ECE 137 A Mid-Term Exam

Wednesday, February 8, 2023

Do not open exam until instructed to.

Closed book: Class crib sheet and 1 page (both sides) 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.

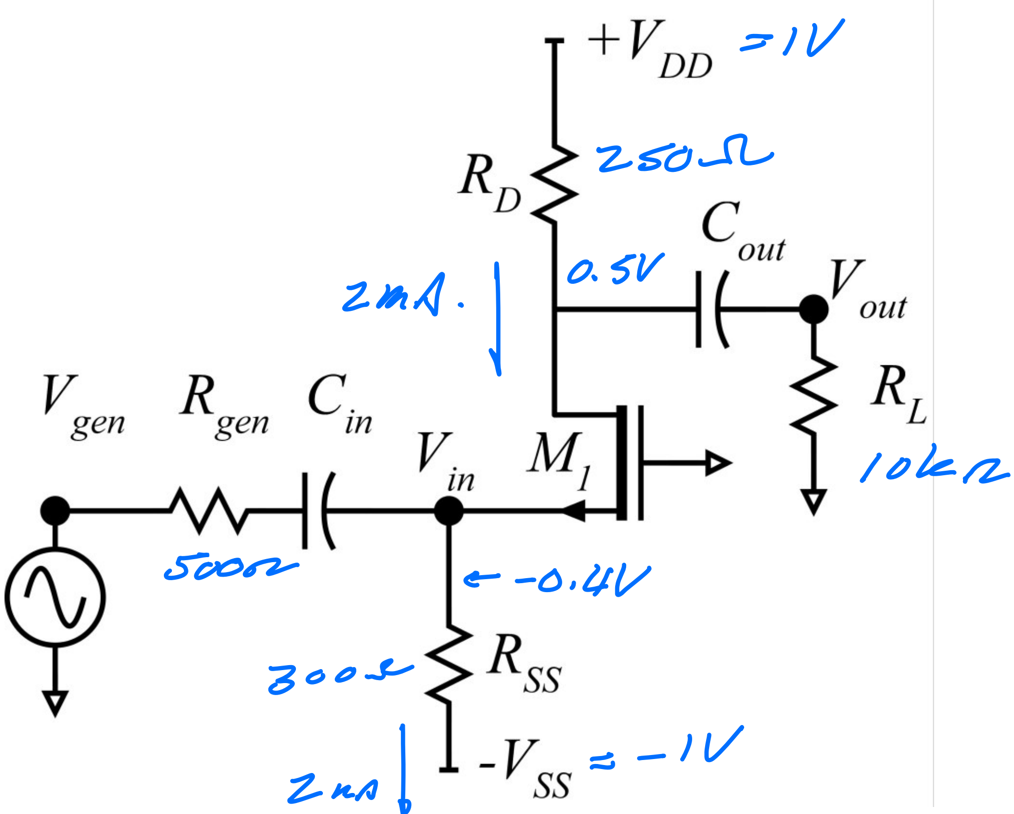
Name: Solution

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

b

Problem 1, 47 points

You will be working on the circuit below:



The transistor has

M1: $K_\mu = \mu c_{gs} W_g / 2L_g = 10\text{mA/V}^2 \cdot (W_g / 1\mu\text{m})$

$K_v = c_{gs} v_{inj} W_g = 2\text{mA/V} \cdot (W_g / 1\mu\text{m})$

$\Delta V = v_{inj} L_g / \mu = 0.1\text{V}$, $V_{th} = 0.3\text{V}$, $1/\lambda = 4\text{V}$

The supplies are +1.0V and -1.0 V

You are to bias the transistor at 2mA drain current, with -0.4 V DC source voltage, and with +0.5 V drain voltage

$R_{gen} = 500\ \Omega$, $R_L = 10\text{k}\Omega$

C_{in} and C_{out} are very large (AC short-circuits at the signal frequency)

b

Part a, 10 points
DC bias.

