ENGR-2300

Electronic Instrumentation

Quiz 2

Fall 2017

Name Soln

Section ___

Question I (20 points) ___________

Question II (20 points) ___________

Question III (20 points) ___________

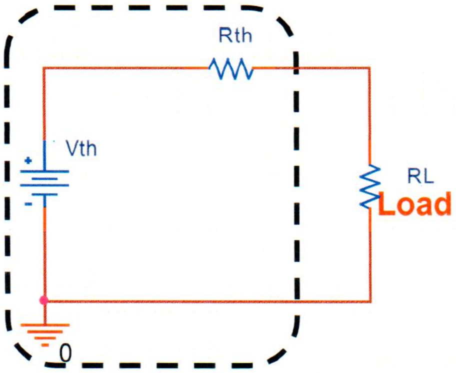
Question IV (20 points) ___________

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.

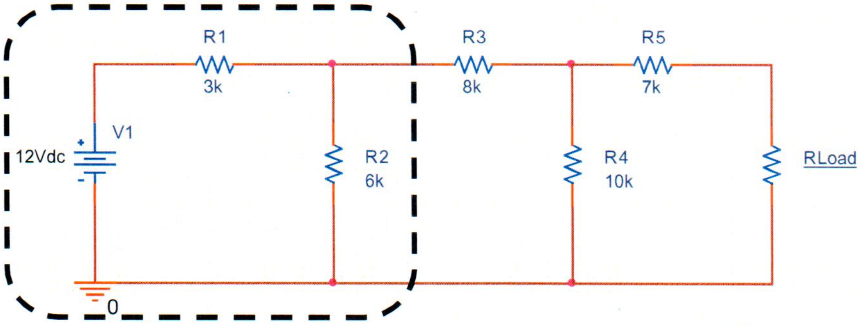
1. Thevenin Equivalent And Circuit Concepts



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.

In this problem, you are to find the Thevenin voltage and resistance for various parts of the circuit below. For clarity, the circuit will be redrawn at each step.

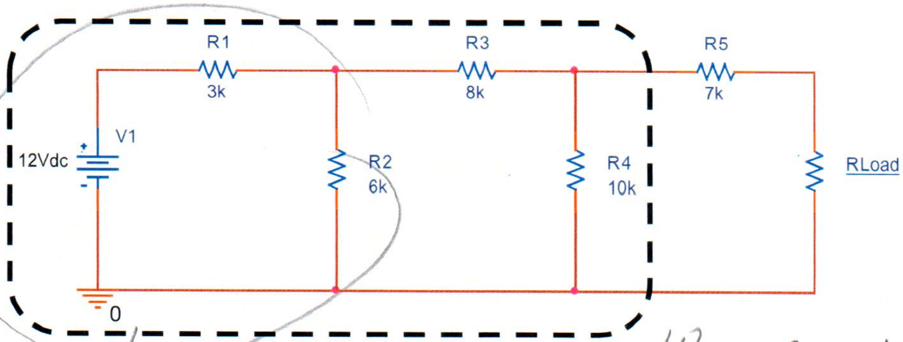
a) **Circuit 1:** Find and sketch the Thevenin Equivalent Voltage source for the part of the circuit inside the dashed line (i.e. resistors R1 and R2 and the voltage source V1). {4pts}

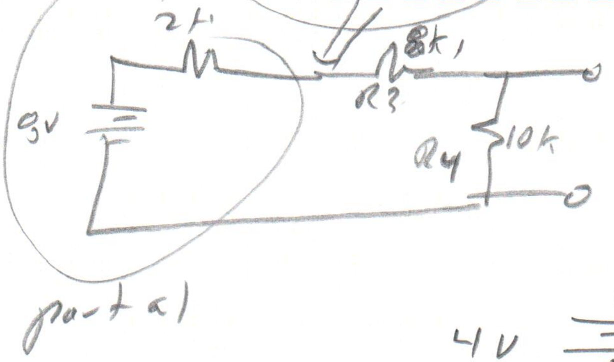


$$\underbrace{V_{oc} = \frac{6}{3+6}\cdot 12 = 8V, \quad I_{sc} = \frac{12}{3k} = 4mA, \quad R_{eq} = 3//6 = 2k\Omega}_{\text{Find any 2}}$$

