ENGR-2300

Electronic Instrumentation

Quiz 2

Fall 2019

Name SOLUTIONS

RIN ____________

Question I (20 points) ___________

Question II (20 points) ___________

Question III (20 points) ___________

Question IV (20 points) ___________

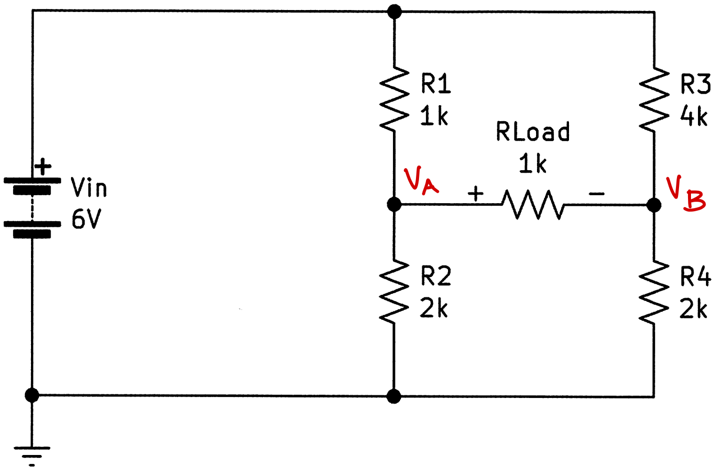
LMS Question is worth an additional 20pts

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. Thèvenin Equivalent And Voltage Follower (20 points)

The Thèvenin Equivalent Circuit provides a very simple replacement for much more complex circuits. If we have this simple circuit, analyzing changing loads becomes quite easy. In this problem, you are to find the Thèvenin voltage and resistance for a circuit.



a) Find Thèvenin Voltage for the circuit assuming RLoad as load resistor. {4pts}

$V_{Th} = V_A - V_B$ (after removing load resistor)

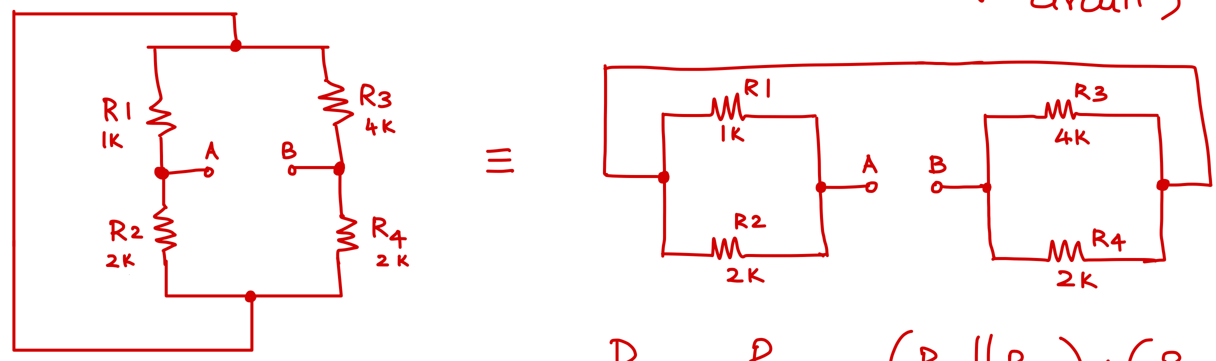
$$V_A = V_{in}\left(\frac{R2}{R_1+R_2}\right) = 4V$$

$$V_B = V_{in}\left(\frac{R4}{R_3+R_4}\right) = 2V$$

$$V_{Th} = V_A - V_B = \boxed{2V}$$

b) Find the Thèvenin Resistance. {4 pts}

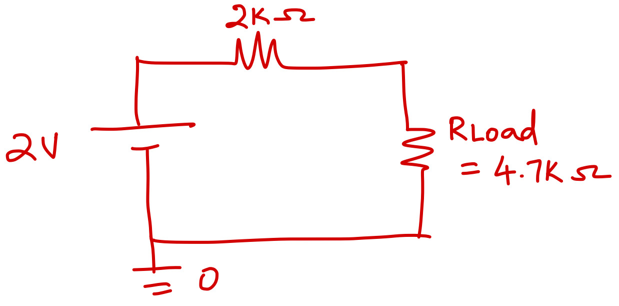
To find R_{Th}, switch V_{in} off $\Rightarrow V_{in} = 0$ (Replace by short circuit)



