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Signature: ________________ EEE 313 Spring 2012

Bilkent University
Department of Electrical and Electronics Engineering
EEE 313 Electronic Circuit Design
Midterm Examination #1
14 March 2012, 17.40

(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 **3 significant digits**. Double check your numerical calculations.
- 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.

Useful constants and formulas:

Boltzmann's constant: 86×10^{-6} eV/K°

Electron charge: 1.6×10^{-19} Coulombs

Drain currrent equation for n-channel MOSFET:

$I_D = K_n(V_{GS} - V_{TN})^2$ for $V_{GS} - V_{TN} \le V_{DS}$

$I_D = K_n(2(V_{GS} - V_{TN})V_{DS} - {V_{DS}}^2)$ for $V_{GS} - V_{TN} \ge V_{DS}$

Drain currrent equation for p-channel MOSFET:

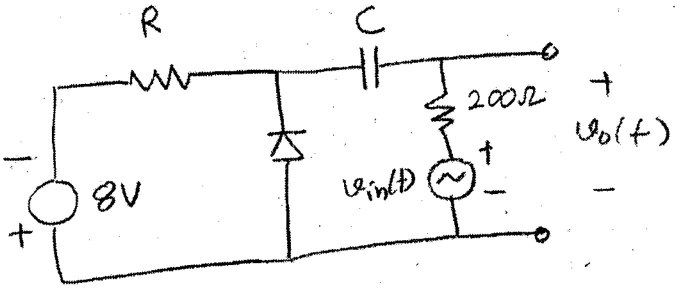
$I_D = K_p(V_{SG} + V_{TP})^2$ for $V_{SG} + V_{TP} \le V_{SD}$

$I_D = K_p(2(V_{SG} + V_{TP})V_{SD} - {V_{SD}}^2)$ for $V_{SD} + V_{TP} \ge V_{SD}$

Other equations must be deduced by the students.

Please do not write below this line

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



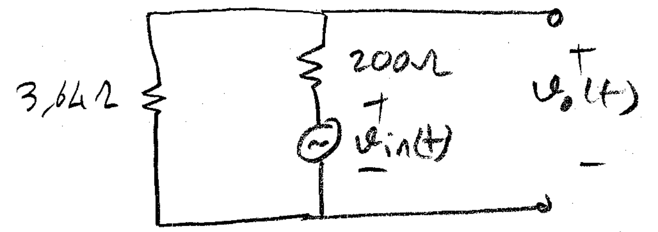
1. (24 points) At the circuit given above, the diode is ideal except $V\gamma$=0.7Volts. The value of the resistor R is 1kΩ. Vin(t) is equal to 0.5cos(1000t). Answer the following:

a) (6 points) Find the DC current flowing through the diode,
b) (6 points) Draw the AC equivalent circuit assuming C is very large,
c) (6 points) Calculate and plot $v_o(t)$
d) (6 points) Write a condition on the value of C in order to be assume that it is very large.

a-) $I_d = \dfrac{8V - 0.7V}{1000\Omega} = \boxed{7.3 \times 10^{-3} A}$

b-) $r_d = \dfrac{V_T}{I_d} = \dfrac{26.6mV}{7.3mA} = \boxed{3.64\Omega}$ assuming small signal appr.

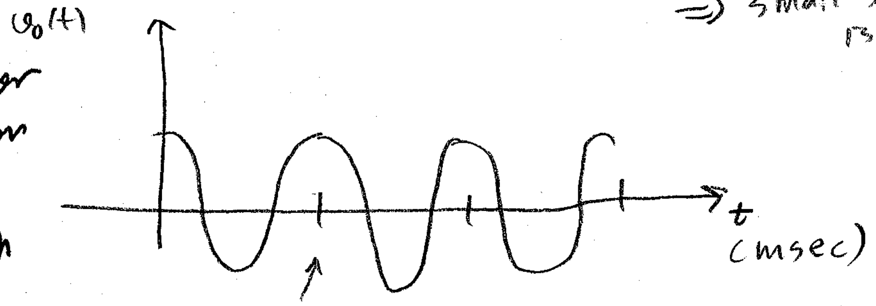
(3) for circuit
(3) for rd



c-) $v_o(t) = 0.5\cos 1000t \cdot \dfrac{3.64 \times 0.5}{200+3.64} = \boxed{8.94 \times 10^{-3} V} \ll V_T$

