ENGR-2300

Electronic Instrumentation

Quiz 2

Spring 2017

Name Soln

Section ___

Question I (20 points) ___________

Question II (20 points) ___________

Question III (20 points) ___________

Question IV (20 points) ___________

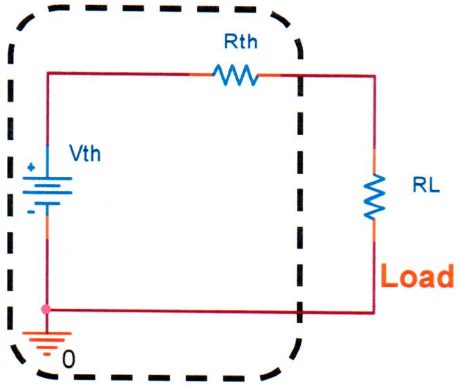
LMS Question is worth an additional 20pts

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.

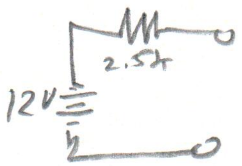
Soln.

1. Thevenin Equivalent And Circuit Concepts



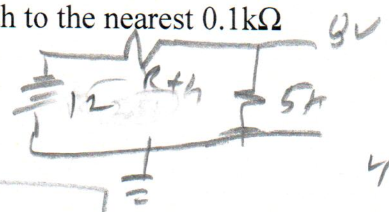
The Thevenin Equivalent Circuit consists of a voltage source in series with a resistor, which provides a very simple replacement for much more complex circuits. If we have this simple source, analyzing changing loads becomes quite easy.

Soln



a) (4pts) For an unknown circuit, the voltage across RL was measured for different values of RL. The results are displayed in the table. Find and draw the Thevenin Equivalent Circuit, determine Vth to the nearest 0.1V and Rth to the nearest 0.1kΩ

RL	Vload
1kΩ	3.43V
5kΩ	8.0V
500kΩ	11.7V
1MegΩ	12.0V



$8 = \frac{5}{5+R_{th}} \cdot 12$

$40 + 8R_{th} = 60$

$8R_{th} = 20$

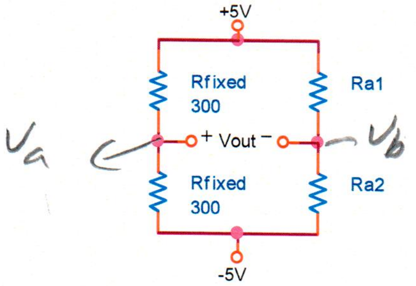
$\boxed{R_{th} = 2.5k\Omega}$

1) small change use 12V as $V_{oc} = V_{th}$

2) then use any data set

OR use any 2 data point and solve for V_{th} + R_{th}

b) {4 pts} Circuit concepts: Strain Gauge. The circuit shown is the strain gauge used in Exp. 5. Assume that if the beam is unstressed, Ra1 and Ra2 are both 300Ω. Determine Vout if the beam is moved so that Ra1=300.5Ω and Ra2=299.5Ω Be sure to note the polarity of Vout.



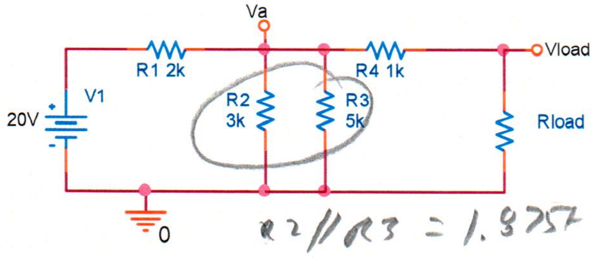
$V_{out} = V_a - V_b$

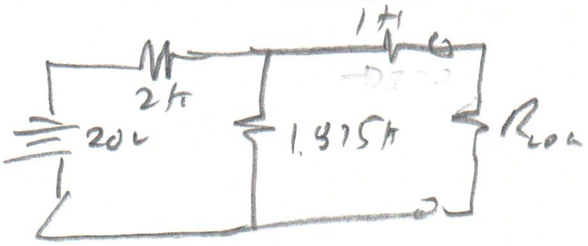
$V_a = (5-(-5))\frac{300}{300+300} + (-5) = 0V$