$$R_{Th} = R_{AB} = (R_1 \| R_2) + (R_3 \| R_4)$$

$$= \boxed{2K\Omega}$$

c) Find the current though RLoad after it is changed from 1kΩ to 4.7kΩ in the circuit. {2 pts}



$$I_{RLoad} = \frac{2V}{6.7K}$$

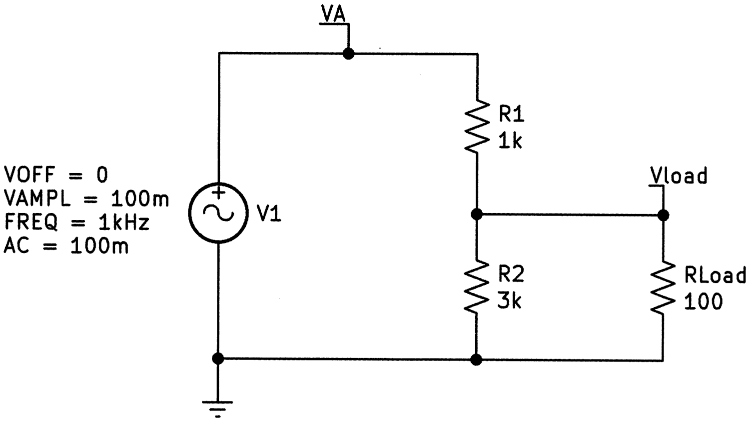
$$= \boxed{\begin{array}{l} 0.298 \text{ mA} \\ \text{or } \ 298.5 \ \mu A \end{array}}$$

d) [✓ **True**] or **False**: A battery can be represented using a Thèvenin equivalent circuit. {1 pt}

e) **True** or [✓ **False**:] Thèvenin equivalent circuits are only useful for a specific load impedance{1 pt}

f) Two students, students X and Y, are given the same task. They are both asked to design a circuit that is able to take in a sinusoidal voltage source V1 with 100 mV amplitude, as shown in circuit diagrams below, and deliver the same sinusoid but with an amplitude of 75 mV to a load resistor of 100Ω.

i. Student X designs a voltage divider as shown below. Will this student satisfy the design criterion? Provide reason for your answer by calculating Vload.{2 pts}

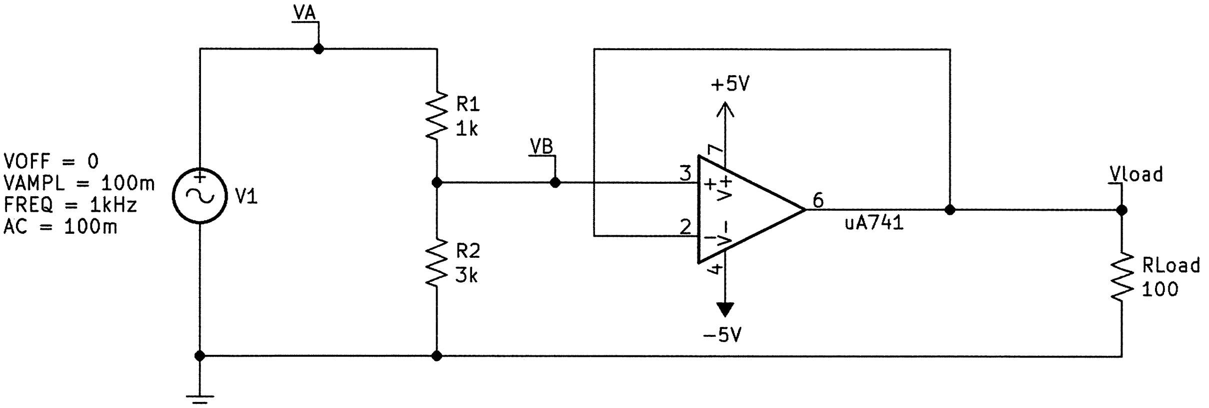


$$V_{load} = \frac{\frac{R2 \cdot R_{Load}}{R_2 + R_{Load}} V_A}{R_1 + \frac{R2 \cdot R_{Load}}{R_2 + R_{Load}}}$$

$$= 8.83 \text{ mV} \ll 75\text{mV}$$

No

ii. Student Y designs a voltage follower as shown below. Will this student satisfy the design criterion? Provide reason for your answer by calculating Vload .{2 pts}

