ENGR-2300

Electronic Instrumentation

Quiz 2

Fall 2018

Name SOLUTIONS

Section ___

Question I (20 points) ___________

Question II (20 points) ___________

Question III (20 points) ___________

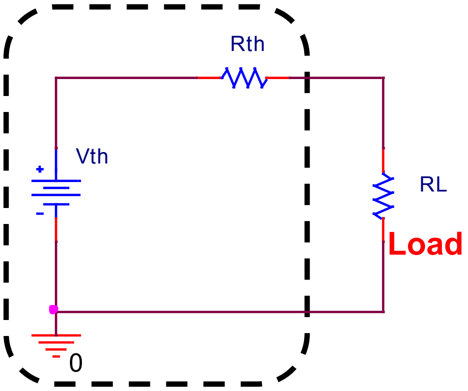
Question IV (20 points) ___________

LMS Question is worth an additional 20pts

Total (80 points) ______________

On all questions: SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS. No credit will be given for numbers that appear without justification. Read the entire quiz before answering any questions. Also it may be easier to answer parts of questions out of order.

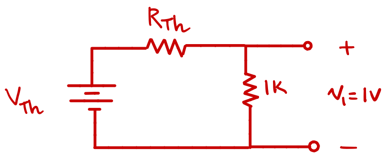
1. Thevenin Equivalent And Circuit Concepts



The Thevenin Equivalent Circuit consists of a voltage source in series with a resistor, which provides a very simple replacement for much more complex circuits. If we have this simple source, analyzing changing loads becomes quite easy.

a) Two measurements are performed in order to determine the unknowns, Vth and Rth. In the first measurement load resistor RL is 1kΩ and is later changed to 5kΩ. For these two cases, the voltage across the load resistor, VL, is experimentally found to be 1.0V and 2.5V respectively, as shown in table below. Using these two measurements, find the two unknowns, Vth and Rth. {5pts}

RL (in ohms)	VL (in volts)
1k	1.0
5k	2.5

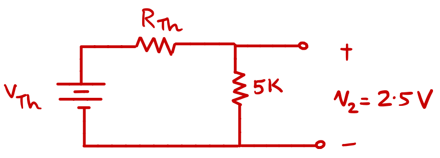


Using Voltage division

$$v_1 = V_{Th}\left(\frac{1K}{1K+R_{Th}}\right)$$

$$\Rightarrow V_{Th} \times 1K = R_{Th} + 1K$$

$$\Rightarrow \boxed{V_{Th} = \frac{R_{Th}}{1K} + 1} \quad eq^n 1$$



Using Voltage division

$$v_2 = V_{Th}\left(\frac{5K}{5K+R_{Th}}\right)$$

$$V_{Th} \times 5K = 12.5K + 2.5R_{Th}$$

$$\Rightarrow \boxed{V_{Th} = \frac{R_{Th}}{2K} + 2.5} \quad eq^n 2$$

Solving $eq^n 1$ and $eq^n 2$;

$eq^n 1 - eq^n 2 \Rightarrow$

$$\frac{R_{Th}}{2K} - 1.5 = 0$$

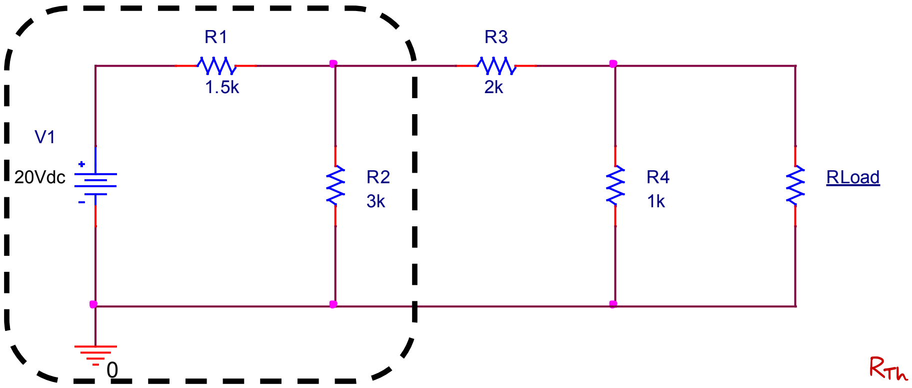
$$\boxed{R_{Th} = 3K\Omega}$$

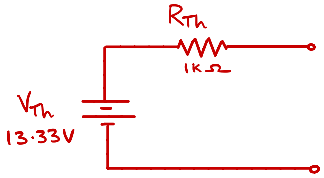
$$V_{Th} = \frac{R_{Th}}{1K} + 1 = 4.0V$$

