Homework Assignment #6

ECE 0257 – Spring 2019

Name

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Collaborators

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Book Problems

Sedra & Smith 7.1

Sedra & Smith 7.25

Sedra & Smith 7.29

Sedra & Smith 7.30

Sedra & Smith 7.33

Sedra & Smith 7.122

Simulation Problems

Exercises (a) – (n)

Check-list Before Submission

- ☐ Write within boxes, no boxes are moved
- ☐ Write your full names in designated area
- ☐ Save this file as a PDF before uploading, keep the number of pages (**18**) unchanged
- ☐ Notify "TO BE CONTINUED" accordingly if you used the extra pages (page 16-18)

Sedra & Smith 7.1

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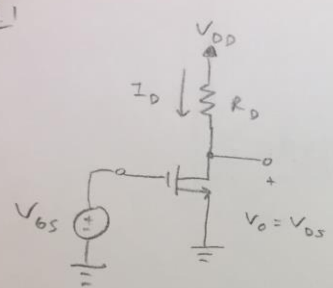
CoE 0257
Homework 6

7.1



$V_{DD} = 5\text{ V}$

$V_t = 0.5\text{ V}$

$k_n = 10\ \frac{\text{mA}}{\text{V}^2}$

$R_D = 20\text{ k}\Omega$

Saturation: $V_{DS} \geq V_{GS} - V_T$ (Point A)

Point A is (V_t, V_{DD})

$= (0.5\text{ V}, 5\text{ V})$

B is where $V_{GS} - V_T > V_{DS}$

$(V_{GS}|_B,\ V_{GS}|_B - V_T)$

$$V_{GS}|_B = V_t + \frac{\sqrt{2k_nR_DV_{DD}+1} - 1}{k_nR_D}$$

$$= 0.5 + \frac{\sqrt{2(.01\text{ A/V}^2)(20{,}000\ \Omega)(5\text{ V})+1} - 1}{(.01\text{ A/V}^2)(20{,}000\ \Omega)} = 0.72\text{ V}$$

$V_{GS}|_B - V_t = 0.72 - 0.5 = 0.22\text{ V}$

Point A: $(0.5\text{ V}, 5\text{ V})$
Point B: $(0.72\text{ V}, 0.22\text{ V})$

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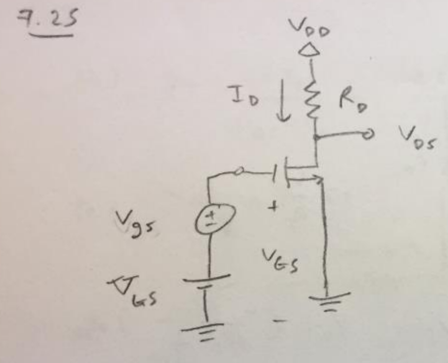
7.25



$V_t = 0.4\ V$

$k_n = 5\ \frac{mA}{V^2}$

$V_{GS} = 0.6\ V$

$V_{DD} = 1.8\ V$

$R_D = 10\ k\Omega$

(a) $I_D = \frac{1}{2}\left(5\ \frac{mA}{V^2}\right)(0.6\ V - 0.4\ V)^2 = \boxed{0.1\ mA}$

$V_{DS} = V_{DD} - I_D R_D = 1.8\ V - (0.1\ mA)(10\ k\Omega) = \boxed{0.8\ V}$

(b) $g_m = \left(5\ \frac{mA}{V^2}\right)(0.6 - 0.4) = \boxed{\frac{1\ mA}{V^2}}$

(c) $\frac{V_o}{V_i} = -g_m R_D = -\left(\frac{1\ mA}{V^2}\right)(10\ k\Omega) = \boxed{-10}$

(d) $\lambda = 0.1\ V^{-1}$

$r_o = \frac{|V_A|}{I_D} = \frac{1}{\lambda I_D} = \frac{1}{(0.1\ V^{-1})(0.1\ mA)} = 100\ k\Omega$

$A_v = -g_m\left(\frac{R_D r_o}{R_D + r_o}\right) = \frac{1\ mA}{V^2}\left(\frac{100 \cdot 10}{100 + 10}\right) = \boxed{-9.09\ \frac{V}{V}}$

Sedra & Smith 7.29

$I_D \quad \lambda I_D \quad (0.1\,V^{-1})(0.1\,mA)$

$$A_v = -g_m\left(\frac{R_D r_o}{R_D + r_o}\right) = 1\,\frac{mA}{V^2}\left(\frac{100\cdot 10}{100+10}\right) = \boxed{-9.09\ \frac{V}{V}}$$

7.29 $\mu_n C_{ox} = 250\ \frac{\mu A}{V^2}$ $\quad g_m = 2\ \frac{mA}{V}$ @ $I_D = 0.25$ mA

$V_t = 0.5$ V $\quad$ Find W for g_m and V_{GS}

$L = 0.5\ \mu m$

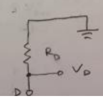
$$2\ \frac{mA}{V} = \sqrt{2\left(250\ \frac{\mu A}{V^2}\right)\frac{W}{0.5\,\mu m}(0.25\ mA)}$$

$$\boxed{W = 16\ \mu m}$$

$$2\ \frac{mA}{V} = \frac{2(0.25\ mA)}{V_{GS} - 0.5\ V} \qquad V_{GS} = \frac{2(0.25\ mA)}{2\ \frac{mA}{V}} + 0.5\ V$$

$$\boxed{V_{GS} = 0.75\ V}$$

7.30 $+V_{DD}$ $\quad \lambda = 0$



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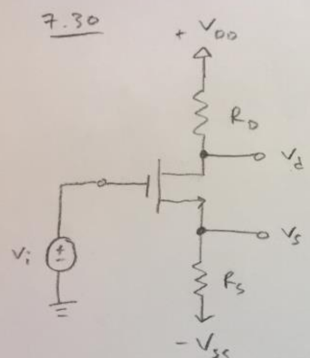
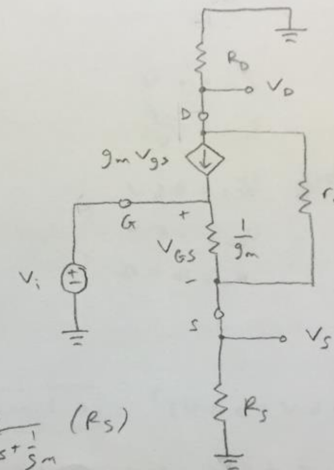
7.30