Find the following:
FET gate width Wg= 16.3 μm Rss= 300Ω RDD= 250Ω

2 $\left[V_{gs} - V_{th} = 0.4V - 0.3V = 0.1V \leftarrow \right.$ mobility or velocity limited. $\left. \right]$

So $I_D = 10\frac{mA}{V^2} \cdot \frac{W_g}{1\mu m} \cdot (V_{gs} - V_{th})^2 \left(1 + \frac{V_{DS}}{4V}\right)$

4

$2mA = 10\frac{mA}{V^2} \cdot \frac{W_g}{1\mu m} (0.1V)^2 \left(1 + \frac{0.9V}{4V}\right)$

$W_g = 1\mu m \cdot \frac{2mA}{0.1mA} \frac{1}{1 + 0.9/4} = 16.3\mu m$

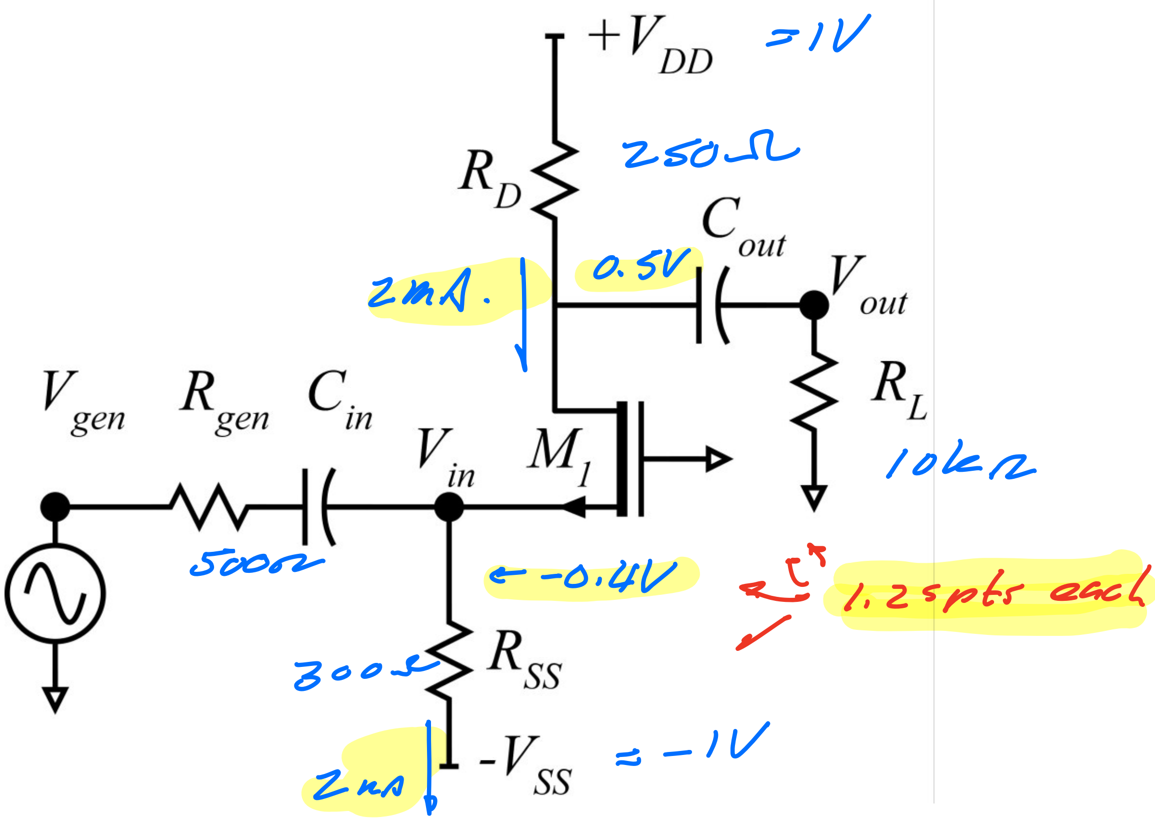
2 $\left[R_{SS} = \frac{1^V - 0.4V}{2mA} = \frac{0.6V}{2mA} = 0.3k\Omega = 300\Omega \right.$

2 $\left[R_{DD} = \frac{1 - 0.5V}{2mA} = \frac{0.5V}{2mA} = 0.25k\Omega = 250\Omega \right.$

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,** give **all resistor values**, and give the **FET width**.