V_{Th} = 4.0 V

R_{Th} = 3 KΩ

b) For a completely different circuit shown below, **find** and **sketch** the Thevenin Equivalent Voltage source for the part of the circuit inside the dashed line (i.e. resistors R1 and R2 and the voltage source V1).{4pts}



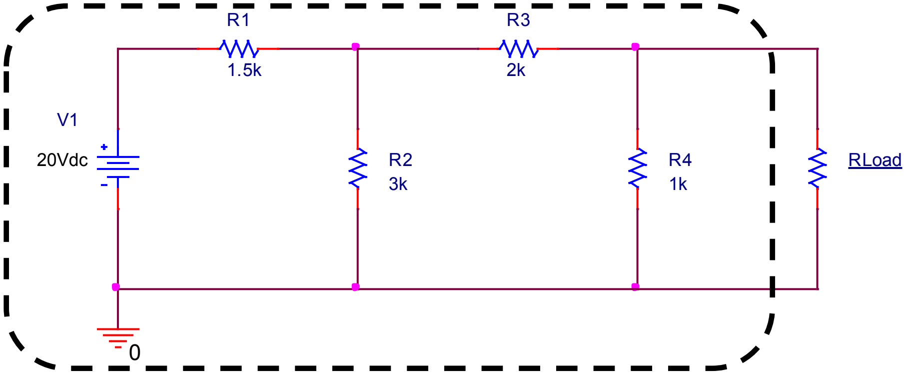


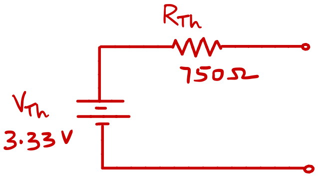
$$V_{Th} = V1 \left(\frac{3K}{4.5K} \right)$$

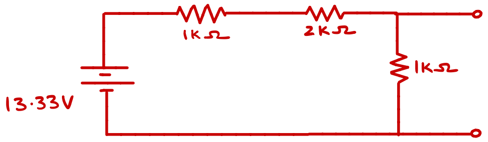
$$= 13.33V$$

$$R_{Th} = 3K \parallel 1.5K = 1K\Omega$$

c) **Find** and **sketch** the Thevenin Voltage source for the entire circuit (i.e. resistors R1, R2, R3, R4, and the voltage source V1). {4pts}







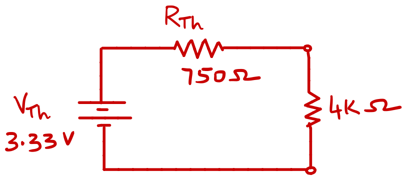
$$V_{Th} = 13.33 \left(\frac{1K}{1K+2K+1K} \right) = 3.33\ V$$

$$R_{Th} = 1K \parallel 3K = 0.75K = 750\Omega$$

V_{Th} = 3.33V

R_{Th} = 750Ω

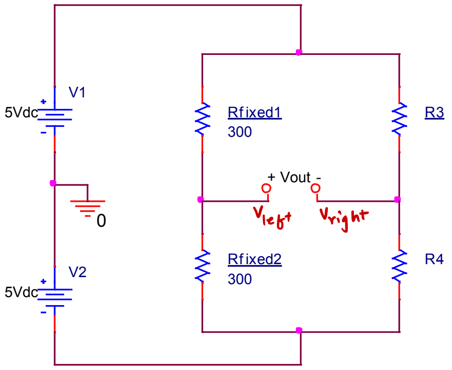
d) Using the Thevenin equivalent circuit obtained in part c, find the current through load resistor when Rload = 4kΩ. {3pts}



$$I_{RLoad} = \frac{3.33\ V}{4750\ \Omega} = 0.702\ mA$$
$$= 702\ \mu A$$

$(I_{Rload})_{4k}$ = 0.702 mA

e) Circuit concepts: Strain Gauge. The circuit shown the strain gauge used in Exp. 5. Assume that if the beam is unstressed, R3 and R4 are both 300Ω. Determine Vout if the beam is moved so that R3=340Ω and R4=260Ω. Be sure to note the polarity. {4pts}