$$V_{th} = V_{oc} = 8V \quad R_{th} = R_{eq} \text{ or } = \frac{V_{oc}}{I_{sc}} = 2k\Omega$$

b) Circuit 2: Find and sketch the Thevenin Voltage source for the part of the circuit inside the enlarged dashed line (i.e. resistors R1, R2, R3, R4 and the voltage source V1). {4pts}

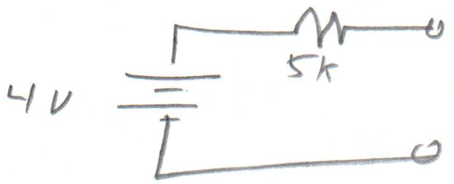




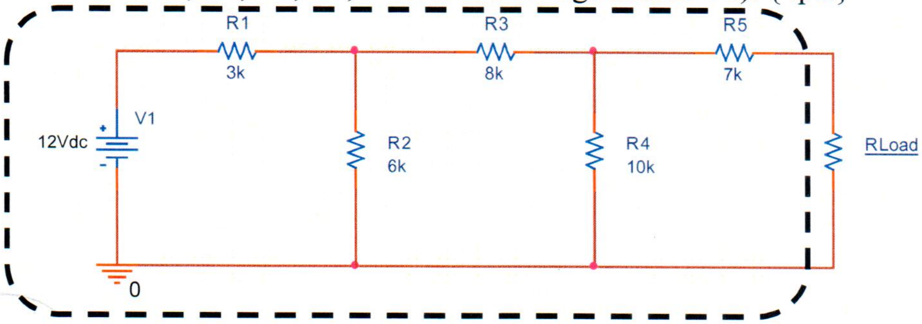
$V_{oc} = \frac{10}{10+10} \cdot 8 = 4V$

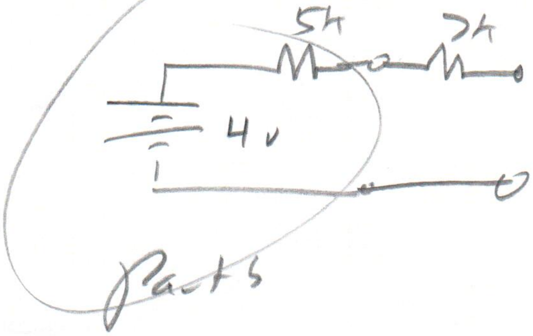
$I_{sc} = 8/10k = 0.8mA$

$R_{eq} = 10k//10k = 5k$



c) Circuit 3: Find and sketch the Thevenin Voltage source for the entire circuit (i.e. resistors R1, R2, R3, R4, R5 and the voltage source V1). {4pts}





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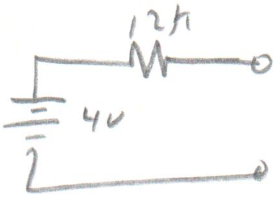
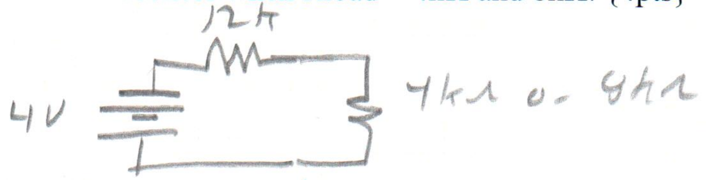


V_{Th} = 4V

R_{Th} = 12k

Soln

d) Using the Thevenin equivalent circuit obtained in part c, find the current through load resistor when Rload = 4kΩ and 8kΩ. {4pts}