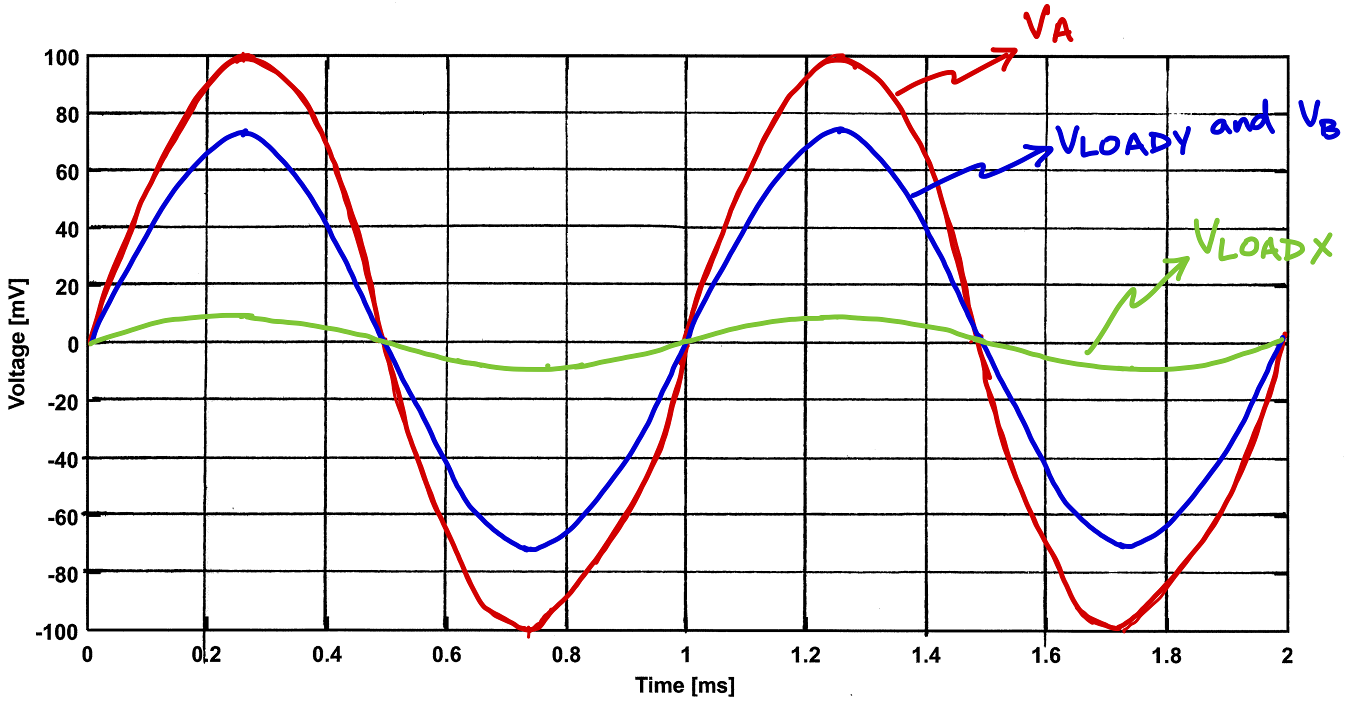


$V_B = \frac{R_2}{R_1+R_2} V_A = 75mV$

$V_B = V_{Load}$ (Voltage follower)

YES!

iii. Sketch the voltage waveform, Vload, measured by students X and Y across the load resistor. Also sketch voltage waveforms for VA (same for both students) and pin 3 of op-amp, VB (only for student Y), on the same plot. Label your line plots clearly. Use VloadX, VloadY, VA, and VB for labelling. {4 pts}

