Midterm 2

EE40 - Summer 2014

Gerd Grau

Name:

Discussion section:

Discussion GSI:

Student ID:

Instructions:

Unless otherwise noted on a particular problem, you must show your work in the space provided or on the back of the exam pages.

Underline your answers to each problem with a double line.

Simplify your answers as far as possible unless otherwise noted.

Be sure to provide units where necessary.

GOOD LUCK!

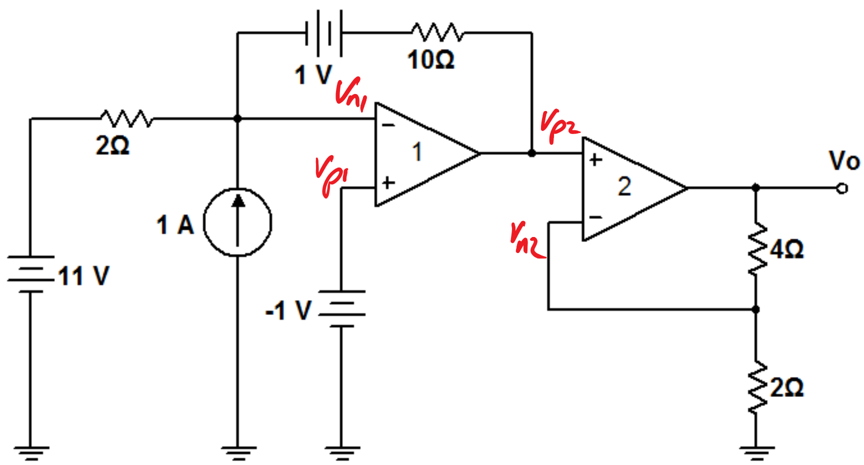
Question	Points	Max
1		9
2		15
3		22
4		18
Total		64

9

Question 1 (9 points):

Consider the below op-amp circuit under DC conditions. Assume the op-amp is ideal and that you can apply the negative feedback assumption.

a) Calculate the output voltage V_o.
b) Do you see any problem with this result for real op-amps such as those in our lab?



a) $v_{p1} = v_{n1} = -1V$

KCL at v_{n1}: $\frac{11-(-1)}{2} + \frac{v_{p2} - 1 - (-1)}{10} + 1 = 0$

$v_{p2} = 10 \times \left(-\frac{12}{2} - 1\right) = -70\ V$ 7

Second stage is non-inverting amplifier

$\Rightarrow v_o = \left(1 + \frac{4}{2}\right) \cdot v_{p2} = 3 \cdot (-70) = \underline{-210\ V}$

b) v_o is limited by supply voltage.

Typical op-amps are in the range ~±5-25V

-210V is too large for typical op-amps 2

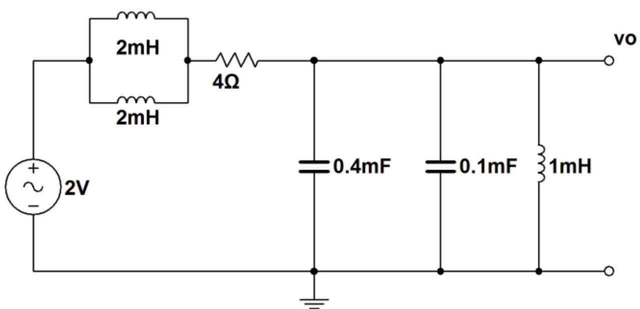
15

Question 2 (15 points):

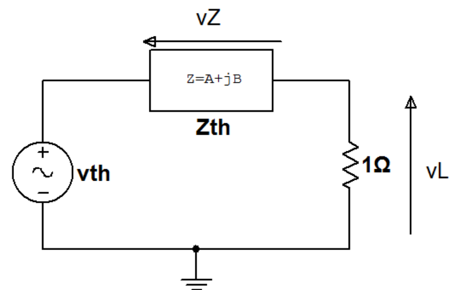
a) Find and draw the Thevenin equivalent circuit of the below circuit in terms of the equivalent open circuit voltage (magnitude and phase) and Thevenin complex impedance (in the form a+bj). The AC frequency of operation is ω=2000rad/sec.

b) A 1Ω resistor is connected across the output of the equivalent circuit as illustrated in the second circuit diagram. Draw the phasor diagram showing the source voltage, the voltage across the Thevenin impedance and the voltage across the 1Ω load.

