ECE 137 A Mid-Term Exam

Thursday, February 9, 2017

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.

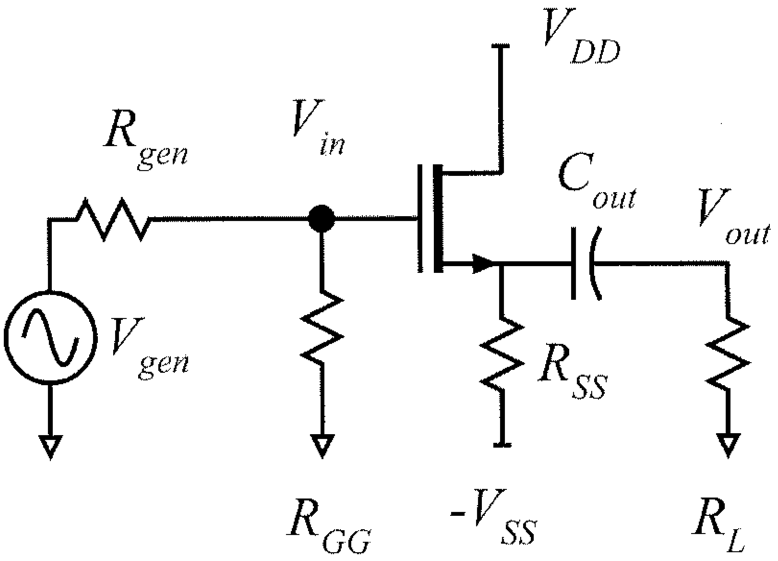
Use any and all reasonable approximations (5% accuracy is fine.),
AFTER STATING and approximately Justifying them.

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=22nm, μ=180 cm^2/V-s, $\varepsilon_{r,ox}$=3.8, T_{ox}=1nm, v_{sat}=10^{7}cm/s, $V_{th}=0.3$V, $1/\lambda$=10V,

From which we calculate:

$c_{ox}v_{sat}$=3.36 mA/V/μm, $\mu c_{ox}/2L_g$ =13.8 mA/V^2/μm, $\Delta V = L_g v_{th}/\mu$=0.122V,

The supplies are +2V and -2 V

You are to bias the transistor at 2mA drain current, and with -0.5 V DC source voltage.

R_{GG}=10 MΩ, R_{gen}=100 kΩ, R_L=1 kΩ

C_{out} are is 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= 4.3μm Rss= 750Ω

2 Transistor is biased at $V_g = 0$ & $V_s = -1/2\,V$

$\longrightarrow V_{gs} = 1/2\,V.$

2 $\Delta V = L_g v_{sat}/\mu = 0.122V$, so FET is velocity-limited

$V_{th} + \Delta V = 0.422V$

2 $$\Rightarrow I_D \cong C_{ox} \cdot v_{inj} \cdot W_g \cdot (V_{gs} - V_{th} - \Delta V/2)(1+\lambda V_{DS})$$

λ: Ignore for DC.

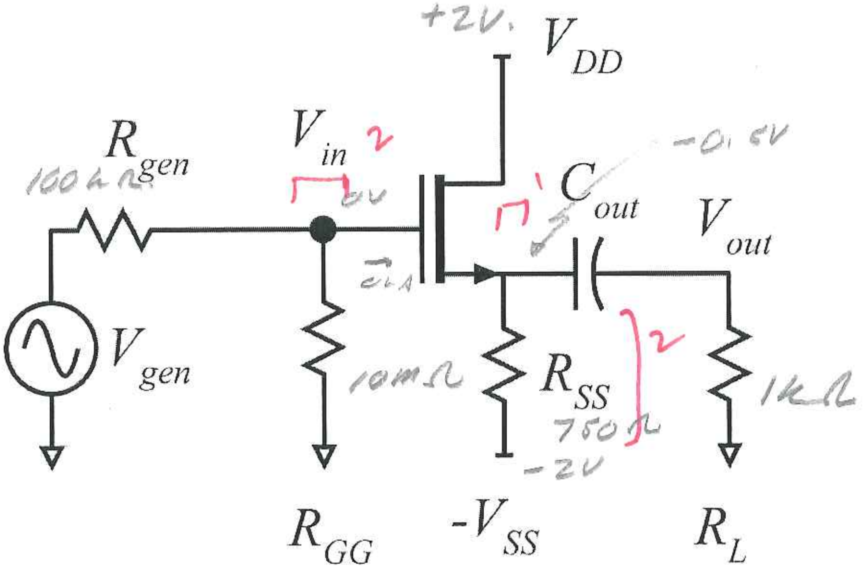
2 $$2\,mA = 3.36\,\frac{mA}{V} \cdot \frac{1}{\mu m} \cdot (0.5V - \underbrace{0.061V}_{\Delta V/2} - \underbrace{0.3V}_{V_{th}}) \cdot W_g$$

$$2\,mA = 3.36\,\frac{mA}{V} \cdot \frac{W_g}{1\mu m}\,(0.139V) \longrightarrow W_g = 4.3\mu m$$