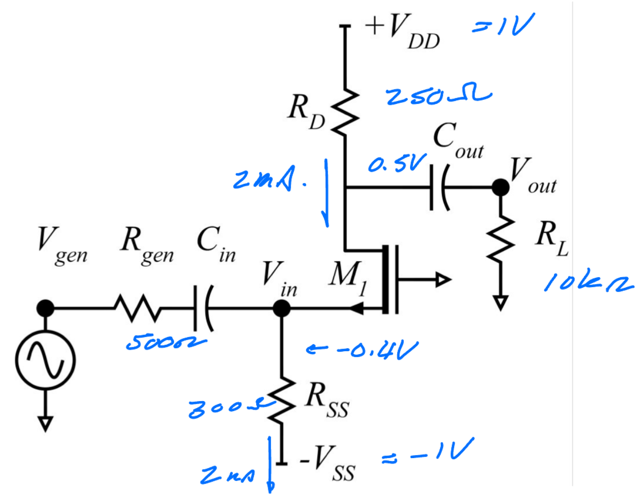
This is mostly for the TAs to use to check students' work.

b

Part c, 5 points

Find the FET small signal parameters

gm=__40mS__ Rds=__2kΩ__



M1: $K_\mu = \mu c_{gs} W_g / 2L_g = 10\text{mA/V}^2 \cdot (W_g / 1\mu\text{m})$

$K_v = c_{gs} v_{inj} W_g = 2\text{mA/V} \cdot (W_g / 1\mu\text{m})$

$\Delta V = v_{inj} L_g / \mu = 0.1\text{V}$, $V_{th} = 0.3\text{V}$, $1/\lambda = 4\text{V}$

3 $$g_m = \frac{2I_D}{V_{gs} - V_{th}} = \frac{2 \cdot 2\text{mA}}{0.4\text{V} - 0.1\text{V}} = \frac{4\text{mA}}{0.1\text{V}} = 40\text{ mS}$$

2 $$R_{DS} = \frac{1}{\lambda I_D} = \frac{4\text{V}}{2\text{mA}} = 2\text{k}\Omega$$

b

40mS 2kΩ

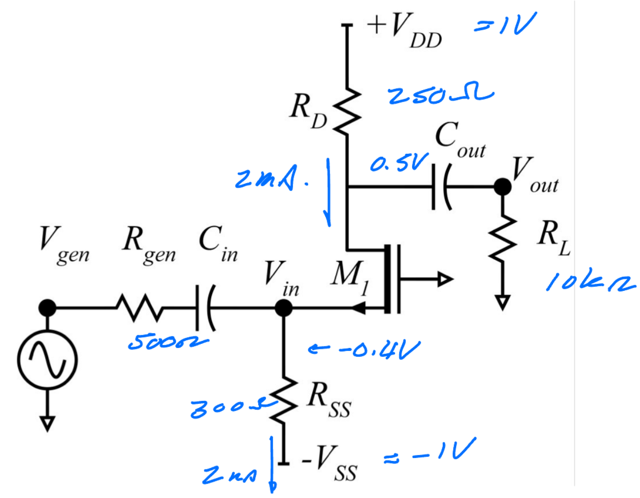
Part d, 10 points.

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

Vout/Vin= 0.866

Rin, amplfier = 116.8Ω

gm= 40mS Rds= 2kΩ



M1: $K_\mu = \mu c_{gs} W_g / 2L_g = 10\text{mA/V}^2 \cdot (W_g / 1\mu\text{m})$

$K_v = c_{gs} v_{inj} W_g = 2\text{mA/V} \cdot (W_g / 1\mu\text{m})$

$\Delta V = v_{inj} L_g / \mu = 0.1\text{V}$, $V_{th} = 0.3\text{V}$, $1/\lambda = 4\text{V}$

