Name: Tarik Reyhan **Section:** _______

Signature: _______________ **EEE 313 Spring 2014-2015**

Bilkent University
Department of Electrical and Electronics Engineering
EEE 313 Electronic Circuit Design
Midterm 1
25 March 2015, 17:50
(4 questions, 120 minutes)

- This is a **closed book**, closed notes exam. No cheat sheet allowed.
- All cell-phones should be completely **turned off**.
- Use a calculator for numerical computations. Carry at least **4 significant digits** during calculations. Your final answer should be at least **3 significant digits**.
- Be sure to write the **units** of all numerical results.
- **Show** all work clearly.
- Please put your **final answer** for each part inside a box for easy identification. Do not give multiple answers, they will not be graded.
- Do not remove the **staple** from the exam sheets or separate pages of the exam. All extra pages must be stamped to your exam.
- You may leave the exam room when you are done. However, please do not leave during the **last five minutes** of the exam.
- At the end of the exam, please stay seated unitl **all** exam papers are collected.

FET equations:

n-channel MOSFET

$i_D = K_n(v_{GS} - V_{Tn})^2$ SAT

$i_D = K_n\left[2(v_{GS} - V_{Tn})v_{DS} - v_{DS}^2\right]$ NON-SAT

p-channel MOSFET

$i_D = K_p(v_{SG} + V_{Tp})^2$ SAT

$i_D = K_p\left[2(v_{SG} + V_{Tp})v_{SD} - v_{SD}^2\right]$ NON-SAT

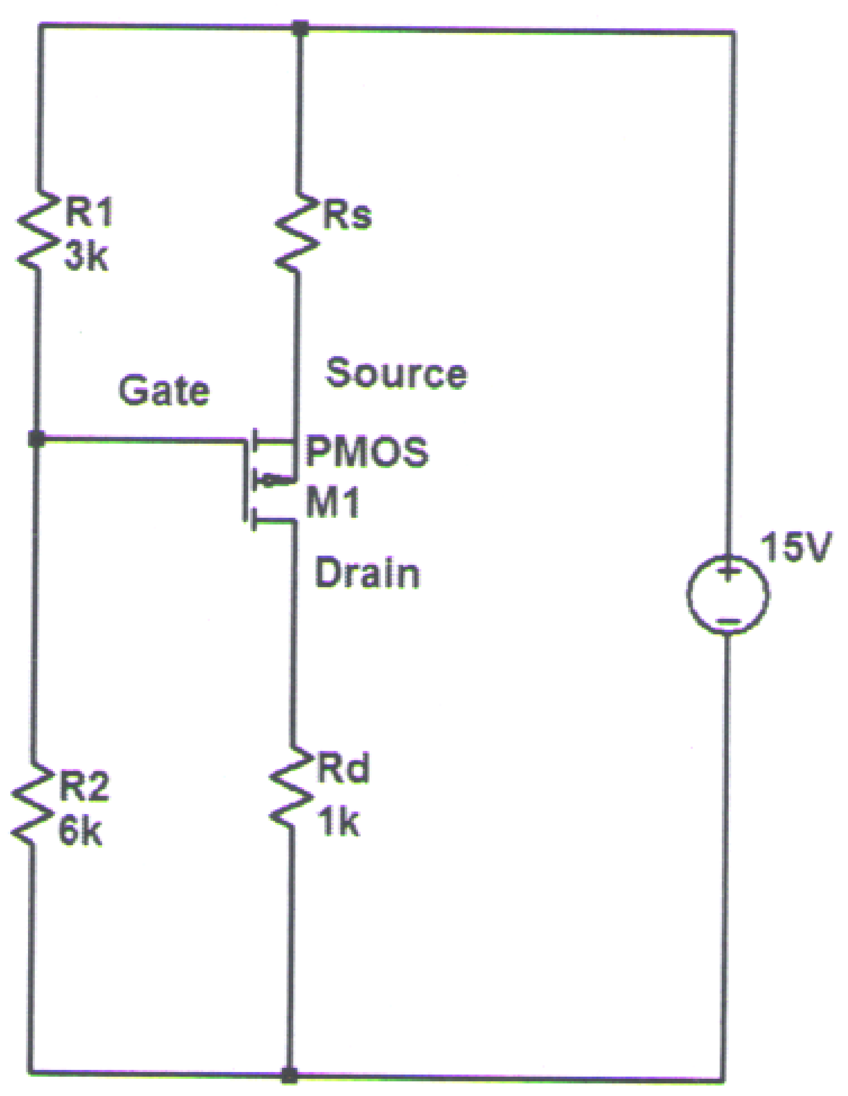
n-channel JFET

$i_D = \frac{I_{DSS}}{V_p^2}(v_{GS} - V_P)^2$ SAT

$i_D = \frac{I_{DSS}}{V_p^2}\left[2(v_{GS} - V_P)v_{DS} - v_{DS}^2\right]$ NON-SAT

Please do not write below this line

1. 20 pts.	
2. 20 pts.	
3. 24 pts.	
4. 36 pts.	
Total 100 pts.	