$\lambda = 0$

$\boxed{V_{GS} = 0.75 \text{ V}}$



$i = \frac{V_i}{R_S + \frac{1}{g_m}}$

$V_D = \left(-\frac{V_i}{R_S+\frac{1}{g_m}}\right) R_D$

$$\boxed{\frac{V_D}{V_i} = \frac{-R_D}{R_S+\frac{1}{g_m}}}$$

$$v_i = g_m v_{gs}\left(\frac{1}{g_m} + R_s\right)$$

$$V_s = \frac{V_i}{R_s+\frac{1}{g_m}}(R_s)$$

$$V_d = -g_m V_{gs} R_D$$

$$V_s = g_m V_{gs} R_s$$

$$\boxed{\frac{V_s}{V_i} = \frac{R_s}{R_s+\frac{1}{g_m}}}$$

$$\frac{V_s}{V_i} = \frac{g_m V_{gs} R_s}{g_m V_{gs}\left(\frac{1}{g_m}+R_s\right)} = \frac{g_m R_s}{1+g_m R_s}$$

$$\frac{V_D}{V_i} = \frac{-g_m V_{gs} R_d}{g_m V_{gs}\left(\frac{1}{g_m}+R_s\right)} = -\frac{g_m R_d}{1+g_m R_s}$$

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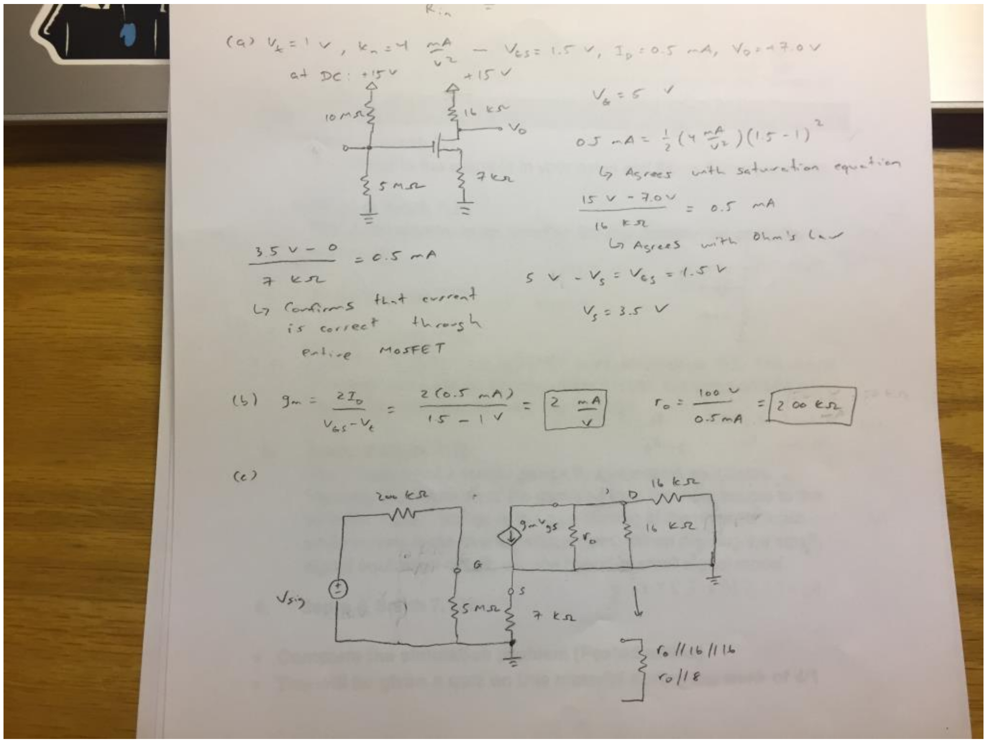


(a) $V_t = 1\text{ V}$, $k_n = 4\ \frac{mA}{V^2}$ — $V_{GS} = 1.5\text{ V}$, $I_D = 0.5\text{ mA}$, $V_D = 7.0\text{ V}$

at DC:

