ECE 137 A Mid-Term Exam

Thursday February 6, 2014

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.

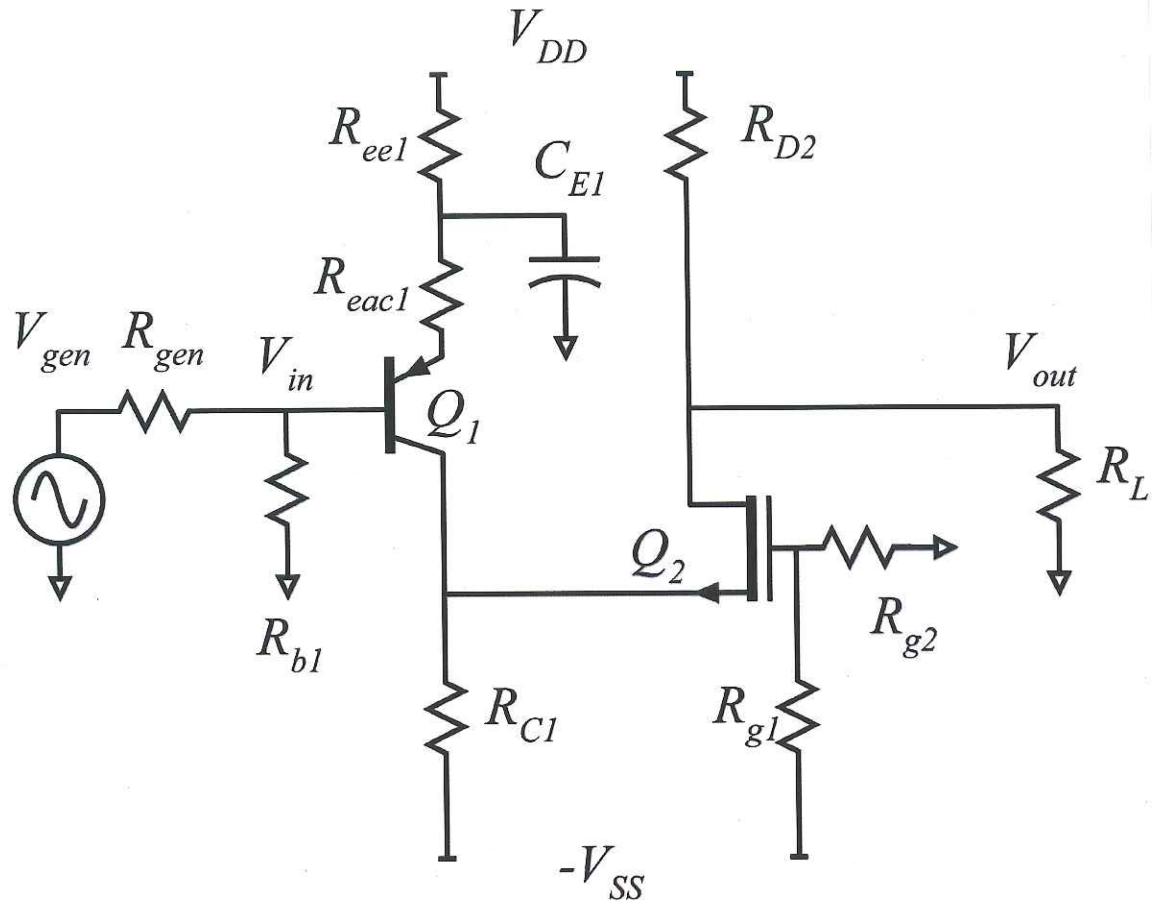
Use any and all reasonable approximations (5% accuracy is fine.) , ***AFTER STATING and approximately Justifying them.***

Name: Solution "B"

Part	Points Received	Points Possible
1a		7
1b		7
1c		6
1d		15
1e		15
1f		6
1g		14
2a		12
2b		13
2c		5
TOTAL		100

Problem 1, 70 points

You will be working on the circuit below:



Q1: $\beta = 50$, V_A=50 V

Q2: Velocity-limited $V_{th} = 0.2V$, $1/\lambda =$ infinity, $\Delta V = L_g v_{th} / \mu$=0.1V, $c_{ox} v_{th} W_g$=5mA/V

The supplies are +3V and -3V

Rgen=1000 Ohms, RL=5,000 Ohms. Rg2=50kOhms, Reac1=37 Ohms, Rb1=10kOhms

Ce1 is very large (AC short-circuit)

Part a, 7 points

DC bias.

