ENGR-2300

Electronic Instrumentation

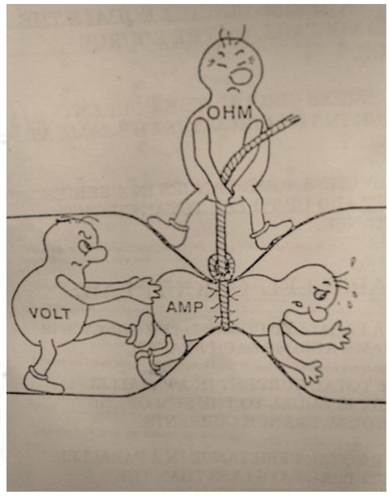
Quiz 2

Spring 2016

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.

A Few Images and Thoughts in Honor of April Fools Day

"Aha!"

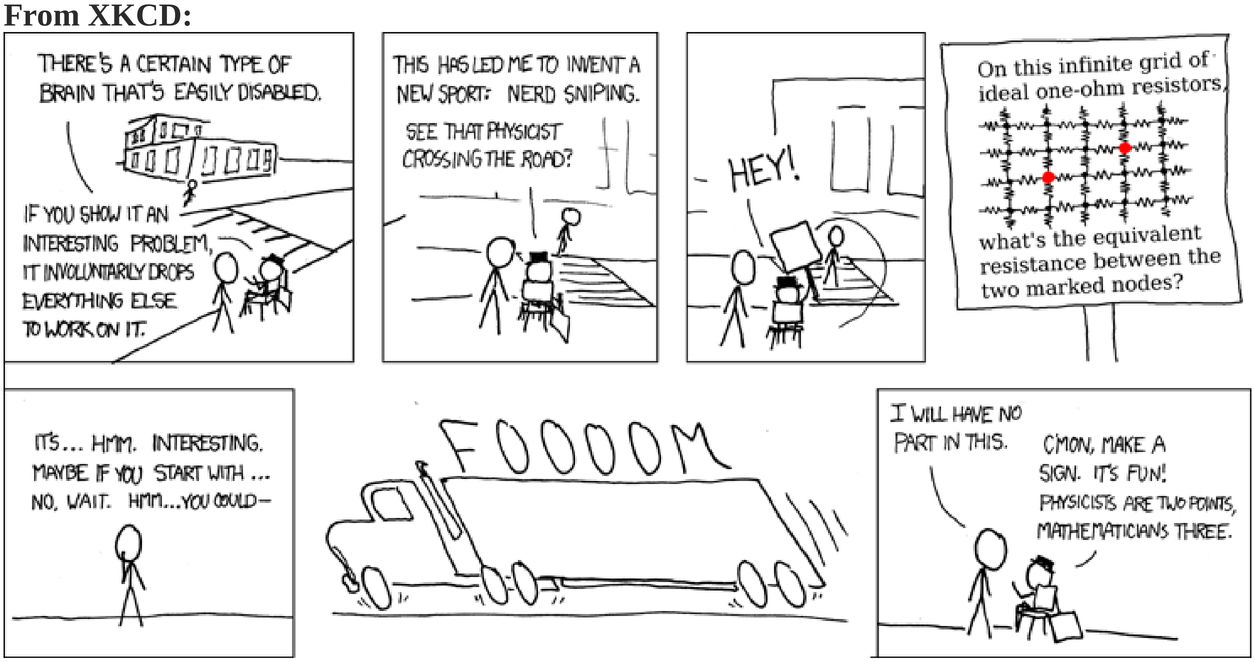


The class was quietly doing its lesson when Russell, suffering from problems at home, prepared to employ an attention-getting device.

From The Engineering Commons Podcast:

- Caltech students pulled off the Great Rose Bowl Hoax during the 1961 Rose Bowl football game, causing the University of Washington's card section to display messages that were altered from their intended configuration. In the final display, captured by network television, the card section spelled out "Caltech," leaving little doubt as to who had pulled off the prank.
- In a similar prank, carried out at the 1984 Rose Bowl game, the Rose Bowl scoreboard was hacked to display the message, "Caltech 38, MIT 9." This stunt gained one of the perpetrators credit in the course, "Experimental Projects in Electrical Circuits."