⇒ small signal approximation is correct

(3) points for calculation
(3) points for graph



$\dfrac{2\pi}{1000}$ sec = 159.1msec

as $\dfrac{2\pi}{T} = 1000 \Rightarrow T = \dfrac{2\pi}{1000}$ sec d-) continued

The detailed solution is

$$\vec{V_o} = \vec{V_{in}} \frac{rd//R}{rd//R + 200 + \frac{1}{jwC}} \Rightarrow$$

$\left|\frac{1}{jwC}\right|$ must small enough in order not to affect the ratio $\frac{rd//R}{rd//R + 200 + \frac{1}{jwC}} \Rightarrow$

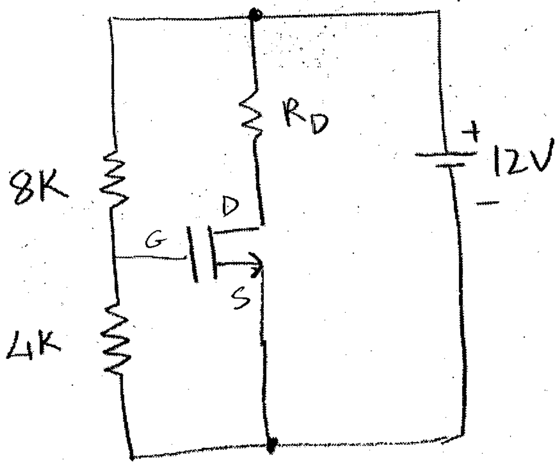
$$\left|\frac{1}{jwC}\right| << rd//R + 200 \Rightarrow$$

$$C >> \frac{1}{w(rd//R + 200)} = \frac{1}{1000\left(\frac{3.64 \times 1000}{1000 + 3.64} + 200\right)}$$

$$C >> \frac{1}{1000(200 + 3.63)} = \frac{1}{1000 \times 203.63} =$$

$$C >> 4.91 \times 10^{-6} F$$

$$\boxed{C >> 4.91 \mu F}$$



2. (20 points) At the circuit given above, the transistor is an n-channel enhancement mode MOSFET with V_{TN}=2 Volts and $K_n=1\times10^{-3}A/V^2$. $R_d=1.5k\Omega$.

a) (15 points) Find the bias (Voltages and currents of the transistor) of the transistor,

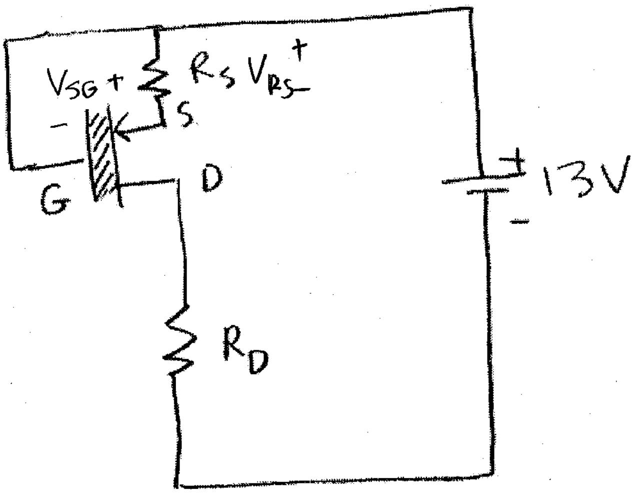
b) (5 points) Verify the bias ~~of the~~ ~~transistor~~. ~~sat~~ state of the transistor

a-) $V_{GS} = 12V \times \frac{4k}{8+4k} = 12V \frac{\times 4}{12} = 4V$ assume SAT

$I_d = K_n(V_{GS} - V_{TN})^2 = 10^{-3} A/V^2 [4-2]^2 = 4mA$

$V_{DS} = 12V - I_D R_D = 12 - 4\times10^{-3}\times1.5\times10^{3} = 12 - 6 = 6V$

b-) $6V = V_{DS} > V_{GS} - V_{TN} = 2V$ ✓ SAT



3. (20 points) At the depletion-mode p-channel MOSFET circuit given above, $V_{TP}=4$ Volts and $K_P=3\mathrm{x}10^{-3}\mathrm{A/V}^2$. $R_d=2\mathrm{k}\Omega$ and $R_S=1\mathrm{k}\Omega$

a) (15 points) Find the bias of the transistor,

b) (5 points) Verify the solution.