V_{in} is at (approxiately) zero volts DC.

The gate of Q2 is to be biased at -2 Volts

The drain is to be biased at zero volts.

Q1 is to be biased at 2 mA emitter current

Q2 is to be biased at 1 mA drain currrent.

Find the following:

Rc1= 167Ω Rg1= 25kΩ Ree1= 1.11kΩ

~~Rg1~~= ________ $R_{D2} = 3k\Omega$

(1) $I_{D2} = 1mA = (5mA/V)(V_{gs} - V_{th} - \Delta V)$

$1mA = (5mA/V)(V_{gs} - 0.2V - 0.1V)$

$V_{gs1} = 0.2V + 0.1V + 1mA/(5mA/V)$

$= 0.5V.$

(1) $V_{s1} = -0.5V - 2V = -2.5V$

(1) R_{C1} carries 3mA $(I_{C1} + I_{D2})$

$R_{C1} = \frac{3V - 2.5V}{3mA} = 167\Omega.$

(1) Base of Q1 @ 0V → $V_E \cong 0.7V.$

(1) $R_{EE1} = \frac{3V - 0.7V}{2mA} - R_{EAC1} = 1.15k\Omega - 37\Omega = 1.11k\Omega.$

(1) $R_{D2} = \frac{3V - 0V}{1mA} = 3k\Omega$

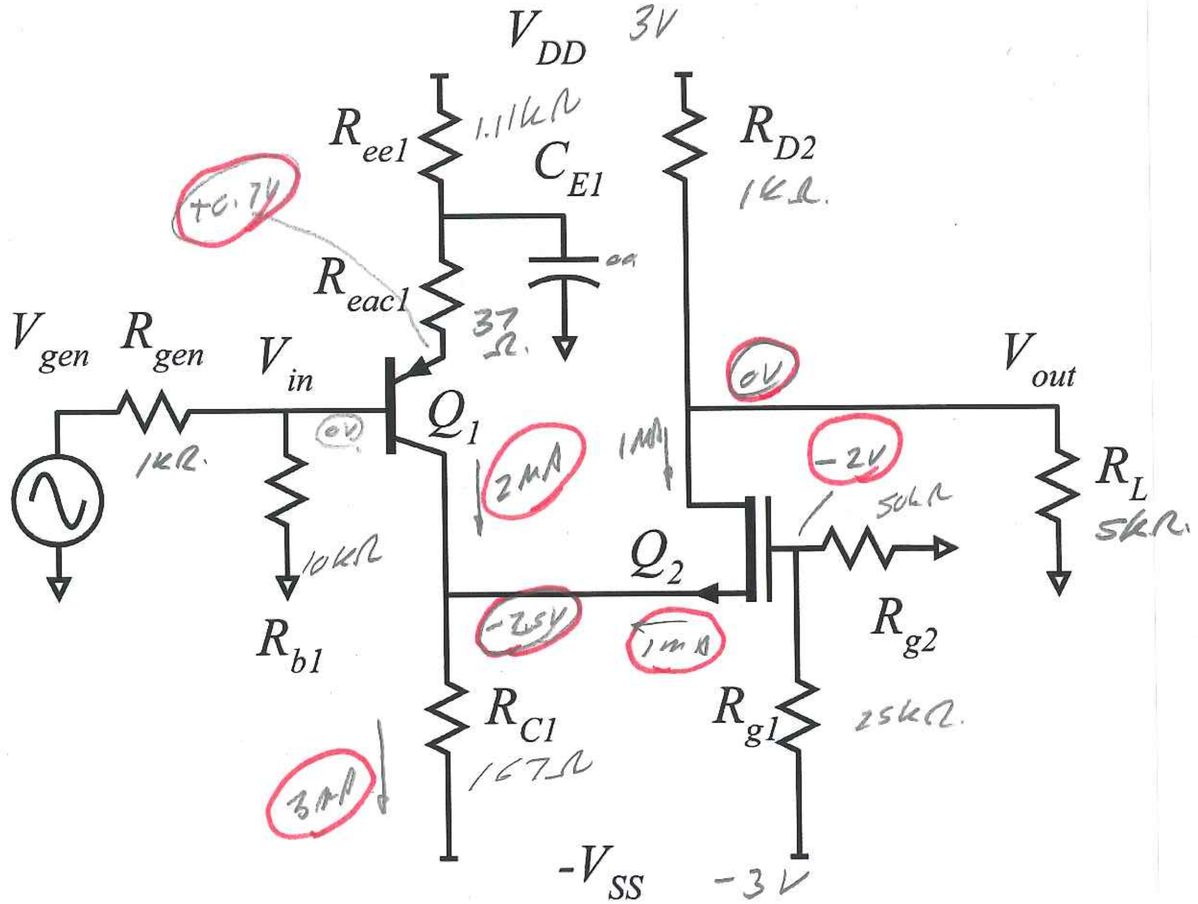
(1) R_{g2} carries $2V/50k\Omega = 40\mu A$