2 $$R_{ss} = \frac{2V - 0.5V}{2mA} = \frac{1.5V}{2mA} = 0.75\,k\Omega = 750\,\Omega.$$

Part b, 5 points

DC bias



$1/\lambda = 10V.$

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

$W_g \cdot C_{ox} \cdot v_{sat} = 3.36 \frac{mA}{V} \cdot \frac{W_g}{1\mu m} = 14.4 \frac{mA}{V.}$

$R_{DS} = 5k\Omega$

$g_m = 16.6mS$

b

Part c, 5 points

Using the actual (nonzero) FET λ parameter, find the FET small signal parameters
gm= 18.1mS Rds= 5kΩ

$$g_m \triangleq \frac{\partial I_D}{\partial V_{GS}} = C_{ox} \cdot \frac{W}{L} \cdot V_{ov} (1 + \lambda V_{DS})$$

$$= 3.36 \frac{mA}{V} \cdot 4.3 \mu m \left(1 + \frac{2.5V}{10V}\right)$$

$$= 18.06 \, mS$$

3

$$R_{DS} = \begin{cases} \frac{1}{\lambda I_D} = \frac{10V}{2mA} = 5k\Omega \\ \text{or} \\ \frac{V_{DS} + 1/\lambda}{I_D} = \frac{10V + 2.5V}{2mA} = 6.25 k\Omega \end{cases}$$

2

either answer acceptable; I will use 5kΩ in the solution.

Part d, 10 points.

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

Vout/Vin= 0.877

Rin, amplfier = 10MΩ.

$$R_{Leq} = R_{SS} \| R_L \| R_{DS}$$

$$= 750\Omega \| 1k\Omega \| 56k\Omega = 395\Omega. \quad \Big] \; 3$$

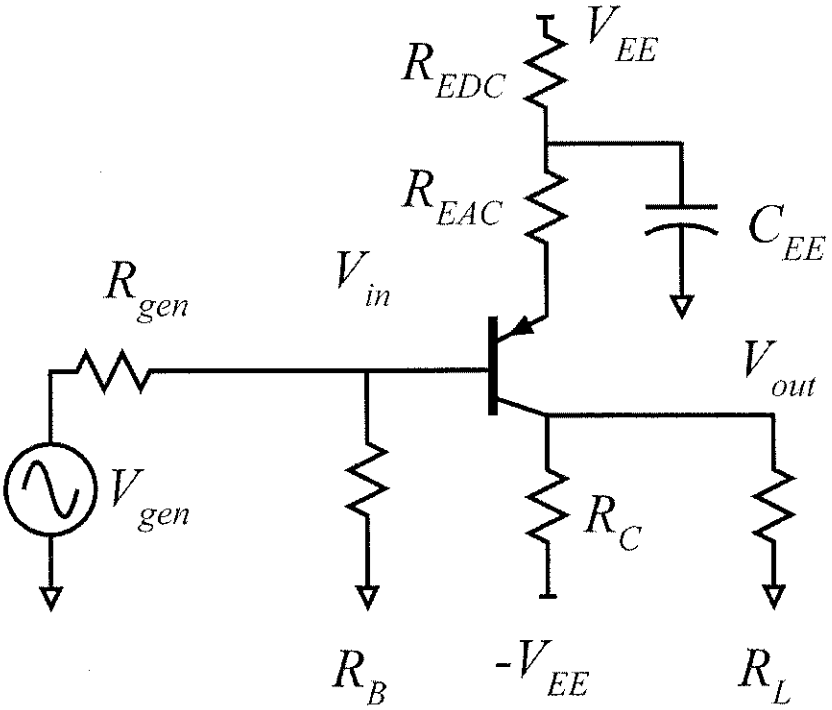
$$1/g_m = \frac{1}{18.1mS} = 55.2\Omega \quad \Big] \; 2$$

$$A_v = \frac{R_{Leq}}{R_{Leq} + 1/g_m} = \frac{395\Omega}{395\Omega + 55.2\Omega} = \underline{\underline{0.877}} \quad \Big] \; 3$$

$$R_{in\,Amp} = R_{gg} = 10M\Omega \quad \Big] \; 2$$

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 10mA collector current.
The DC collector bias voltage is 0V.
R_L is 500Ω, R_{gen} is 100 Ω, R_b is 1 kΩ, R_{EAC} is 25 Ω
C_{EE} is very large. Assume that it is an AC short-circuit.

Part a, 10 points

DC bias.

