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.

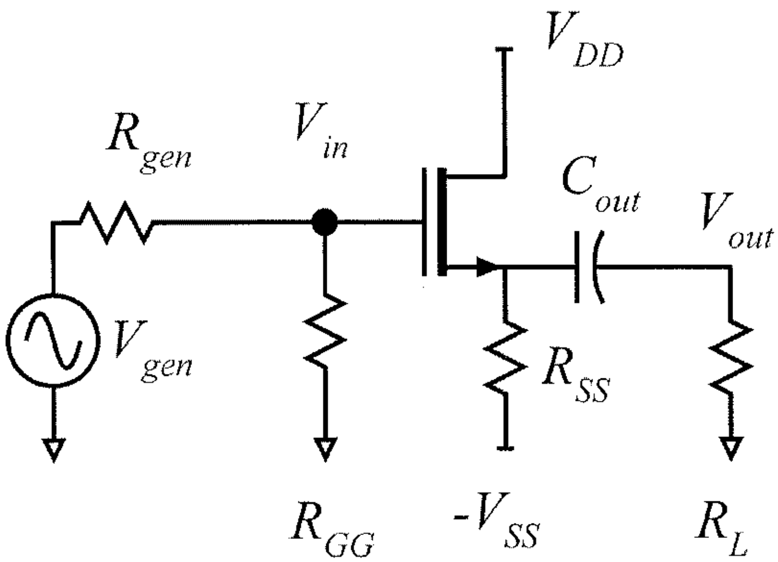
Use any and all reasonable approximations (5% accuracy is fine.),
AFTER STATING and approximately Justifying them.

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

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 +1V and -1 V

You are to bias the transistor at 1.5mA drain current, and with -0.40 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= 10.9μm   Rss= ~~1.06kΩ~~ (400 Ω)

Transistor is biased with $V_g = 0V$ & $V_s = -0.4V$] 2
→ $V_{gs} = 0.4V$

$V_{th} + \Delta V = 0.3V + 0.122V$
→ FET is mobility limited.] 2

$$I_D = \frac{\mu C_{ox}}{2L_g} \frac{W_g}{1\mu m} \cdot (1 + \lambda V_{DS})(V_{gs} - V_{th})^2$$
(1 + λV_DS) — ignore for DC.] 2

$$1.5mA = 13.8\frac{mA}{V^2} \cdot \frac{W_g}{1\mu m} \underbrace{(V_{gs} - V_{th})^2}_{0.1V}$$] 2

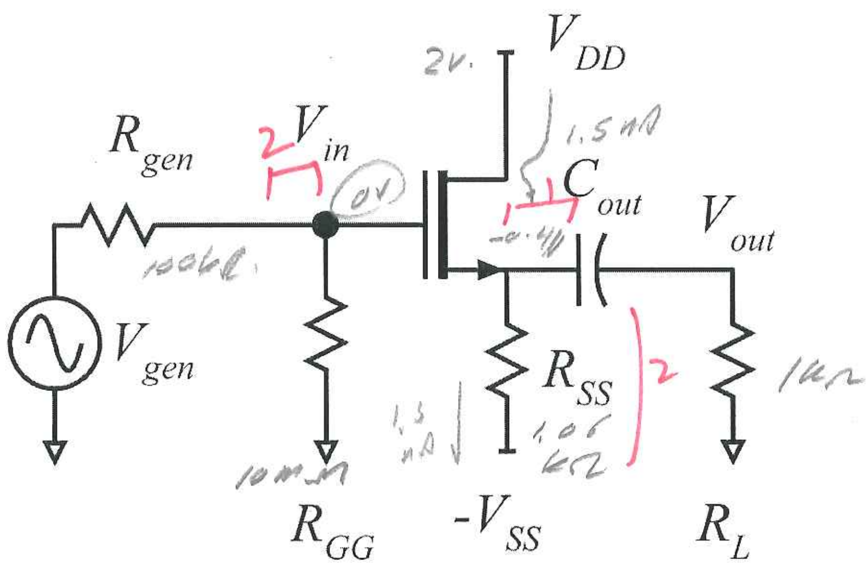
$\Rightarrow W_g = 10.87\mu m$

~~$R_{ss} = \frac{2V - 0.4V}{1.5mA} = 1.06k\Omega$~~] 2

$$\frac{1V - 0.4V}{1.5mA} = 400\Omega$$

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

Using the actual (nonzero) FET λ parameter, find the FET small signal parameters
gm=_37.3mS_ Rds=_6.66 kΩ_

