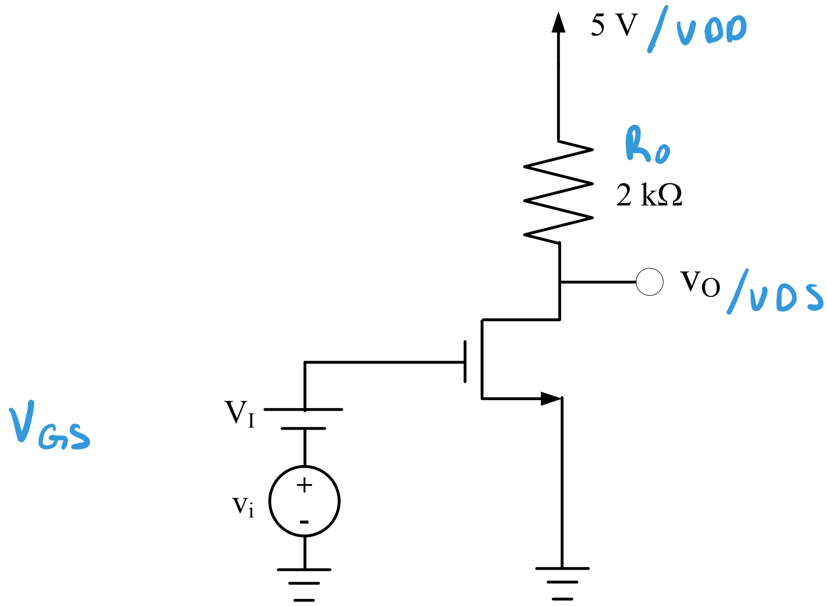
Print Your Name____

1. **[25 points]** Consider the following circuit where V_t=1V, and $k'_n(W/L) = 1mA/V^2$.



a. [10 points] Find transition points A and B and plot the voltage transfer characteristic (VTC). Use the axes on the next page and label the plot clearly including each axis. Assume that λ=0 for the DC biasing.

Point A: $V_I = V_t = 1v$

$V_O = V_{DD} = 5v$

Point B:

$V_O\ (V_{DS}) = V_I\ (V_{GS}) - V_t$

$V_I = V_{GS} = V_t + \dfrac{\sqrt{1 + 2(R_O k'_n \frac{W}{L} V_{DD}} - 1}{R_O k'_n \frac{W}{L}}$

$V_I = 2.791V$

$V_O = V_{DS} = V_I - V_T$

$V_O = 1.791V$

Point C

$V_{GS} = V_I = V_{DD} = 5v$

$V_{DS} = V_O = \dfrac{V_{GS}}{1 + R_O k'_n \frac{W}{L}(V_{GS} - V_t)}$

$V_O = \dfrac{5v}{1 + (1)(2)(5-1)}$

$V_O = 0.5556v$

A: (5, 1)

B: (1.791, 2.791)

C: (0.5556, 5)

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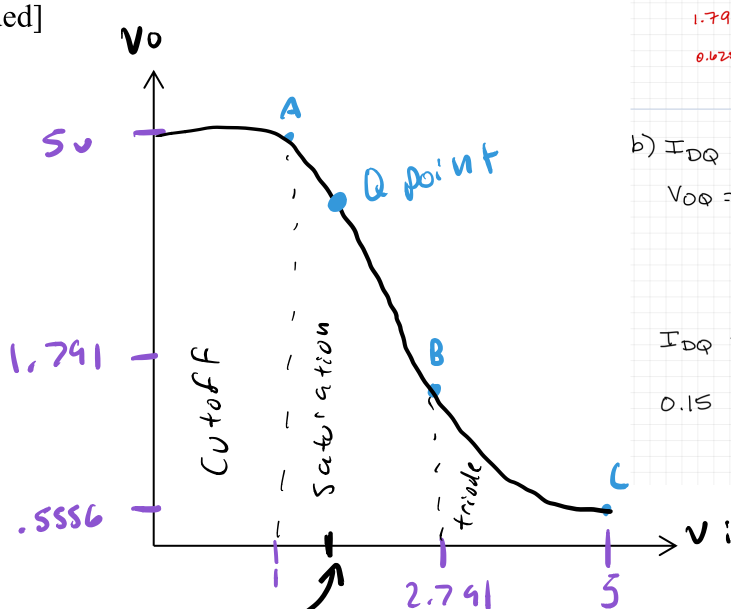
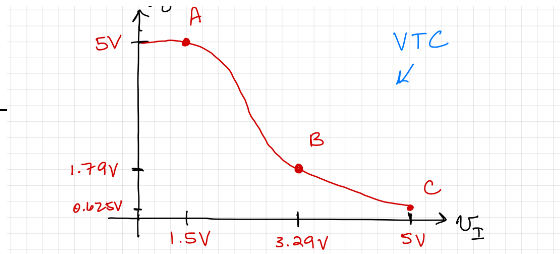
1. [continued]





