\Omega \cong 26\Omega$.

Part e, 5 points

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

(Vin/Vgen) = ______________________________

(Vout/Vgen) = ______________________________

3 $$\frac{v_{in}}{v_{gen}} = \frac{26\Omega}{26\Omega + 75\Omega} = \frac{26}{101} = 0.257$$

2 $$\frac{v_o}{v_{gen}} = 0.257 \cdot 100 = 25.7$$

b

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:

$I_{CQ} = 1mA$

$I_{C,min} = 0mA$

$\Delta I_C = 1mA$ max

4

$R_{Leq} = 2.6k\Omega$

$\Delta V_{out} = 2.6k\Omega \cdot 1mA = 2.6V$, negative

4.

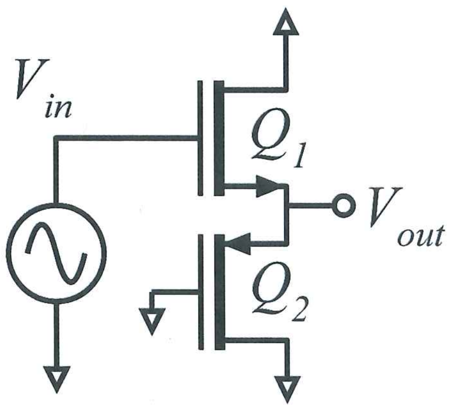
Saturation:

3 [$V_{CE,Q} = 4.7V$

3 [$V_{CE,min} = V_{CE,sat} \approx 1/2 V$

1 [$\Delta V_{out} = 4.2V$, 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.

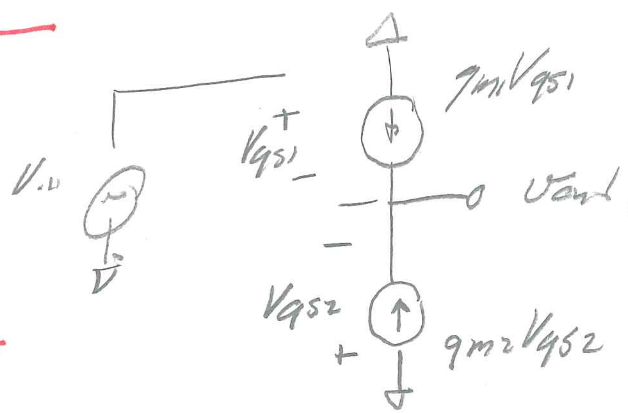
Transistor 1 has transconductance gm1.
Transistor 2 has transconductance gm2.

The drain-source resistances Rds of both transistors are infinity (so you don't need to draw it!)

Part a, 8 points

Draw the small-signal equivalent circuit

8



takes off points* if controlling voltages not shown

* 3 points for each missing control voltage

Part b, 8 points

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

Vout/Vin= ___________________

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

$g_{m1} V_{gs1} + g_{m2} V_{gs2} = 0$

but $V_{gs1} = V_{in} - V_{out}$

$V_{gs2} = -V_{out}$.

$g_{m1}(V_{in} - V_{out}) + g_{m2}(-V_{out}) = 0$.

$g_{m1} \cdot V_{in} = (g_{m1} + g_{m2}) V_{out}$

4. [$\dfrac{V_{out}}{V_{in}} = \dfrac{g_{m1}}{g_{m1} + g_{m2}}$.

b

Part c, 4 points

gm1= 1 mS   gm2= 2 mS
Give a numerical value for Vout/Vin.

Vout/Vin= ___________________

4.

$$\frac{v_o}{v_{in}} = \frac{g_{m1}}{g_{m1} + g_{m2}} = \frac{1}{3}.$$