$V_b = (5-(-5))\frac{299.5}{300.5+299.5} + (-5) = -8.3mV$

Soln

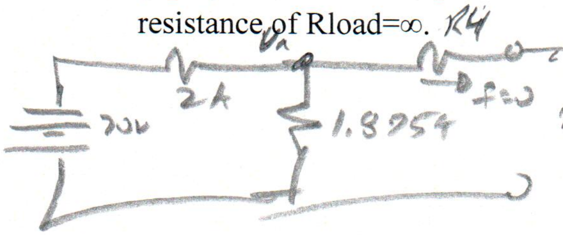
c) For the circuit shown, Rload represents the resistance of variable load connected to the circuit of interest.





$R2 // R3 = 1.875k$

i. {4pts} Determine the open circuit Vload, the voltage across the Rload when the resistance of Rload=∞.



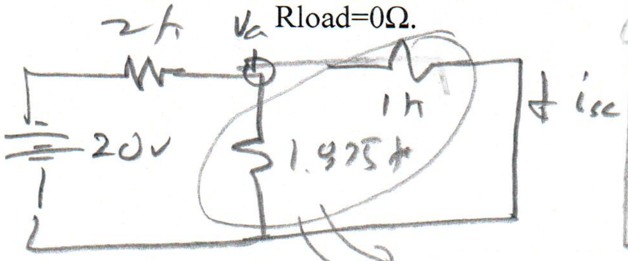
$V_{R4} = I \cdot R_4 = 0$

$V_{oc} = V_a = 20\left(\frac{1.875}{1.875+2}\right)$

$= 9.68$

$V_{\text{open circuit}} =$ 9.68V

ii. {4pts} Determine the short circuit current, I_{sc}, the current through Rload when Rload=0Ω.



$R_{parallel} = 0.652k$

Find V_a

$V_a = \frac{0.652k}{2k+0.652k} \cdot 20$

$= 4.92V$

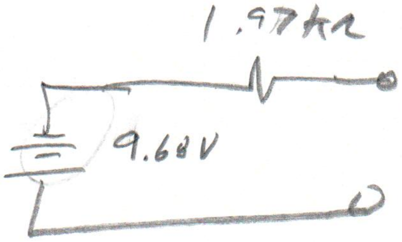
$I_{sc} =$ 4.92mA

$I_{sc} = \frac{V_a}{1k} = 4.92mA$

iii. {2pts} Draw the Thevenin equivalent circuit.

$R_{th} = \frac{V_{oc}}{I_{sc}} = \frac{9.68V}{4.92mA} = 1.97k\Omega$

$V_{oc} = V_{th} = 9.68$

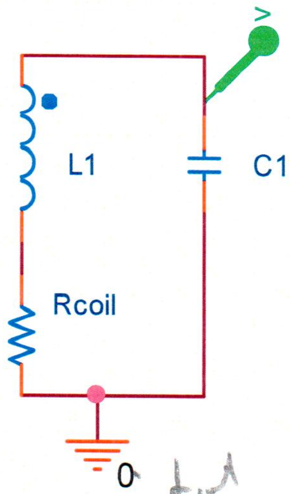


iv. {2pts} Determine the voltage Va when Rload =∞Ω and when Rload=0Ω. Hint: use the previous results.

