ECE 137 A Mid-Term Exam

Wednesday, February 5, 2025

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.

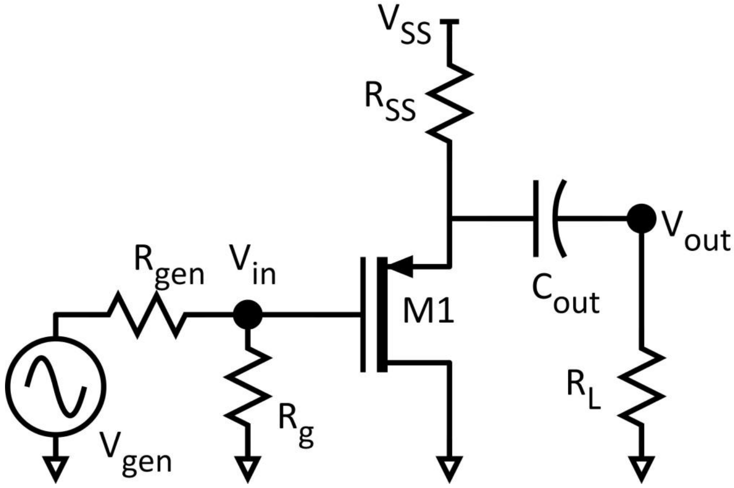
Name: Solution

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

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

$\Delta V = v_{inj} L_g / \mu = 0.1\text{V}$, $|V_{th}|$=0.25 V, $1/\lambda = 5\text{V}$

The supply is +2.0V.
You are to bias the transistor at 1mA drain current,
and with +0.35 V DC source voltage.
R_{gen}=100 kΩ, R_G=1 MΩ, R_L=5kΩ

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

b

Part a, 10 points
DC bias.

Find the following:
FET gate width Wg= 9.35 μm Rss= 1.65 kΩ

2 $V_{gs} - V_{th} = 0.1V$

2 $I_D = k_\mu (V_{gs} - V_{th})^2 (1 + \lambda V_{DS}) = 1mA$

$1 mA = K_\mu (0.1 V)^2 (1 + 0.35V/5V)$

3 $K_\mu = \frac{1 mA}{10^{-2} V^2} \frac{1}{1 + 0.35/5} = 93.5 \ mA/V^2$

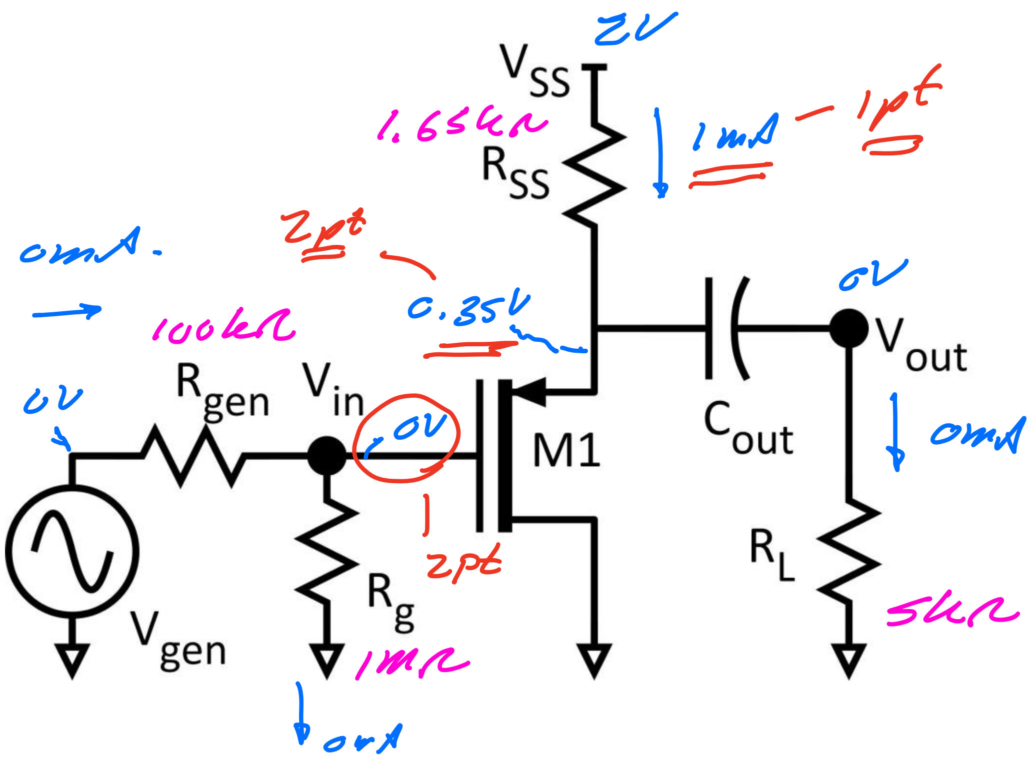
$W_g = 1 \mu m \cdot \frac{93.5 mA/V^2}{10 \ mA/V^2} = 9.35 \mu m.$