$R_{g1} = \frac{3V - 2V}{40k\Omega} = 25k\Omega$

Q1: β = 50, V_A = 50V
Q2: V_{th} = 0.2V, λ = 0V⁻¹ ΔV = 0.1V, 5mA/V.

Part b, 7 points

DC bias



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

Part c, 6 points

Find the small signal parameters of Q1 and Q2.

Transistor Q1: gm= 77mS Rce= 50kΩ Rbe= 1.3kΩ

Transistor Q2: gm= 5mS Rds= ∞ Ω.

Q1: $I_C = 2\,mA$, $V_A = 100V$, $\beta = 100$

1.5 [$g_m = \frac{2mA}{26mV} = 76.9\,mS = 1/13\Omega$

1.5 [$R_{BE} = \beta/g_m = 100 \cdot 13\Omega = 1.3\,k\Omega$

1 [$R_{CE} = \frac{V_{CE}+V_A}{I_C} \cong \frac{V_A}{I_C} = \frac{100V}{2mA} = 50k\Omega$

Q2: $I_D = 1\,mA$

1 [$g_m = 5\,mA/V = 5mS$

1 [$R_{DS} = \infty$ because $\lambda = 0\,V^{-1}$

b

Part d, 15 points.

Find the small signal voltage gain (Vd2/Vs2) of Q2 and Q2's small-signal input resistance.

Vd2/Vs2= 9.38

Rin,q2= 200Ω

3.5 [Q2: common gate

3.5 [Because $R_{DS} = \infty$, $R_{in2} = 1/g_{m2} = 200\Omega$

3.5 [$R_{Leq2} = R_{D2} \parallel R_L = 3k\Omega \parallel 5k\Omega = 1.88k\Omega$

3.5 [$\frac{V_{D2}}{V_{S2}} = \frac{R_{Leq2}}{R_{in2}} = \frac{1.88k\Omega}{200\Omega} = 9.38$

Part e, 15 points

Find the small signal voltage gain (Vc1/Vb1) of Q1 and the *** amplifier *** input resistance.

Vc1/Vb1= -1.82

Rin,amplifier = $3.33\ k\Omega$

2 [Q1 - Common emitter with degeneration

$1/g_m = 13\Omega$, $R_{EAC} = 37\Omega$

2 [$R_{out,Q1} = R_{CB1}(1 + g_{m1} r_{EAC1}) = 5k\Omega\,(1 + 37/13)$ = very large, neglect

3 [$R_{LEQ1} = R_{in2} \,\|\, R_{C1} \,\|\, R_{out\,Q1}$
$= 200\Omega \,\|\, 167\Omega = 91.0\,\Omega$

3 [$A_{v1} = \dfrac{-R_{LEQ1}}{1/g_{m1} + r_{EAC1}} = \dfrac{-91\Omega}{13\Omega + 37\Omega} = -1.82$

3 [$R_{in\,Q1} = \beta(r_{EAC1} + 1/g_{m1}) = 100 \cdot (37\Omega + 13\Omega)$ [50Ω]
$= 5k\Omega$

2. [$R_{in\,Amp} = R_{in\,Q1} \,\|\, R_{B1} = 5k\Omega \,\|\, 10k\Omega = 3.33k\Omega$

Part f, 6 points

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

(Vout/Vin) = -17.1

(Vin/Vgen) = 0.770

(Vout/Vgen) = -13.1

2 [$V_i / V_{gen} = \frac{R_{in}}{R_{in} + R_{gen}} = \frac{3.33k\Omega}{1k\Omega + 3.33k\Omega} = 0.770$

2 [$V_o / V_{in} = A_{v1} \cdot A_{v2} = (-1.82)(9.38) = -17.1$

2 [$V_o / V_{gen} = (V_o/V_i) \cdot (V_{in}/V_{gen}) = -17.1 \cdot (0.770) = -13.1$

b

Part g, 14 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 = −1.71V.