Va (Rload at ∞) = 9.68V

Va (Rload=0) = 4.92V

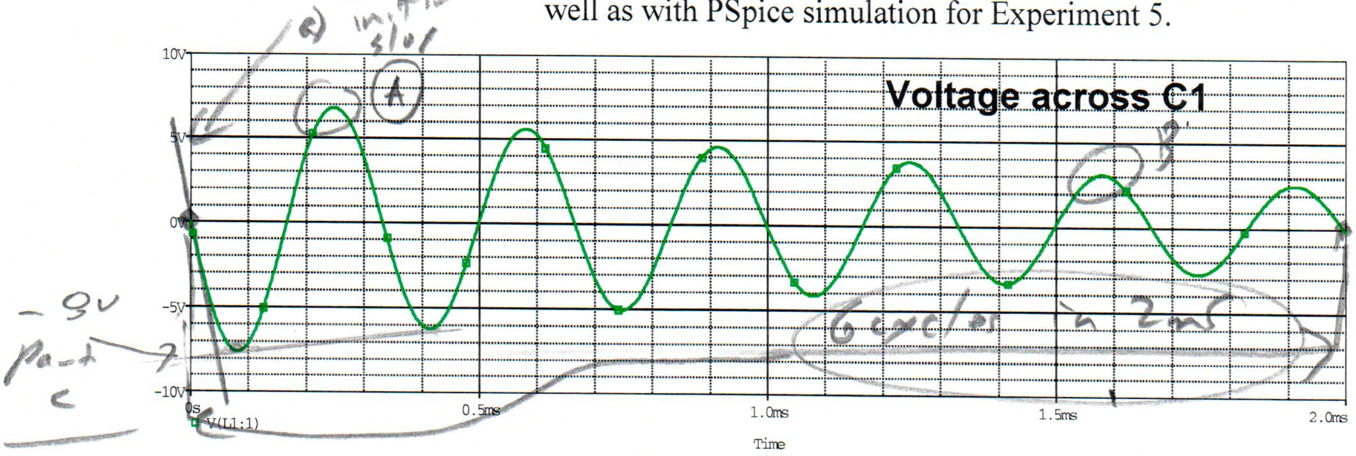
2. Harmonic Oscillators and Math



For the circuit shown, Rcoil and L1 are the effective resistance and inductance of a real (not ideal) coil. At low frequencies the capacitor acts close to ideal. The models more complicated at high frequencies.

In the real circuit, Rcoil and L1 are distributed along the length of the inductor. It is often useful to use a lumped parameter model – all of the R is included into one (ideal) resistor and all of the L is included in one (ideal) coil.

The circuit being modeled is simply an inductor in parallel with a capacitor. At t=0 there is stored energy in the magnetic field of the inductor as was done in both as physical experiment as well as with PSpice simulation for Experiment 5.



The horizontal scale is time (2ms full scale) and the vertical scale is Voltage (-10V to +10V).

a. Estimate the greatest |dV/dt| on this plot, give the value and mark the time point on the graph. This is for later in the problem. {1pt}

initial slope = max slope $\simeq \frac{10V}{0.06ms} \simeq 1.7 \times 10^5$ V/sec

$\boxed{\pm 20\% \text{ okay}}$

b. Find the decay constant α and the angular frequency ω for this data. Mark the points used on the plot. {6 pts}

Ⓐ ~7V at t = 0.25ms

Ⓑ ~3V at t = 1.68mS

$$7 = V_1 e^{-\alpha(0.25 \times 10^{-3})}$$

$$3 = V_1 e^{-\alpha(1.68 \times 10^{-3})}$$

at peaks sin(ωt) = 1

Ratio $\frac{7}{3} = e^{-\alpha(-1.43 \times 10^{-3})}$

ln of both side

$$0.847 = \alpha(1.43 \times 10^{-3})$$

$$f = \frac{6}{2ms} = 3\,kHz$$

$$\boxed{\omega = 2\pi f = 18.8 \times 10^3 \text{ radian/sec}}$$

allow 18×10^3 to 20×10^3

$$\boxed{\alpha = 590 \text{ sec}^{-1}}$$

allow 570 - 630

c. Write the mathematical expression for the voltage across C1, in one of the forms $V(t) = Ae^{-\alpha t}\cos\omega t$ or $V(t) = Ae^{-\alpha t}\sin\omega t$, depending on which form fits the data better. Give real values for the constants and provide units where appropriate. {4 pts}