$V_G = 5\text{ V}$

$0.5\text{ mA} = \frac{1}{2}\left(4\ \frac{mA}{V^2}\right)(1.5-1)^2$

↳ Agrees with saturation equation

$\frac{15\text{ V} - 7.0\text{ V}}{16\text{ k}\Omega} = 0.5\text{ mA}$

↳ Agrees with Ohm's law

$\frac{3.5\text{ V} - 0}{7\text{ k}\Omega} = 0.5\text{ mA}$

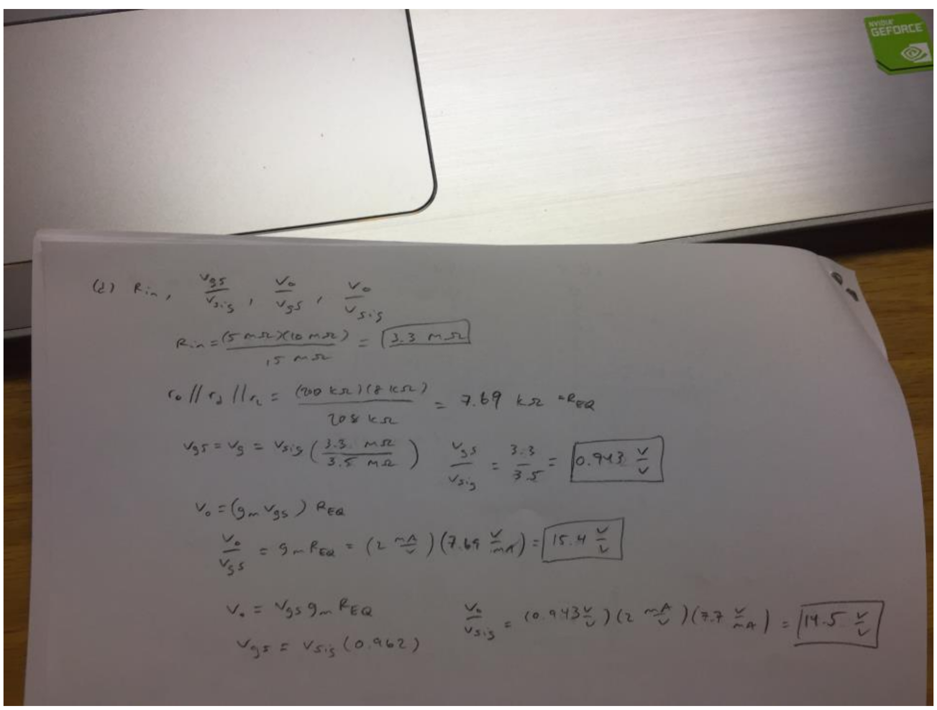
↳ Confirms that current is correct through entire MOSFET

$5\text{ V} - V_S = V_{GS} = 1.5\text{ V}$

$V_S = 3.5\text{ V}$

(b) $g_m = \frac{2I_D}{V_{GS}-V_t} = \frac{2(0.5\text{ mA})}{1.5 - 1\text{ V}} = \boxed{2\ \frac{mA}{V}}$ $r_o = \frac{100\text{ V}}{0.5\text{ mA}} = \boxed{200\text{ k}\Omega}$

(c)



(d) R_{in}, $\frac{v_{gs}}{v_{sig}}$, $\frac{v_o}{v_{gs}}$, $\frac{v_o}{v_{sig}}$

$R_{in} = \frac{(5\text{ M}\Omega)(10\text{ M}\Omega)}{15\text{ M}\Omega} = \boxed{3.3\text{ M}\Omega}$

$r_o \| r_d \| r_L = \frac{(200\text{ k}\Omega)(8\text{ k}\Omega)}{208\text{ k}\Omega} = 7.69\text{ k}\Omega = R_{EQ}$

$v_{gs} = v_g = v_{sig}\left(\frac{3.3\text{ M}\Omega}{3.5\text{ M}\Omega}\right)$ $\frac{v_{gs}}{v_{sig}} = \frac{3.3}{3.5} = \boxed{0.943\ \frac{V}{V}}$

$v_o = (g_m v_{gs}) R_{EQ}$

$\frac{v_o}{v_{gs}} = g_m R_{EQ} = \left(2\ \frac{mA}{V}\right)\left(7.69\ \frac{V}{mA}\right) = \boxed{15.4\ \frac{V}{V}}$

$v_o = v_{gs} g_m R_{EQ}$

$v_{gs} = v_{sig}(0.962)$

$\frac{v_o}{v_{sig}} = \left(0.943\ \frac{V}{V}\right)\left(2\ \frac{mA}{V}\right)\left(7.7\ \frac{V}{mA}\right) = \boxed{14.5\ \frac{V}{V}}$