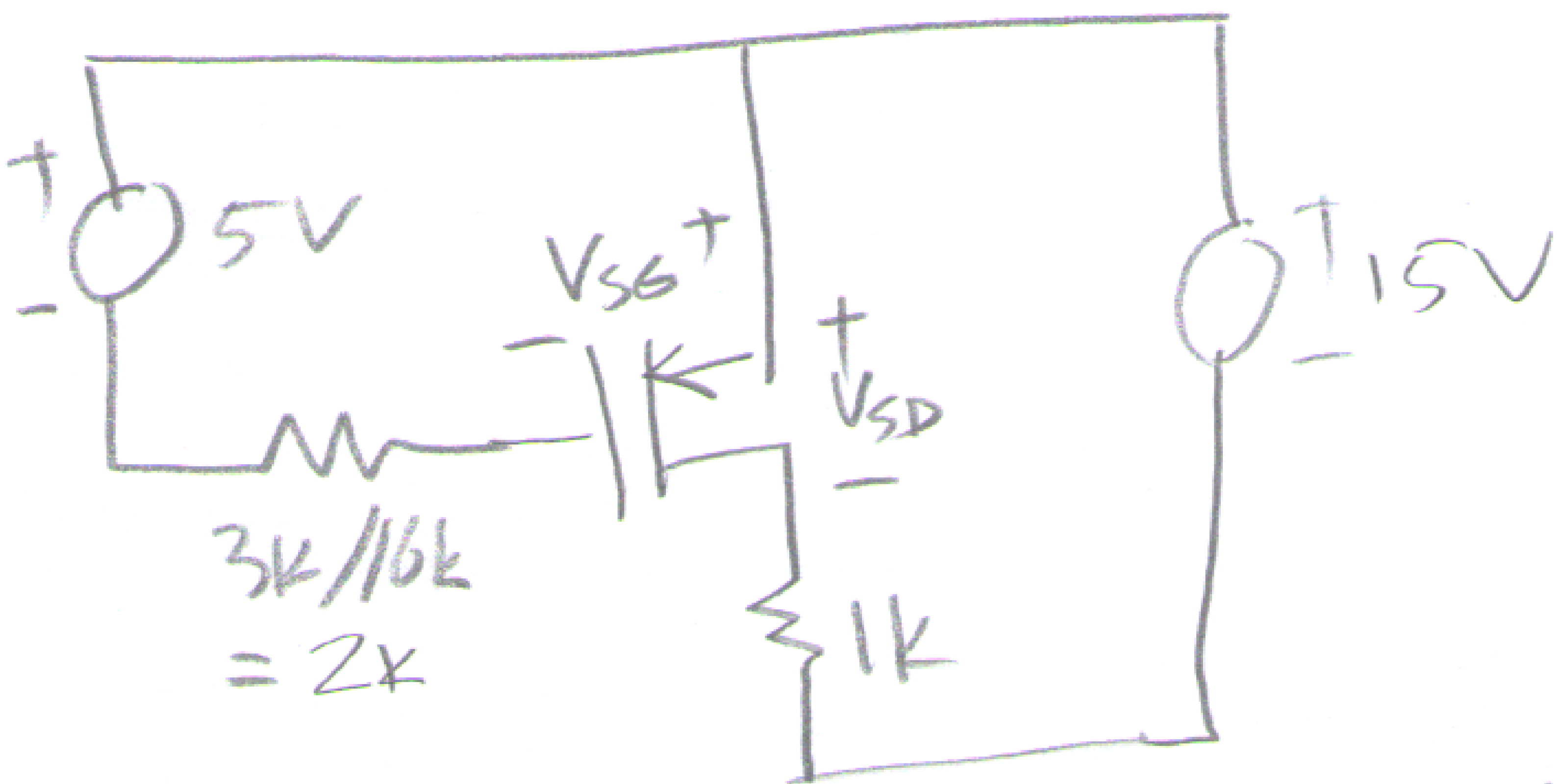
1) (20 points) At the enhencement-mode p-channel MOSFET circuit given above, $V_{TP} = -2V$ ~~V_{TP}=2~~Volts and $K_P=4x10^{-3}A/V^2$.

a) (10 points) Find the bias of the transistor for $R_s=0\Omega$ and verify the solution.

b) (10 points) Find the bias of the transistor for $R_s=500\Omega$ and verify the solution.

Solutions:

a-)



$V_{SG} = 5V \Rightarrow I_D = K_P\left[V_{SG} + V_{TP}\right]^2$ assuming SAT

$\Rightarrow I_D = 4\times10^{-3}\left[5-2\right]^2 = 4\times10^{-3}\times 9 = 36mA$

$V_{SD} = 15 - I_D \times 1000\Omega = 15-36 = -21V \Rightarrow$ not plausable $\Rightarrow$ not SAT

Assuming nonsat:

$I_D = K_{TP}\left[2(V_{SG}+V_{TP})V_{SD} - V_{SD}^2\right]$ and

$V_{SD} = 15 - I_D\times1000 \Rightarrow I_D = \frac{15-V_{SD}}{1000}$

$\frac{15-V_{SD}}{\cancel{1000}} = 4\times\cancel{10^{-3}}\left[2(5-2)V_{SD} - V_{SD}^2\right]$

$15 - V_{SD} = 4\times6V_{SD} - 4V_{SD}^2 \Rightarrow$

$4V_{SD}^2 - 25V_{SD} + 15 = 0$

$$\underbrace{4}_{a} V_{SD}^2 \underbrace{-25}_{b} V_{SD} \underbrace{+15}_{c} = 0$$

$$V_{SD_{1,2}} = \frac{-b}{2a} \pm \frac{\sqrt{b^2-4ac}}{2a} = \frac{25}{8} \pm \frac{\sqrt{625-240}}{8}$$

$$= \frac{25}{8} \pm \frac{\sqrt{385}}{8} = 3.125 \pm 2.452677$$

$$= 0.672322,\ 5.5\cancel{7}\cancel{7}077 \Rightarrow \text{SAT not plausable}$$

$$\Rightarrow I_D = \frac{15-0.672322}{1000\Omega} = 14.3277\text{ mA but}$$

I_D is also given by the transistor equation

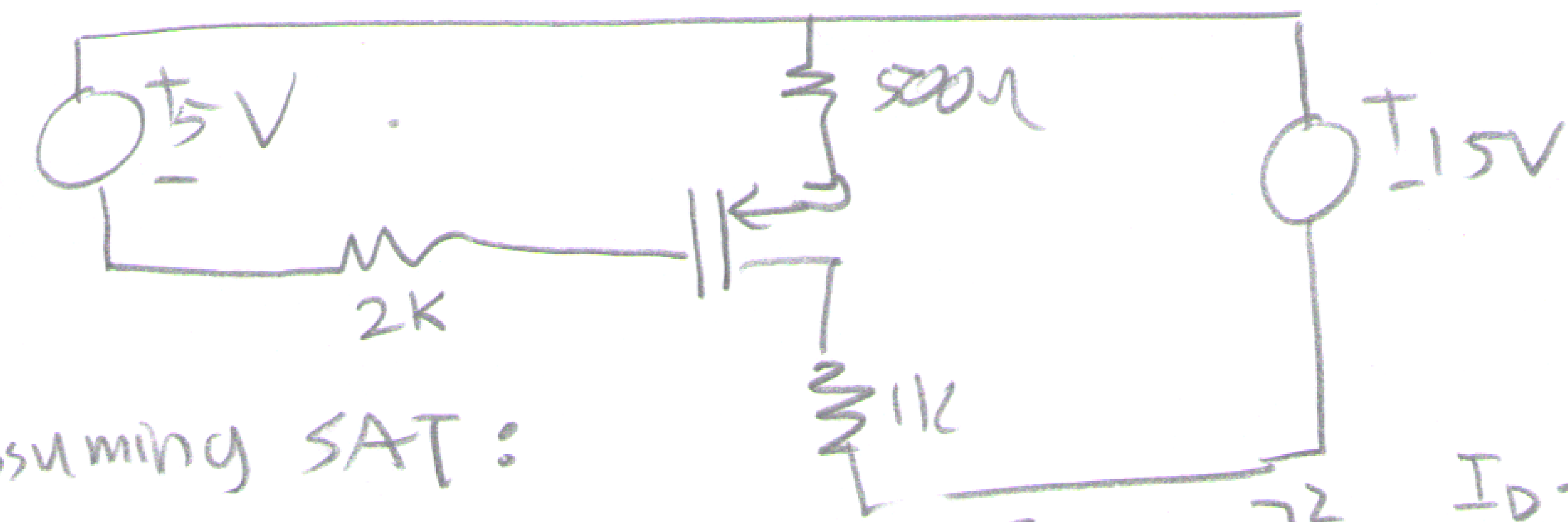
$$I_D = K_p\left[2(V_{SG}-V_{TP})V_{SD} - V_{SD}^2\right]$$