Find the following:

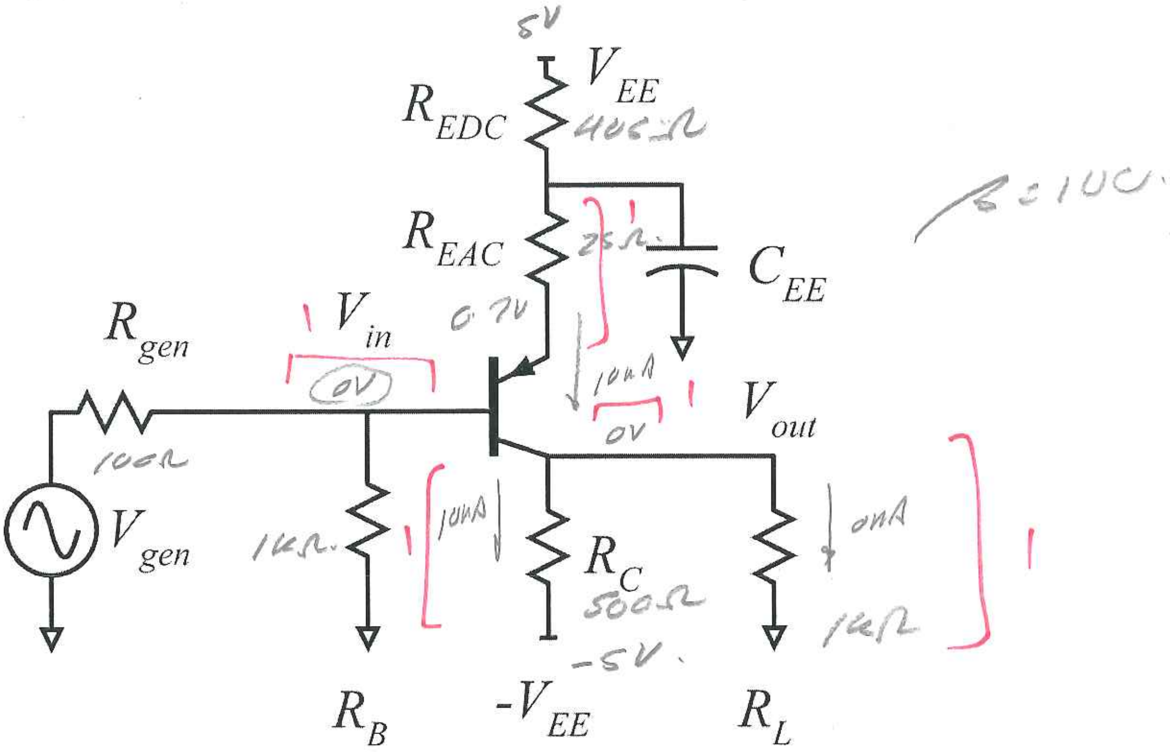
~~R_{EE} =~~________ R_C = 500Ω R_{EDC} = 405Ω

$$R_C = \frac{5V}{10mA} = 500\Omega \quad]\ 5$$

$$5\ [\ R_{EDC} = \frac{5V - 0.7V}{10mA} - 25\Omega = 430\Omega - 25\Omega = 405\Omega.$$

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=_385 mS.__ Rce=__$\infty\ \Omega$.__ Rbe=__260Ω.

$$g_m = \frac{10mA}{26mV} = \frac{1}{2.6\Omega} = 385 mS \quad \Big] \; 1$$

$$R_{CE} = \frac{V_A + V_{CE}}{I_C} = \frac{\infty + V_{CE}}{I_C} = \infty\,\Omega \quad \Big] \; 2$$

$$R_{BE} = \beta / g_m = 100 \cdot 2.6 = 260\Omega. \quad \Big] \; 2$$

Part d, 10 points.

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

Vout/Vin= -12.1

Rin,amp= $724\,\Omega$

$$R_{Leq} = R_C \parallel R_L = 500\,\Omega \parallel \cancel{1k\Omega} = 333\,\Omega$$ 2.5

500 Ω = 250 Ω

$$A_v = \frac{-R_{Leq}}{1/g_m + R_{EAC}} = \frac{-333\,\Omega}{2.6\,\Omega + 25\,\Omega} = -\cancel{12}.1$$ 2.5

-9.06

$$R_{i,T} = \beta(1/g_m + R_{EAC}) = 100(1.3\,\Omega + 25\,\Omega)$$

$$= 100(26.3\,\Omega) = 2.63\,k\Omega$$ 2.5

$$R_{i,Amp} = 2.63\,k\Omega \parallel \underset{R_B}{\underset{\uparrow}{1\,k\Omega}} = 72\cancel{4}\,\Omega.$$ 2.5