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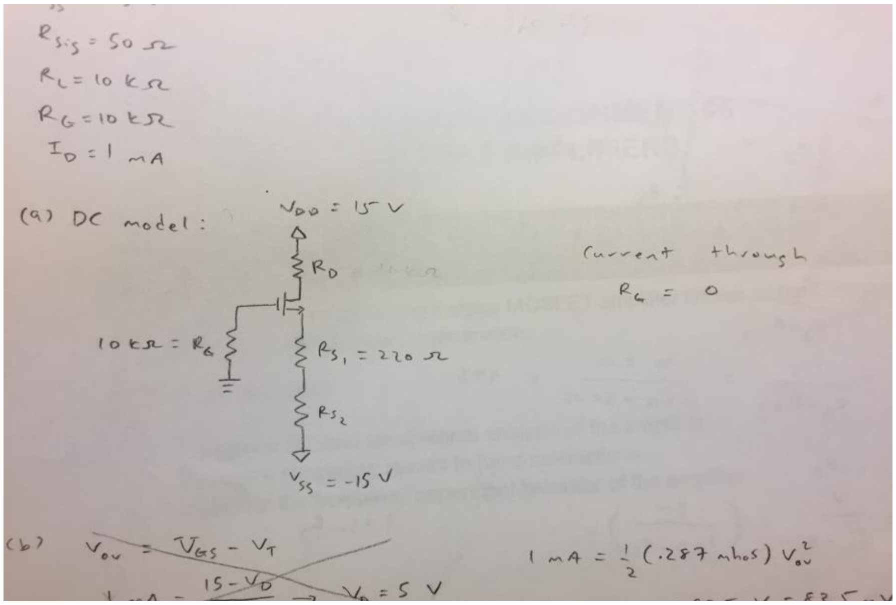
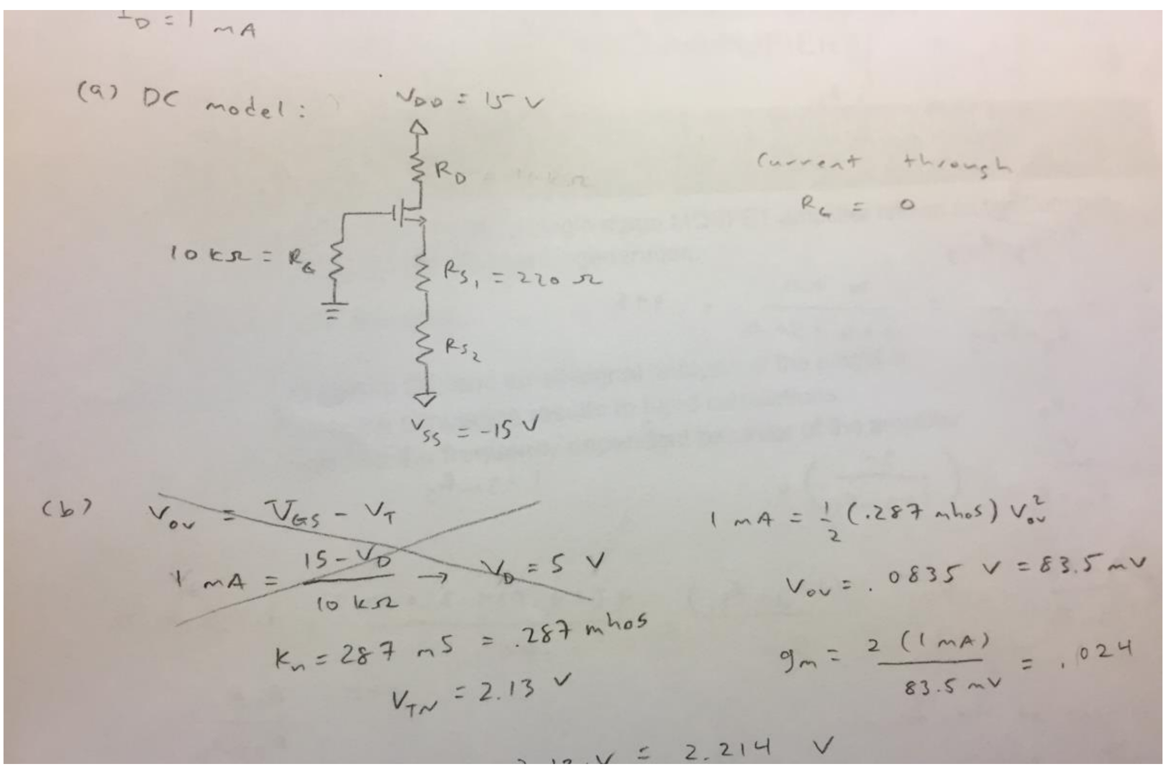
MOSFET AMPLIFIER SIMULATION (a)

Current through $R_G = \ 0$



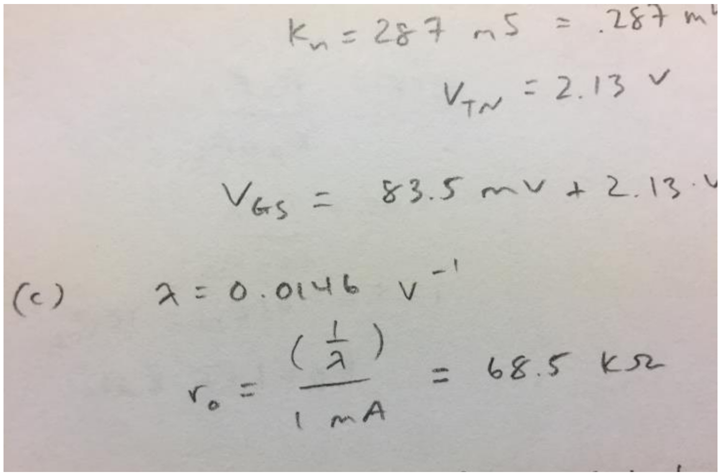
MOSFET AMPLIFIER SIMULATION (b)

$V_{OV} = \ 83.5\ mV$ $\qquad g_m = \ .024$ $\qquad V_{GS} = \ 2.214\ V$



MOSFET AMPLIFIER SIMULATION (c)

$r_o = \quad 68.5\ kohms$



$K_n = 287\ mS = .287\ m$

$V_{TN} = 2.13\ V$

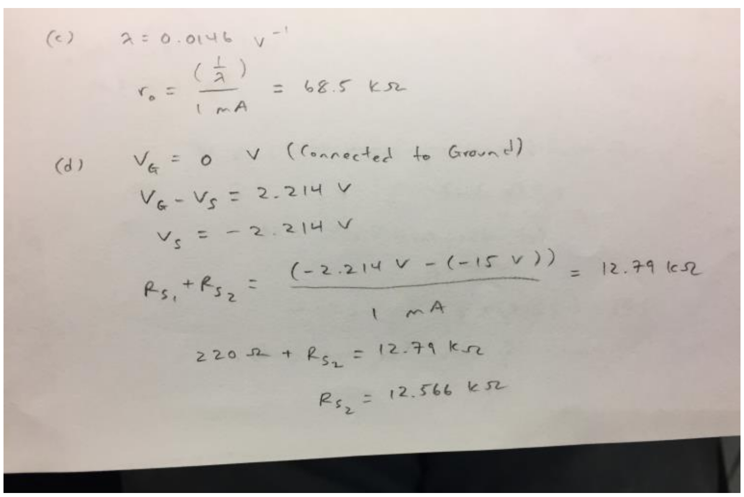
$V_{GS} = 83.5\ mV + 2.13\ V$

(c) $\lambda = 0.0146\ V^{-1}$

$$r_o = \frac{\left(\frac{1}{\lambda}\right)}{1\ mA} = 68.5\ k\Omega$$

MOSFET AMPLIFIER SIMULATION (d)