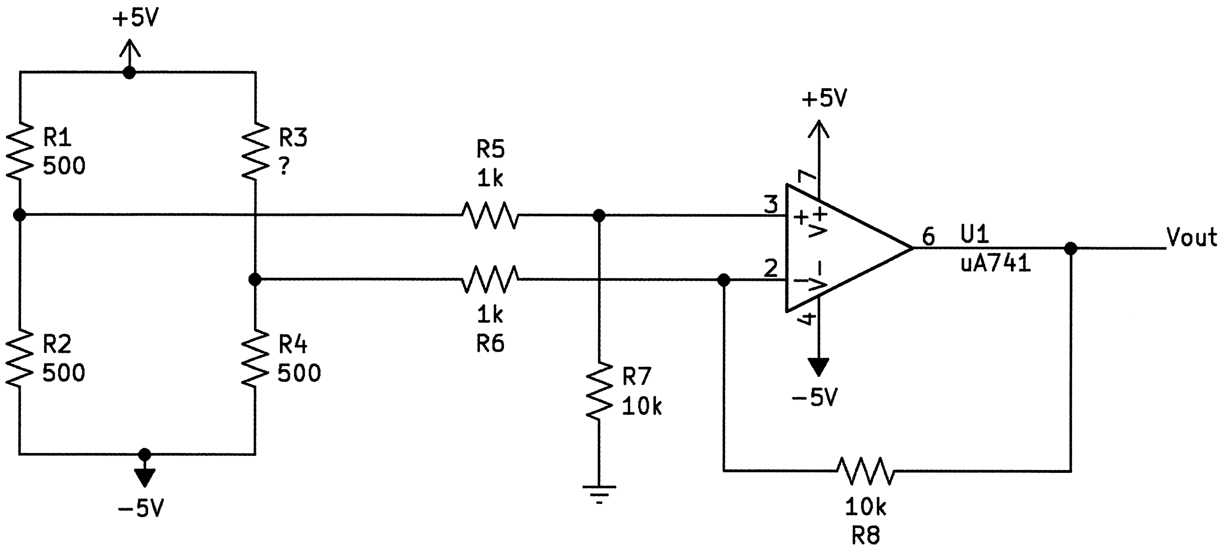


V_A amplitude → 100mV

V_{LOADX} amplitude = 8.8mV

V_B and V_{LOADY} → 75mV

2. Strain Gauges and Bridges (20 points)



a) If Vout for the Bridge/Amp circuit output is 650 mV, find the value of R3. {8 pts}

Differential amplifier:

$$V_{out} = \frac{R8}{R6}(V_2 - V_1) = \frac{R7}{R5}(V_2 - V_1)$$

$$V_2 = [5-(-5)]\frac{R2}{R_1 + R2} - 5 = 0V$$

$$650\,mV = \frac{10K}{1K}(0 - V_1)$$

$$V_1 = -65\,mV = [5-(-5)]\frac{R4}{R_3 + R_4} - 5$$

$$\Rightarrow V_1 = 10\frac{R4}{R_3 + R_4} - 5V = -65\,mV$$

$$\Rightarrow \frac{R4}{R_3 + R_4} = 0.4935 \Rightarrow \boxed{R_3 = 513\Omega}$$

b) Now consider that R4 is an atmospheric pressure sensor, located higher than sea level. At sea level, the sensor would balance the bridge (Vout = 0 V). Due to the increased elevation, there is a consistent offset away from 0 V due to the decreased average pressure. It is desired to re-balance the bridge to account for this (e.g., the offset is removed). To do this, a "trim" resistor is added. Assuming the solution from part a. is the offset value, what value would your trim resistor be and where would you place it? {4 pts}

Multiple options

① 13Ω resistor in series with R4.

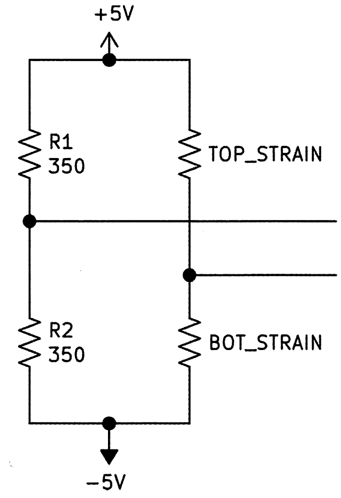
OR

② 13Ω resistor in series with R1.