b) $I_{DQ} = 0.15\,mA$

$V_{OQ} = V_{DSQ} = V_{DD} - I_{DQ} R_D$

$= 5 - (0.15)(10)$

$\boxed{V_{OQ} = 3.5V}$

$V_{IQ} = V_{GSQ}$

$I_{DQ} = \frac{1}{2} k'_n \frac{W}{L} (V_{IQ} - V_t)^2$

$0.15 = \frac{1}{2}(.2)(V_{IQ} - 1.5)^2$

$\boxed{V_{IQ} = 2.72\,V}$

b. [5 points] If V_{GSQ} = 1.5V find V_{OQ} and I_{DQ}. Label the Q-point on the plot above.

$V_{GSQ} = 1.5v$

$I_{DQ} = \frac{1}{2} k'_n \frac{w}{L} (V_{GSQ} - V_t)^2$

$I_{DQ} = \frac{1}{2} (1)(1.5-1)^2 = .125\,mA$

$V_{OQ} = V_{DD} - I_Q R_D = 5-(.125)(2) = 4.75v$

Q point = (1.5, 4.75)

c. [5 points] Draw the small signal model and find the voltage gain, v_o/v_i. Let r_o=200kΩ.

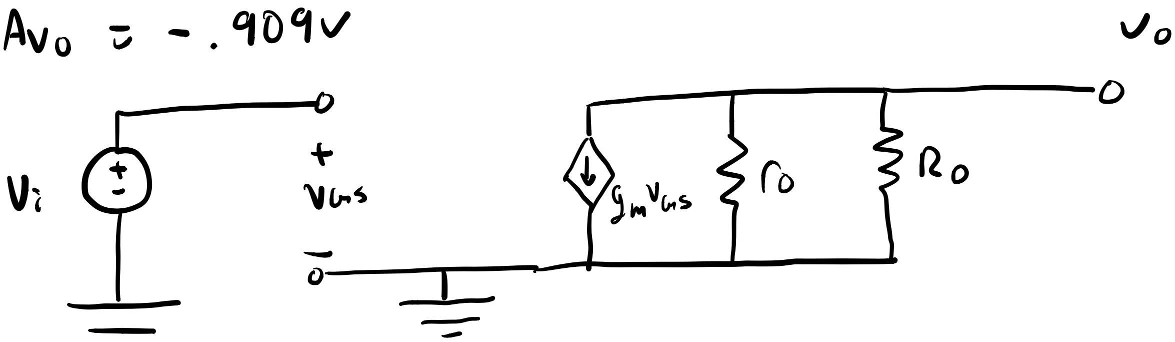
$A_{vo} = \frac{v_o}{v_i} = -g_m R_D$

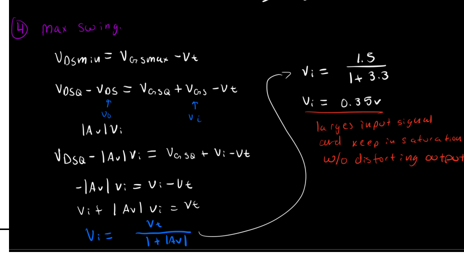
$\frac{r_o R_D}{r_o + R_D}$

$A_{vo} = -(k'_n \frac{w}{L}(V_{GQ} - V_t)) R_D$

$A_{vo} = -[1(1.5-1)](2 \| 220)$

$A_{vo} = -.909v$





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1. [continued]

d. [5 points] What is the largest (peak) value of a sinusoid (small signal) that can be applied at the input such that the transistor remains in saturation?