a-) $0V = V_{SG} + I_D\, 1000\Omega = V_{SG} + 3\times\cancel{10^{-3}}\left(V_{SG} + (+4)\right)^2 \times \cancel{1000}$

assuming SAT

$0 = V_{SG} + 3\left[V_{SG}^2 + 8V_{SG} + 16\right] = V_{SD} + 3V_{SG}^2 + 24V_{SG} + 48$

$0 = 3V_{SG}^2 + 25V_{SG} + 48$

$\quad a \qquad b \qquad c$

$V_{SG1,2} = \frac{-25}{6} \pm \frac{\sqrt{625-12\times 48}}{6} = \frac{-25\pm 7}{6} = \frac{-18}{6}, \frac{-32}{6}$

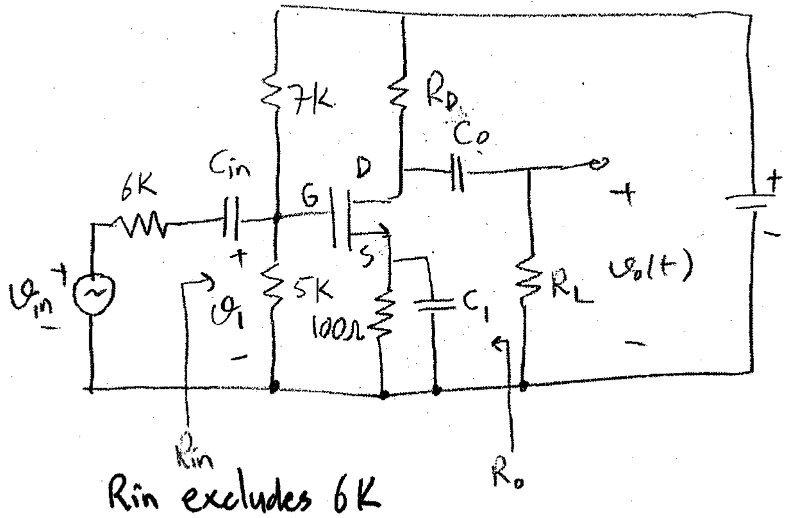
$= -3, -5\frac{2}{3}$, $\left|-5\frac{2}{3}\right|$ is larger than $|V_{TP}| \Rightarrow$ not applicable

$I_D = 3\times10^{-3}(-3+4)^2 = 3mA$

$\Rightarrow V_{SG} = -3V$, $V_{SD} = 13V - I_D\, 2000 - I_D 1000 = 13 - 3\times10^{-3}\times\cancel{3000} = 13-9 = 4V$

b-) $I_d = 3mA$, $V_{SG} = -3V \Rightarrow V_{SD} = 4$, $V_{SG} = 0 - \underbrace{3\times10^{-3}}_{I_d}\times\underbrace{10^{3}}_{R_S} = -3V$

$V_{SD} = 4V > V_{SG} + V_{TP} = -3+4 = 1V$ ✓ $\Rightarrow$ SAT



Rin excludes 6K

4. (36 points) At the circuit given above, the transistor is an n-channel enhancement mode MOSFET with V_{TN}=1 Volts and K_n=3.333x10^{-3}A/V^2. R_D=400Ω and R_L=1000Ω. Answer the following:

(7) a-) (7points Derive the equation for g_m in terms of I_D & K_n at saturation

(8) ~~a)~~ b) (~~9~~ 8points) The drain current turns out to be 10mA and the transistor is at saturation. Draw the AC equivalent circuit. (6) for short AC capacitors