$$= 4\times10^{-3}\left[2(5-2)0.672322 - 0.672322^2\right]$$

$= 14.3276\text{m}\cancel{A}$ ← same as above ⇒

Nonsat is verified

b-)



Assuming SAT:

$$I_D = K_p\left[V_{SG}+V_{TP}\right]^2 = 4\times10^{-3}\left[V_{SG}-2\right]^2 = \frac{I_D - V_{SG}}{500} \Rightarrow$$

$$5 - V_{SG} = 2\left[V_{SG}-2\right]^2 = 2V_{SG}^2 - 8V_{SG} + 8 \Rightarrow$$

$$\underbrace{2}_{a} V_{SG}^2 \underbrace{-7}_{b} V_{SG} \underbrace{+3}_{c} = 0 \Rightarrow$$

$$V_{SG_{1/2}} = \frac{+7}{4} \pm \frac{\sqrt{49-4\times2\times3}}{4} = \frac{7}{4} \pm \frac{\sqrt{25}}{4} = \frac{7}{4} \pm \frac{5}{4} = \frac{12}{4}, \cancel{\frac{2}{4}}$$

$$V_{SG} = \frac{12}{4} = 3V \Rightarrow I_D = 4\times10^{-3}\left[3-1\right]^2 = 4\text{mA} \Rightarrow$$

$$V_D = 4\times10^{-3}\times1000\Omega = 4V,\quad V_S = 15 - 4\cdot10^{-3}\times500 = 15-2 = 13V$$

$$V_{SD} = 13-4 = 9V > V_{SG} + (-2) = 3-2 = 1\ ✓ \Rightarrow \text{SAT}$$

$$V_{SG} = 5V - I_D\times500\Omega = 5V - 4\times10^{-3}\times500 = 5-2 = 3V \Rightarrow ✓$$

state and bias verified

Q.1 (b) An alternative solution:

$$15 = I_D\,(0.5\times10^{3}) + V_S \quad \left[I_D = 4\times10^{-3}\,(V_S - V_g + V_{TP})^2 \right]$$

$$15 = 0.5\times\cancel{10^{3}}\times 4\times\cancel{10^{-3}}\,[V_S - 10 - 2]^2$$

$$15 = 2\,(V_S^2 - 24 + 144)$$

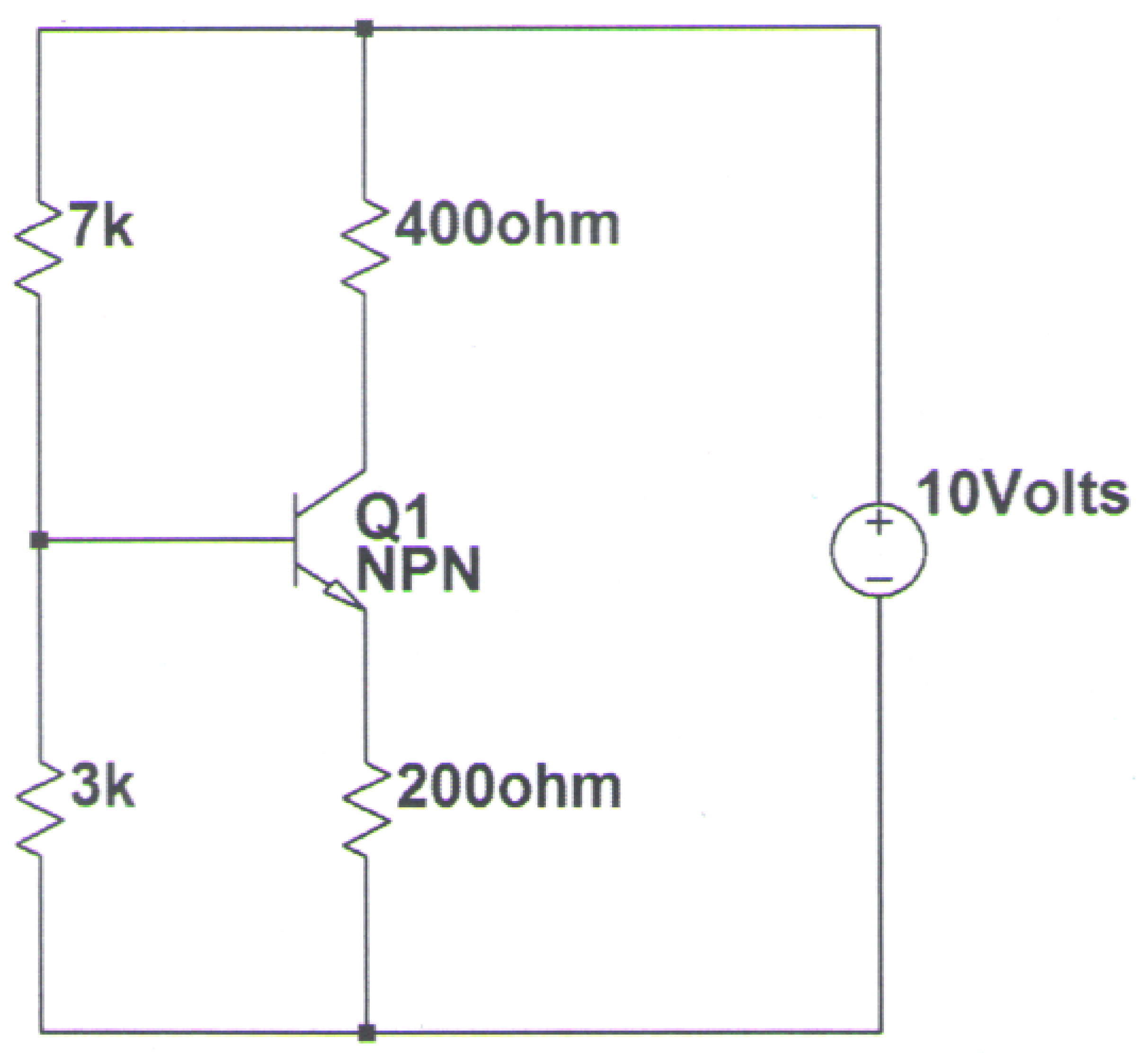
$$\underset{a}{2V_S^2} - \underset{b}{47V_S} + \underset{c}{273} = 0$$