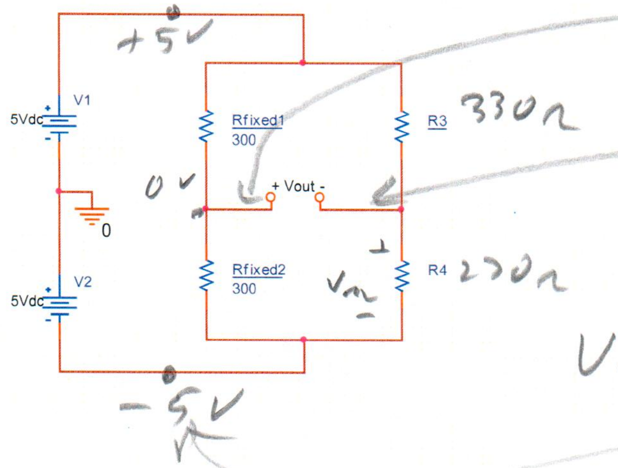
$I_{8k} = \frac{4V}{12k+8k} = \frac{4}{20k} =$ 0.2 mA = 200 μA

$I_{4k\Omega} = \frac{4V}{12k+4k} = 0.125$ mA

$(I_{Rload})_{4k}$ = 0.125 mA

$(I_{Rload})_{8k}$ = 0.2 mA or 200 μA

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=330Ω and R4=270Ω. Be sure to note the polarity. {4pts}



@ (+) 0v

(−)

$V_{R4} = \frac{270}{270+330} \cdot 10 = 4.5V$

Vat (−) ⇒ −5V + 4.5V = −0.5

Vout = 0.5V

Vout = Voltage at (+) − Voltage at (−)

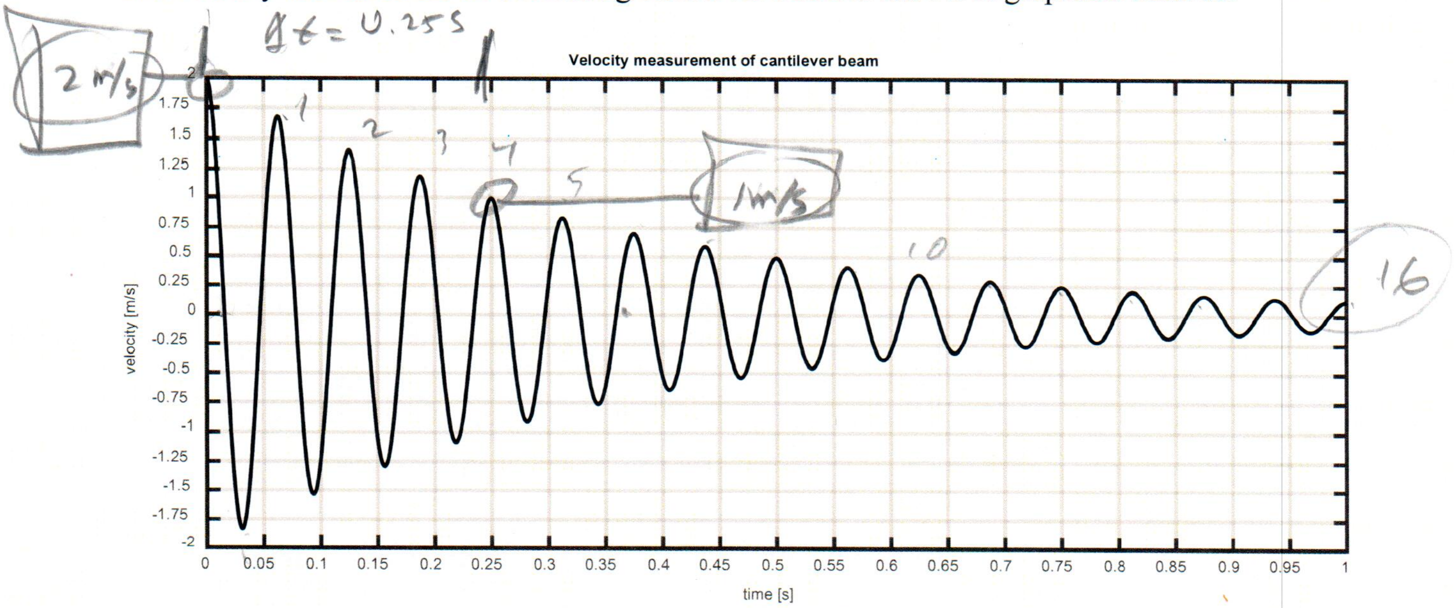
= 0 − (−0.5) = 0.5V

3/0.01

Soln

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}

(Or 16 cycles in 1 sec)