$$V_{left} = [5-(-5)]\left(\frac{300}{300+300}\right) - 5V$$
$$= 5V - 5V = 0V$$

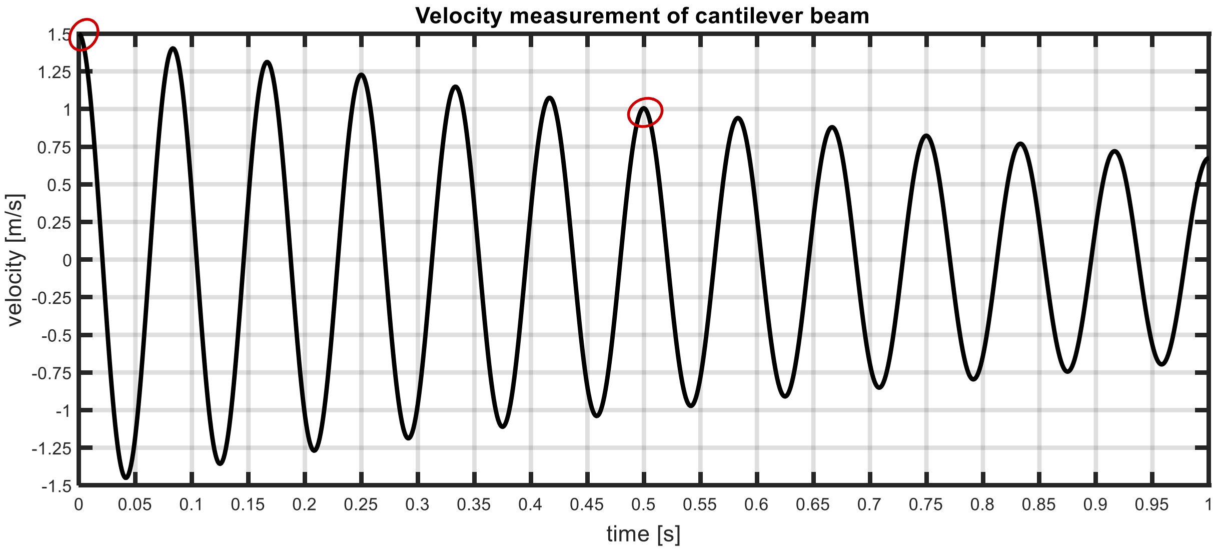
$$V_{right} = [5-(-5)]\left(\frac{260}{260+340}\right) - 5V$$
$$= -0.667\ V$$

$$V_{out} = V_{left} - V_{right} = 0 - (-0.667)$$
$$= 0.667\ V$$

Vout = 0.667 V

2. Harmonic Oscillators and Math

The velocity measured for an oscillating cantilever beam is shown in graphical form as:



The horizontal scale is time (0.05 sec per division) and the vertical scale is velocity (0.25m/s per division).

a. Find the decay constant α and the angular frequency ω for this function. Mark the points used on the plot. {5pts}

$v_1 = v_0 e^{-\alpha(t_1 - t_0)}$

$1 = 1.5 e^{-\alpha(0.5)}$

$\alpha = -\frac{1}{0.5} \ln\left(\frac{1}{1.5}\right)$

$= \boxed{0.811 \ sec^{-1}}$

6 cycles in 0.5 sec

$\Rightarrow$ 12 cycles in 1 sec

$\Rightarrow f = 12 \ Hz$

$\omega = 2\pi f = 24\pi$ rad/sec

$\boxed{\omega = 75.4 \ rad/sec}$

b. Write the mathematical expression for the velocity in the form $v(t) = Ae^{-\alpha t}\cos \omega t$ in m/s. Use real values for the constants and provide units where appropriate. {4pts}

$$\boxed{v(t) = 1.5 \, e^{-0.811t} \cos[75.4t] \quad m/s}$$

c. Find the approximate acceleration *a(t)* of the beam from your answer to part b. Again, use real values for the constants and provide units where appropriate. *Hint: Keep only the largest term in your expressions.* $(fg)' = fg' + f'g$ {4pts}

$$a(t) = \frac{dv(t)}{dt} = \frac{d}{dt}\left(1.5\, e^{-0.811t} \cos[75.4t]\right)$$

$$= 1.5\, e^{-0.811t} [-\sin(75.4t)] \times 75.4 + (-0.811)\, 1.5\, e^{-0.811t} \cos(75.4t)$$