736 Ω

b

Part e, 5 points

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

(Vin/Vgen) = 0.879

(Vout/Vgen) = $-10.\cancel{6}$

-7.97

$$v_i/v_{ge} = \frac{R_{in}}{R_{in}+R_{gen}} = \frac{724\,\Omega}{724\,\Omega+100\,\Omega}$$

$$= 0.877$$

2.5

$$v_o/v_i = \frac{v_{in}}{v_{ge}}\cdot\frac{v_o}{v_i} = 0.87\cancel{6}\cdot(-12.1)$$

$$= -10.\cancel{6}$$

2.5

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 = 3.33 V ↓. 2.5V ↓

Saturation of Q1; Maximum ΔVout resulting = ____________________

Cutoff

$\Delta I_c = 10mA$ 3

$R_{Leq} = 3\cancel{3}3\Omega$ 250Ω

$\Delta V_{out} = 10mA \cdot 333\Omega = 3.\cancel{3}3V\downarrow$ 4 7

2.5V ↓

Saturation

$V_{CE\,sat} = 1/2 V$

$V_{CE,b.b} = 0.7V$

$\Delta V_{CE} = 0.2V$ ← acceptable answer 8

$$\Delta V_{out} = \Delta V_{CE} \cdot \frac{\delta V_{out}}{\delta V_{CE}} = \Delta V_{CE} \cdot \frac{R_{Leq}}{R_{Leq} + R_{ECC}}$$

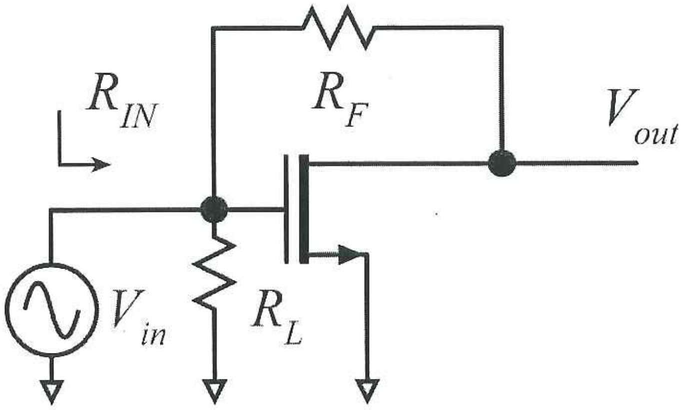
$$= 0.2V \cdot \frac{333\Omega}{333\Omega + 25\Omega} = 0.2V \cdot 0.93 =$$

$$= 0.186V.$$

more exact answer is OK

Problem 3, 20 points

nodal analysis



You will be working on the circuit to the left.

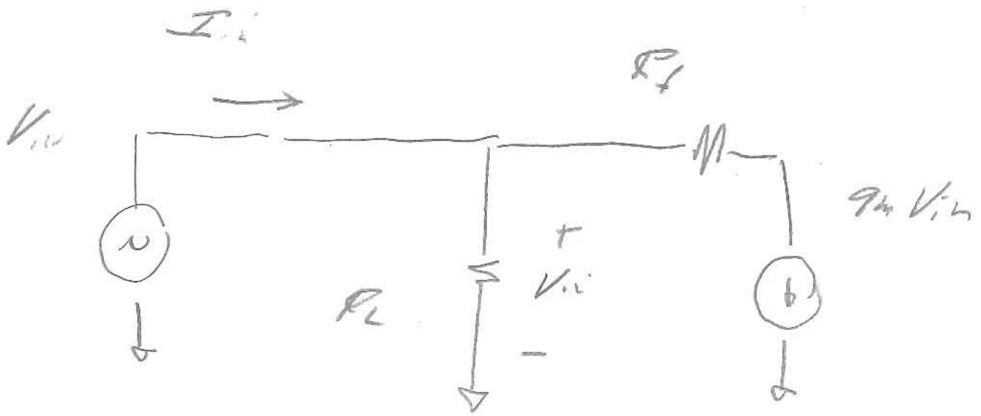
Ignore DC bias analysis. You don't need it.

The transistor has transconductance gm.

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

Part a, 8 points

Draw the small-signal equivalent circuit



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Part b, 8 points

Find, by nodal analysis, a small-signal expression for Rin.

Rin= ___________________

the currents in the 2 branches are

V_{in} / R_L and $g_m V_{in}$] 4

$R_{in} = R_L \| 1/g_{m1}$] 4

Part c, 4 points

gm= 1 mS , R_L =3kOhm, $R_f = 2$ kOHm.
Give a numerical value for Rin.

Rin= 750Ω

$$R_i = R_L \,//\, 1/g_m = 3k\Omega \,//\, 1k\Omega$$
$$= 750\Omega$$

4