3 $R_{SS} = \frac{2V - 0.35V}{1mA} = \frac{1.65V}{1mA} = 1.65 k\Omega.$

b

Part b, 5 points

DC bias



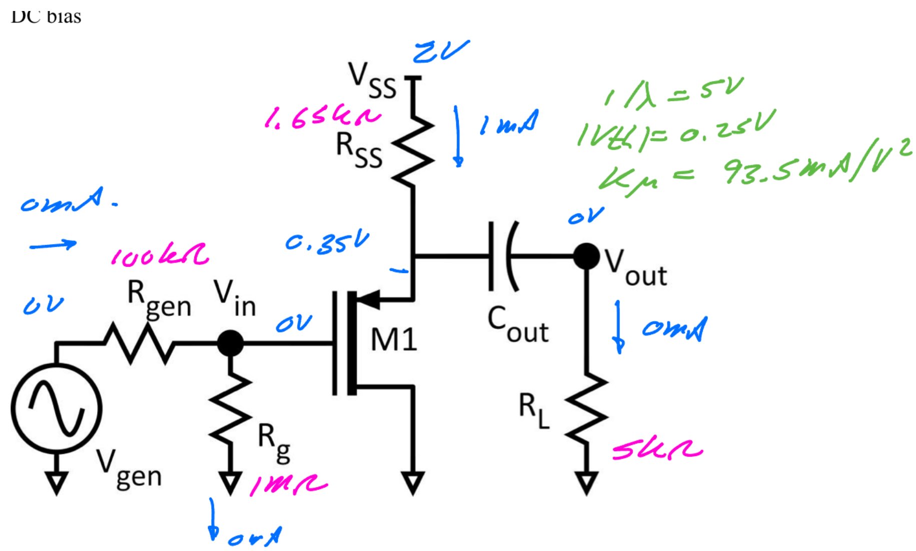
On the circuit diagram above, label the DC voltages at **ALL nodes** and the DC currents through **ALL resistors,** give **all resistor values**, and give the **FET width**.

This is mostly for the TAs to use in understanding what values, correct or incorrect, have been used to solve the problem

b

Part c, 5 points

Find the FET small signal parameters
gm=_20mS_ Rds=_5 kΩ_.



3 mobility limited:

$$g_m = 2I_D/(V_{gs}-V_{th}) = 2(1mA)/100mV = \underline{20mS}$$

2 $$R_{DS} \cong 1/\lambda I_D = 5V/1mA = 5k\Omega$$

b

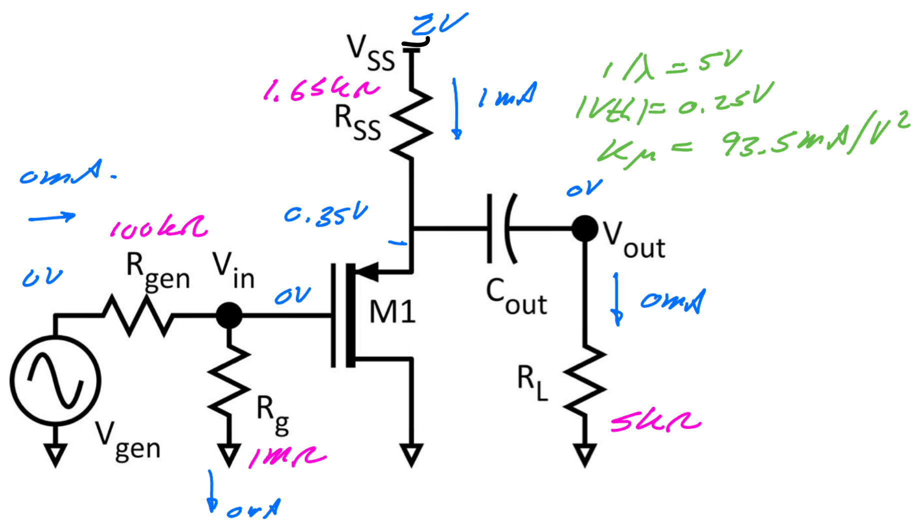
Part d, 10 points.

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

Vout/Vin= 0.952

Rin, amplifier = 1 MΩ

DC bias



3 $R_{Leq} = R_L \| R_{SS} \| R_{DS}$

$= 1.65k\Omega \| 5k\Omega \| 5k\Omega = 994\Omega$

2 $1/g_m = 1/20mS = 50\Omega$

3 $V_o/V_i = R_{Leq}/(R_{Leq} + 1/g_m)$

$= 994\Omega/(994\Omega + 50\Omega) = 0.952$

2 $R_{in} = R_g = 1M\Omega$

b

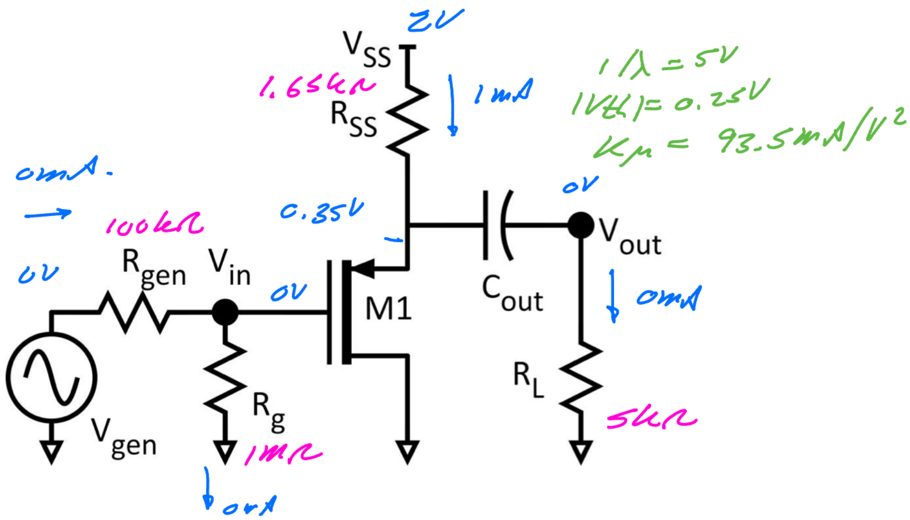
Part e, 2 points

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

(Vin/Vgen) = 0.909

(Vout/Vgen) = 0.866

DC bias



1 $\left[V_{in}/V_{gen} = \underset{1M\Omega}{R_{in}} / [R_{in} + \underset{100k\Omega}{R_{gen}}] = 0.909 \right.$