$V_{DSmin} = V_{GSmax} - V_t$

$V_{DSQ} - V_{DS} = V_{GSQ} + V_{GS} - V_t$

$V_{DSQ} - |A_v| v_i = V_{GSQ} + V_i - V_t$

$$V_i = \frac{\overset{\text{given}}{V_t}}{1 + \underbrace{|A_v|}_{\text{voltage gain.}}}$$

$$V_i = \frac{1}{1 + .909}$$

$$\boxed{V_i = 0.5238V}$$

2. **[10 points]** A PMOS transistor has $V_t = -2V$, $k'_p(W/L) = 90\ \mu A/V^2$, $V_{SG} = 4V$ and $V_{SD} = 3V$.

a. [5 points] Calculate the drain current, I_D, and resistance, r_o, for: $\lambda = 0$

$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right) (V_{GS} - |V_t|)^2$

$I_D = \frac{1}{2} (90\,nA/V^2)(4-2)^2$

$I_D = 180\,nA \quad .000180A$

$$r_o = \frac{1}{\lambda I_D} = \infty / \text{undefined.}$$

b. [5 points] Calculate the drain current, I_D, and resistance, r_o, for: $V_A = 50V$

$$r_o = \frac{V_A}{I_D} = \frac{50}{.000180} = 277.7\,k\Omega$$

$$\lambda = \frac{1}{V_A} = .02$$

$$\boxed{I_D' = I_D(1 + .02 \cdot 3) = .356\,mA}$$

Metric Prefix	Symbol	Multiplier (Traditional Notation)	Exponential	Description
Yotta	Y	1,000,000,000,000,000,000,000,000	10^{24}	Septillion
Zetta	Z	1,000,000,000,000,000,000,000	10^{21}	Sextillion
Exa	E	1,000,000,000,000,000,000	10^{18}	Quintillion
Peta	P	1,000,000,000,000,000	10^{15}	Quadrillion
Tera	T	1,000,000,000,000	10^{12}	Trillion
Giga	G	1,000,000,000	10^{9}	Billion
Mega	M	1,000,000	10^{6}	Million
kilo	k	1,000	10^{3}	Thousand
hecto	h	100	10^{2}	Hundred
deca	da	10	10^{1}	Ten
base	b	1	10^{0}	One
deci	d	1/10	10^{-1}	Tenth
centi	c	1/100	10^{-2}	Hundredth
milli	m	1/1,000	10^{-3}	Thousandth
micro	μ	1/1,000,000	10^{-6}	Millionth
nano	n	1/1,000,000,000	10^{-9}	Billionth
pico	p	1/1,000,000,000,000	10^{-12}	Trillionth
femto	f	1/1,000,000,000,000,000	10^{-15}	Quadrillionth
atto	a	1/1,000,000,000,000,000,000	10^{-18}	Quintillionth
zepto	z	1/1,000,000,000,000,000,000,000	10^{-21}	Sextillionth
yocto	y	1/1,000,000,000,000,000,000,000,000	10^{-24}	Septillionth

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3. **[20 points]** You are given a common gate amplifier using an NMOS transistor for which V_t=0.8V, $k'_n(W/L)$ = 2mA/V^2, and λ=0. The Q-point is at V_{GSQ} = 1.5 V. There is a drain resistance, R_D=4.7kΩ and a load resistance, R_L=10kΩ. The amplifier is driven by a signal source, v_{sig}, in series with a signal resistance, R_{sig}, 400 Ω.

   a. [5 points] Find I_{DQ} and g_m.