$$V_{S_{1,2}} = \frac{-b}{2a} \pm \frac{\sqrt{b^2-4ac}}{2a} = \frac{47}{4} \pm \frac{\sqrt{47^2-8\times273}}{4} = \frac{47}{4} \pm \frac{5}{4}$$

$$V_{S_{1,2}} = \frac{52}{4},\ \frac{42}{4} = 13,\ 10.5$$

$$V_{SG} = 13-10\ ,\quad 10.5-10 = 3,\ \cancel{0.5}\ V \Rightarrow I_D = 0$$

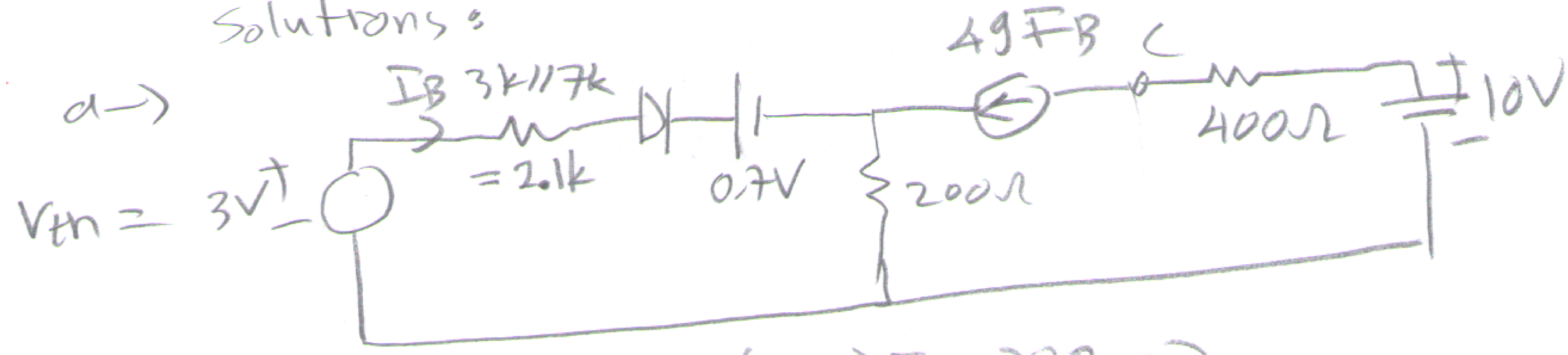
$$\Rightarrow \boxed{V_{SG} = 3\,V}$$



2) (20 points) At the circuit given above, β=49, V_{CESAT}=0.4Volts and V_{BESAT}=0.7Volts.
   a) (12 points) Find the quiescent vaules of the transistor voltage and curents.
   b) (8 points) Verify the state of the transistor.

Solutions :

a-)



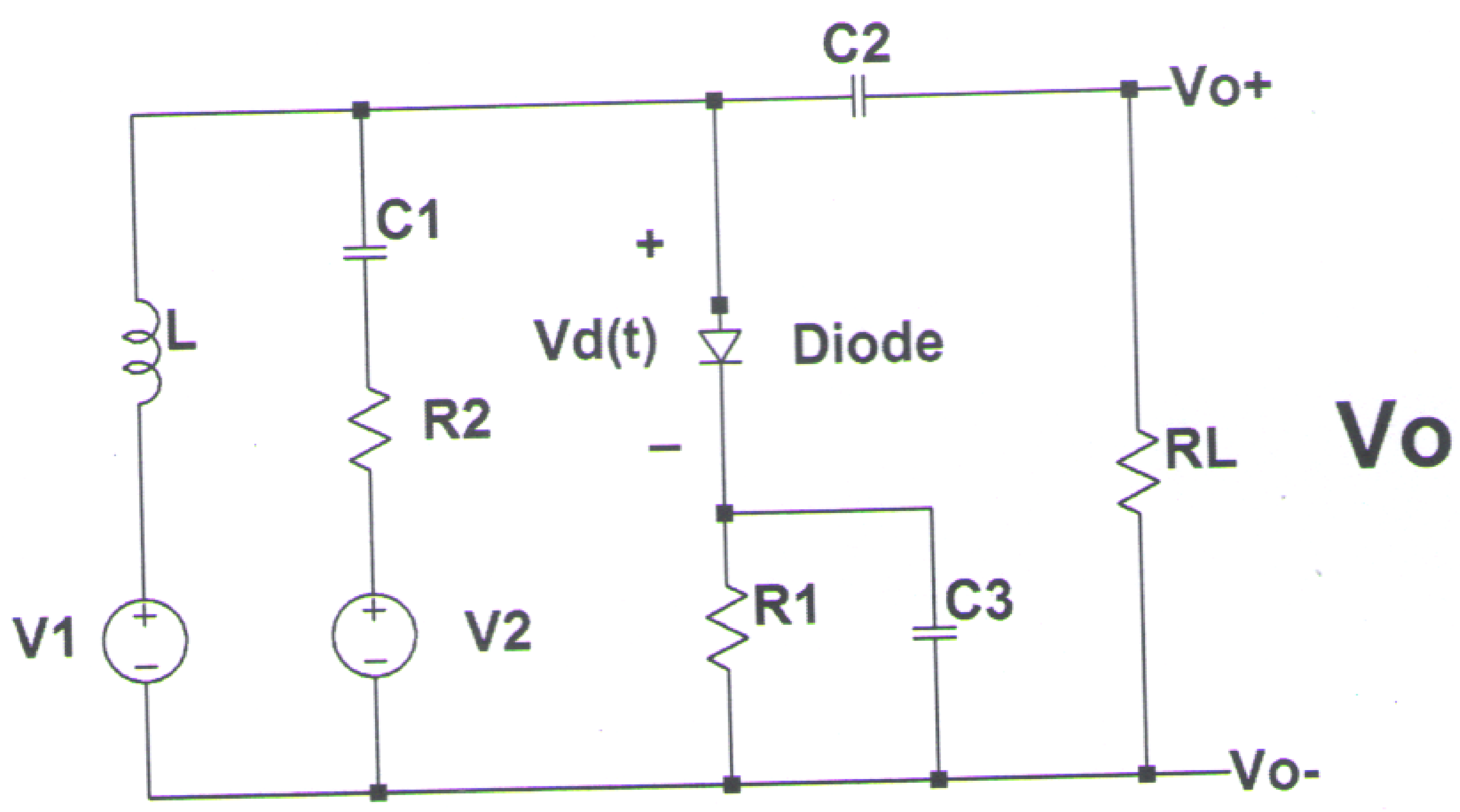
$V_{th} = 3V = 2100 I_B + 0.7V + (\beta+1) I_B \cdot 200 \Rightarrow$