1 $\left[V_{out}/V_{gen} = V_o/V_{in} \cdot V_{in}/V_{gen} \right.$

$= 0.952 \cdot 0.909 = 0.866$

b

Part f, 15 points

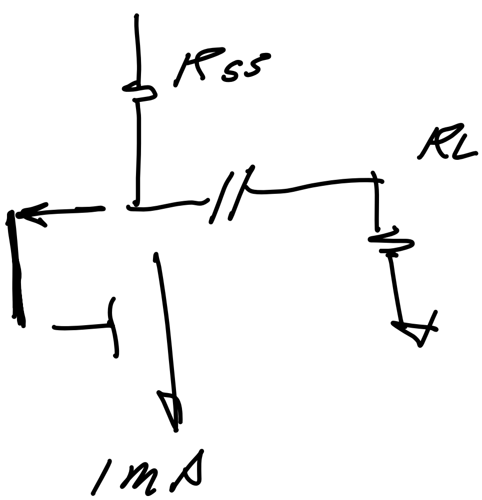
Now you must find the maximum signal swings. Find the output voltage due to the knee voltage and cutoff in M1. ***Give the sign (+ or -) in your answers below.***

Cutoff of M1; Maximum ΔVout resulting = 1.24V ↑

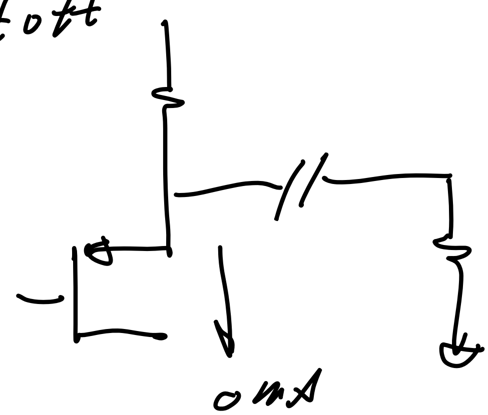
Knee voltage of M1; Maximum ΔVout resulting = −0.24V ↓