4 cycles in 0.25 sec

$f = \frac{4}{0.25} = 16\ Hz$

$\omega = 2\pi f = 100.5\ Hz$

for α 2m/s at t = 0

1m/s at t = 0.25

$Accel = 2e^{-\alpha t}$ m/s

(t=0 Accel = 2 m/sec)

times when cos ωt = 1

at t=1 Accel = 1 ⟹ $1 = 2e^{-0.25\alpha}$ $\alpha = \frac{-1}{0.25}\ln 0.5$

$= 2.77\ sec^{-1}$

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}

$$v(t) = 2e^{-2.77t}\cos 101t \text{ m/sec}$$

Soln.

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}

$$a(t) = \frac{d}{dt}(v(t)) = \frac{d}{dt}\left(2e^{-2.77t}\cos 101t\right)$$

$$= (2)\left(\cancel{-2.77e^{-2.77t}\cos 101t} + 101e^{-2.77t}(-\sin 101t)\right)$$

$$101 >> 2.77 \quad a(t) \sim -202e^{-2.77t}\sin 101t$$

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} Expect $B \sim 0.02$

$$x(t) = 0.02e^{-2.77t}\sin(101t) \text{ meters}$$

$\frac{dx(t)}{dt}$ => only kept second term again

$$vel \simeq (0.02)(e^{-2.77t})(-101)(\cos 101t)$$

$$\simeq +2.02e^{-2.77t}\cos(101t)$$

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 6800 μF capacitor and need to make an inductor. What value of inductance is necessary to achieve this frequency? {3pts}

$$w = \frac{1}{\sqrt{LC}} \qquad 101 = \frac{1}{\sqrt{LC}} \qquad L = \frac{1}{(101)^2 C}$$

$$LC = \frac{1}{1.02 \times 10^4} \qquad = 0.014\ H$$

$$= 14\ mH$$

Soln.

3. Operational Amplifier Applications

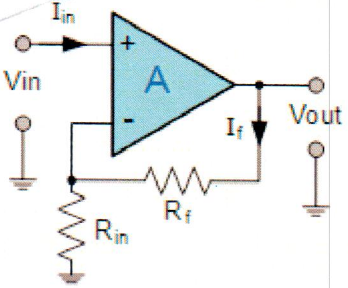
a. {2pts}For diagram shown determine Vout(t) if:

Vin(t)=0.4sin5000t Volts

R_{in}=1kΩ

R_f=5kΩ

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}} = -5$$



$V_{out}(t) = -2 \sin 5000t$ V

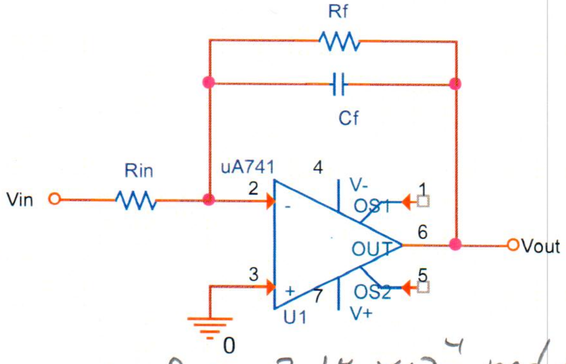
or $2 \sin(5000t + 180°)$ V

b. For the circuit shown:

Rin=1kΩ

Rf=20kΩ

Cf=0.2uF



i. {4pts}AC Steady State: if Vin is a sinusoidal waveform with a frequency of 5kHz, determine ω and determine the transfer function H(jω) plugging the component values.