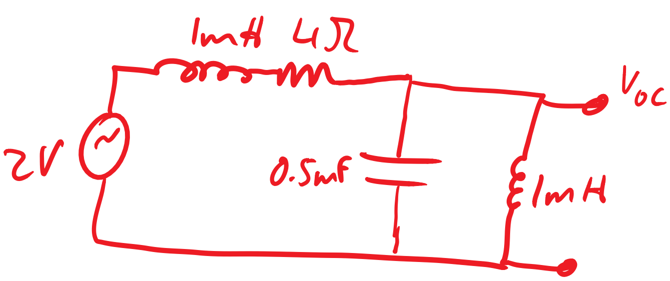
Circuit for part a):



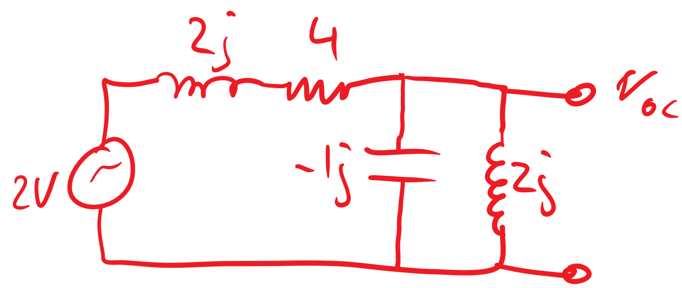
Equivalent circuit for part b):

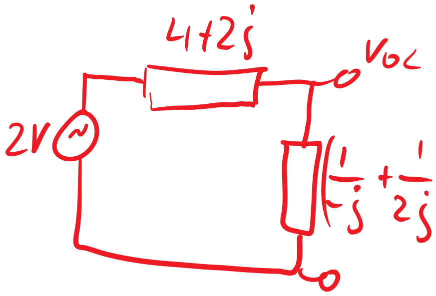


a) simplify circuit:



Impedances:





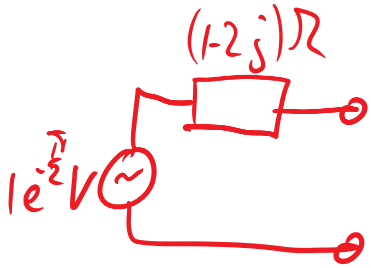
$$\left(\frac{1}{-j}+\frac{1}{2j}\right)^{-1} = j\left(-1+\frac{1}{2}\right)^{-1} = -2j$$

Potential divider:

$$V_{th} = V_{oc} = 2\times\frac{-2j}{4+2j-2j} = -j = \underline{1Ve^{-\frac{\pi}{2}}}$$

Equivalent impedance:

$$Z_{th} = (4+2j)\,||\,(-2j) = \frac{(4+2j)\cdot(-2j)}{4+2j-2j} = \underline{(1-2j)\,\Omega}$$



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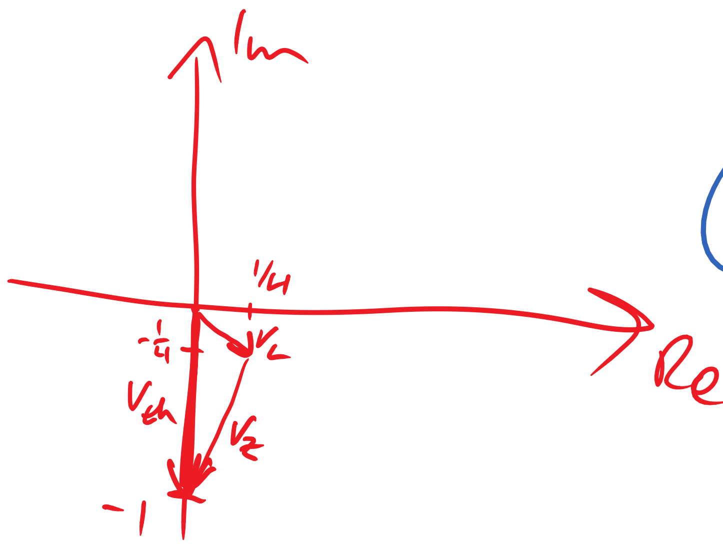
b) $V_{th} = 1e^{-\frac{\pi}{2}} = -j$

$$V_L = \frac{1}{1+1-2j}\cdot 1e^{-\frac{\pi}{2}} = \frac{1}{2-2j}\cdot(-j) = \frac{2+2j}{4+4}(-j) = \frac{1}{4} - \frac{1}{4}j$$