34.2 mS

3

$$g_m \triangleq \frac{\partial I_D}{\partial V_{GS}} = 2 \cdot \frac{\mu C_{ox}}{2 L_g} \cdot W_g (1+\lambda V_{DS})(V_{GS}-V_{th})$$

$$= 2 \cdot 13.8 \frac{\mu A}{V^2} \cdot \frac{10.9 \mu m}{1 \mu m} \left(1 + \frac{2.4V}{10V}\right)(0.1V)$$

$$= 37.3 \text{ mS}$$

2

$$R_{DS} \approx \frac{1}{\lambda I_D} = \frac{10V}{1.5mA} = 6.66 \text{ k}\Omega$$

or

$$\frac{V_{DS} + 1/\lambda I_D}{I_D} = \frac{2.4V + 10V}{1.5mA} = 8.26 \text{ k}\Omega$$

either answer ok; I will use 6.66 kΩ

Part d, 10 points.

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

Vout/Vin= ~~0. 947~~ 0.904

Rin, amplfier = ____________________

3 $R_{Leq} = R_{SS} \,||\, R_L \,||\, R_{DS} = 1.06k\Omega \,||\, 1k\Omega \,||\, 6.66k\Omega$

$= \sout{477.6\,\Omega}$ 275.4 Ω

2 $1/g_m = \frac{1}{37.3\,mS} = 26.8\,\Omega$

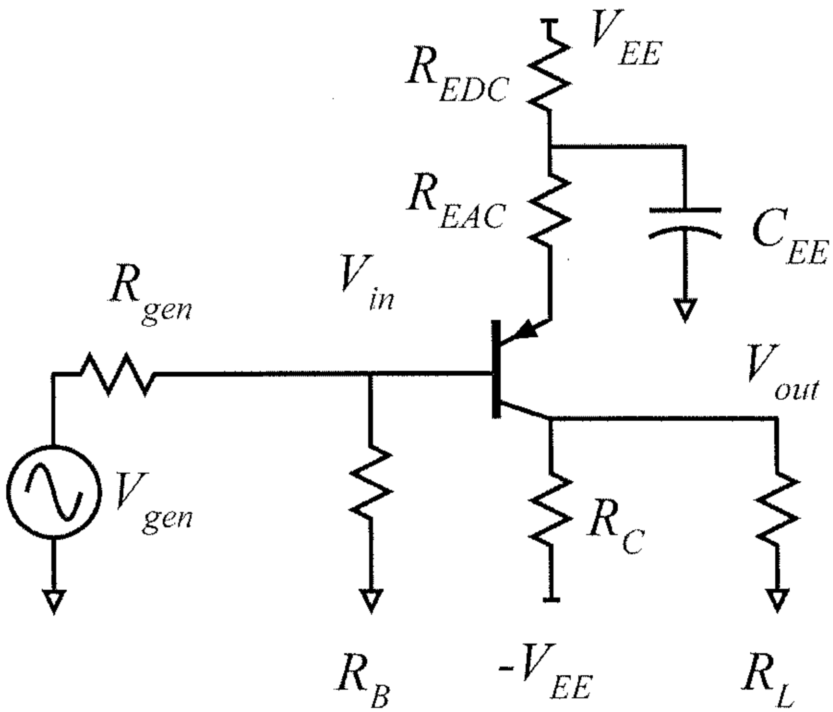
3 $A_v = \frac{R_{Leq}}{R_{Leq} + 1/g_m} = \frac{477.6\,\Omega}{477.6\,\Omega + 26.8\,\Omega}$

$= 0.947$

2 $R_{in,Amp} = R_{gg} = 1M\Omega$

Problem 2, 50 points

You will be working on the circuit below:



Q1: $\beta=100$, $V_A=$ infinity V
The supplies are +15V and -15 V.
You will bias the transistor with 2mA collector current.
The DC collector bias voltage is 0V.
R_L is 1000 Ω, 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} = 7125 Ω~~ R_C = 7.5 kΩ R_{EDC} = 7125 Ω