2 $R_{Leq} = 10k\Omega // 250\Omega = 243\Omega$

3 $R_{inT} = \frac{1}{g_m}\left(\frac{R_{DS} + R_{Leq}}{R_{DS}}\right)$

$= 250\Omega \; \frac{2k\Omega + 243\Omega}{2k\Omega}$

$= 280.6\Omega$

2 $R_{in} = R_{inT} // R_{SS}$

$= 280.6\Omega // 300\Omega = 116.8\Omega$

3 $\frac{v_o}{v_{in}} = \frac{R_{Leq}}{R_{inT}} = \frac{243\Omega}{280.6\Omega}$

$= 0.866$

Part e, 2 points

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

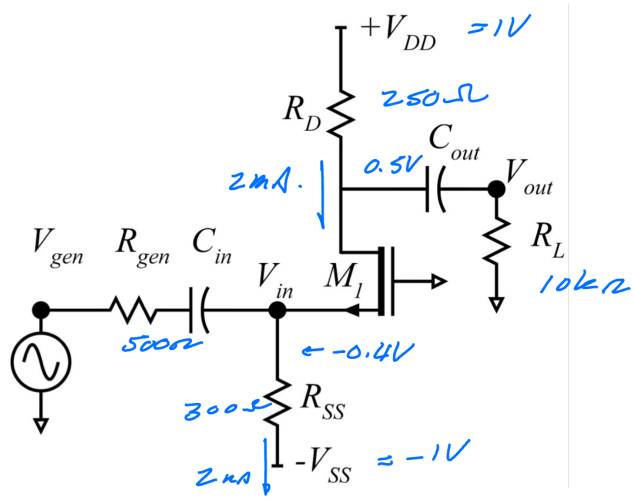
(Vin/Vgen) = 0.189

(Vout/Vgen) = 0.164

Rin, amplfier = 116.8Ω

1

$$\frac{v_{in}}{v_{gen}} = \frac{R_{in,A}}{R_{in,A} + R_{gen}} = \frac{116.8\Omega}{116.8\Omega + 500\Omega} = 0.189$$



M1: $K_\mu = \mu c_{gs} W_g / 2L_g = 10\text{mA/V}^2 \cdot (W_g / 1\mu\text{m})$

$K_v = c_{gs} v_{inj} W_g = 2\text{mA/V} \cdot (W_g / 1\mu\text{m})$

$\Delta V = v_{inj} L_g / \mu = 0.1\text{V}$, $V_{th} = 0.3\text{V}$, $1/\lambda = 4\text{V}$

1

$$v_o/v_{gen} = v_o/v_{in} \cdot v_{in}/v_{gen} = 0.866 \cdot 0.189 = 0.164$$

b

Part f, 15 points

Now you must find the maximum signal swings. Find the output voltage due to the knee voltage and cutoff in M1. ***Give the sign (+ or -) in your answers below.***

Cutoff of M1; Maximum ΔVout resulting = 0.486V ↑ (+)

Keen voltage of M1; Maximum ΔVout resulting = 0.8V ↓ (−)

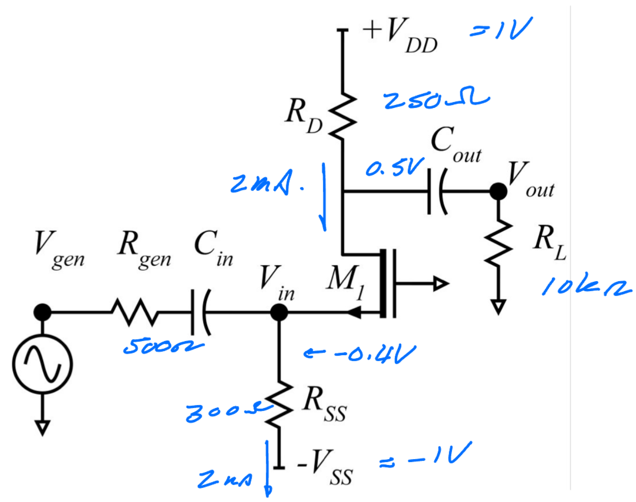
Cutoff

1 [$R_{Leq} = 10k\Omega / 250\Omega = 243\Omega$

3 [$\Delta V_{out} = 2mA \cdot R_{Leq}$

3 [$= 2mA \cdot 243\Omega$

$= 486\,mV$ ↑



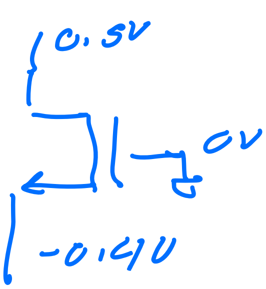
BIAS

$$M1: K_\mu = \mu c_{gs} W_g / 2L_g = 10\text{mA/V}^2 \cdot (W_g / 1\mu\text{m})$$

$$K_v = c_{gs} v_{inj} W_g = 2\text{mA/V} \cdot (W_g / 1\mu\text{m})$$

$$\Delta V = v_{inj} L_g / \mu = 0.1\text{V},\ V_{th} = 0.3\text{V},\ 1/\lambda = 4\text{V}$$

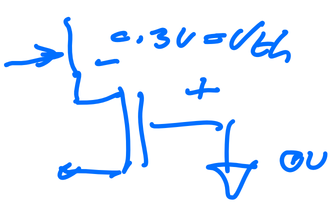
2 [



3 [$\Delta V_{out} = 0.5V + 0.3V = 0.8V$ ↓]