3

BIAS



cutoff



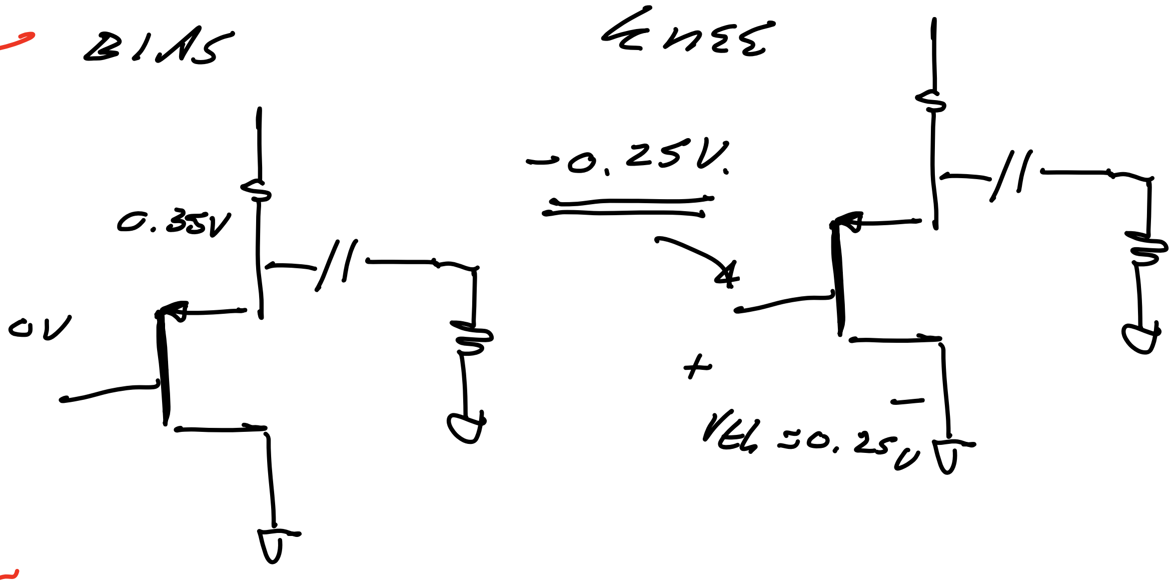
2 $\Delta I_D = 1\text{ mA}$ decrease

2 $\Delta V_{source} = \Delta V_{out} = 1\text{mA} \cdot (R_{SS} \| R_L)$

$= 1\text{mA}(1.24\text{k}\Omega)$

$= 1.24\text{V} \uparrow$

b



3

2 so $\Delta V_{in} = -0.25V$

3 $\rightarrow \Delta V_{out} = -0.25V \cdot (V_o/V_{in})$

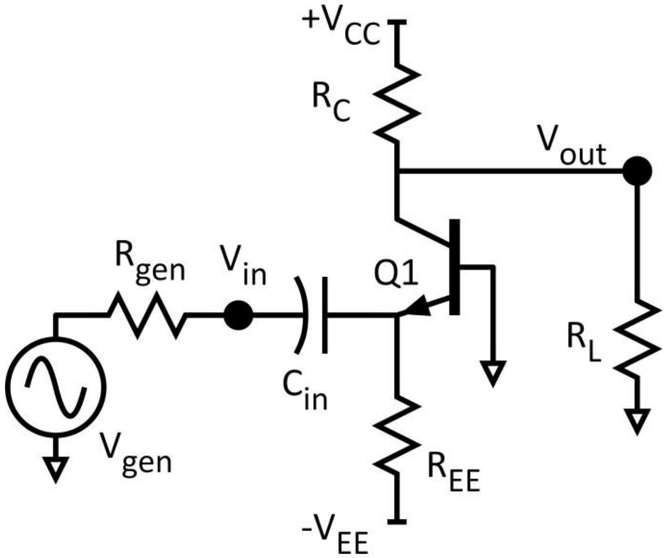
$= -0.25V(0.452) = -0.24V$

-1 pt if the gain is skipped.

b

Problem 2, 33 points

You will be working on the circuit below:



Q1: $\beta = 10^8$, V_A = infinity Volts, Vce,sat=0.5V
The supplies are +2.5V and -2.5 V.
You will bias the transistor with 5mA collector current.
You will bias the transistor with V_{out} = 0 Volts.
R_L is 1 kΩ, R_{gen} is 50 Ω.
C_{in} is very large (AC short-circuit at the signal frequency)

b

Part a, 10 points

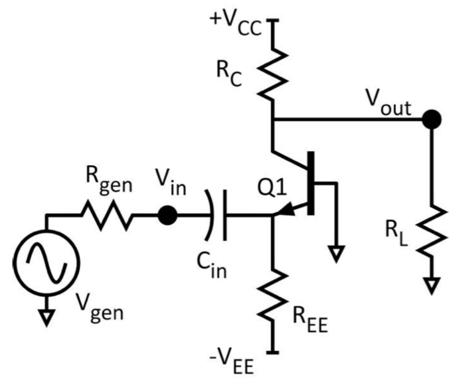
DC bias.

Find the following:

R_{EE} = 360Ω

DC voltage at the emitter of Q1: $V_{\text{DC\_emitter}}$ = −0.7V] 4

Hint: there is no DC blocking capacitor in series with Vout .



Q1: $\beta = 10^8$, V_A = infinity Volts, Vce,sat=0.5V
The supplies are +2.5V and -2.5 V.
You will bias the transistor with 5mA collector current.
You will bias the transistor with V_{out} = 0 Volts.
R_L is 1 kΩ, R_{gen} is 50 Ω.
C_{in} is very large (AC short-circuit at the signal frequency)