$R_{S2} = \quad 12.566\ kohms$



(c) $\lambda = 0.0146\ V^{-1}$

$$r_o = \frac{\left(\frac{1}{\lambda}\right)}{1\ mA} = 68.5\ k\Omega$$

(d) $V_G = 0\ V$ (Connected to Ground)

$V_G - V_S = 2.214\ V$

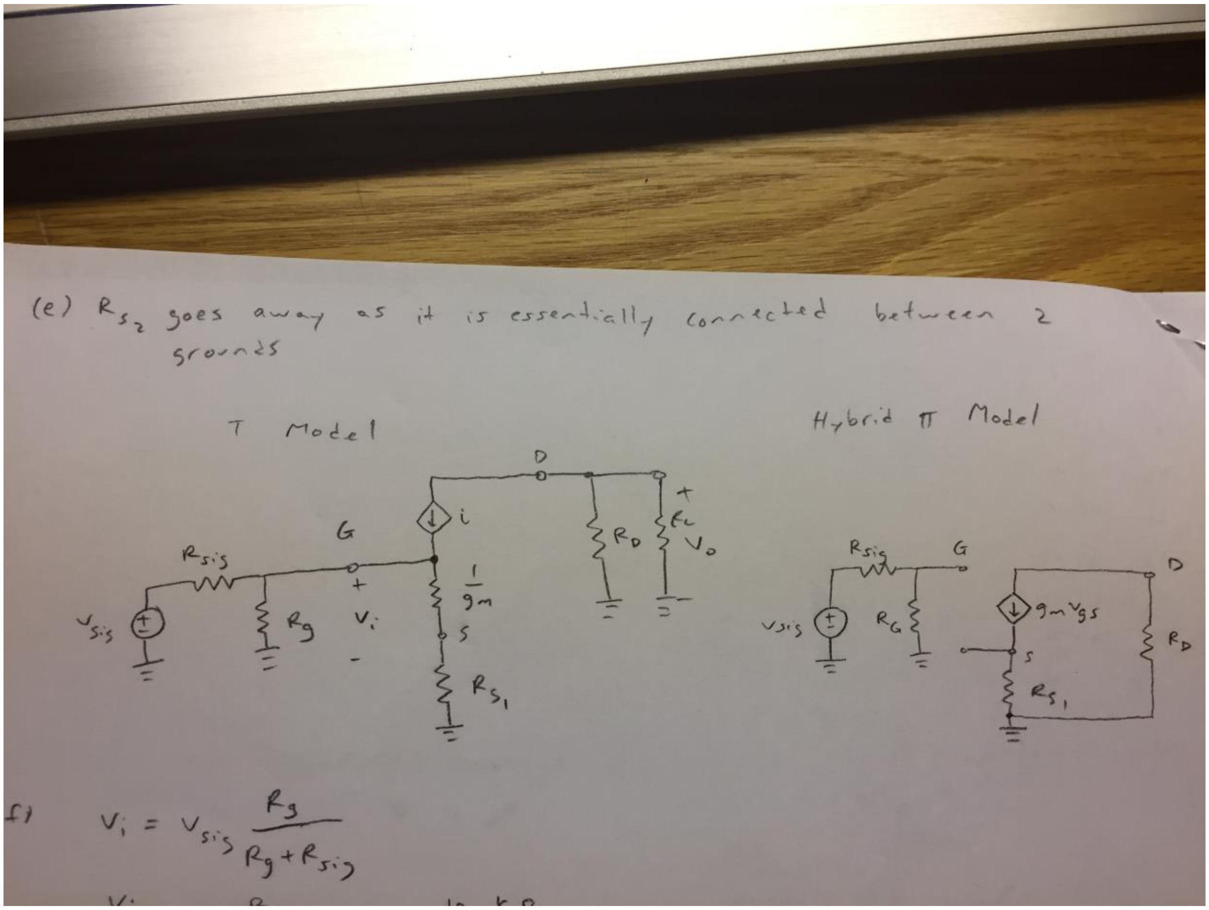
$V_S = -2.214\ V$

$$R_{S_1} + R_{S_2} = \frac{(-2.214\ V - (-15\ V))}{1\ mA} = 12.79\ k\Omega$$

$220\ \Omega + R_{S_2} = 12.79\ k\Omega$

$R_{S_2} = 12.566\ k\Omega$

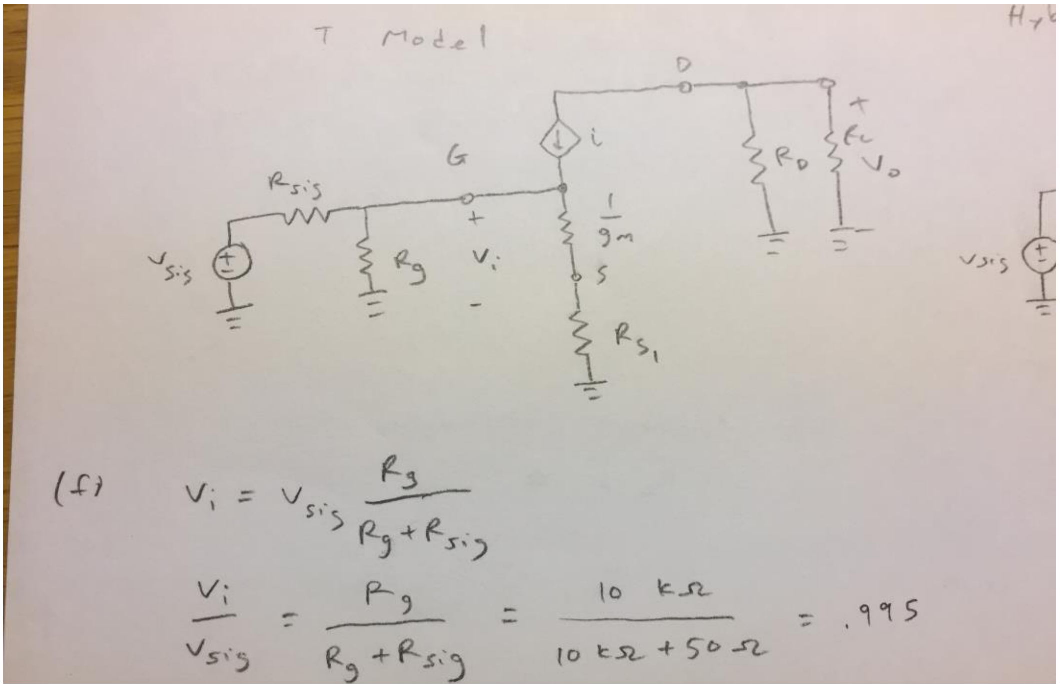
MOSFET AMPLIFIER SIMULATION (e)