OR

③ 19.73 KΩ resistor in parallel with R3.

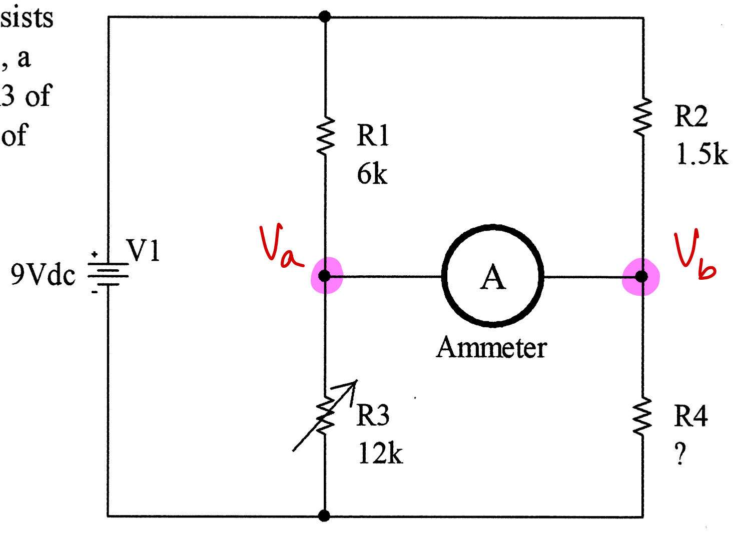
c) In experiment 5 and project 2, the bridge had two strain gauges in it, as shown below. One was on the top of the beam and the other was on the bottom. What is the usefulness in having two strain gauges? {2pts}



As the beam bends, one of the strain gauges increases in resistance while the other decreases at the same rate.

This effectively doubles the sensitivity of the measurement.

d) A circuit, shown to the right, consists of two fixed resistors R1 and R2 , a variable resistor, the resistance R3 of which can be adjusted, a resistor of unknown value R4 , and 9.0 volt battery. When R3 is adjusted to 12k ohms, there is zero current through the ammeter. What is the unknown resistance R4 ? {5 pts}



Zero current through ammeter ⇒ $V_a = V_b$

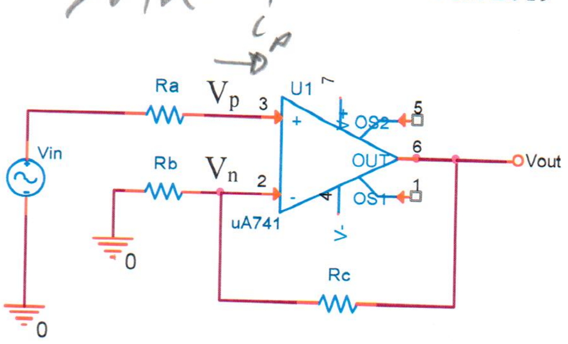
$$V_a = 9\left(\frac{R3}{R1+R3}\right) = 9\left(\frac{12K}{18K}\right) = 6V$$

$$V_b = 9\left(\frac{R4}{R_2+R_4}\right) = \frac{9R_4}{1.5K+R_4} = 6V$$

$$\Rightarrow 9R_4 = 9K + 6R_4 \Rightarrow \boxed{R_4 = 3K\Omega}$$

e) **True or [✓ False]:** Considering a bridge with only 1 active element (e.g., bridge from part a), the resistor in the same leg as the active element (R4) must be the same value as the two resistors in the other leg (R1,R2). {1 pt}

3. Operational Amplifier Applications



a. For diagram shown V_p is the voltage on the non-inverting op amp terminal.

i. (2pts) Determine V_p it terms of Vin. Assume an ideal op amp and use the Golden Rules, a.k.a. the op amp analysis rules.

$i_p = 0$ $V_{Ra} = 0$ $\boxed{V_p = V_{in}}$

ii. (2pts)Explain in 25 words or hopefully less how you determine the answer to part i.