Saturation of Q1; Maximum ΔVout resulting = +25.3V.

Cutoff of Q2; Maximum ΔVout resulting = + 1.88V.

Knee voltage of Q2; Maximum ΔVout resulting = −2.4V.

Note: A_{v2} = 9.38

Cutoff Q1:

1 [$\Delta I_C|_{max}$ = 2mA − 0mA = 2mA decrease.

3.5 1 [R_{Leq1} = 91Ω

1 [$\Delta V_{C1}|_{max}$ = 91Ω · 2mA = 182mV, ↓ negative-going.

½ [ΔV_{out} = 182mV · A_{v2} = 182mV · 9.38 = −1.71 V

Saturation Q1

1 [V_{CEQ} = 0.7V + 2.5V = 3.2V, V_{CEsat} ≅ 0.5V

3.5 1 [$\Delta V_{CE}|_{max}$ = 3.2V − 0.5V = 2.7V]

[neglecting ΔV_E, ΔV_C = +2.7V ↑] 1

½ [ΔV_{out} = 2.7V (9.38) = +25.3V

Cutoff Q2

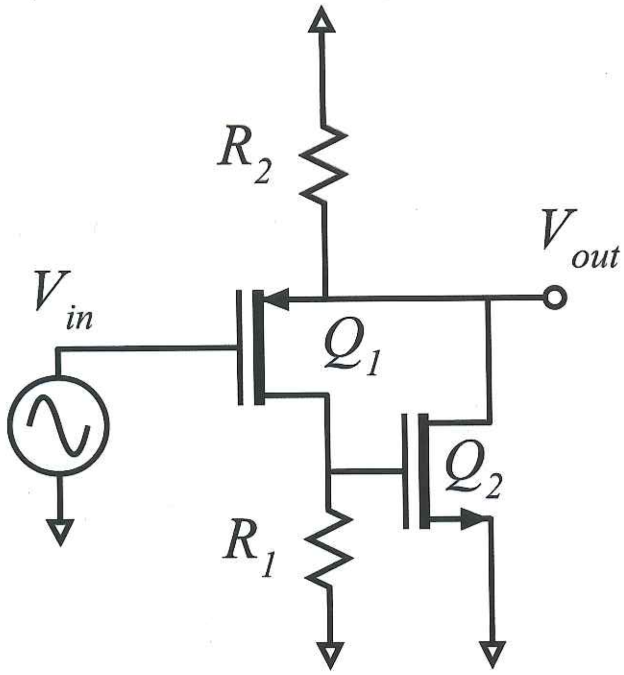
3.5 1.5 [I_{DQ} = 1mA, ⇒ $\Delta I_D|_{max}$ = 1mA (decrease)

2 [ΔV_{out} = 1mA · R_{Leq} = 1mA · 1.88kΩ = +1.88V ↑

Knee Q2 1 [V_{DSQ} = 2.5V] [$V_{DS}|_{knee}$ = 0.1V (velocity-saturated)] 2

3.5 ½ [ΔV_{DS} = 2.4V ↓

Problem 2, 30 points
nodal analysis



You will be working on the circuit to the left.