3 [Knee

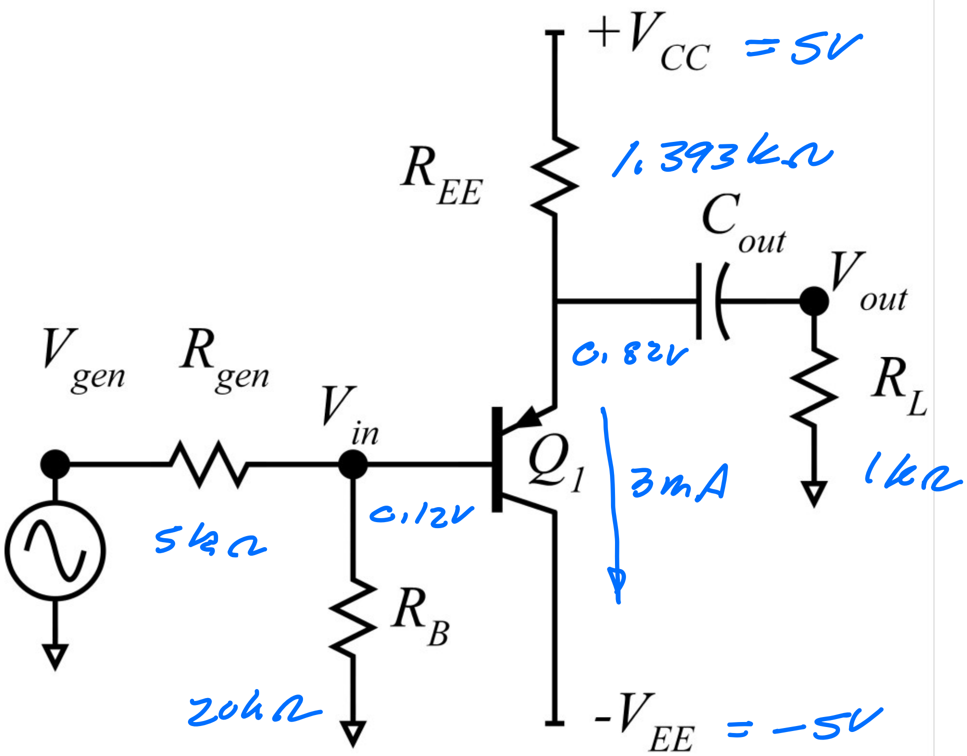
$V_D = -0.3V$



b

Problem 2, 33 points

You will be working on the circuit below:



Q1: $\beta = 100$, V_A = infinity V, Vce,sat=0.5V
The supplies are +5V and -5 V.
You will bias the transistor with 3mA collector current.
R_L is 1 kΩ, R_{gen} is 5 kΩ, R_B is 20 kΩ,
C_{out} is very large (AC short-circuit at the signal frequency)

b

Part a, 10 points

DC bias.

Find the following:

R_{EE} = 1.40 kΩ

DC voltage at the base of Q1: V_{DC_base} = + 0.12 V

Hint: there is no DC blocking capacitor in series with Vgen or Rgen.