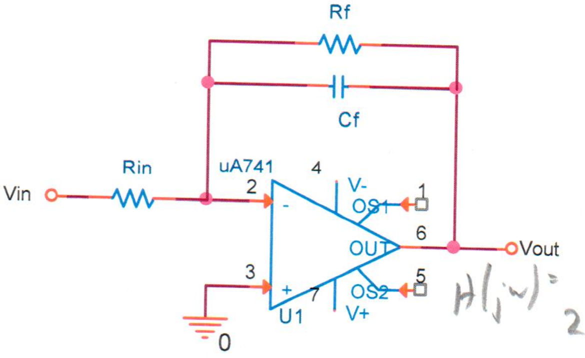
Op Amp analysis rules: input current to + and - term is zero, Voltage on Ra = 0, $V_p = V_{in}$

OR: Since the input current is 0, V_p equals V_{in}

iii. (2pts) For this circuit, if Vin(t)=0.2cos2000t Volts, Ra=1kΩ, Rb=1kΩ, Rc=5kΩ What is Vout(t)? Non-inverting conf.

$$\frac{V_{out}}{V_{in}} = \left(\frac{R_c}{R_b}+1\right) = 6 \quad \underline{V_{out} = 1.2\cos 2000t}$$

b. The circuit shown is a Miller Integrator. Given: Rin=2kΩ, Rf=20kΩ, Cf=0.5uF



i. (3pts)AC Steady State: if Vin is a sinusoidal waveform with a frequency of 500Hz, determine ω and determine the complete transfer function H(jω) plugging the component values. For the complete, don't simplify by assuming ω is either very large or small. Leave H(jω) as a ratio.

$$H(jw) = \frac{20}{2+j63}$$

$$\Uparrow$$

$W = 2\pi f = 3141\ \text{rad/sec}$

From Crib sheet: $H(jw) = \frac{R_f}{R_{in}(1+jwR_fC_f)} = \frac{20k}{2k(1+j(3.14k)(20k)(5\times10^{-7}))}$

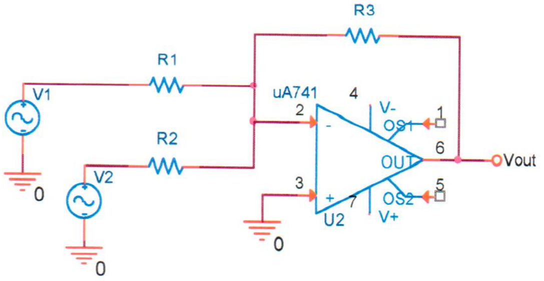
ii. (2pts) If Vin=0.1V (dc) what is Vout? And for this case is the circuit an integrator? (Yes or No)?

for dc, C_f is open $V_{out} = \frac{-R_f}{R_1} V_{in} = (-10)(0.1V) = -1V$

No - Not an integrator

Soln

c. For the circuit shown answer the following questions:



i. (4pts) Determine Vout if:
V1=1V dc, V2=1cos(5000t)V
R1=2kΩ, R2=1kΩ, R3=6kΩ

Adder $V_{out} = \frac{-R_2}{R_1} V_1 + \frac{-R_3}{R_2} V_2$

$= \left(\frac{-6}{2}\right)(1) + \frac{-6}{1} \cdot 1\cos(5000t) = \left(-6\cos 5000t - 3\right)V$

also good

ii. (2pts) Assume that the op amp is ideal except that it has finite voltage supplies. For this circuit to work as you have determine in part i. what are the restrictions on V+ and V-?

V_{out} max $= 6 - 3 = 3V$

V_{out} min $= -6 - 3 = -9V$

Need $(V-) \leq -9V$ $V+ \geq 3V$

Good answer is $V- = -9V$
$V+ = +9V$

d. (1pts) An integrator with an triangle wave input will have a sineware at the output?

True or [✓ False]

$\int_a^b mt\,dt = \frac{1}{2}mt^2\Big|_a^b$

Not sinewave

e. (1pts) A differentiator circuit with a tringle wave input will have a square wave at the output?

[✓ True] of False

$\frac{d}{dt}(mt) = m$ m = slope of ~~[illegible]~~ triangle input

f. (1pt) The reason that two strain gauges are mounted on the cantilever beam rather than just one is to improve reliability?