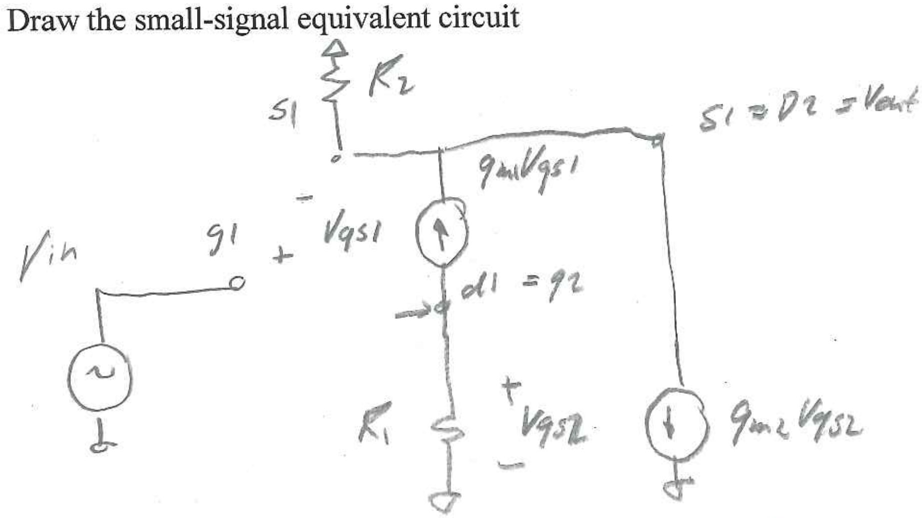
Ignore DC bias analysis. You don't need it.

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!)

<u>Part a, 12 points</u>

Draw the small-signal equivalent circuit



point off if gm generators not labelled or controlling voltages not identified.

Part b,13 points

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

Vout/Vin= ________________

there are two unknown node voltages: V_{out}, V_{g2}

$\Sigma I = 0$ @ $V_{g2} = V_{d1}$: (+ = current leaving)

4 $[0 = g_{m1} V_{gs1} + V_{g2}/R_1]$

$0 = g_{m1}(V_{in} - V_{out}) + V_{g2}/R_1 = 0$

$$V_{g2}(1/R_1) + V_{out}(-g_{m1}) = -g_{m1} V_{in}$$

$\Sigma I = 0$ @ V_{out} (+ = current leaving)

4. $[g_{m2} V_{gs2} - g_{m1} V_{gs1} + V_{out}/R_2 = 0]$

$g_{m2} V_{g2} - g_{m1}(V_{in} - V_{out}) + V_{out}/R_2 = 0$

$$V_{g2}(g_{m2}) + V_{out}(g_{m1} + 1/R_2) = g_{m1} V_{in}$$

b

$$\begin{bmatrix} 1/R_1 & -g_{m1} \\ g_{m2} & g_{m1} + 1/R_2 \end{bmatrix} \begin{bmatrix} V_{g2} \\ V_{out} \end{bmatrix} = \begin{bmatrix} -g_{m1} \\ g_{m1} \end{bmatrix} V_{in}$$

$V_{out} = N / D$

$$D = \begin{vmatrix} 1/R_1 & -g_{m1} \\ g_{m2} & g_{m1} + 1/R_2 \end{vmatrix} = (1/R_1)(g_{m1} + 1/R_2) + g_{m1} g_{m2}$$

$$N = \begin{vmatrix} 1/R_1 & -g_{m1} \\ g_{m2} & g_{m1} \end{vmatrix} V_{in} = (g_{m1}/R_1 + g_{m1} g_{m2}) V_{in}$$

$$\frac{V_{out}}{V_{in}} = g_{m1} \frac{(g_{m2} + 1/R_1)}{(1/R_1)(g_{m1} + 1/R_2) + g_{m1} g_{m2}}$$ ← 5

(ignore)

$$V_o/V_{in} = \frac{g_{m1}(1 + g_{m2} R_1)}{g_{m1} + 1/R_2 + g_{m1} g_{m2} R_1}$$

$$= \frac{g_{m1}(1 + g_{m2} R_1)}{g_{m1}(1 + g_{m2} R_1) + 1/R_2} = \frac{R_2}{\frac{1}{g_{m1}(1 + g_{m2} R_1)} + R_2}$$

other form

12A

$1/R_1 = 1mS$

$1/R_2 = 0.5mS$

Part c, 5 points

gm1= 1 mS   gm2= 10 mS   , R1=1kOhm, R2=2kOhm
Give a numerical value for Vout/Vin.

Vout/Vin= ___________________

$$\frac{V_{out}}{V_{in}} = \frac{1mS\,(10mS + 1mS)}{(1mS)(1mS + 0.5mS) + (1mS \cdot 10mS)}$$

$$= \frac{1\,(11)}{(1.5)+10} = \frac{11}{11.5}$$ ✓

$$= \underline{0.956}$$

5.

b