$\omega = 2\pi f = 3.14 \times 10^4$ rad/sec

$\frac{1}{R_f C_f} = 250$ $\omega >> \frac{1}{R_f C_f}$

so $H(j\omega) = -\frac{1}{j\omega R_{in} C_f} = \frac{-1}{j\omega(1000)(2\times10^{-7})} = \left(\frac{-1}{j\omega}\right)(5000)$

$H(j\omega) = \frac{-5000}{j\omega}$ OR $\frac{5000j}{\omega}$

ii. {2pts}At what value of the input frequency will the answer given in part i. not be valid? Give the frequency in Hz not in radians per second.

~~R~~ Not valid if ω in not $>> \frac{1}{R_f C_f}$

let $\omega = \frac{1}{R_f C_f} = 250$ or $\boxed{f = 40 Hz}$

since ω should be >>, also reasonable to say any value up to 400Hz

iii. {2pts}What will be the transfer function, Vout/Vin, if Vin is a dc signal?

DC, cap ⇒ open circuit

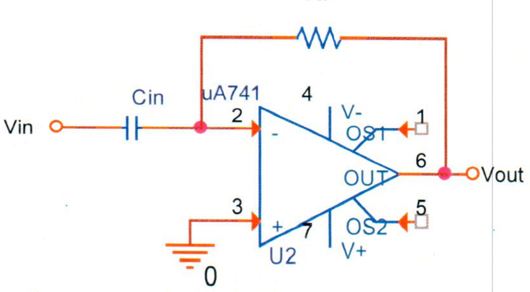
Inverting amp $\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}} = -20$

$\frac{V_{out}}{V_{in}} = -20$

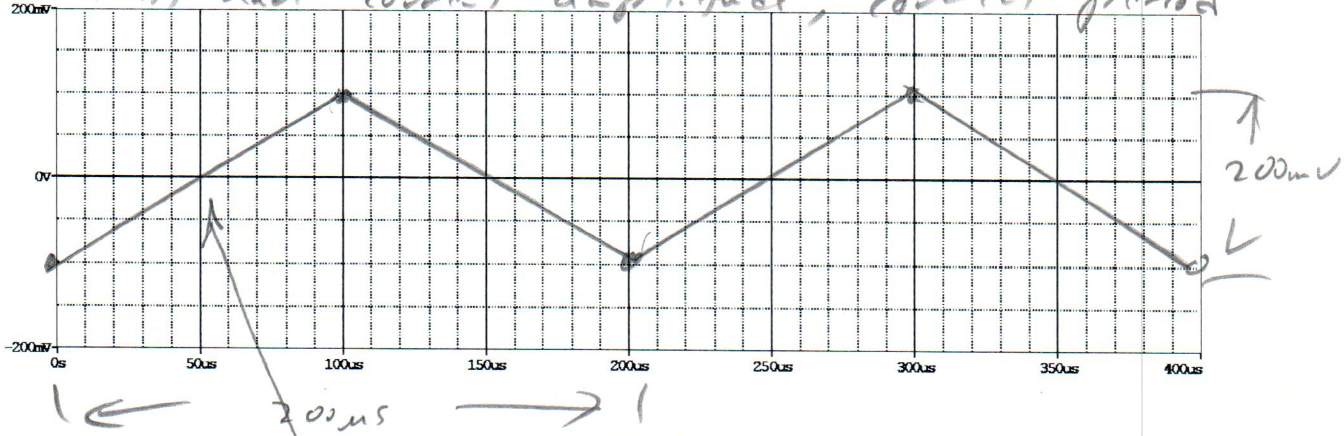
Soln

c. Vin of the circuit shown is a triangle waveform with a peak-to-peak amplitude of 200mV and a frequency of 5kHz. Draw Vin in the graph below and annotate the graph. {2pts}