$I_B = \dfrac{3-0.7}{2100 + 50 \times 200} = \dfrac{2.3}{12100} = 1.9008 \times 10^{-4} A = 190\,\mu A$

$I_C = 49 \times 190\,\mu A = 9.31\,mA \quad I_E = 50 \times 190\,\mu A = 9.5\,mA$

b-) $V_{CE} = 10 - 9.31\,mA \times 400\Omega - 9.5\,mA \times 200\Omega = 10 - 3.724 - 1.9$

$V_{CE} = 4.376V \Rightarrow$ Forward Active



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3) ~~(30~~ points) At the circuit given above, the diode $V\gamma$=0.6Volts. The value of the resistor R_2 is 600Ω. V_1=10Volts, RL=600Ω. C_1, C_2, C_3 and L are very large. $V_2(t)$ is equal to 0.04cos(ωt) Volts. The diode is at room temperature and the ideality factor n=1. Answer the following:

a) (6points) Find the value of ~~R_2~~ R_1 to make the diode forward AC resistance equal to 600 Ω.

b) (6 points) Draw the AC equivalent circuit, for the value of R_1 you have found

c) (6 points) Find the voltage gain of the circuit defined ad ~~Vo/Vin~~ V_o/V_2 in dB's.

d) (6 points) Do we expect to see an undistorted or distorted sinusoidal wave over the diode? Please state the reason behind your answer.

a-) $r_f = \frac{V_T}{I_{DQ}} = \frac{26.6mV}{I_{DQ}} = 600\Omega \Rightarrow I_{DQ} = \frac{26.6mV}{600} = 0.04433\ mA$

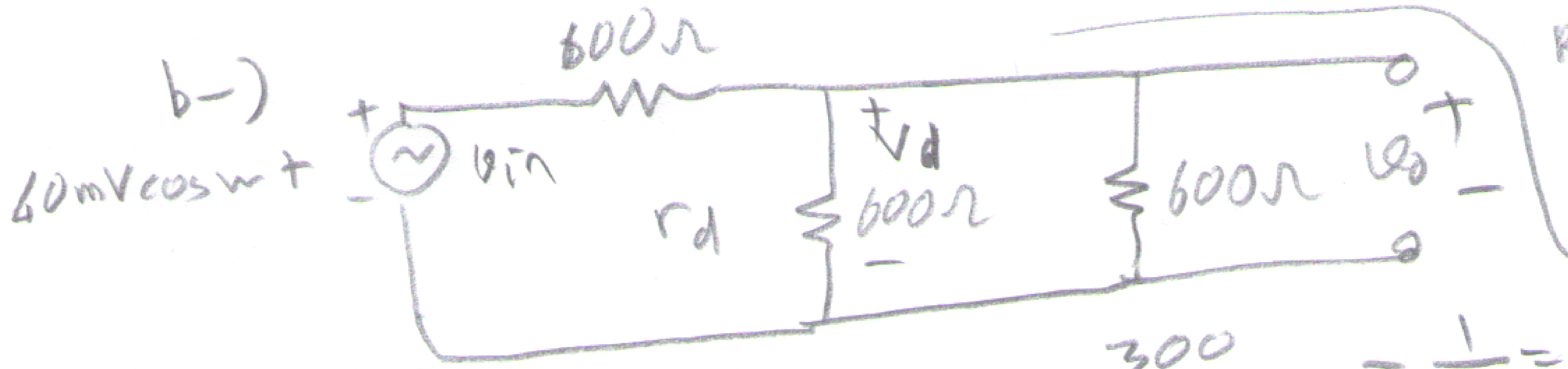
$= 44.33\mu A \Rightarrow$

$R_1 = \frac{10-0.6}{44.33\mu A} = \frac{9.4}{44.33}$

$= 212030$

$= 212k\Omega$

b-)