4 $$R_{EE} = \frac{2.5V - 0.7V}{5mA}$$

3 $$= \frac{1.8V}{5mA} = \frac{3.6V}{10mA}$$

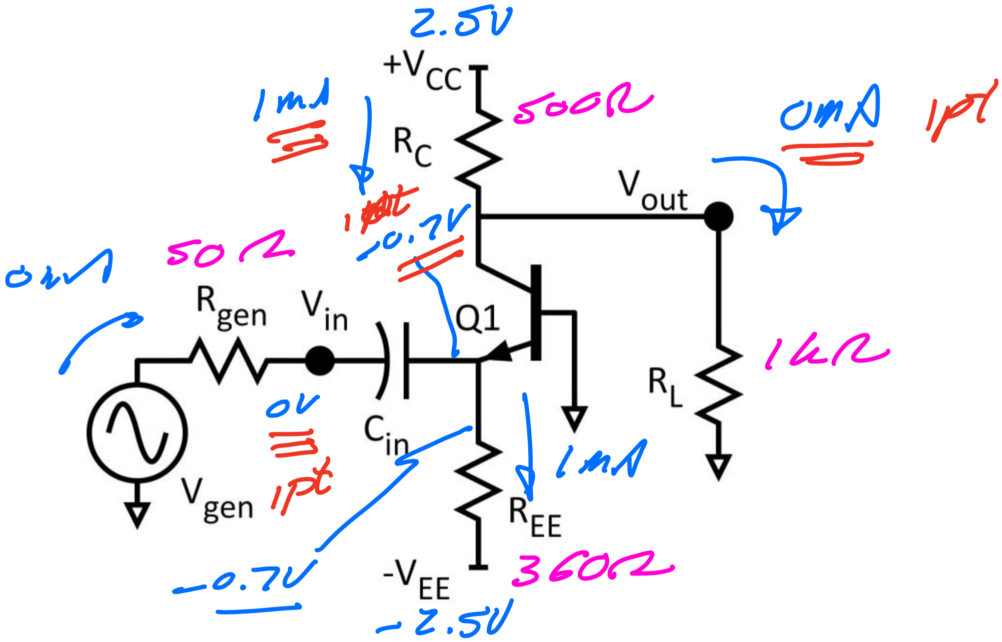
$$= 360\,\Omega$$

b

1

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**,

$$R_C = \frac{2.5V}{5mA} = \frac{5V}{10mA} = 500\Omega$$ 1pt

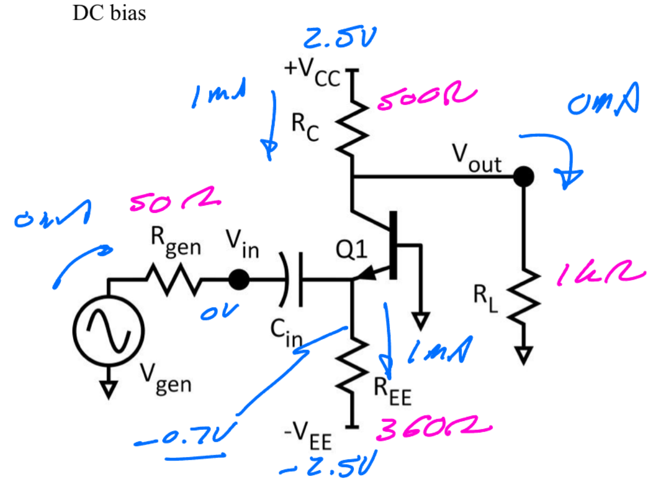
This is mostly for the TAs to use in understanding what values, correct or incorrect, have been used to solve the problem

b

Part c, 5 points

Find the small signal parameters of Q1.
gm=__190 mS__ Rce=__∞ Ω__ Rbe=__∞, large, or $5\cdot10^8\,\Omega$ - all ok.__

DC bias



3 $$g_m = \frac{5\,mA}{26\,mV} = \frac{10\,mA}{52\,mV} = \frac{1}{5.2\,\Omega} = 192\,mS$$

1 $R_{ce} = \infty\,\Omega$ because $V_A \to \infty V$

1 $R_{be} = \beta / g_m = 10^8 \cdot 5.2\,\Omega \to$ large.