at $t=0$, estimate decay $\Rightarrow$ $V_1 \sim -8V$

or calc based on part b

or use -7.5 at $t = 0.08$ ms

570 - 630 allowed

$$V(t) \simeq -8e^{600t}\cos(18.8\times10^3 t)$$

d. Given C1=0.1µF, calculate the values for L1 and Rcoil. {4pt}

$$w = \frac{1}{\sqrt{LC}} \quad L = \frac{1}{w^2 C} = \frac{1}{(18.8\times10^3)^2 \times 10^{-7}} = 28.3\ mH$$

$$\boxed{\simeq 28\ mH}$$

e. Using the result from part a. of this problem, and C1=0.1µF, determine the value of the current in L1 at t=0. Crib sheet for Quiz 1 may help for this and part f below {3 pts}

$$i_c = C\frac{dv_c}{dt} \simeq (10^{-7})(1.7\times10^5)$$

$$i_c(t=0) \simeq 0.017A = 17mA$$

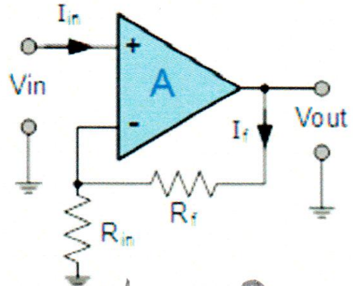
f. The energy stored in the electric field of a capacitor is $W = \frac{1}{2}CV^2$ Determine the peak energy stored in the capacitor. Include units. {2 pts}

$|V|_{max} \sim 7.5V$ or $7.6V$

$$W = \left(\frac{1}{2}\right)(10^{-7})(7.5)^2 = 2.8\ mW$$

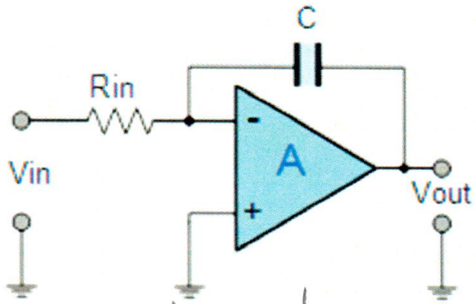
Soln

3. Operational Amplifier Applications
   a. For each diagram list what type of amplifier shown and the equation for Vout as a function of the input signals and the component values. If there is more than one formula for a given circuit, you only need to present one. {6pts}