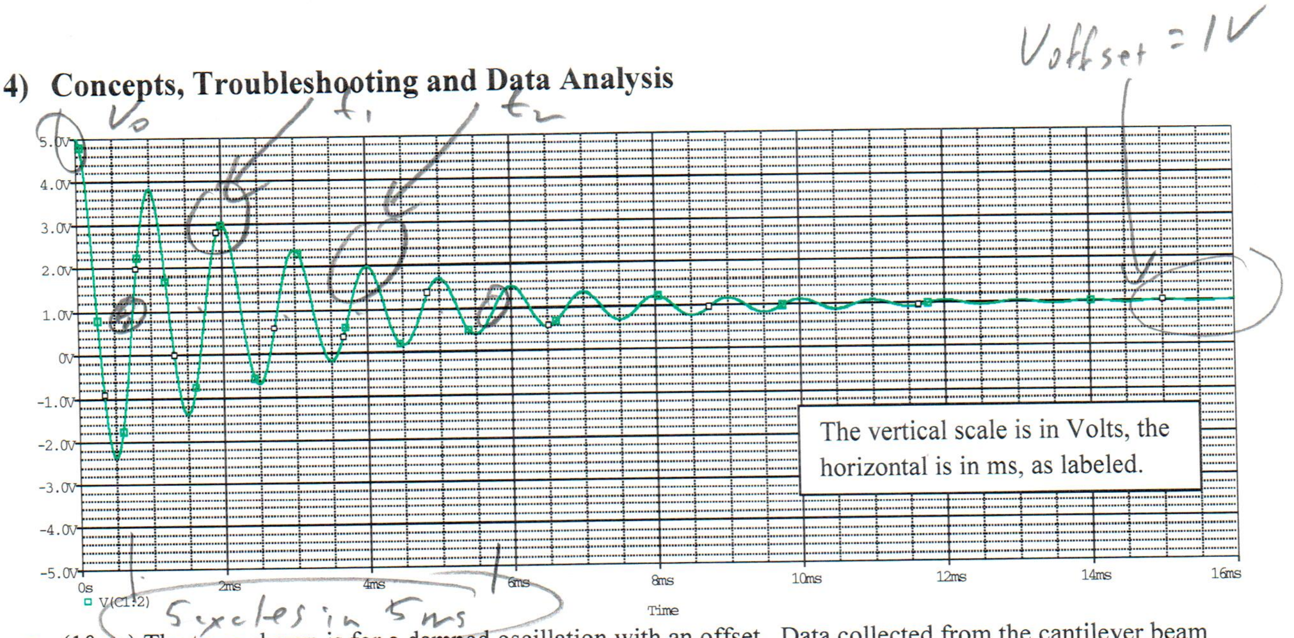
True or [✓ False]

No if either fails the circuit fails

2 - one top one bottom to form ½ of Bridge

No explanation needed

4) Concepts, Troubleshooting and Data Analysis



The vertical scale is in Volts, the horizontal is in ms, as labeled.

a. (10pts) The trace shown is for a damped oscillation with an offset. Data collected from the cantilever beam often has an offset. The equation that represents this data is: rad/sec

volts Volts

$v(t) = V_0 e^{-\alpha t} \cos \omega t + V_{offset}$

Use data from the plot and determine: V_0 , α, ω, and V_{offset} **Include units. You must mark the points on the plot that you used.** Note that this must match the plot starting at time=0sec. ω ⇒ any 2 point

5cycles in 5ms ⇒ 1kHz

$\boxed{\omega = 6.28 \times 10^3 \text{ rad/sec}}$

$\boxed{V_{offset} = 1V}$ Inspection

V_0 can be by inspection 5V at t=0

$\boxed{V_0 = 5 - V_{offset} = 4V}$

For α, pick 2 points where cos(ωt)=1

at t_1 $v(t_1) = V_0 e^{-\alpha t_1} + V_{offset}$

$v(t_1) - V_{offset} = V_0 e^{-\alpha t_1}$

2V at t=4ms

$V(t_2) - V_{offset} = V_0 e^{-\alpha t_2}$

3V at t=2ms

ratio $\frac{V(t_1) - V_{offset}}{V_{t_2} - V_{offset}} = e^{-\alpha(t_1 - t_2)}$

$\frac{3-1}{2-1} = e^{-\alpha(2ms-4ms)}$

ln $(2 = e^{-\alpha(-2\times10^{-3})})$

$\ln(2) = (\alpha)(2\times10^{-3})$

$\boxed{\alpha = 347 \text{ sec}^{-1}}$

b. (2pts) Class room knowledge and tasks:

i. All of the resistors used for the experiments were supplied in the bag of parts.