From XKCD:



National Semiconductor

August 2000

LM741 Operational Amplifier

LM741
Operational Amplifier

General Description

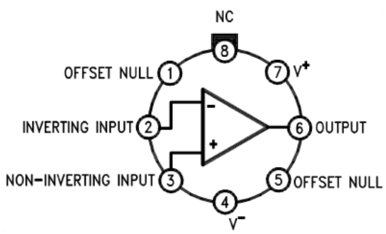
The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Connection Diagrams

Metal Can Package

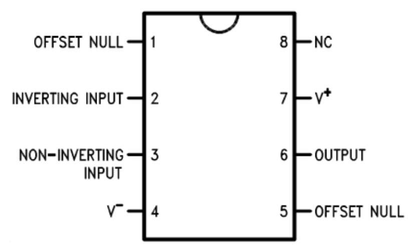


DS009341-2

Note 1: LM741H is available per JM38510/10101

Order Number LM741H, LM741H/883 (Note 1), **LM741AH/883 or LM741CH**
See NS Package Number H08C

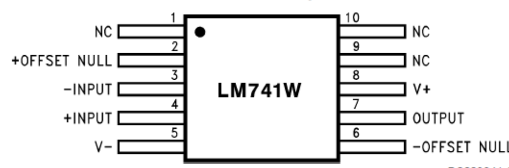
Dual-In-Line or S.O. Package



DS009341-3

Order Number LM741J, LM741J/883, LM741CN
See NS Package Number J08A, M08A or N08E

Ceramic Flatpak

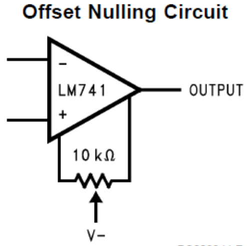


DS009341-6

Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



DS009341-7

LM741

Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

(Note 7)

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation (Note 3)	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage (Note 4)	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	150°C	100°C
Soldering Information			
N-Package (10 seconds)	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C
M-Package			
Vapor Phase (60 seconds)	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C
See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.			
ESD Tolerance (Note 8)	400V	400V	400V

Electrical Characteristics (Note 5)

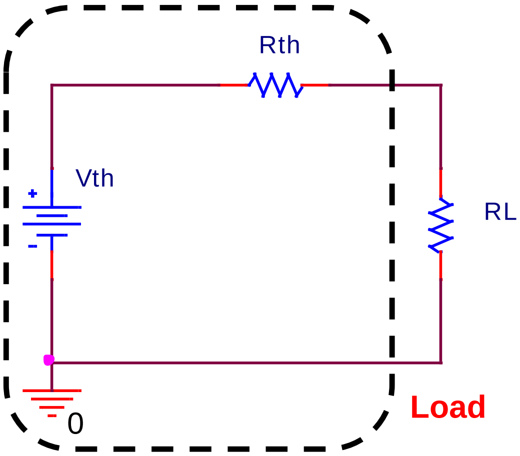
Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	T_A = 25°C										
	$R_S \leq 10$ kΩ					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10$ kΩ						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/°C
Input Offset Voltage Adjustment Range	T_A = 25°C, V_S = ±20V	±10				±15			±15		mV
Input Offset Current	T_A = 25°C		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	T_A = 25°C		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	T_A = 25°C, V_S = ±20V	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, V_S = ±20V	0.5									MΩ
Input Voltage Range	T_A = 25°C							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V

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 = ±20V, V_O = ±15V	50									V/mV
	V_S = ±15V, V_O = ±10V				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
	$R_L \geq$ 2 kΩ,										
	V_S = ±20V, V_O = ±15V	32									V/mV
	V_S = ±15V, V_O = ±10V				25			15			V/mV
	V_S = ±5V, V_O = ±2V	10									V/mV
Output Voltage Swing	V_S = ±20V										
	$R_L \geq$ 10 kΩ	±16									V
	$R_L \geq$ 2 kΩ	±15									V
	V_S = ±15V										
	$R_L \geq$ 10 kΩ				±12	±14		±12	±14		V
	$R_L \geq$ 2 kΩ				±10	±13		±10	±13		V
Output Short Circuit	T_A = 25°C	10	25	35		25			25		mA
Current	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
Rejection Ratio	$R_S \leq$ 10 kΩ, V_{CM} = ±12V				70	90		70	90		dB
	$R_S \leq$ 50Ω, V_{CM} = ±12V	80	95								dB
Supply Voltage Rejection	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
Ratio	V_S = ±20V to V_S = ±5V										
	$R_S \leq$ 50Ω	86	96								dB
	$R_S \leq$ 10 kΩ				77	96		77	96		dB
Transient Response	T_A = 25°C, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		μs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 6)	T_A = 25°C	0.437	1.5								MHz
Slew Rate	T_A = 25°C, Unity Gain	0.3	0.7			0.5			0.5		V/μs
Supply Current	T_A = 25°C					1.7	2.8		1.7	2.8	mA
Power Consumption	T_A = 25°C										
	V_S = ±20V		80	150							mW
	V_S = ±15V					50	85		50	85	mW
LM741A	V_S = ±20V										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							mW
LM741	V_S = ±15V										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				mW