$$= -113.1\, e^{-0.811t} \sin(75.4t) - \boxed{1.22\, e^{-0.811t} \cos(75.4t)}$$

Can be ignored as 113 >> 1.22

$$\boxed{\begin{array}{r} a(t) \approx -113.1\, e^{-0.811t} \sin(75.4t) \\ m/s^2 \end{array}}$$

d. A guess is made for the amplitude of the beam position *x(t)*. The consensus of the team partners is that the displacement is about 2cm or 0.02m. Write the mathematical expression for the position in the form $x(t) = Be^{-\alpha t} \sin \omega t$ in meters, find the approximate velocity *v(t)* and compare the result with your answer to part b. Was the guess high, low or about right? {4pts}

$$\text{If } B = 0.02 \Rightarrow x(t) = 0.02\, e^{-0.811t} \sin(75.4t) \quad m$$

$$v(t) = \frac{d}{dt} x(t) \approx 0.02\, e^{-0.811t} \times 75.4 \cos(75.4t) \rightarrow \text{Only the larger term}$$

$$\approx 1.51\, e^{-0.811t} \cos(75.4t) \quad m/s$$

$$\boxed{\text{About right}}$$

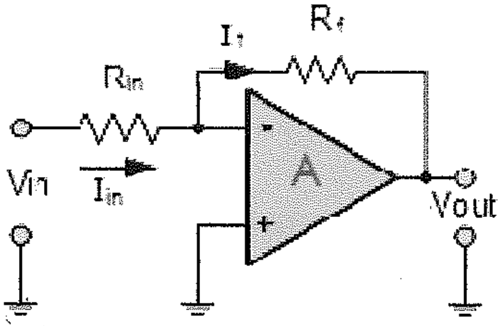
e. Assume that you would like to build an LC oscillator circuit that operates at the same frequency as the beam above. You have an 4700 μF capacitor and need to make an inductor. What value of inductance is necessary to achieve this frequency? {3pts}

$$\omega = \frac{1}{\sqrt{LC}} \Rightarrow 75.4 = \frac{1}{\sqrt{L \times 4700 \times 10^{-6}}}$$

$$\Rightarrow \boxed{L = 37.4\ mH}$$

3. Operational Amplifier Applications

a. (2pts)For diagram shown determine Vout(t) if:
Vin(t)=0.5cos8000t Volts
R_{in}=1kΩ
R_f=7kΩ



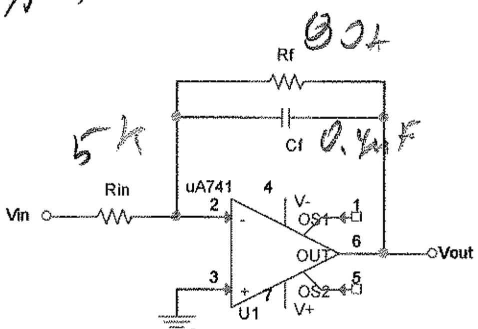
Gain = -7

$V_{out}(t) = -3.5\cos 8000t$ V

b. For the circuit in part a. above, what is I_{in}(t) and what is the effective input impedance, Z_{in} ? (2pts) $I_{in} = V_{in}/R_{in} = 0.5\cos 8000t$ mA

c. For the circuit shown:
Rin=5kΩ
Rf=80kΩ
Cf=0.4uF

$(8\times10^{4})(4\times10^{-7})$
32×10^{-3}
10^{3}



i. AC Steady State: if Vin is a sinusoidal waveform, for what range of frequency will this circuit behave as an integrator? Give the answer in Hz not radian/sec. (2pts) $W >> \frac{1}{R_f C_f}$ $\frac{1}{R_f C_f} = 31.25$ rad/sec

$\omega >> 31.25 \Rightarrow \boxed{f >> 5Hz}$ 1kHz

ii. Give the transfer function, H(jω) if the input has a frequency of 1~~0~~kHz, determine ω and plug in the component values. You are allowed to give the approximate but only if it is appropriate.(4pts)

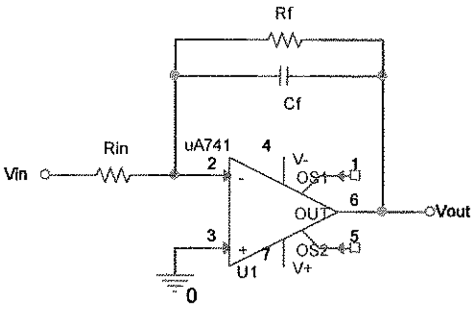
$f >> 5Hz$ so $H(j\omega) \approx \frac{-1}{j\omega R_{in} C_f} = \frac{-1}{(j)(2\pi\times10^3)(5000)(4\times10^{-7})}$