$$V_Z = \frac{1-2j}{2-2j}\cdot(-j) = \frac{(2-j)(2+2j)}{4+4} = \frac{-4+2-2j-4j}{8} = -\frac{1}{4} - \frac{3}{4}j$$

only one of them necessary



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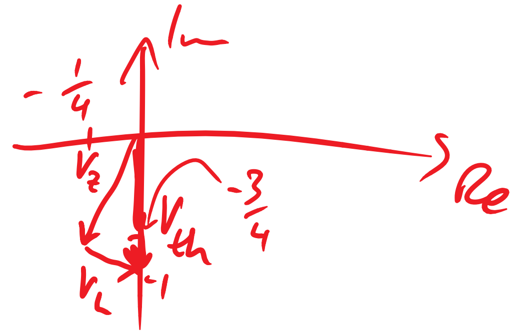
Also correct:



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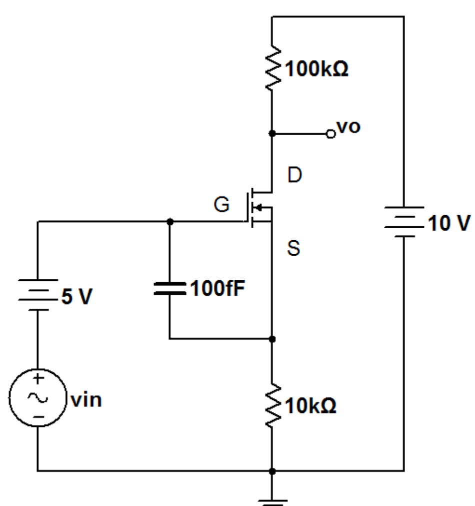
Question 3 (22 points):

Analyze the below MOSFET circuit. The transconductance g_m is 0.1A/V. If any of your results are complex numbers, quote the final result in the form a+bj. If you can round any result to an integer value with an error of less than 1%, then do so.

a) Draw the small signal equivalent circuit i.e. use superposition to only consider AC signals ignoring DC. You can assume that the applied DC voltages put the MOSFET into the operating regime that allows you to use the MOSFET equivalent circuit from class. You can assume that r_d is large enough to be ignored.

b) Find the following parameters assuming that the 100fF capacitor can be ignored and treated as an open circuit:
   i) Gain $A=v_{out}/v_{in}$
   ii) Input impedance $Z_{in}=v_{in}/i_{in}$

c) Now include the capacitor to find those parameters. $\omega=10^{12}$rad/sec.
   i) Gain $A=v_{out}/v_{in}$
   ii) Input impedance $Z_{in}=v_{in}/i_{in}$



a)

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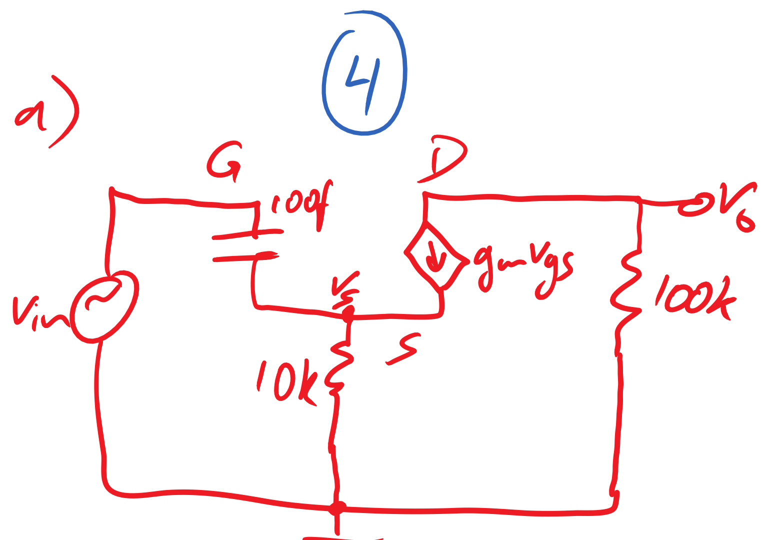

b) i) $V_o = -g_m V_{gs} \times 100k$

$V_{gs} = V_{in} - V_s$

$V_s = g_m V_{gs} \times 10k$

$V_{gs} = V_{in} - g_m V_{gs} \times 10^4$

$V_{gs} = \frac{V_{in}}{1+10^4 g_m}$

$V_o = -10^5 g_m \times \frac{V_{in}}{1+10^4 g_m}$

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$A = \frac{V_o}{V_{in}} = -\frac{10^5 \times 0.1}{\cancel{1}+10^4 \times 0.1} \simeq \frac{-10^5}{10^4} = -10$