b

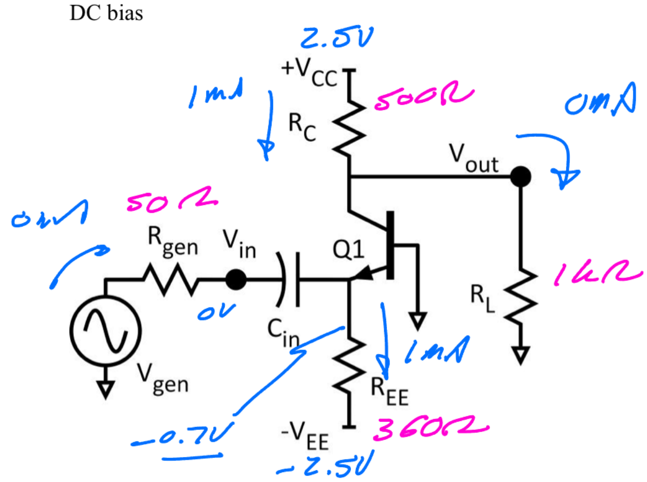
Part d, 10 points.

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

Vout/Vin= 64

Rin,amp= 5.1 Ω

DC bias



3 $R_{Leq} = 1k\Omega \,||\, 500\Omega \,||\, R_{ce}$
$\approx 333.3\,\Omega$

2 $R_{in,T} = 1/g_m = 5.2\,\Omega$

3 $V_{out}/V_{in} = R_{Leq}/R_{inT} = 333.3\Omega/5.2\Omega \approx 64.10$

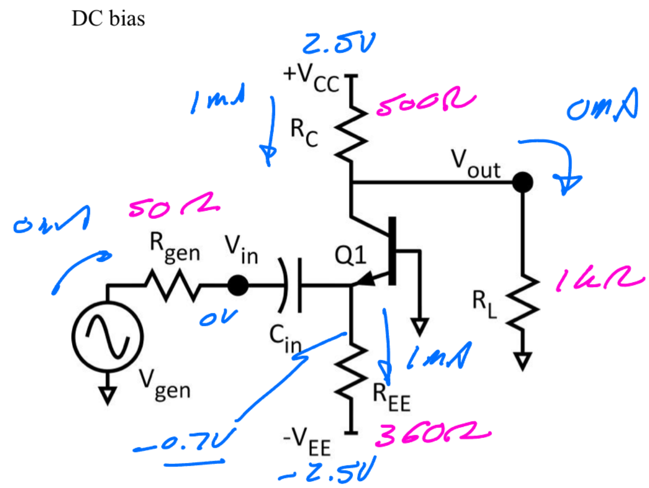
2 $R_{in\,Amp} = R_{in\,T} \,||\, R_{EE} = 5.2\Omega \,||\, 360\Omega = 5.12\Omega$

Part e, 3 points

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

(Vin/Vgen) = 0.0929

(Vout/Vgen) = 5.95



2 $V_i/V_{gen} = R_{in}/(R_{in} + R_{gen}) = 0.0929$

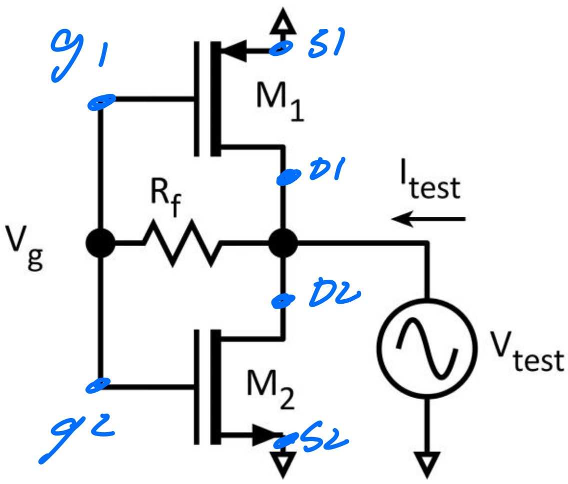
$R_{in} = 5.12\Omega$, $R_{gen} = 50\Omega$

1 $V_o/V_{gen} = V_o/V_i \cdot V_{in}/V_{gen}$

$= 64.1 \cdot 0.0929 = 5.95.$

b

Problem 3, 20 points
nodal analysis



You will be working on the circuit to the left.