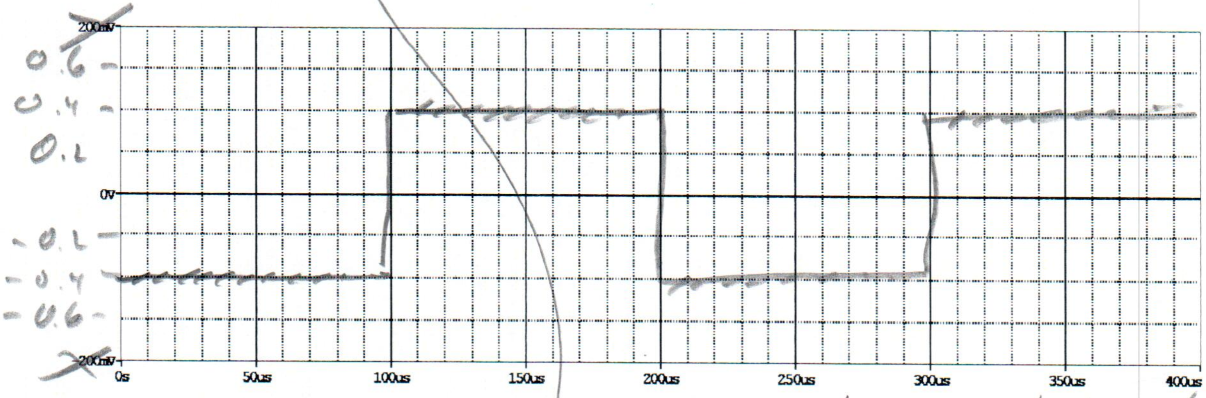
period = 200us



Can start with any phase
must have correct amplitude, correct period



d. In the graph below draw Vout for the circuit in part c. **The input is the one given in part c. Rf=1kΩ and Cin=0.2uF.** Pick and label appropriate values for the y scale. Assume the op-amp is ideal. Annotate the plot as would be done for a report. {4pts}



$$V_{out} = -R_f C_{in} \frac{dV_{in}}{dt}$$

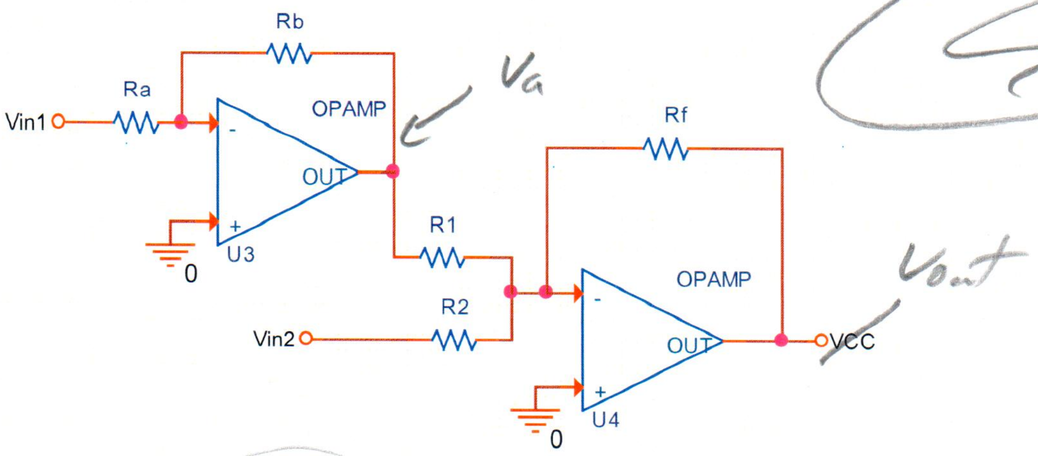
$$\frac{dv_{in} = 200mV}{dt = 100\mu s}$$

time scale is valid

$$= -(1000)(2\times10^{-7})\frac{200mV}{\underbrace{100\mu s}_{2000V/sec}} = -0.4V$$

Soln

e. For the circuit shown, determine Vout in terms of Vin1, Vin2, Ra, Rb, R1, R2, and Rf. (Hint: It may help to first determine the output signal from U3){4pts}



$V_a = -\frac{R_b}{R_a} \cdot V_{in1}$ inverting amp

$V_{out} = \frac{-R_f}{R_1} \cdot V_a - \frac{R_f}{R_2} \cdot V_{in2}$

$V_{out} = \left(\frac{R_f}{R_1}\right)\left(\frac{R_b}{R_a}\right) V_{in1} - \frac{R_f}{R_2} \cdot V_{in2}$

Sola

4) Concepts, Troubleshooting and Data Analysis

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

i. But you didn't need to add the 40Ω resistor. Why not? {1pt}

It represents the internal resistance of the inductor.