ii) $R_{in} = \frac{V_{in}}{i_{in}} = \infty$

1

c) i) $v_o = -g_m v_{gs} \cdot 10^5$ $\qquad v_{gs} = v_{in} - v_s$

KCL at S:

$$\frac{v_s}{10^4} + \frac{-v_{gs}}{\frac{1}{j\omega C}} - g_m v_{gs} = 0 \qquad \frac{1}{j\omega C} = \frac{-j}{10^{12} \cdot 10^{-13}} = -10j$$

$$\frac{v_s}{10^4} + \frac{v_{gs}}{10j} - 0.1 v_{gs} = 0$$

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$$v_s = 10^4 v_{gs}\left(\frac{1}{10} - \frac{1}{10j}\right)$$

$$v_{gs} = v_{in} - v_s = v_{in} - 10^4 v_{gs}\left(\frac{1}{10} - \frac{1}{10j}\right) \Rightarrow v_{gs} = \frac{v_{in}}{1 + 10^4\left(\frac{1}{10} - \frac{1}{10j}\right)}$$

$$v_o = -g_m v_{gs} 10^5$$

$$= -\frac{g_m 10^5}{1 + 10^4\left(\frac{1}{10} - \frac{1}{10j}\right)} \cdot v_{in}$$

$$A = \frac{v_o}{v_{in}} = -\frac{1/10 \cdot 10^5}{\cancel{1} + 10^3(1+j)} \approx -\frac{10^4}{10^3} \cdot \frac{1-j}{1+1} = \underline{-5 \cdot (1-j)}$$

ii)

$$Z_{in} = \frac{v_{in}}{i_{in}} \qquad i_{in} = \frac{v_{gs}}{1/j\omega C} = \frac{v_{gs}}{-10j} = \frac{1}{-10j} \cdot \frac{v_{in}}{1 + 10^4\left(\frac{1}{10} - \frac{1}{10j}\right)}$$

$$Z_{in} = -10j \cdot (\cancel{1} + 10^3(1+j)) \approx -10j \cdot 10^3 (1+j)$$

$$= \underline{10^4 - 10^4 j}$$

4

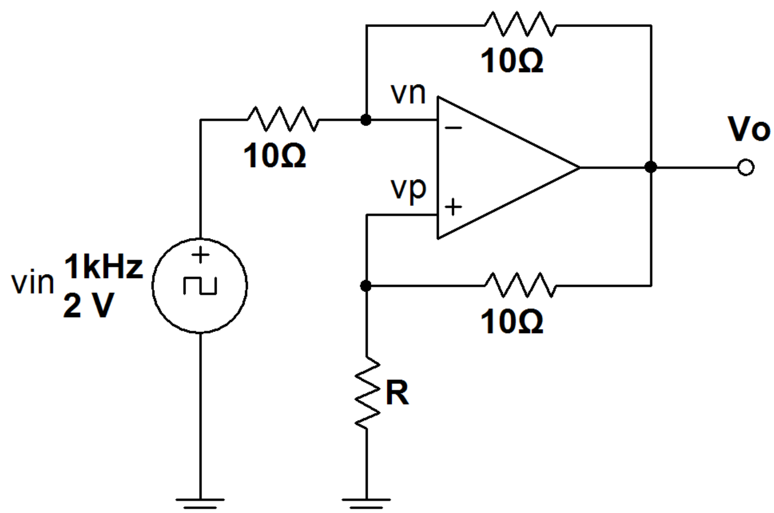
18

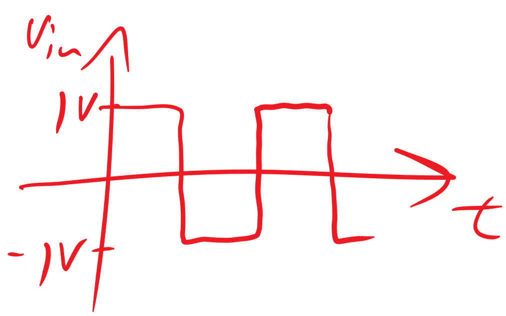
Question 4 (18 points):

Consider the below op-amp circuit. Assume the op-amp is ideal except for a limited supply voltage of ±5V. The input is a 2V peak-to-peak square wave at 1kHz with duty cycle of 50% i.e. the input oscillates between -1V and +1V. Clearly the output is connected to both the negative and positive supply terminal of the op-amp. For each part be careful whether you can use the negative feedback simplification for ideal op-amps.