2 $I_b = 3mA/100 = 30\mu A.$

3 $V_{DC\,base} = I_b \cdot R_b \| R_{gen} = 30\mu A \cdot 4k\Omega$

$= +120 mV$

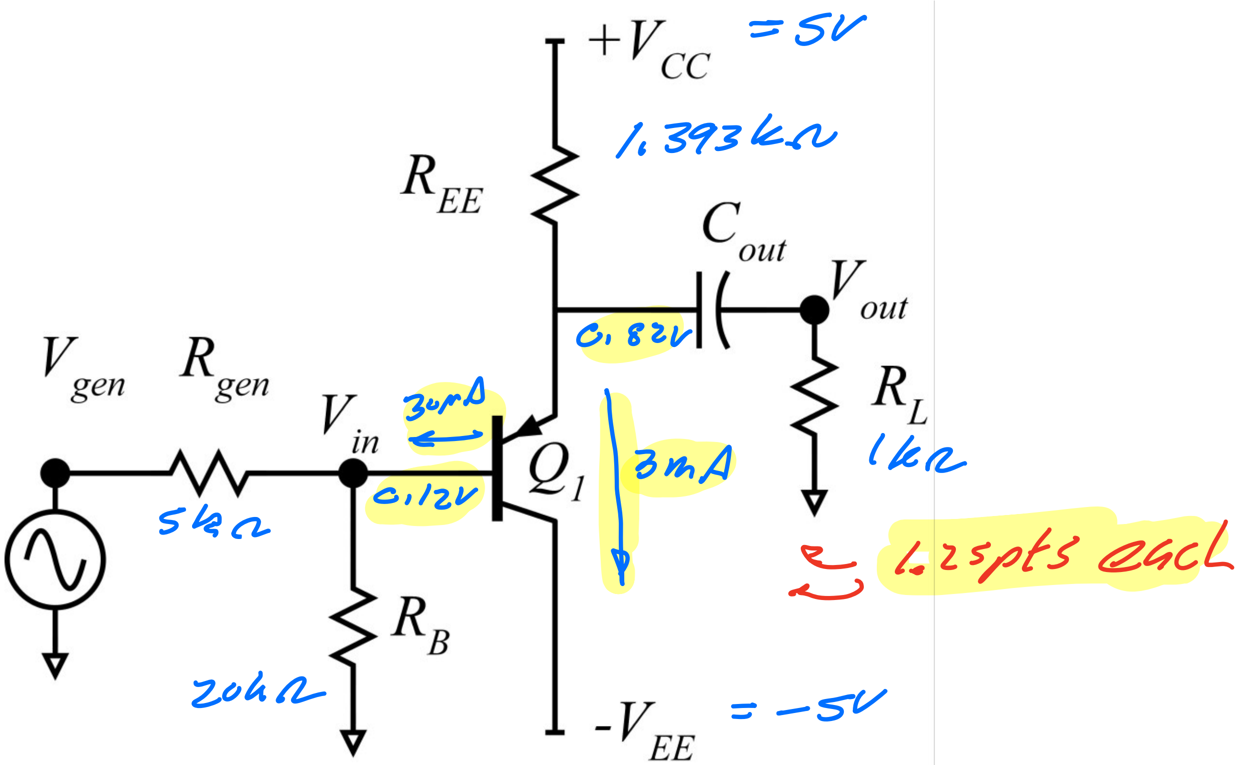
2 $V_E = V_b + V_{be} \cong 0.12V + 0.7V = 0.82V$

3 $R_{EE} = \dfrac{5V - 0.82V}{3mA} = 1.40k\Omega$

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,** and give **all resistor values**,

This is mostly for the TAs
to use to check students' work.

b

Part c, 5 points

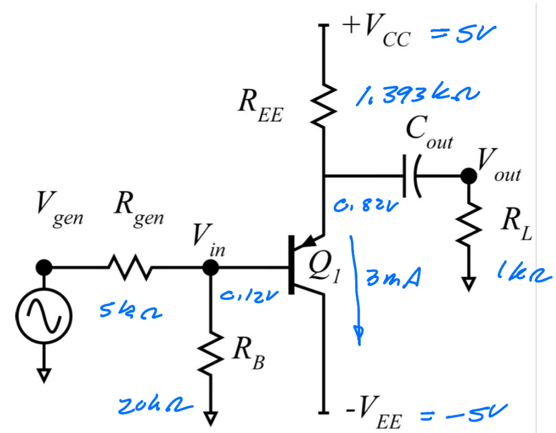
Find the small signal parameters of Q1.

gm= 115mS Rce= ∞ Ω Rbe= 866 Ω

2 $\left[g_m = \dfrac{3\,mA}{26\,mV} = 115\,mS = \dfrac{1}{8.66\,\Omega} \right.$

2 $\left[R_{ce} \simeq \dfrac{V_A}{I_C} = \dfrac{\infty\,V}{I_C} = \infty\,k\Omega. \right.$

1 $\left[r_{be} = \dfrac{\beta}{g_m} = 100 \cdot 8.66\,\Omega = 866\,\Omega \right.$



Q1: $\beta = 100$, V_A = infinity V, Vce,sat=0.5V

The supplies are +5V and -5 V.

You will bias the transistor with 3mA collector current.