Note 2: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

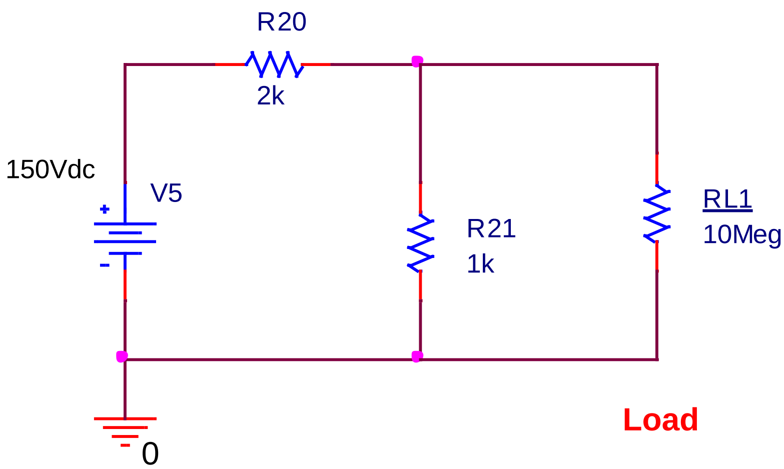
1. Thevenin Equivalent Voltage Source



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 a series of related circuits. While the circuits and their analysis are similar, treat each circuit as a separate problem.

Circuit 1: {4 pts} Find and sketch the Thevenin Equivalent Circuit for the following circuit.



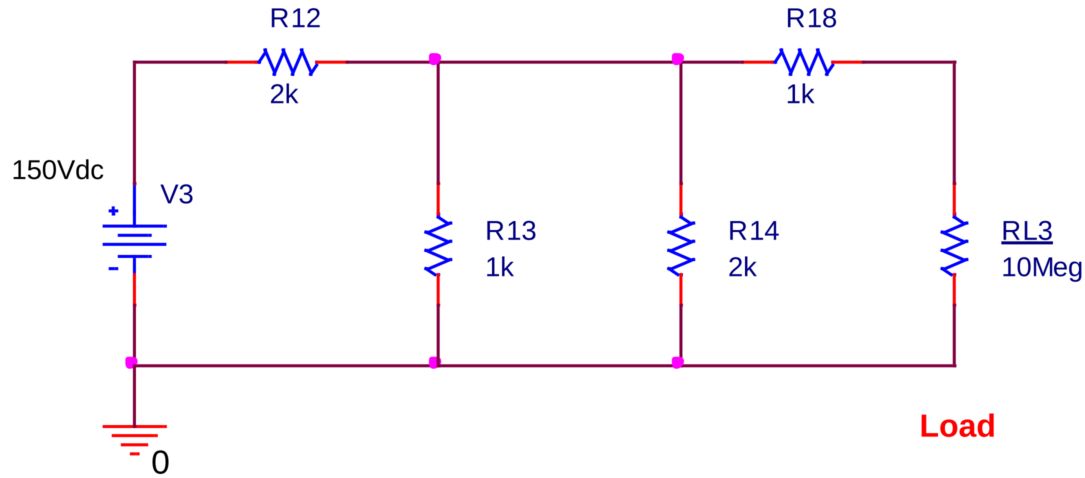
Remove the load, then apply the voltage divider to obtain the open circuit voltage:

$$V_{TH} = V_{oc} = \frac{1}{1+2}150 = 50V$$

Short out the voltage source and then find the parallel combination of R20 and R21

$$R_{TH} = \frac{(1k)(2k)}{1k+2k} = 667\Omega$$

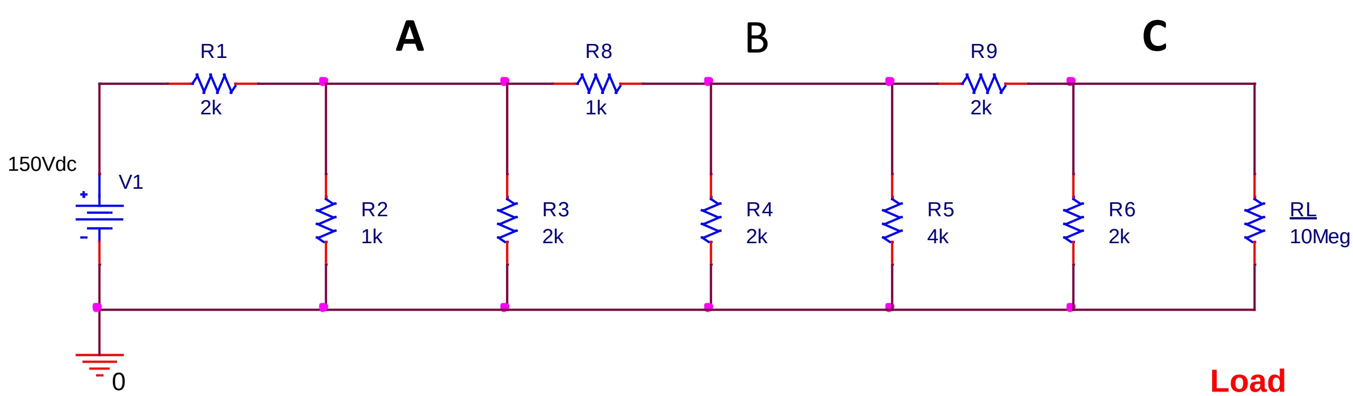
Circuit 2: {4 pts} Find and sketch the Thevenin Equivalent Circuit for the following circuit. Note that it is a modification of Circuit 1.