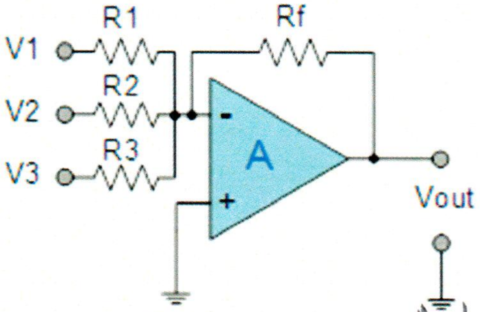
i. Type is: Non-Inverting

Vout= $\left(1+\frac{R_f}{R_{in}}\right)V_{in}$



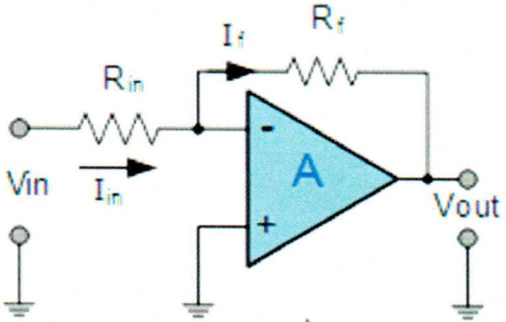
ii. Type is: Integrator

Vout= $-\frac{1}{R_{in}\cdot C}\int V_{in}(t)\,dt$



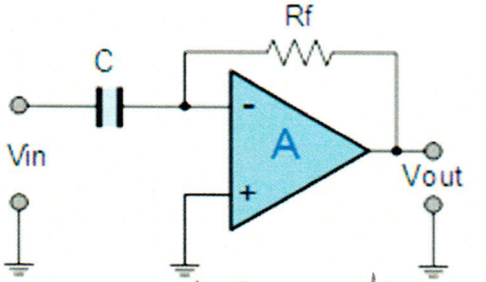
iii. Type is: Summer or Adder

Vout= $-\frac{R_f}{R_1}\cdot V_1-\frac{R_f}{R_2}\cdot V_2-\frac{R_f}{R_3}V_3$



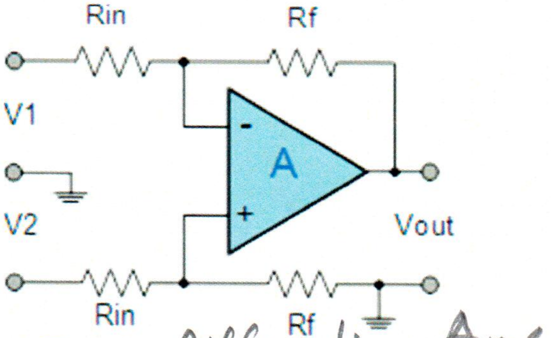
iv. Type is: Inverting

Vout= $-R_f/R_{in}\cdot V_{in}$



v. Type is: differentiator

Vout= $-R_f C\frac{dV_{in}(t)}{dt}$

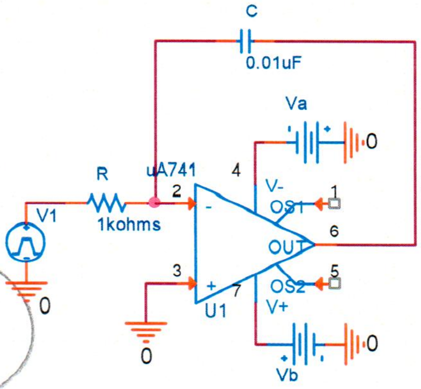


vi. Type is: Differential Amp

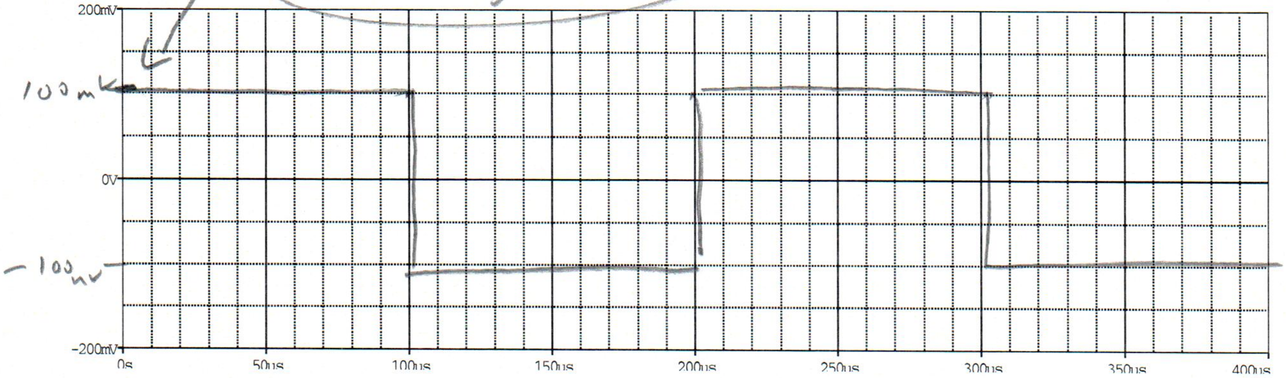
Vout= $\frac{R_f}{R_{in}}(V_2-V_1)$

b. Vin of the circuit shown is connected to the Waveform Generator 1 on the Analog Discovery, which has been configured to be a 5kHz square wave with a amplitude of 100mV (200mVp-p). Draw V1 in the graph below. {2pts}