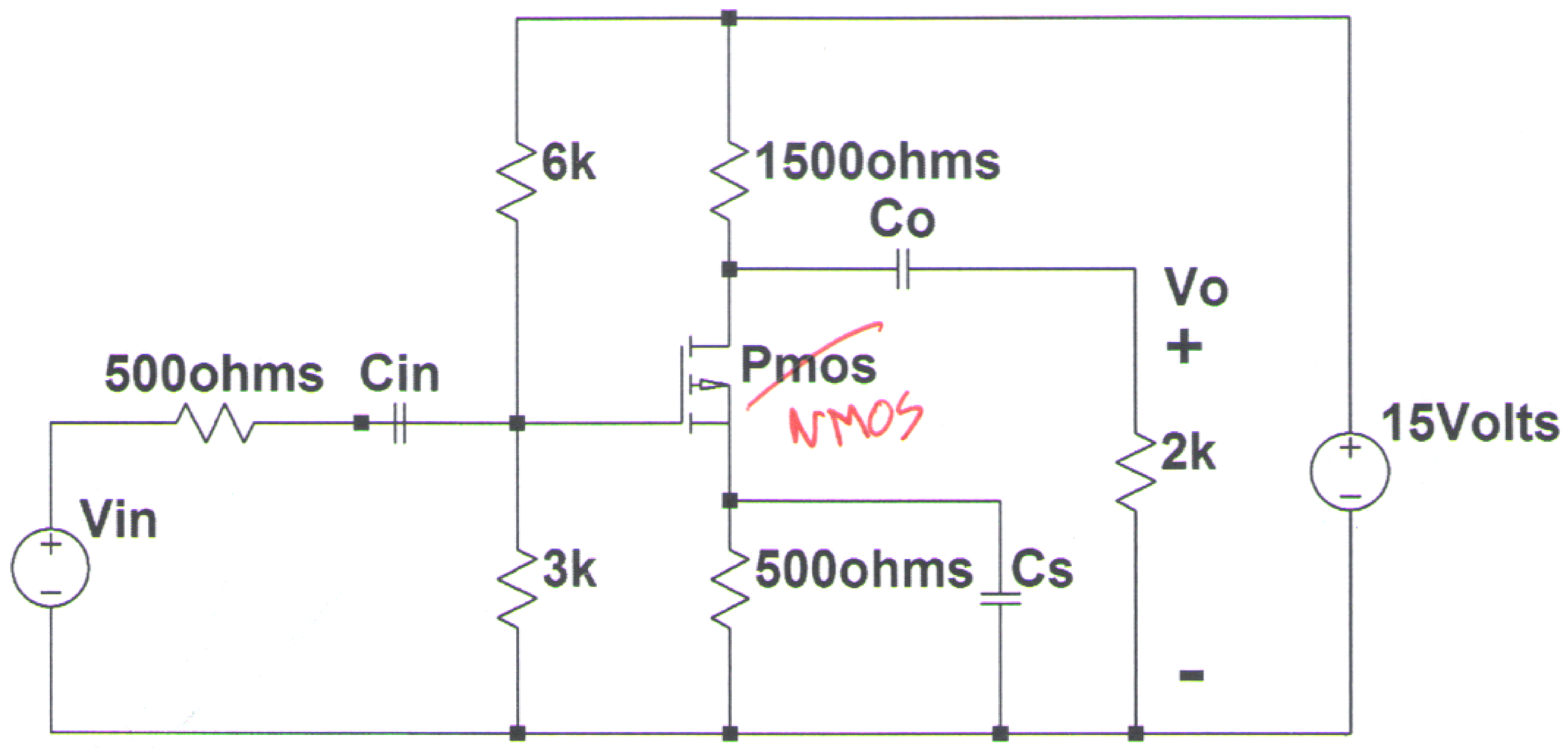


c-) $\frac{v_o}{v_{in}} = \frac{600 \| 600}{600 + 600\|600} = \frac{300}{600+300} = \frac{1}{3} = 20\log_{10}\frac{1}{3} = -9.54\ dB$

d-) $v_d = \frac{v_{in}}{3} = \frac{40mV}{3} = 13.33mV_p \ll 26.6mV$

$\Rightarrow$ no distortion

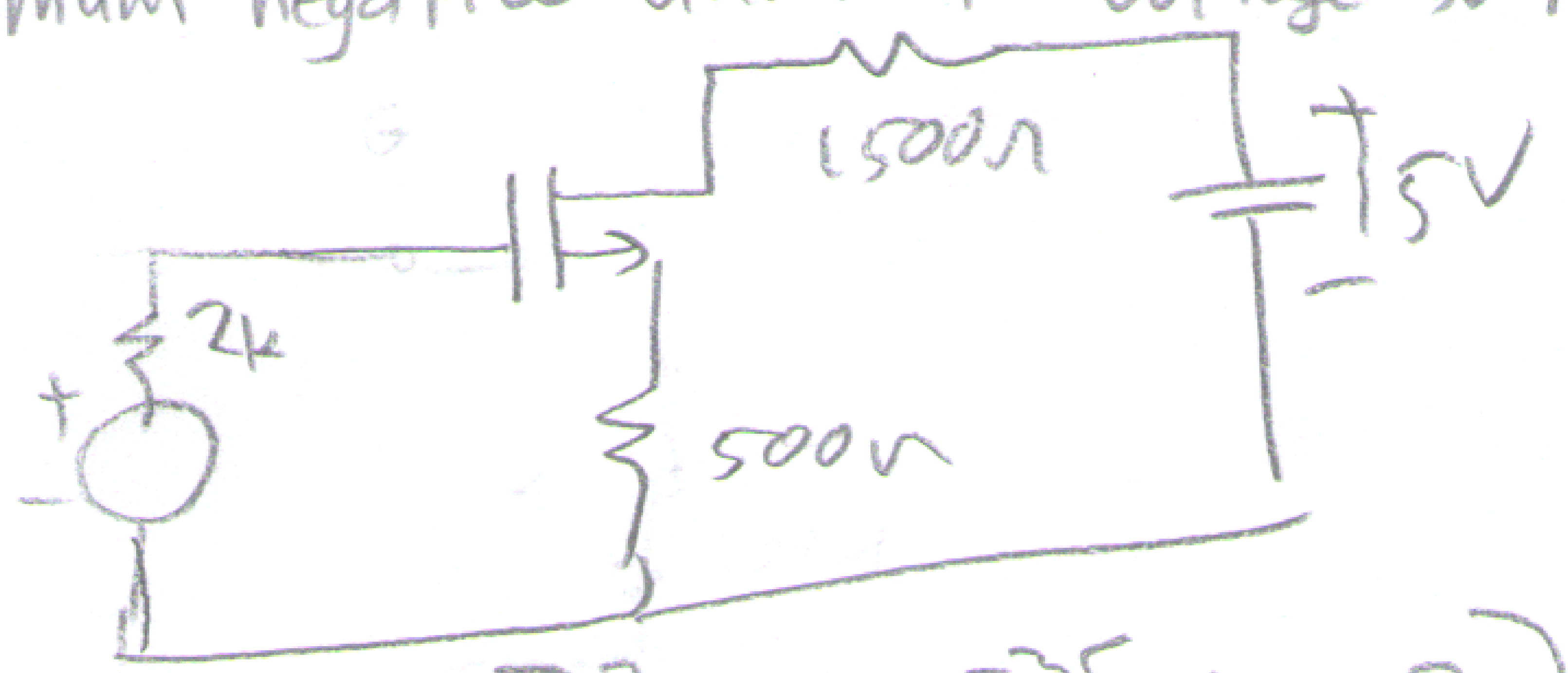
Tarık Reyhan



4) (36 points) In the transistor amplifier circuit given above, a common-source amplifier is shown. It has the parameters; threshold voltage, V_{TN}=2Volts, transconductance parameter, Kn=4mA/V_2 and Early voltage, V_A=100V. C_{in}, C_o and C_s are very large. Be careful about the polarities of voltage sources.