$I_{DQ} = \frac{1}{2} k'n \frac{W}{L} (V_{GSQ} - V_t)^2 = \frac{1}{2} (2mA)(1.5 - .8)^2 = .49mA$

$I_{DQ} = .49mA$

$g_m = k'n \frac{W}{L} (V_{GSQ} - V_t) = (2mA)(1.5 - .8) = 1.4$

   b. [15 points] Draw the small-signal model (use the T-model). Label and solve for the input resistance, R_{in}, the output resistance, R_o, the open-loop voltage gain, A_{vo}, and the overall voltage gain, G_v. You must derive the equations for A_{vo} and G_v (i.e. don't just write equations from your cheat sheet).

$R_{in} = 1/1.4 = 714.29\Omega$

R_O

A_{vO}

G_V

$G_V = \frac{R_O \| R_L}{R_{sig} + 1/g_m} = \frac{(4.7k\Omega \| 10k\Omega)}{400 + 714.29\Omega}$

$G_V = \frac{3197\Omega}{400 + 714.29} = 2.87$

$A_{vO} = g_m \cdot R_O = .0014(4.7k\Omega) = 6.58 V/V$

$R_O = R_D = 4.7k\Omega$

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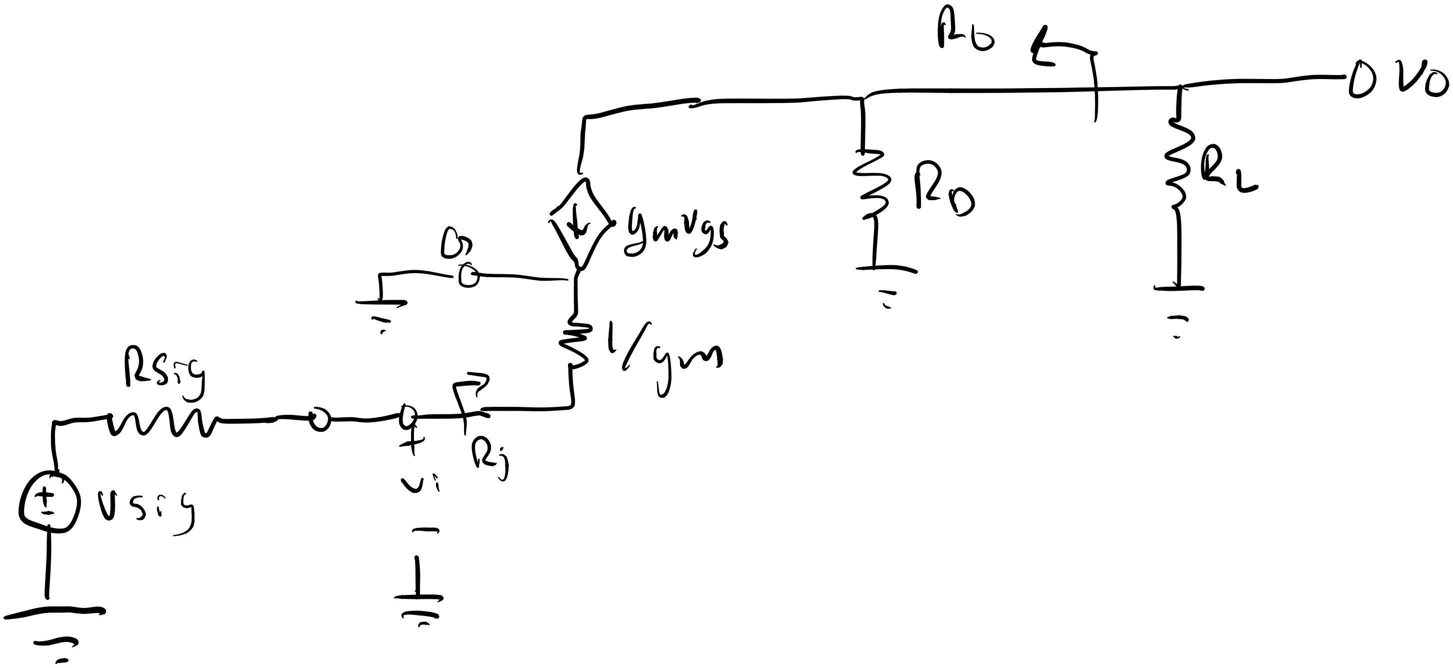
3. [continued]