200μs period

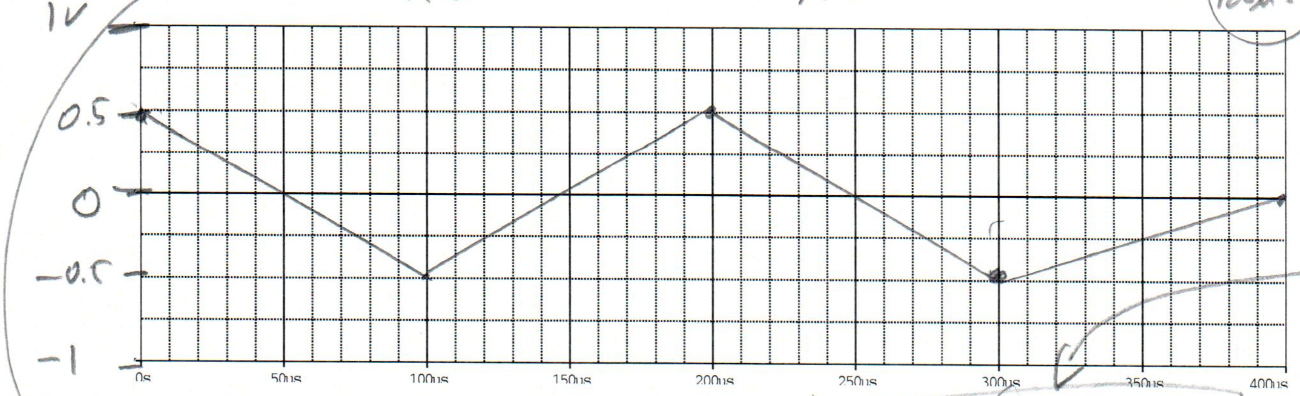


Start positive or negative



c. In the graph below draw Vout for the circuit in part b. The input is the one given in part b. Pick and label appropriate values for the y scale. For this part assume the op-amp is ideal. {6pts}

$V_{out} = -\frac{1}{RC} \int V_{in} dt$ $\frac{1}{RC} = 10^5 = \frac{100V}{ms} = \frac{10V}{100\mu s}$



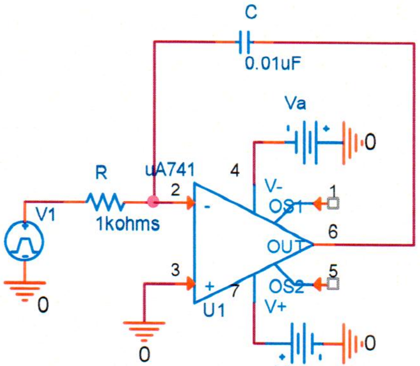
for $0 - 100\mu s$, $V_{in} = 0.1V$, $\boxed{V_{out} = \frac{-1}{RC}(0.1)t}$