7 a. (~~6~~ points) Find the bias of the transistor assuming that $V_A=\infty$.
7 b. (~~6~~ points) Draw the AC equivalent circuit assuming that I_D=4mA.
7 c. (~~6~~ points) Assuming that I_D=4mA, find the small-signal gain,
5 d. (~~6~~ points) Assuming that I_D=4mA, find the input resistance,
5 e. (~~6~~ points) Assuming that I_D=4mA, find the ~~undistorted maximum peak-to-peak swing.~~ max undistorted positive swing
5 f. (6 points) ~~Find the small-signal voltage gain.~~ Write the set of equations to find the maximum negative undistorted voltage swing.

d-)



$V_{th}=5V$

$$I_D = K_n[V_{GS}-V_{TN}]^2 = 4\times10^{-3}[V_{GS}-2]^2 \text{ but also}$$

$$V_{GS}=5-I_D 500 \Rightarrow I_D = \frac{5-V_{GS}}{500} \Rightarrow$$

$$\frac{5-V_{GS}}{500} = 4\times10^{-3}[V_{GS}^2-4V_{GS}+4] \Rightarrow$$

$$5-V_{GS} = 2[V_{GS}^2-4V_{GS}+4] = 2V_{GS}^2-8V_{GS}+8 \Rightarrow$$

$$\underbrace{2V_{GS}^2}_{a}\underbrace{-7V_{GS}}_{b}\underbrace{+3}_{c}=0$$

$$\Rightarrow V_{GS_{1,2}} = \frac{-b}{2a} \pm \frac{\sqrt{b^2-4ac}}{2a} = \frac{7}{4} \pm \frac{\sqrt{49-24}}{4}$$

$$= \frac{7}{4} \pm \frac{5}{4} = \frac{12}{4}, \frac{2}{4} = 3, \cancel{0.5} < V_{TN}$$

$V_{GS} = 3V$

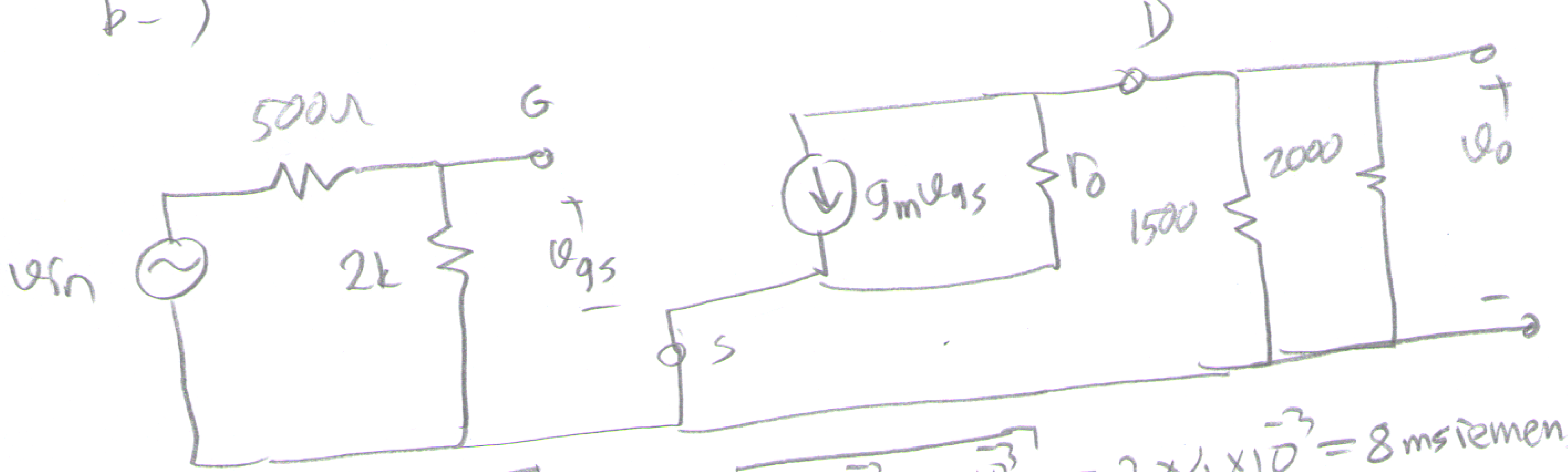
$I_D = 4\times10^{-3}[3-2]^2 = 4mA$

$V_G = 4mA \times 500\Omega = 2V \Rightarrow V_{GS} = 5-2 = 3V \Rightarrow$

$I_D = 4\times10^{-3}[3-2]^2 = 4mA \Rightarrow$ ✓ SAT

$V_{DS} = 15V - 4\times10^{-3}\times2000 = 15V - 8V = 7V > V_{GS}-V_{TN} = 3-2 = 1$ ✓

b-)



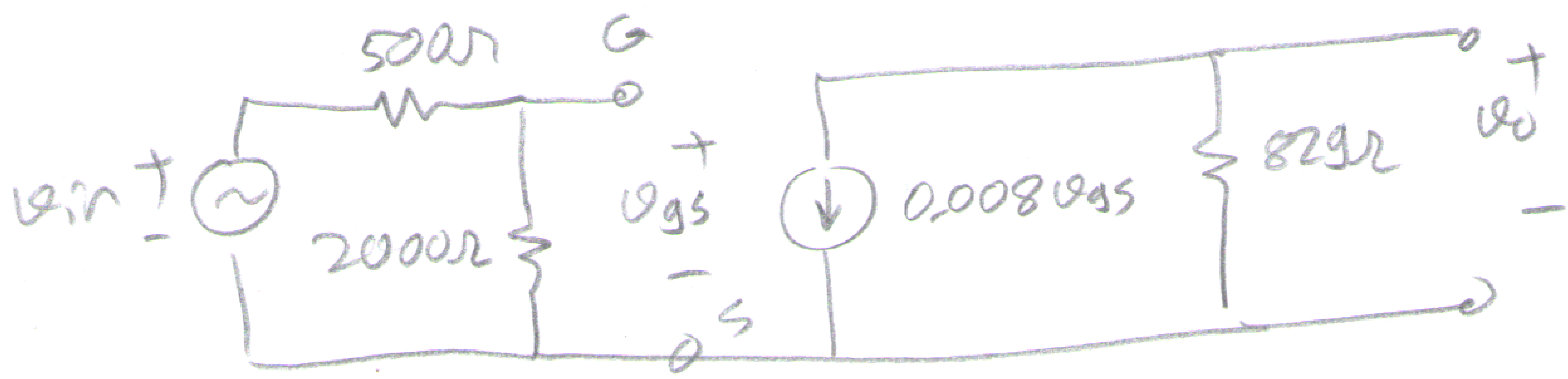
$g_m = 2\sqrt{I_D K_n} = 2\sqrt{4\times10^{-3}\times4\times10^{-3}} = 2\times4\times10^{-3} = 8$ msiemens