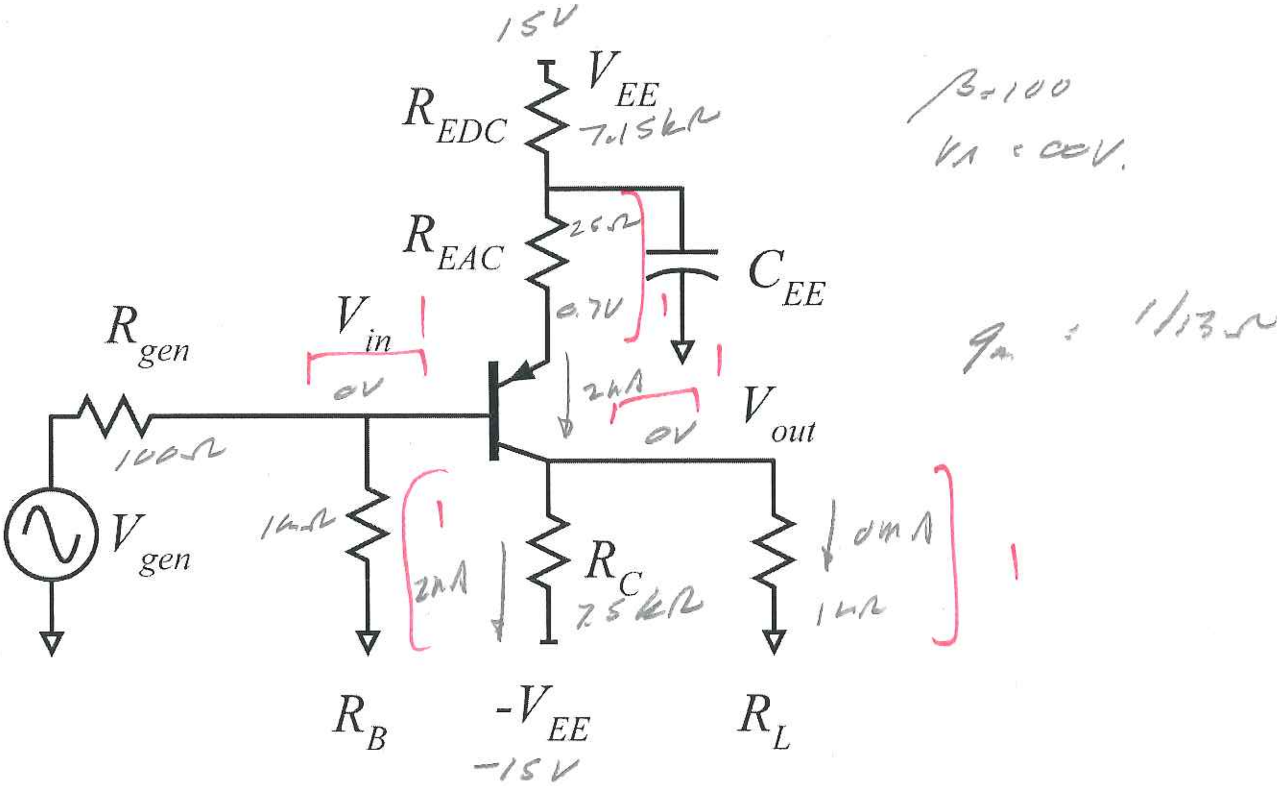
25 Ω

5 $R_{EE} = \frac{15V - 0.7V}{2mA} - R_{EDC} = 7125 \Omega$

5 $R_C = 15V/2mA = 7.5 k\Omega$

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= 76.9 mS Rce=____________ Rbe= 1.3 kΩ

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

$$R_{CE} = \frac{V_A + V_{CE}}{I_C} = \frac{0.7V + \infty}{2mA} = \infty$$] 2

$$R_{be} = \beta/g_m = 100 \cdot 13\Omega = 1.3\,k\Omega$$] 2.

Part d, 10 points.

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

Vout/Vin= − 23.2

Rin,amp= 792Ω

2.5 $R_{Leq} = R_L \,//\, R_C = 1k\Omega \,//\, 7.5k\Omega = 882\Omega$

2.5 $A_v = -\frac{R_{Leq}}{R_{EAC} + 1/g_m} = \frac{882}{25\Omega + 13\Omega} = -23.2$

2.5 $R_{in,T} = \beta\,(1/g_m + R_{EAC}) = 100\,(\underbrace{25\Omega + 13\Omega}_{38\Omega})$

$= 3.8k\Omega$

2.5 $R_{in,Amp} = 3.8k\Omega \,//\, \underset{1k\Omega}{R_B} = 792\Omega.$

Part e, 5 points

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

(Vin/Vgen) = 0.888

(Vout/Vgen) = −20.6

2.5

$$v_{in}/v_{gen} = \frac{R_{in\,Amp}}{R_{in\,Amp} + R_{gen}} = \frac{792\,\Omega}{792\,\Omega + 100\,\Omega}$$

$$= 0.888$$

2.5

$$v_o/v_{gen} = \frac{v_{in}}{v_{gen}} \cdot \frac{v_o}{v_{in}} = 0.888 \cdot (-23.2)$$

$$= -20.6$$

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 = − 1.76V ✓

Saturation of Q1; Maximum ΔVout resulting = + 0.2V.