a) Draw the output waveform of v_o for R=1Ω and the waveform of v_{in} on the same axes. Show your calculations. Can you use the negative feedback assumption? Give a reason.

b) Draw the output waveform of v_o for R=100Ω and the waveform of v_{in} on the same axes. Show your calculations. Can you use the negative feedback assumption? Give a reason.





a) $V_p = V_o \times \frac{1}{1+10} = \frac{V_o}{11}$

KCL: $\frac{V_{in} - V_n}{10} + \frac{V_o - V_n}{10} = 0$

$V_n = \frac{V_{in} + V_o}{2}$

If $V_o = +5V$, $V_p = \frac{5}{11} < 0.5V$. Minimum $V_n = \frac{-1+5}{2} = 2$

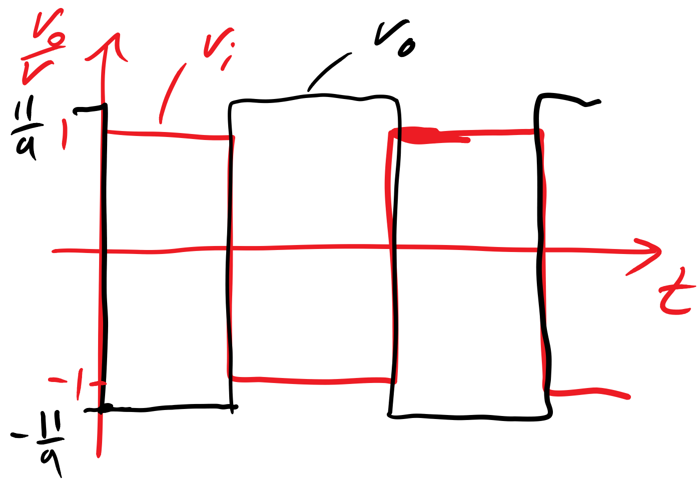
⇒ $V_n > V_p$ ⇒ contradiction. V_o does not rail ⇒ negative feedback (similarly for $V_o = -5V$).

$\Rightarrow v_n = v_p = \frac{v_o}{11}$

$$\frac{v_{in} - \frac{v_o}{11}}{\cancel{10}} + \frac{v_o - \frac{v_o}{11}}{\cancel{10}} = 0$$

$$v_{in} + \frac{9}{11} v_o = 0$$

$$v_o = \frac{-11}{9} v_{in}$$



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b) $v_p = \frac{100}{100+10} v_o = \frac{10}{11} v_o$

If $v_o = +5V$, $v_p = \frac{50}{11} V > 4V$. Maximum $v_n = \frac{v_o + v_{in}}{2} = \frac{5+1}{2} = 3V$

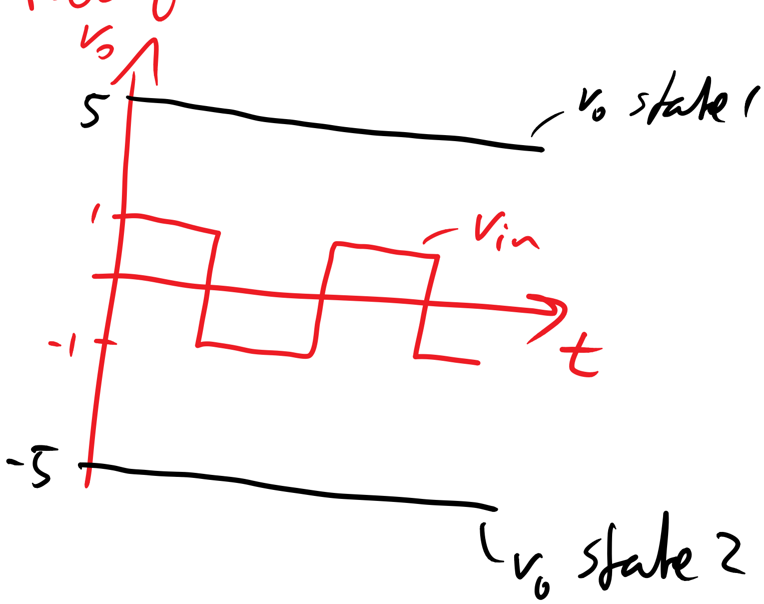
$\Rightarrow v_p - v_n > 0 \Rightarrow$ positive feedback

similarly for $v_o = -5V$

$\Rightarrow$ Input can never switch the output

$\Rightarrow$ Output depends on initial state on startup

Two possible states:



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