R_L is 1 kΩ, R_{gen} is 5 kΩ, R_B is 20 kΩ,

C_{out} is very large (AC short-circuit at the signal frequency)

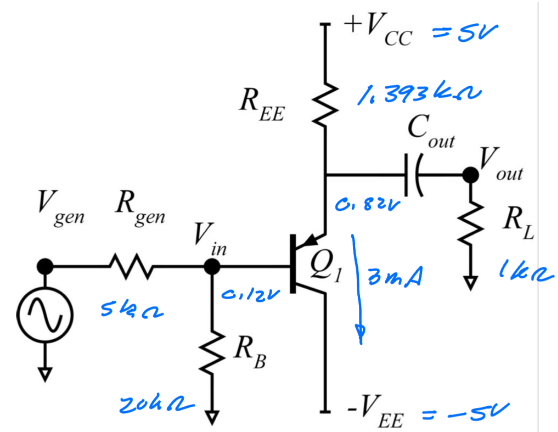
b

Part d, 10 points.

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

Vout/Vin= 0.985

Rin,amp= 14.9kΩ



Q1: $\beta=100$, V_A = infinity V, Vce,sat=0.5V
The supplies are +5V and -5 V.
You will bias the transistor with 3mA collector current.
R_L is 1 kΩ, R_{gen} is 5 kΩ, R_B is 20 kΩ,
C_{out} is very large (AC short-circuit at the signal frequency)

$$g_m = \frac{3mA}{26mV} = 115mS = \frac{1}{8.66\Omega}$$

3

$$R_{Leq} = R_{CC} \| R_{EE} \| R_L$$
$$= \infty\Omega \| 1.39k\Omega \| 1k\Omega =$$
$$= 581\Omega$$

3

$$A_v = \frac{v_o}{v_i} = \frac{R_{Leq}}{R_{Leq} + 1/g_m}$$
$$= \frac{581\Omega}{581\Omega + 8.66\Omega} = 0.985$$

2

$$R_{iT} = \beta (581\Omega + 8.66\Omega) = 59.0k\Omega$$
100

2

$$R_{iA} = R_{iT} \| R_B = 59k\Omega \| 20k\Omega = 14.9k\Omega$$

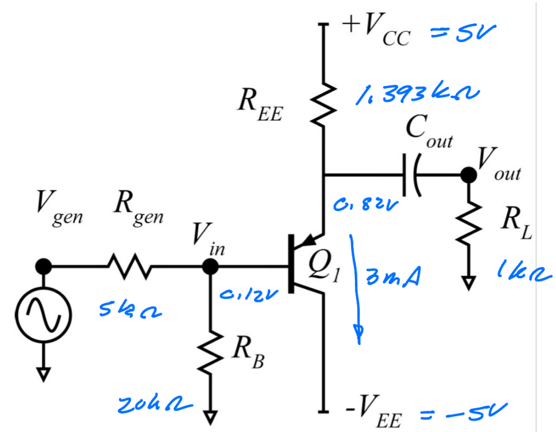
b

Part e, 3 points

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

(Vin/Vgen) = 0.750

(Vout/Vgen) = 0.740



Q1: $\beta = 100$, V_A = infinity V, Vce,sat=0.5V
The supplies are +5V and -5 V.
You will bias the transistor with 3mA collector current.
R_L is 1 kΩ, R_{gen} is 5 kΩ, R_B is 20 kΩ,
C_{out} is very large (AC short-circuit at the signal frequency)

Vout/Vin= 0.985

Rin,amp= 14.9kΩ

3

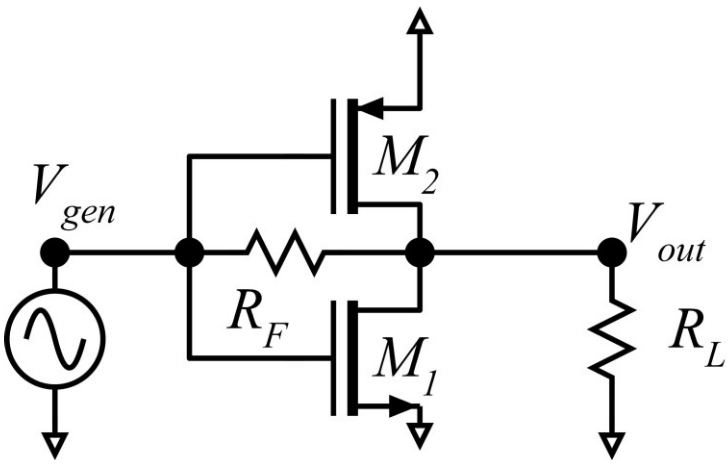
$$\frac{v_{in}}{v_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}} = \frac{14.9\,k\Omega}{14.9\,k\Omega + 5\,k\Omega} = 0.750$$

2

$$\frac{v_o}{v_{gen}} = \frac{v_o}{v_i} \cdot \frac{v_i}{v_{gen}} = 0.986 \cdot 0.750 = 0.740$$

b

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.