(e) R_{S_2} goes away as it is essentially connected between 2 grounds

f) $V_i = V_{sig} \frac{R_g}{R_g + R_{sig}}$

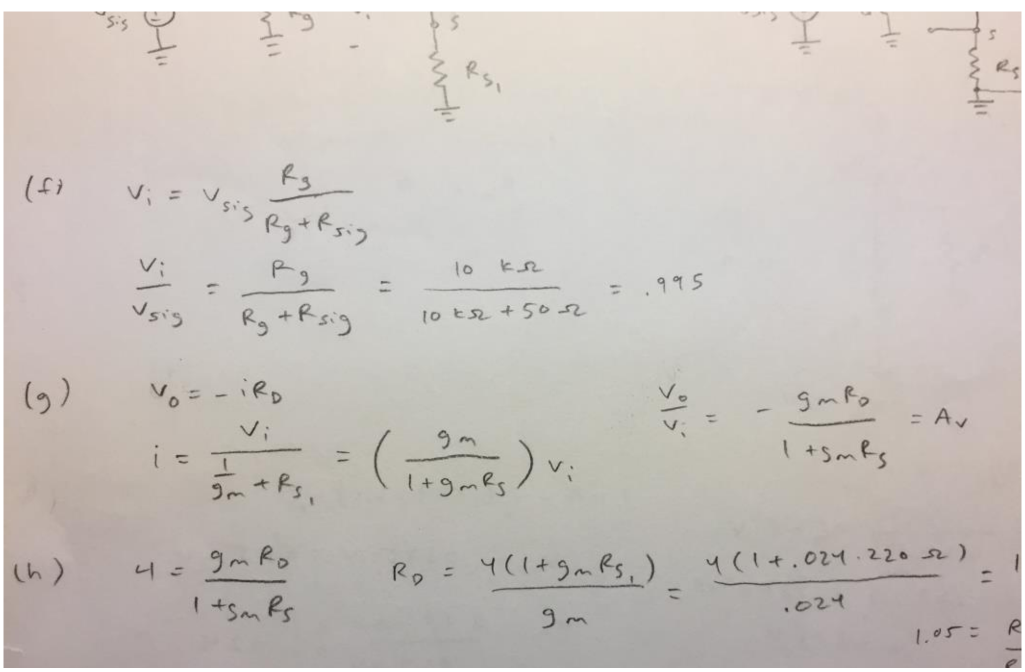
MOSFET AMPLIFIER SIMULATION (f)

$$\frac{v_i}{v_{sig}} = .995$$



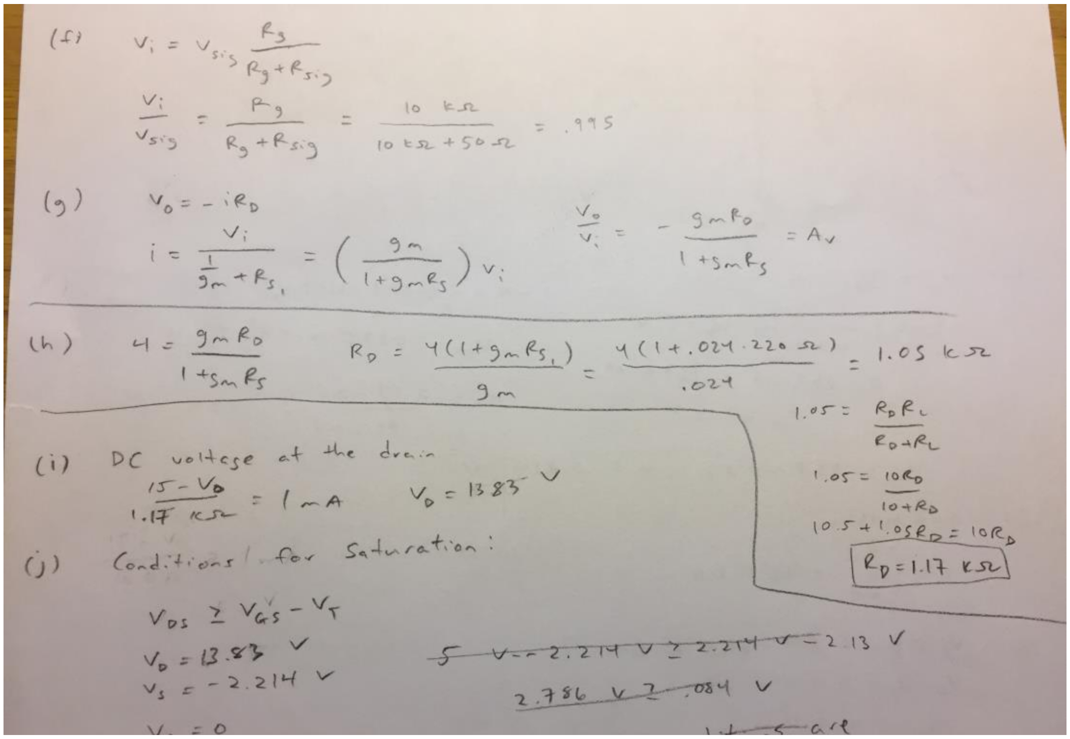
MOSFET AMPLIFIER SIMULATION (g)

$$A_v = \frac{v_o}{v_i} = \ -gmRd/(1 + gmRs)$$



MOSFET AMPLIFIER SIMULATION (h)