True or [✓ False]

ii. Before any signatures will be provided by the instructors or TAs. hand-drawn schematics must be prepared for all circuits in the experiment.

[✓ True] or False

c. (6pts) Consider the strain gauge circuit on the cantilever beam. Which of the following can be used as a measurement of the beam tip velocity? Circle *Yes* or circle *No*

i. The strain gauge bridge signal with just a differential op amp circuit? *Yes* or [✓ *No*]

ii. The accelerometer with just a differential amplifier? *Yes* or [✓ *No*]

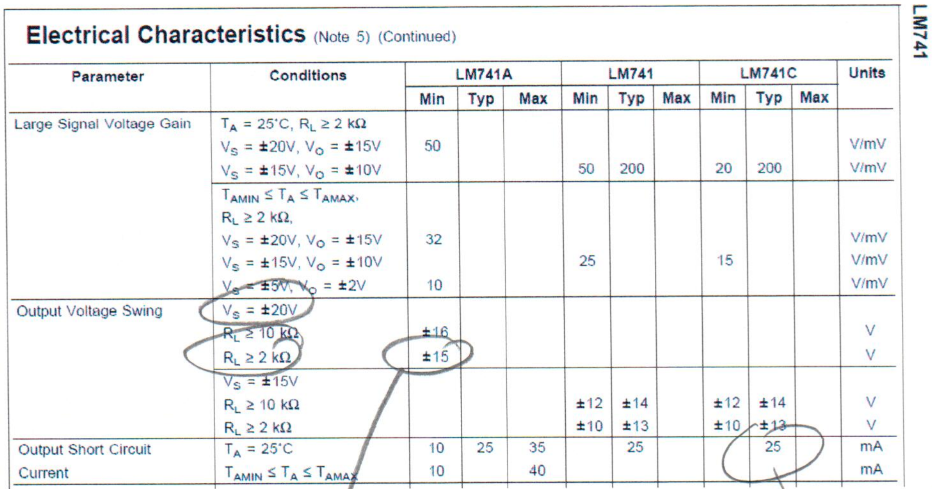
iii. The accelerometer with just a differentiator op amp circuit? *Yes* or [✓ *No*]

iv. The strain gauge bridge signal with a differential op amp plus a differentiator op amp circuit? [✓ *Yes*] or *No*

v. Is there another configuration of signal and circuit that can be used to measure the beam velocity? **And if yes, what is that circuit?** [✓ *Yes*] or *No*

2pt

accelerometer with integrator circuit



LM741

Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	$T_A = 25°C$, $R_L \geq 2\ k\Omega$										
	$V_S = \pm 20V$, $V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
	$R_L \geq 2\ k\Omega$,										
	$V_S = \pm 20V$, $V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V$, $V_O = \pm 2V$	10									V/mV
Output Voltage Swing	$V_S = \pm 20V$										
	$R_L \geq 10\ k\Omega$	±16									V
	$R_L \geq 2\ k\Omega$	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10\ k\Omega$				±12	±14		±12	±14		V
	$R_L \geq 2\ k\Omega$				±10	±13		±10	±13		V
Output Short Circuit Current	$T_A = 25°C$	10	25	35		25			25		mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA

d. (2pts) Using the 741 op amp data sheet information above, answer the following questions:

i. If LM741A op-amp is powered with a +20V supply and a -20V supply, (V_S in data sheet), what is the range of output voltages that can be obtained if the load resistance is 2kΩ?

± 15V assured

ii. If a 80Ω load resistor is connected between output of a LM741C op-amp and ground, for a circuit using +15V and -15V supplies, what is the expect range of obtainable output voltages?

$(25mA) \times 80\Omega = 2V$

±2V