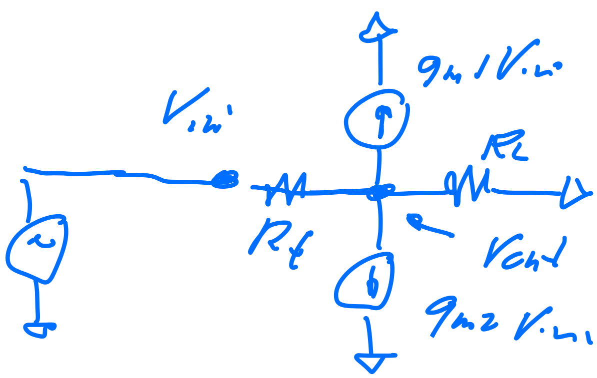
The transistors M1 and M2 have transconductance $g_{m1} = g_{m2} = g_m$

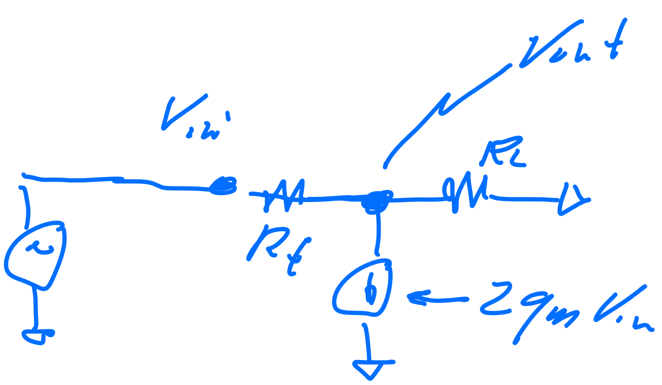
The drain-source resistances are $R_{DS1} = R_{DS2} = R_{DS} = \infty\ \Omega$ (so you don't need to draw them!)

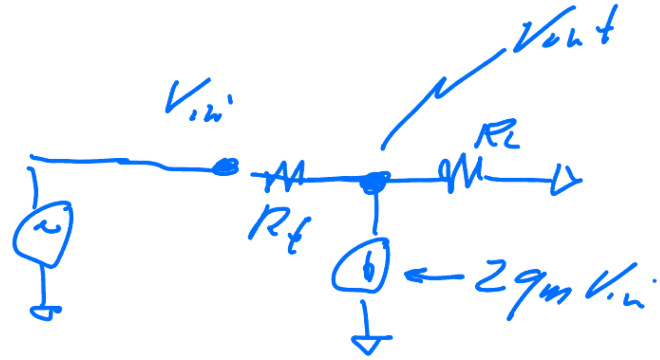
Part a, 8 points

Draw the small-signal equivalent circuit

Partial credit breakdown:
Vout & Vin labelled:
correct value of gm element?
correct topology







Part b, 8 points

Find, by nodal analysis, a small-signal expression fo

16

A_v= $-(2g_m - 1/R_f)/(1/R_f + 1/R_L)$

2 ΣI @ $V_{out} = 0$.

2 $$\frac{V_{out} - V_{in}}{R_f} + \frac{V_{out}}{R_L} + 2g_m V_{in} = 0$$

2 $$V_{out}\left(\frac{1}{R_f} + \frac{1}{R_L}\right) = -2g_m V_{in} + \frac{V_{in}}{R_f}$$

2 $$\frac{V_{out}}{V_{in}} = \frac{-(2g_m - 1/R_f)}{(1/R_f + 1/R_L)}$$

b

Part c, 4 points

gm= 1 mS , RF=1 kOhm, RL= 2 kOhm.
Give a numerical value for A_v.

A_v= -1.5

$$\frac{V_{out}}{V_{in}} = -\frac{(2g_m - 1/R_f)}{(1/R_f + 1/R_L)}$$

$$= -(2g_m - 1/R_f)(R_f \| R_L)$$

2 $$= -(2mS - 1mS)(1k\Omega \| 2k\Omega)$$

$$= -1mS \cdot 666\Omega$$

2 $$= -2/3$$

b