$= \left(\frac{-1}{j}\right)(0.08) = +0.08j$

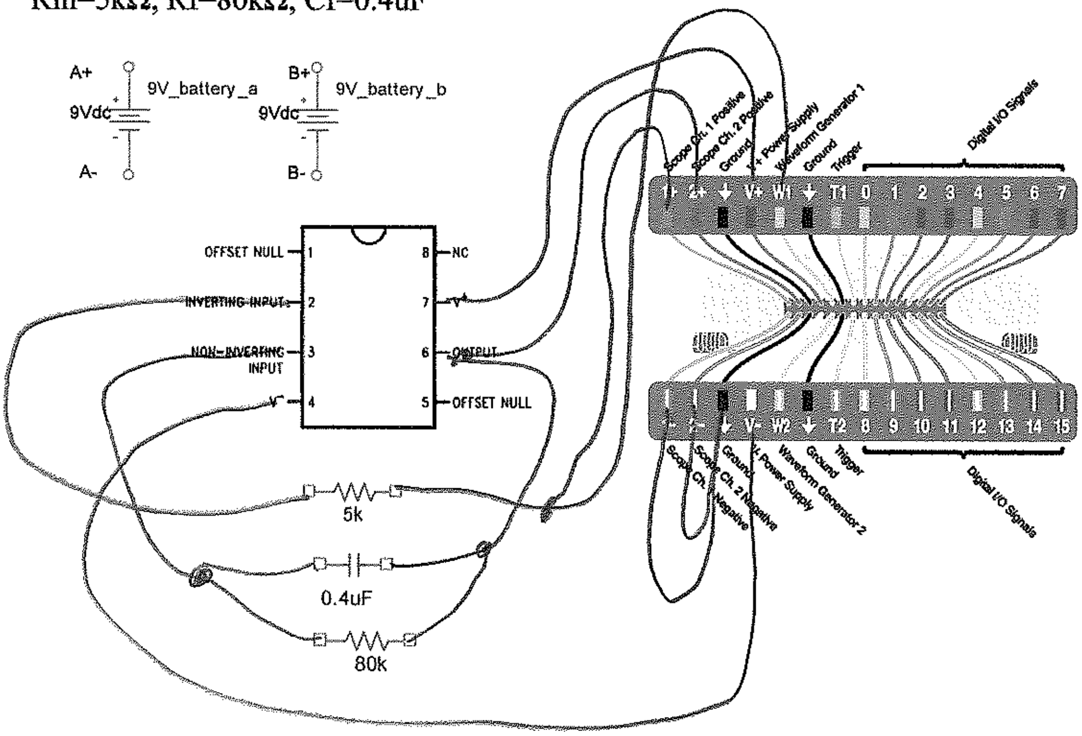
iii. What is the transfer function if Vin is a dc value? (2pts)

$C_f \Rightarrow$ open, gain $= -\frac{R_f}{R_{in}} = -16$ $\frac{V_{out}}{V_{in}} = H(0Hz) = -16$

d. Now build the circuit. **Draw lines to represent wires** to show how this circuit would be **built and tested** using the Analog Discovery as the signal source and the oscilloscope display. You must power the op-amp, either using batteries or the power supplies of the Analog Discovery. The figure shown is for the Analog Discovery 2, but the connections are the same for the original board. **Again – draw lines to build and test this circuit.** (4pts)



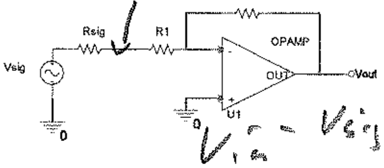
Rin=5kΩ, Rf=80kΩ, Cf=0.4uF



e. Real signal sources have effective source impedance, the internal resistance of a battery is one example, but waveform generators also have a source impedance, Rsig in this problem. Determine Vout as a function of Vsig, Rsig, R1 and R2 for both of these circuits: (4pts) (Note: Rsig is part of the signal source and typically not under your control. R1 and R2 and the circuit configuration are what you design and build.)