cutoff: $\Delta I = 2mA$, $R_{Leq} = 882\Omega$

$\Delta V_{out} = 882\Omega \cdot 2mA = 1.76V$ ✓

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saturation

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

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

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

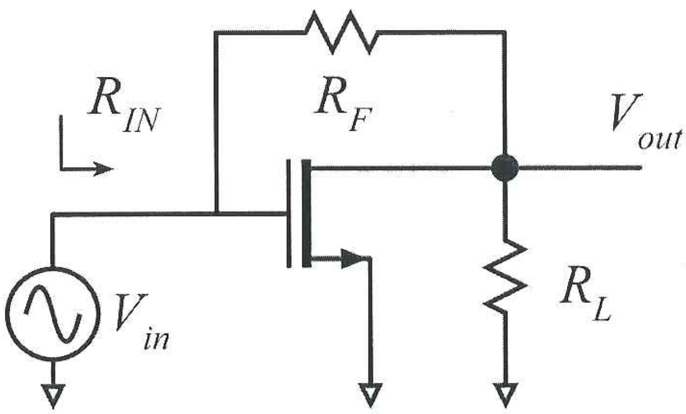
8

$$\Delta V_{out} = \Delta V_{CE} \cdot \frac{\delta V_o}{\delta V_{CE}} = \Delta V_{CE} \cdot \frac{R_{Leq}}{R_{Leq} + r_{eac}}$$

$$= 0.2V \cdot \frac{882\Omega}{882\Omega + 25\Omega} = 0.194V$$

more exact answer; either ok.

Problem 3, 20 points
nodal analysis



You will be working on the circuit to the left.

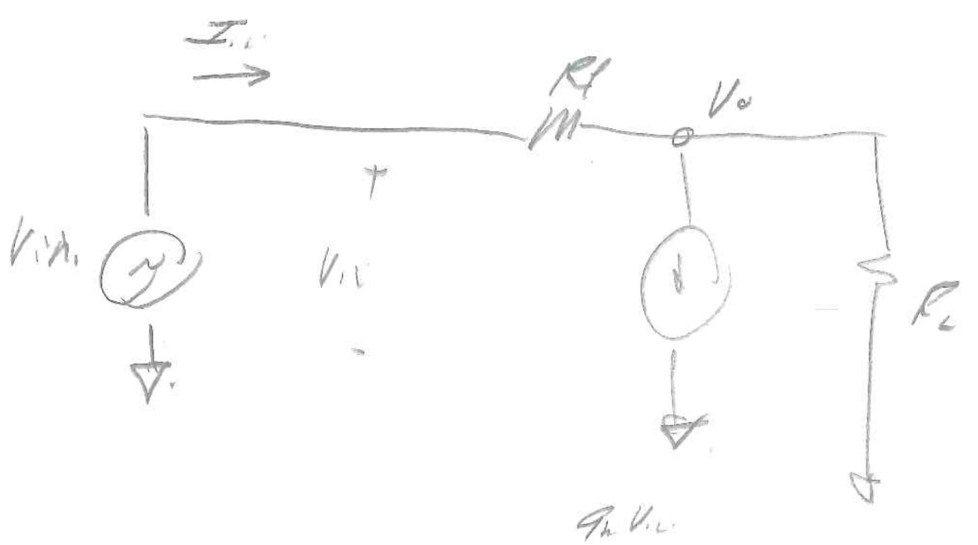
Ignore DC bias analysis. You don't need it.

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= ___________________

$G_L = 1/R_L$

$G_f = 1/R_f$

4

ΣI @ $V_{out} = 0$

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

$$V_{in}(g_m - G_f) + V_o(G_f + G_L) = 0.$$

$$V_o = V_{in} \frac{(G_f - g_m)}{G_f + G_L}$$

4

$$I_{in} = (V_{in} - V_o)G_f = G_f V_{in}\left[1 + \frac{g_m - G_f}{G_f + G_L}\right]$$

$$\frac{I_{in}}{V_{in}} = \frac{1}{R_{in}} = G_f\left[\frac{G_f + G_L + g_m - G_f}{G_f + G_L}\right]$$

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

$$\boxed{R_{in} = \frac{R_f + R_L}{1 + g_m R_L}}$$

Part c, 4 points

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

Rin= 1.25 kΩ

$$R_{in} = \frac{R_f + R_L}{1 + g_m R_L}$$

4

$$= \frac{5k\Omega}{1 + 3k\Omega \cdot 1mS} = \frac{5k\Omega}{4} = 1.25 k\Omega$$