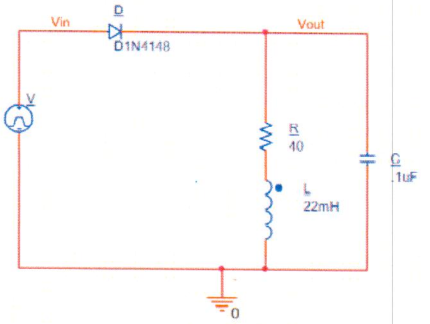


Figure D-3.

ii. Energy is lost as a function of time in the harmonic oscillator circuit as Vout was oscillating. Which component in the circuit shown in part i. of this problem causes the energy loss? {1pt}

R → Only R causes energy loss, C & R can store + release energy but in the ideal case they don't "lose" energy.

lost greatest when i_L is greatest, $i_L = -i_c = -C\frac{dV_c}{dt}$

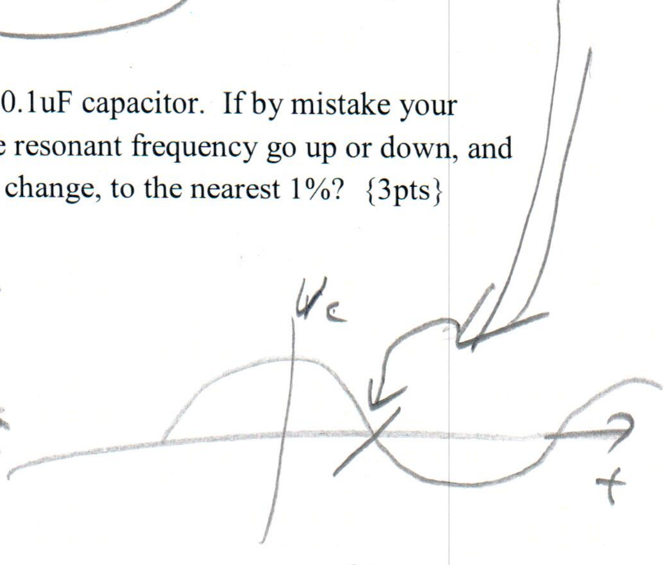
iii. Continuing with the energy loss question, will the energy loss be most rapid when the voltage on the capacitor is at the maximum, or at 0V or energy loss doesn't vary with time? Circle one. {2pts} $i_L = -i_c = -C\frac{dV_c}{dt}$, $\frac{dV_c}{dt}$ greatest

peak energy loss at: Vcap is at a peak [✓ Vcap=0] doesn't vary when $V_c = 0$

iv. The capacitor used in for this circuit is a 0.1uF capacitor. If by mistake your partner used a 0.2uF capacitor, would the resonant frequency go up or down, and by what percentage would the frequency change, to the nearest 1%? {3pts}

$w = \frac{1}{\sqrt{LC}}$ if C doubles

- $\sqrt{C}$ increases by $\sqrt{2}$
- w drops by factor of $\frac{1}{\sqrt{2}}$



$\frac{1}{\sqrt{2}} = 70.7$

$\Delta f = (1 - 0.707) = .293 \Rightarrow 29.3\%$

Soln.

b. **Classroom Knowledge and Tasks** {4pts} True or False

- i. The only way to know that you have the correct resistor is to take a new one each time from the bin labeled with that value.

  False — color code or meter

- ii. The Analog Discovery board should be calibrated at the beginning of the semester.

  True

- iii. Before beginning a lab, at least one team member must read over and be generally acquainted with the experiment or project write-up and the other **required reading** materials listed on the EILinks page.