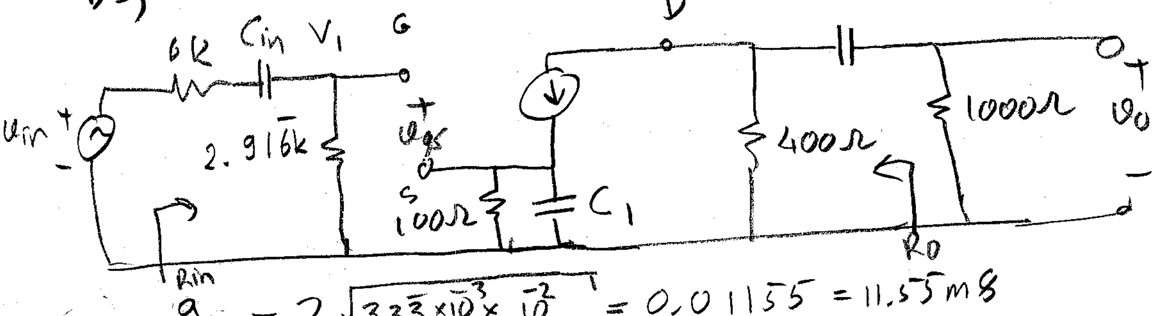
(7) c-) ~~b)~~ (~~9~~ 7 points) Find the voltage gain of the amplifier defined as Vo/Vin assuming that C_{in}, C_o and C_1 are very large.

(7) d-) ~~c)~~ (~~9~~ 7 points) Find the input and output impedances of the amplifier again assuming that Cin, Co and C1 are very large.

(7) e-) ~~d)~~ (~~9~~ 7 points) Find a condition (inequality) which imposes a limit on C_{in} if the frequency of operation is 1000Hz.

a-) $I_d = K_n(V_{GS}-V_{TN})^2 \Rightarrow \frac{dI_d}{dV_{GS}} = 2K_n(V_{GS}-V_{TN}) = 2K_n \frac{I_d^{1/2}}{K_n^{1/2}} = 2\sqrt{K_n I_d}$

b-)



$g_m = 2\sqrt{3.33\overline{3}\times10^{-3}\times10^{-2}} = 0.01155 = 11.55\,mS$

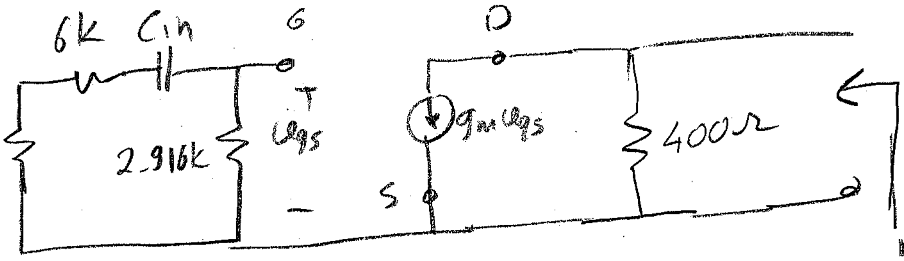
c-) $v_o = -g_m\, 285.7\, v_{gs} = -3.3\, v_{gs} = -3.3 \times \frac{2.916}{6+2.916} v_{in} = -1.079\, v_{in}$

$\Rightarrow \frac{v_o}{v_{in}} = -1.079$

d-) $R_{in} = 7K \parallel 5K = 2.916k\Omega$ as G is open for DC

$R_o = 400\Omega$ as a current source controlled by an independent source is open circuit.

or if you short the input source, the circuit becomes



The current source becomes a constant current source with no AC component ⇒ open circuit ⇒

$R_o = 400\Omega$

e-) $v_1 = v_{in} \cdot \dfrac{2916\,\Omega}{6000 + 2916 + \frac{1}{j\omega C_{in}}}$ this function which can also be written as

$$\frac{v_1}{v_{in}} = \frac{2916}{8916 + \frac{1}{j\omega C_{in}}}$$ settles to $\dfrac{2916}{8916}$ as $\omega \to \infty$

which is when $\left|\dfrac{1}{j\omega C_{in}}\right| \ll 8916\Omega$ ⇒

$$\boxed{\left|\frac{1}{j\omega C_{in}}\right| \ll 8916\Omega}$$

$$C_{in} \gg \frac{1}{2\pi \times 1000 \times 8916} = 1.785 \times 10^{-8} F = 17.85 \times 10^{-9} F$$

$$\boxed{17.85\,nF}$$