$R_D = \quad 1.17\ kohms$



(f) $v_i = v_{sig} \frac{R_g}{R_g + R_{sig}}$

$\frac{v_i}{v_{sig}} = \frac{R_g}{R_g + R_{sig}} = \frac{10\ k\Omega}{10\ k\Omega + 50\ \Omega} = .995$

(g) $v_o = -iR_D$

$i = \frac{v_i}{\frac{1}{g_m} + R_{s_1}} = \left(\frac{g_m}{1+g_m R_s}\right) v_i$

$\frac{v_o}{v_i} = -\frac{g_m R_D}{1+g_m R_s} = A_v$

(h) $4 = \frac{g_m R_D}{1+g_m R_s}$

$R_D = \frac{4(1+g_m R_{s_1})}{g_m} = \frac{4(1+.024 \cdot 220\ \Omega)}{.024} = 1.05\ k\Omega$

$1.05 = \frac{R_D R_L}{R_D + R_L}$

$1.05 = \frac{10 R_D}{10 + R_D}$

$10.5 + 1.05 R_D = 10 R_D$

$\boxed{R_D = 1.17\ k\Omega}$

(i) DC voltage at the drain

$\frac{15 - V_D}{1.17\ k\Omega} = 1\ mA \qquad V_D = 13.83\ V$

(j) Conditions for Saturation:

$V_{DS} \geq V_{GS} - V_T$

$V_D = 13.83\ V$

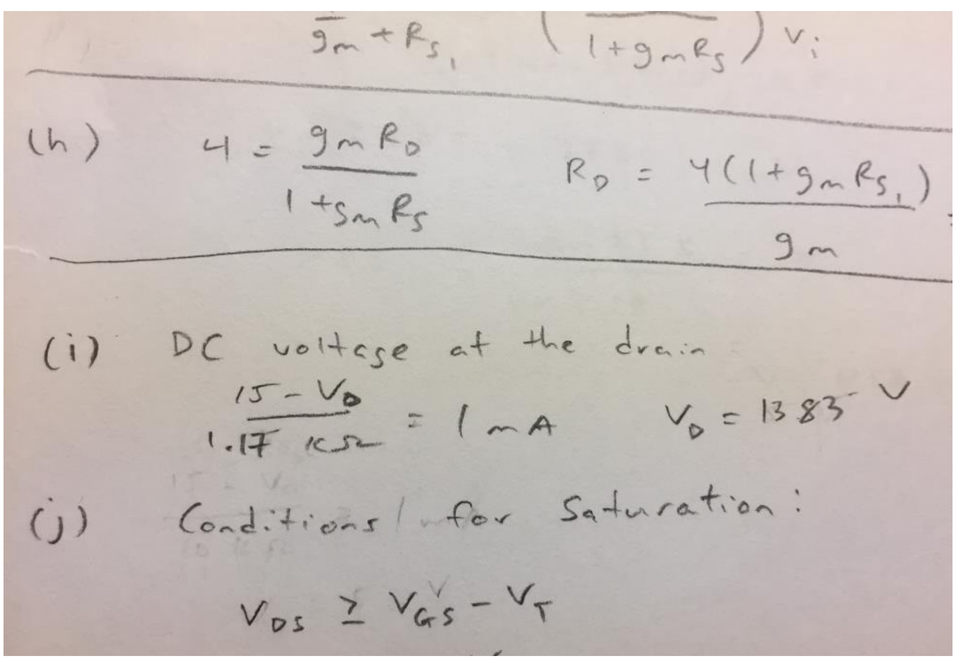
$V_S = -2.214\ V$

$\cancel{5\ V - -2.214\ V \geq 2.214\ V} = 2.13\ V$

$2.786\ V \geq .084\ V$

MOSFET AMPLIFIER SIMULATION (i)

$V_D = \quad 13.83\ V$



$\frac{1}{g_m} + R_{s_1} \qquad \left(\frac{g_m}{1+g_m R_s}\right) v_i$

(h) $4 = \frac{g_m R_D}{1+g_m R_s} \qquad R_D = \frac{4(1+g_m R_{s_1})}{g_m}$

(i) DC voltage at the drain

$\frac{15 - V_D}{1.17\ k\Omega} = 1\ mA \qquad V_D = 13.83\ V$

(j) Conditions for Saturation:

$V_{DS} \geq V_{GS} - V_T$

MOSFET AMPLIFIER SIMULATION (j)

The conditions for saturation are satisfied because Vds is greater than Vgs – Vt. Vd = 13.83 V, Vs = -2.214 V, Vg = 0, Vt = 2.13 V.