  True

- iv. Before beginning a lab, hand-drawn circuit diagrams must be prepared for <u>all</u> circuits either to be analyzed using PSpice or physically built and characterized using your Analog Discovery board.

  True

c. 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

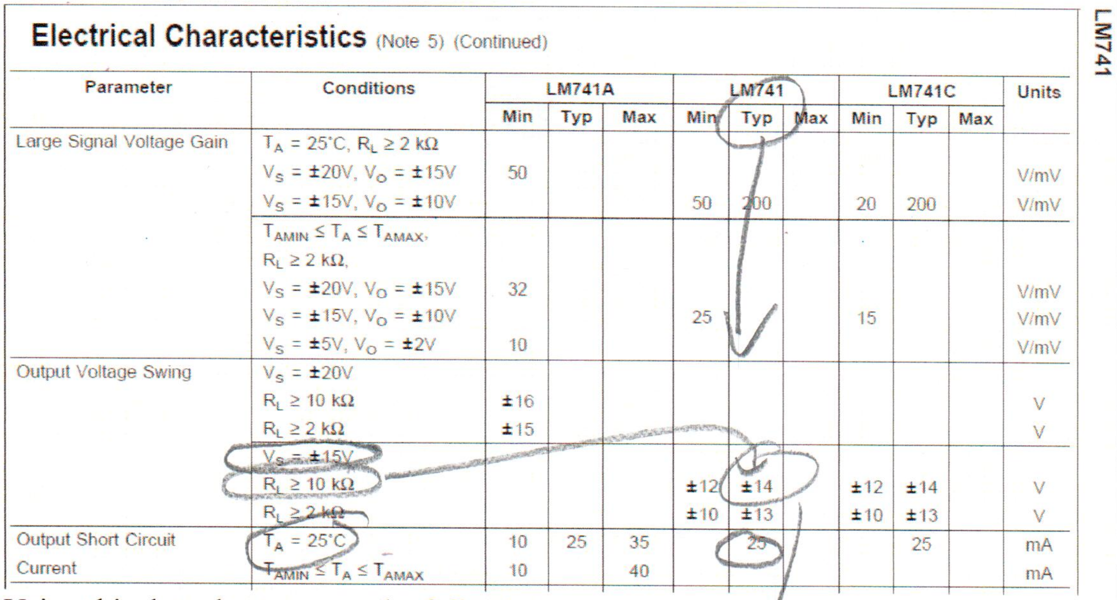
d. The strain gauge on the beam provides 2 voltage signals. The difference between the signals is a measure of the beam deflection. Which of the following op-amp configurations works best to amplify that deflection measurement? Circle one. {2 pts}

Voltage Follower Inverting Non-Inverting [✓ Differential]

Adder Integrator Differentiator

Soln

e. The following is from the 741 data sheet:



Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	$T_A = 25°C$, $R_L \geq 2$ kΩ										
	$V_S = \pm 20V$, $V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $R_L \geq 2$ kΩ,										
	$V_S = \pm 20V$, $V_O = \pm 15V$	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	$V_S = \pm 20V$										
	$R_L \geq 10$ kΩ	±16									V
	$R_L \geq 2$ kΩ	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10$ kΩ				±12	±14		±12	±14		V
	$R_L \geq 2$ kΩ				±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

LM741

Using this data sheet answer the following:

i. If LM741 op-amp is powered with a +15V supply and a -15V supply, (V_S in data sheet), what is the maximum output voltage you would typically expect the op-amp to be able to achieve if the load resistance is 10kΩ? {2pts}

±14V

ii. If the LM741 op-amp uses +15V and -15V supplies and has typical performance at 25°C. For what value of the load resistance, Rload, would you expect that the output voltage to be limited to no more than 5V due to the current limit of the op-amp? Give the value of Rload. {2pts}

Typ ⇒ 25mA max output current

$V = IR$

$R = \frac{V}{I} = \frac{5}{0.025} = \underline{200\Omega}$

f. Name the professor and a TA who is typically in your section of EI. First names count. {1pts}