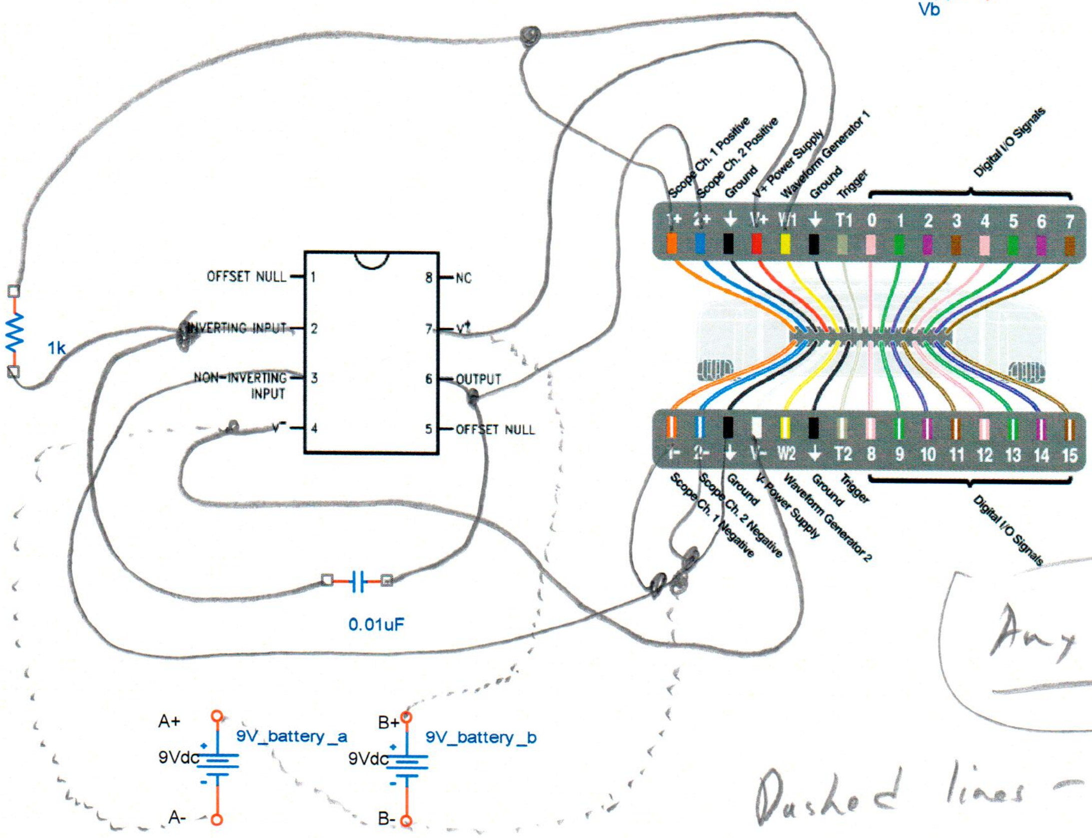
$= \frac{-1V}{100\mu s}$

1) 1Vp-p triangle wave
2) If Vin positive, slope is negative
3) DC shift is okay

Soln

d. Now build the circuit.
{4pts}Draw lines 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.





Any ground

Dashed lines – Battery option

e. {2pts} The real 741 wouldn't behave very well of this circuit. What would be the main source of error in the output? And what version of this circuit could be used to avoid the problem?

DC offset or DC imperfections result in the output saturating.

OR The op-amp will saturate.

Use the Miller Integrator ⇒ OR add a resistor across C

Solu

4) Concepts, Troubleshooting and Data Analysis

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

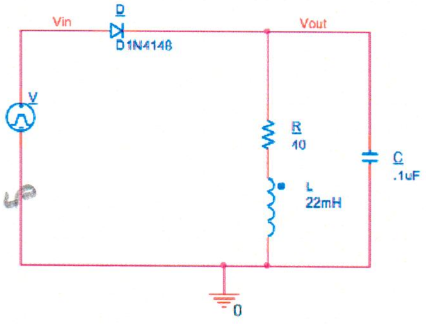


Figure D-3.

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

40Ω is the internal resistance of the coil.

ii. {1pt}There weren't sufficient 22mH inductors this semester, so many teams used 2 10mH inductors to approximate the 22mH inductor. Should the 10mH inductors be placed [✓ in series] or in parallel to best substitute for the 22mH inductor?

Series

iii. {6pt} It was found that the 10mH inductors each had an internal resistance of 25Ω. So compared to using the 22mH inductor (as shown in part i. of this problem) answer the following, (remember you are using 2 of the 10mH inductors to substitute for 1 22mH inductor.)

i. Would the resonant frequency of the 10mH version be [✓ higher] or lower than that of the 22mH version?

20mH

higher

$w = \frac{1}{\sqrt{LC}}$ smaller L ⇒ larger w

ii. By what percentage would the frequency change, to the nearest 1%?

20mH is 91% of 22mH $w_2 = \frac{1}{\sqrt{0.91 L_1 C}}$ $w_1 = \frac{1}{\sqrt{L_1 C}}$

$\frac{w_2}{w_1} = \frac{1}{\sqrt{0.91}} \simeq 1.048$

5% high

iii. Would the oscillation decay [✓ more] or less quickly for the 10mH version compared to the 22mH version?

$\alpha = \frac{R}{2L}$ R is 50 vs 40

L is 20 vs 22

α increases

decay more quickly

Soln

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

   i. Resistors needed for the experiments were provided in the bag of parts handed out at the beginning of the semester.