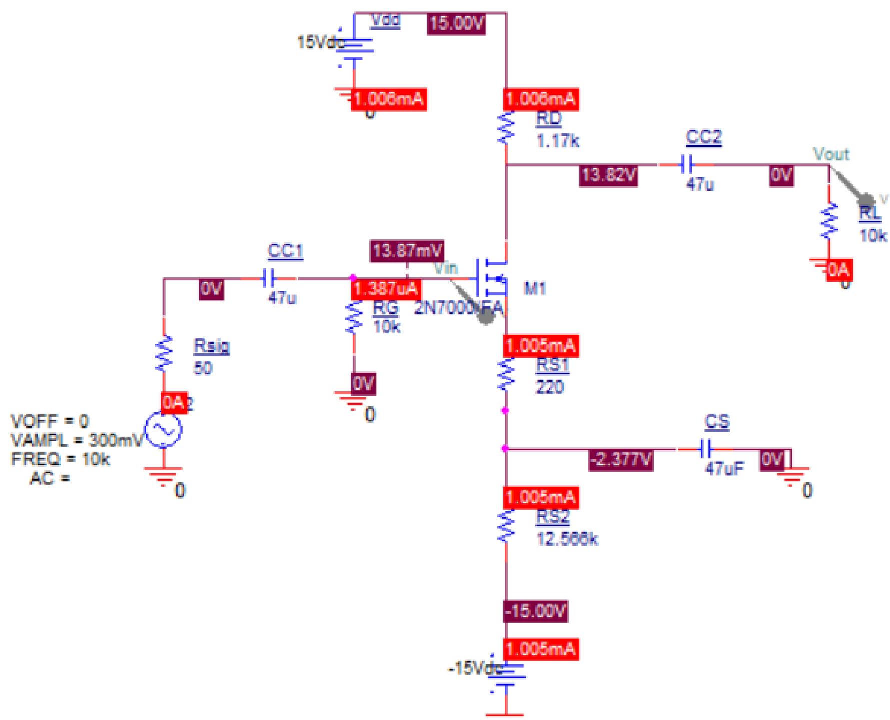
Vds = 16.044 V

Vgs – Vt = .084 V

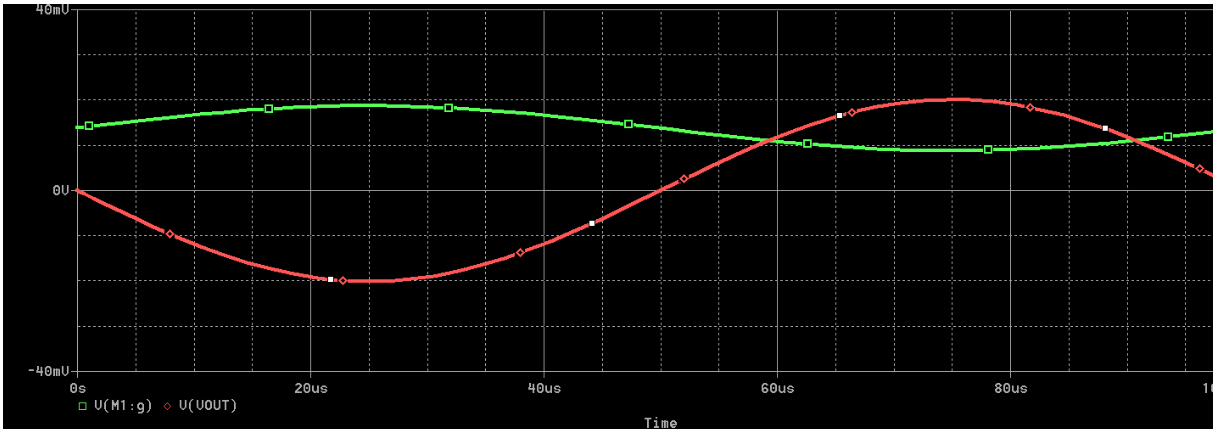
MOSFET AMPLIFIER SIMULATION (k)

$V_{GS} =$ 2.16 V $V_{DS} =$ 16.096 V $I_D = 1.006\ mA$

The values are close, though there is some error.



MOSFET AMPLIFIER SIMULATION (l)



MOSFET AMPLIFIER SIMULATION (m)

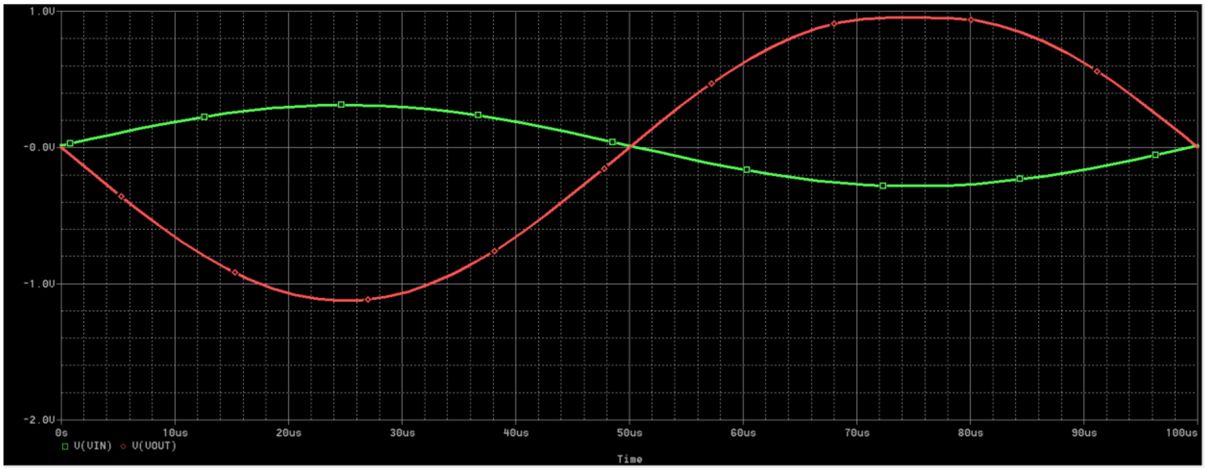
$A_v = \quad -3.31$

I found the values of the input and the output voltages at their peaks. The amplitude of the input was 5.506, while the amplitude of the output was -18.224, resulting in a gain of -3.31.

MOSFET AMPLIFIER SIMULATION (n)

$Amplitude =$ 300 mV

This distortion occurs because the small-signal condition is no longer met.



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