4. **[10 points]** Consider the circuit given where V_t = -1.2V, k'_p(W/L) = 150 μA/V^2, and λ=0. Design the resistor, R, such that V_{GS} = 2.1V.

$V_t = V_{SG} = -1.2v$

$k'_n (W/L) = 150 \mu A/v^2$

$\lambda = 0$

$R = ?$

$V_{GS} = 2.1v$

$I_D = \frac{1}{2}(150)(2.1 - 1.2)^2$

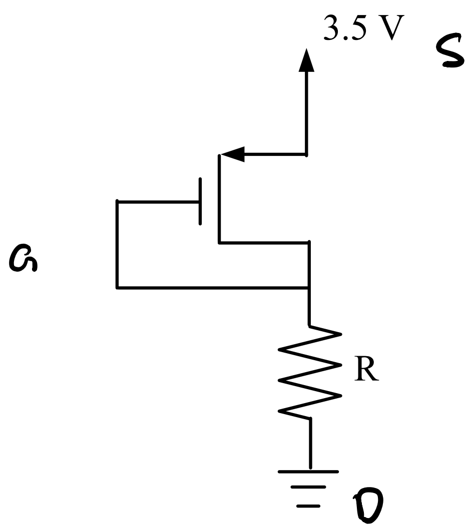
$I_D = 60.75 \mu A$

$V_D = V_S - V_{GS}$

$V_D = 1.4V$

$R = \frac{V_D}{I_D} = \frac{1.4}{60.75E\text{-}6}$

$R = 23.05 k\Omega$



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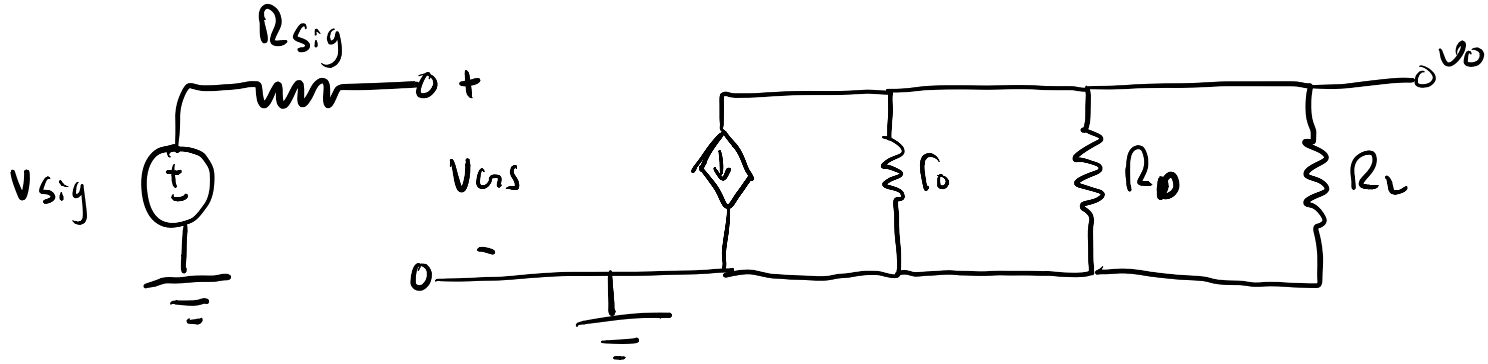
5. [20 points] A common source amplifier is fed with a 0.5 MΩ source and connected to a 15 kΩ load. The MOSFET has $V_t = 1.5V$, $k'_n(W/L) = 2\ mA/V^2$, and V_A=30V. The circuit is DC-biased at I_{DQ} = 0.5mA The drain resistor is 8 kΩ and the load resistor is 10kΩ. Draw the small signal model and find the overall voltage gain, G_V, the output resistance, R_O, and the input resistance, R_{in}.