$r_o = \frac{V_A}{I_D} = \frac{100V}{4\times10^{-3}A} = 25\times10^{3}\Omega = 25k\Omega \Rightarrow$

The AC equivalent circuit becoms

$r_{eq} = 25k // 1.5k // 2k = 25k // 0.8571 = 0.8287k\Omega$

$= 829\Omega$

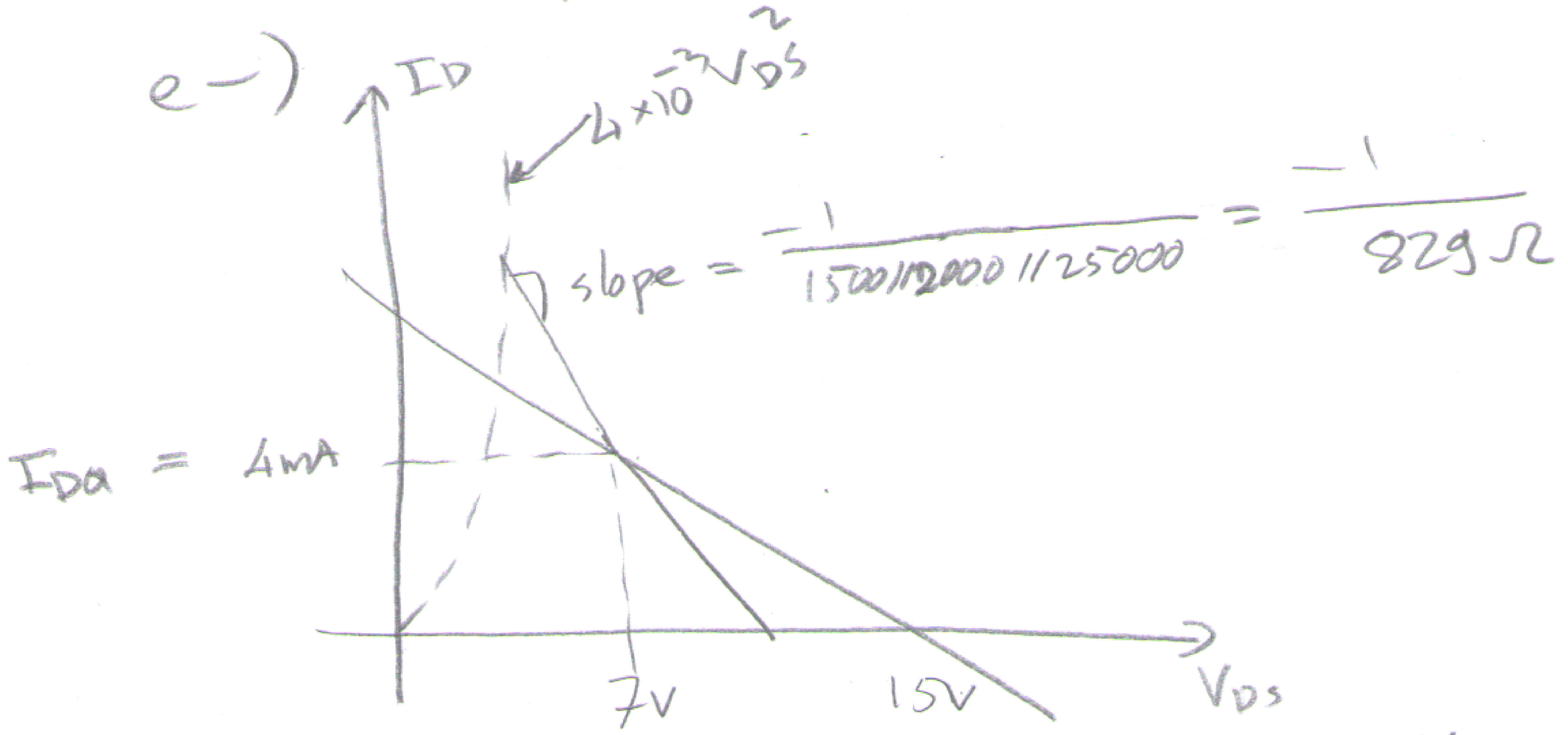


c-) $v_o = 0.008\, v_{gs} \times 829 = 829 \times 0.008 \times \frac{2000}{2500} v_{in} \Rightarrow$

$$\frac{v_o}{v_{in}} = \frac{829 \times 0.008 \times 4}{5} = 5.3056$$

d-) The input resistane is 2k

e-)



$V_t = I_{DQ} * R_D \| R_L = 4\,mA \times 829\Omega = 3.316\,V$

f-) The AC loadline is given by

$$\frac{\Delta I}{\Delta V} = -\frac{1}{829\Omega} = \frac{I_D(t) - 4mA}{V_{DS}(t) - 7V}$$

$-(V_{DS}(t) - 7) = (I_D(t) - 4mA)\, 829\Omega \Rightarrow$

$829 I_D(t) - 4 \times 10^{-3} \times 829 = 7 - V_{DS}(t)$

$$I_D(t) = \frac{7 + 3.316 - V_{DS}(t)}{829}$$

$$I_D(t) = \frac{10.316}{829} - \frac{1}{829} V_{DS}(t) \Rightarrow$$

$$\boxed{\begin{array}{c} I_D(t) = 0.012444 - \frac{1}{829} V_{DS}(t) \\ \text{and} \\ I_D(t) = K_n V_{DS}^2 = 4 \times 10^{-3} V_{DS}^2 \end{array}}$$

IF the question (4-f) were to be solved:

f-) $-\dfrac{V_{DS} - 10.316}{829} = 4\times10^{-3} V_{DS}^2$

$4\times10^{-3} V_{DS}^2 + 0.00121\, V_{DS} - 0.01244 = 0$

$\underset{a=1}{V_{DS}^2} + \underbrace{0.3025}_{b} V_{DS} - \underbrace{3.11}_{c} = 0$

$V_{DS_{1,2}} = \dfrac{-b}{2a} \pm \dfrac{\sqrt{b^2-4ac}}{2a} = \dfrac{-0.3025}{2} \pm \dfrac{(0.3025^2 + 4\times3.11)^{1/2}}{2}$

$V_{DS_{1,2}} = -\dfrac{0.3}{2} \pm \dfrac{12.4915^{1/2}}{2} = -0.15 \pm 1.7672\ V$

$V_{DS_{1,2}} = -\cancel{1.917},\ 1.6172\ V$

$V\_ = 7 - 1.6172 = 5.3828\ V$