   False

   ii. There is no reasonable need to ever calibrate the Analog Discovery board.

   False

   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 works best to amplify the signal from a stain gauge bridge circuit? Circle one. {2 pts}

Voltage Follower Inverting Non-Inverting [✓ Differential]

Adder Integrator Differentiator

d. Which of the following op-amp configurations works best to connect to the output of a strain guage if it is desired to find the velocity of the beam? Circle one. {2 pts}

Voltage Follower Inverting Non-Inverting Differential

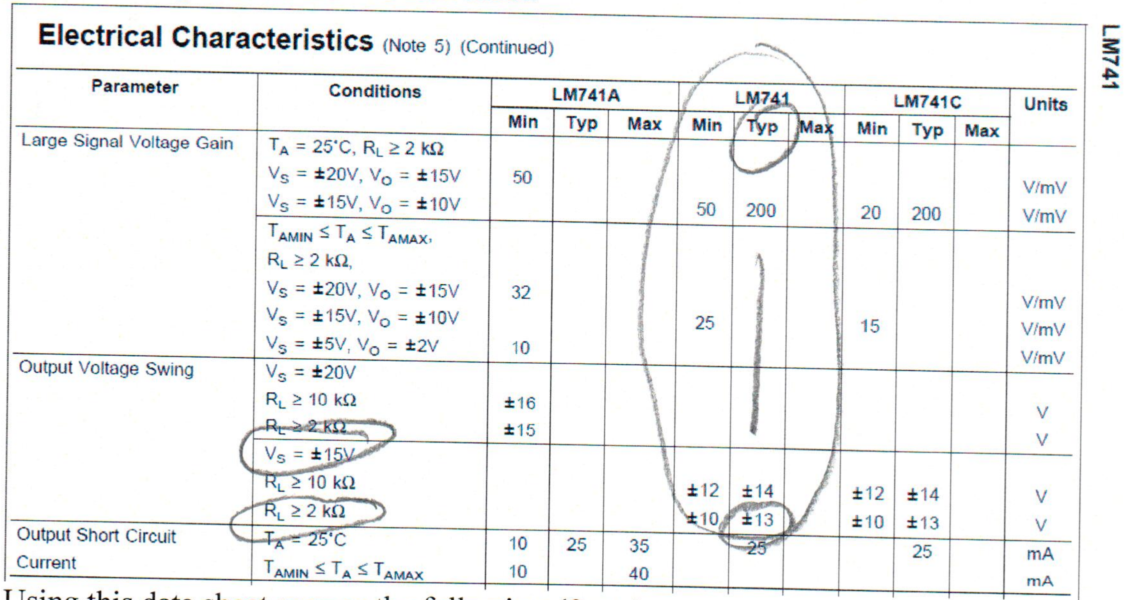
Adder Integrator [✓ Differentiator]

$$v(t) = \frac{d}{dt} x(t)$$

e. Circle the correct answer for the following:
The calibration constant for the ADXL150 accelerometer is given on page 3 of the Project 2 write-up. It is also in the Class 14 lecture slides. It can also be found on the data sheet which is available on the course website. (hint: these are either all true or all false) {1 pts}

[✓ ***True***] False

f. 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										
	$V_S = \pm20V$, $V_O = \pm15V$	50									V/mV
	$V_S = \pm15V$, $V_O = \pm10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
	$R_L \geq 2$ kΩ,										
	$V_S = \pm20V$, $V_O = \pm15V$	32									V/mV
	$V_S = \pm15V$, $V_O = \pm10V$				25			15			V/mV
	$V_S = \pm5V$, $V_O = \pm2V$	10									V/mV
Output Voltage Swing	$V_S = \pm20V$										
	$R_L \geq 10$ kΩ	±16									V
	$R_L \geq 2$ kΩ	±15									V
	$V_S = \pm15V$										
	$R_L \geq 10$ 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 {2 pts}:
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 2kΩ?

± 13 V

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