0.5MΩ source — G_v — $I_{DQ} = 0.5mA$

15kΩ load — R_o — $R_D = 8k\Omega$

$V_t = 1.5v$ $k'_n \frac{W}{L} = 2mA/v^2$ — R_{in} — $R_L = 10k\Omega$



$$r_o = \frac{V_A}{I_{DQ}} = \frac{30}{.5mA} = 60k\Omega$$

$$R_{in} = \infty$$

$$R_o = (r_o \| R_D) = 7.06k\Omega$$

$$V_{gsQ} = V_t + \sqrt{\frac{2I_{DQ}}{k'_n \frac{W}{L}}} = 2.207v$$

$$g_m = .002(2.207 - 1.5)$$

$$g_m = .001414$$

$$G_v = -g_m(r_o \| R_D \| R_L)$$

$$G_v = -.001414(60\|10\|18) = -5.85\ v/v$$

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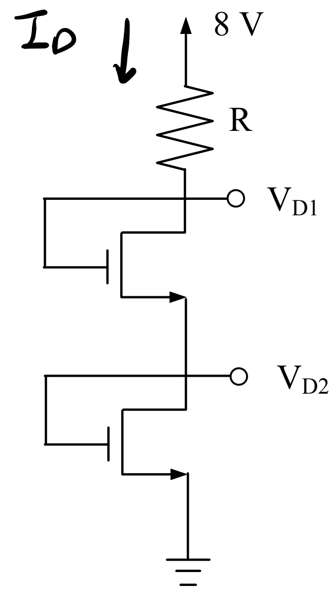
6. [15 points] Find the V_{D1} and V_{D2} and design the resistor for a drain current of 1mA given that both MOSFETS have V_t=1V and k'_nW/L=5 mA/V^2.

$V_{D1} = ?$ $\quad I_D = 1mA$

$V_{D2} = ?$ $\quad V_t = 1V$

$R = ?$ $\quad k'_n \frac{W}{L} = 5mA/V^2$



$$I_D = \frac{1}{2}(k'_n \tfrac{W}{L})(V_{GS1} - V_t)^2$$

$$1mA = \frac{1}{2}(5mA)(V_{GS1} - 1)^2$$

$$\sqrt{1/(2.5)} + 1 = V_{GS1}$$

$$V_{GS1} = 1.632V$$

$$V_{GS1} = V_{D1} - V_{D2}$$

$$V_{D2} = 1.63V$$

$$V_{D1} = 3.26V$$

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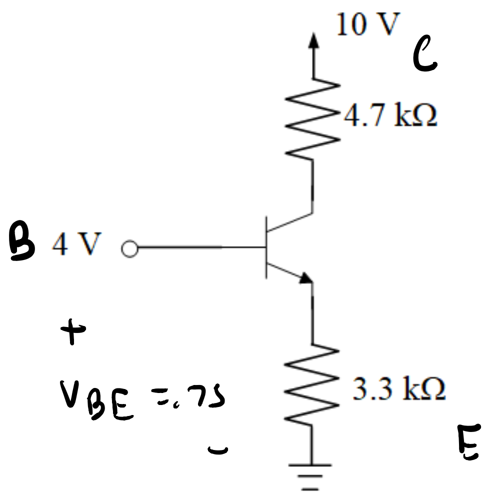
7. [15 points] Given the following npn BJT with V_{BE}=0.75 V and α=.99. What are the base, collector, and emitter currents?

$V = I \Omega$



$i_C = \alpha \cdot i_E = 975 nA$

$i_B = 985 nA - 975 nA = 10 nA$

$i_E = \dfrac{3.25}{3.3k\Omega} = 985 nA$

$V_E = 4 - .75 = 3.25v$