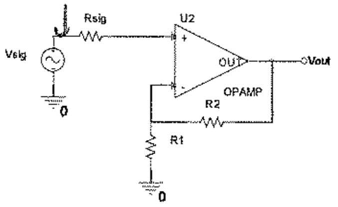
$V_{out} = \frac{-R_2}{R_1} V_{in}$

V_{in}



$V_{in} = V_{sig}\left(\frac{R_1}{R_1+R_{sig}}\right)$

V_{in}



Vout = $\frac{-R_2}{R_1} V_{in} = \frac{-R_2}{R_1} \cdot \frac{R_1}{R_1+R_{sig}} V$

$= \frac{-R_2}{R_1+R_{sig}} \cdot V_{sig}$

3.5

Vout = $\frac{R_1+R_2}{R_1} \cdot V_{sig}$

EI

4) Concepts, Troubleshooting and Data Analysis

a. Real components compared to ideal: In Experiment 5 you built this circuit:

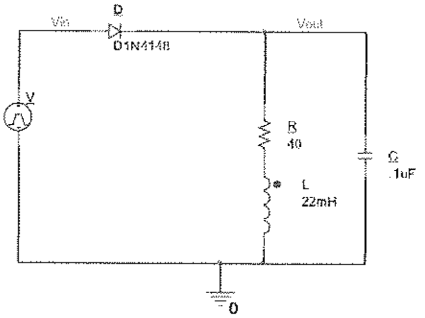


Figure D-3.

  i. But you didn't to add the 40Ω resistor. Why not? (1pt)

Represents winding resistance of coil.

OR ⇒ 40Ω is resistance of coil

or internal resistance of coil

  ii. From the experiment and simulation you know that the voltage on the capacitor and the current in the inductor are both signals that have a decaying oscillation. Continuing with the energy loss question, will the energy loss smoothly decay or will vary with the current in the inductor? Circle one the statement below that best describes the rate of energy loss during the decaying oscillation. (2pts)

energy loss:

[✓ Peaks when I_L is at a peak]   Peaks when I_L=0   smoothly decays

  iii. The capacitor used in for this circuit is a 0.1uF capacitor. If by mistake your partner used a 0.05uF capacitor, would the resonant frequency go up or down, and by what percentage would the frequency change, to the nearest 1%? (3pts)

$w_1 = \frac{1}{\sqrt{LC}}$ $w_2 = \frac{1}{\sqrt{0.5LC}}$ $\frac{w_2}{w_1} = \frac{1}{\sqrt{0.5}} = 1.41$ $w_2 = 1.41 \times w_1$

w_2 41% higher than w_1

b. Explain in 25 words or less: Why does the Miller Integrator (practical integrator) have a resistor across the capacitor while the ideal integrator doesn't have one? {2pts}

Without R any dc imperfections ~~of~~ would be integrate so the op-amp would saturate.

Adding R_f limits the dc gain.

c. **Classroom Knowledge and Tasks** (4pts) True or False

i. The resistor used for the experiments in this course weren't provided in the bag of parts, rather they are in the bins on the center table.

True

ii. When measuring the transfer function for a circuit under test, it is only necessary to measure the output signal.

False

iii. During experiment in this course using the 741 op-amp as an inverting amplifier with a gain of -5 and an input of 4V dc, the output will be -20V.

False ⇒ will saturate at lower voltage

iv. When starting a new experiment and asking for first time to have a signature you must have hand-drawn circuit diagram for only the circuit that is being tested or simulated. The other hand-drawn diagrams can be completed later.

False – all diagrams must have been completed

d. Which of the following op-amp configurations is used to convert the accelerometer output to get a velocity measurement. Circle one. (2 pts)

Voltage Follower Inverting Non-Inverting Differential

Adder [✓ Integrator] Differentiator

e. Your experiment report has a plot of a sinewave voltage trace from the Analog Discovery oscilloscope instrument. List three things that must appear on the plot either by hand or by computer. (3pts)

time scale, voltage scale, signal amplitude, frequency, period

5 /10

f. List each of the following as true or false. Assume the op-amp is ideal, a voltage source is connected to Vin, and that there is a resistive load connected between Vout and ground. (~~2pts~~ Optional

i. The input impedance of the voltage follower if very large.

True

ii. The output current of the voltage follower is equal to the input voltage divided by the load resistance.

True $V_{out} = V_{in}$, $I_{out} = \frac{V_{out}}{R_{Load}} = \frac{V_{in}}{R_{Load}}$

g. Name the professor and a TA who is typically in your section of EI. First names count. (1pts)

✓