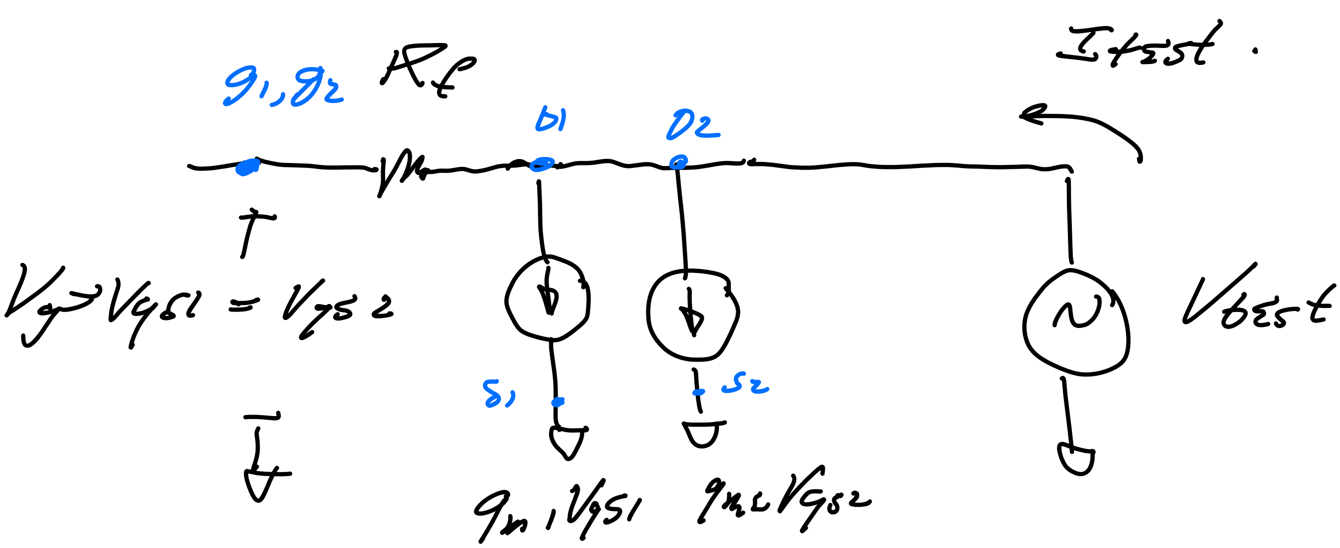
Ignore DC bias analysis. You don't need it.

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

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

Part a, 8 points

Draw the small-signal equivalent circuit



location of Vgs must be identified

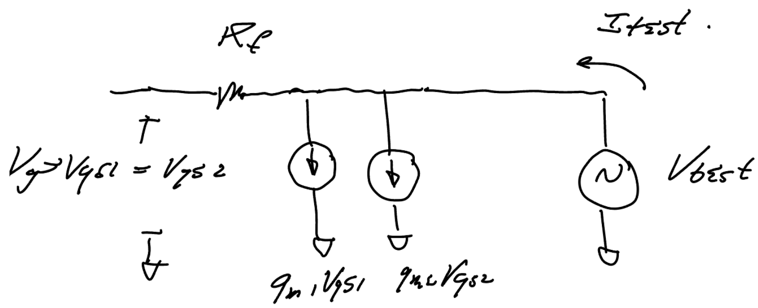
otherwise, $\boxed{-4\text{ pts}}$

b

Part b, 8 points

Find, by nodal analysis, a small-signal expression for $G_{out} = 1/R_{out} = I_{test}/V_{test}$

$G_{out} =$ $2g_m$



$V_g = V_{test}$ because current in R_f is zero.

$\Rightarrow I_{test} = (g_{m1} + g_{m2}) \cdot V_{test}$

$= 2g_m V_{test}$

$G_{out} = 2g_m$

b

Part c, 4 points

gm= 1 mS , RF=1 kOhm,
Give a numerical value for G_{out}

G_{out} = 2 mS

4 $G_{out} = 2 g_m = 2 mS.$

b