Remove the load, then apply the voltage divider to obtain the open circuit voltage. First find the parallel combination of R13 and R14 as the bottom resistor in the divider. This is also 667Ω.

Then the voltage divider expression gives $V_{TH} = V_{oc} = \frac{667}{667+2000} 150 = 37.5V$ Note that there is no current through R18, so it does not affect the open circuit voltage. It does play a role in the Thevenin resistance. Short out the voltage source, find the parallel combination of R12, R13, R14 (trivially equal to 500Ω) and then add R18 in series to get R_{TH} = 1.5kΩ

Circuit 3: {4 pts} Find and sketch the Thevenin Equivalent Circuit for the following circuit. Note that it is a modification of the previous circuits.



Open circuit for V_{TH}: First find voltage at A by combining all resistors from R2 on. R9+R6 = 4k, then this combo in parallel with R5 (also 4k) which equals 2k. That combo in parallel with R4 (also 2k) which equals 1k. That combo in series with R8 (also 1k) which equals 2k. That combo in parallel with R3 (also 2k) which equals 1k. That combo in parallel with R2 (also 1k) which equals 500Ω. The voltage divider at A is then $V_A = \frac{500}{500+2000}150 = 30V$. Then, simple dividers give us each voltage $V_B = \frac{1000}{1000+1000}30 = 15V$ and $V_{TH} = V_C = \frac{2000}{2000+2000}30 = 7.5V$ To find the resistance, short out the source V1 and combine resistors left to right. R1||R2||R3 = 500Ω. Then add R8 in series (1.5kΩ) and find the parallel combo with 2k||4k or $\frac{1}{R} = \frac{1}{1.5k} + \frac{1}{2k} + \frac{1}{4k} = \frac{8}{12k} + \frac{6}{12k} + \frac{3}{12k} = \frac{17}{12k}$. The combo is R=706Ω. Then add 2k and find the parallel combo with 2k or $R_{TH} = \frac{2.7k(2k)}{4.7k} = 1.15k$

Calculations: {3 pts} Determine the voltages at the nodes marked A, B and C in Circuit 3.

Already determined above. 30V, 15V and 7.5V

Application: {3 pts} Using each of your three Thevenin Equivalent Circuits, determine the load voltage and power delivered to the load for a load resistance of 2kΩ.

Load voltage from voltage divider and power from V^2/R

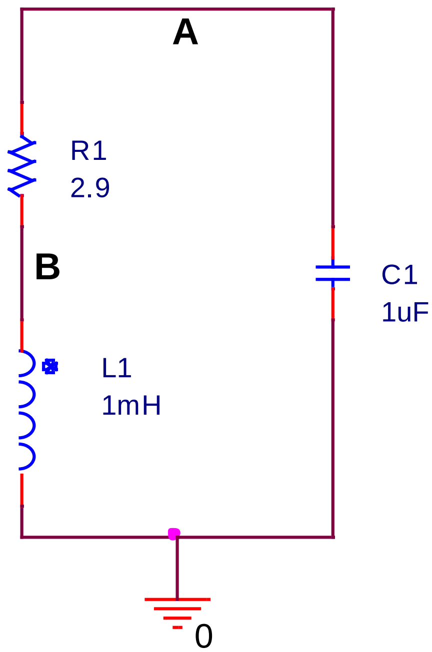
Circuit	VTH	RTH	RLOAD	VLOAD	PLOAD
1	**50**	**667**	**2k**	**37.5**	**703mW**
2	**37.5**	**1.5k**	**2k**	**21.4**	**229mW**
3	**7.5**	**1.15k**	**2k**	**4.76**	**11.3mW**

All results also checked with PSpice.

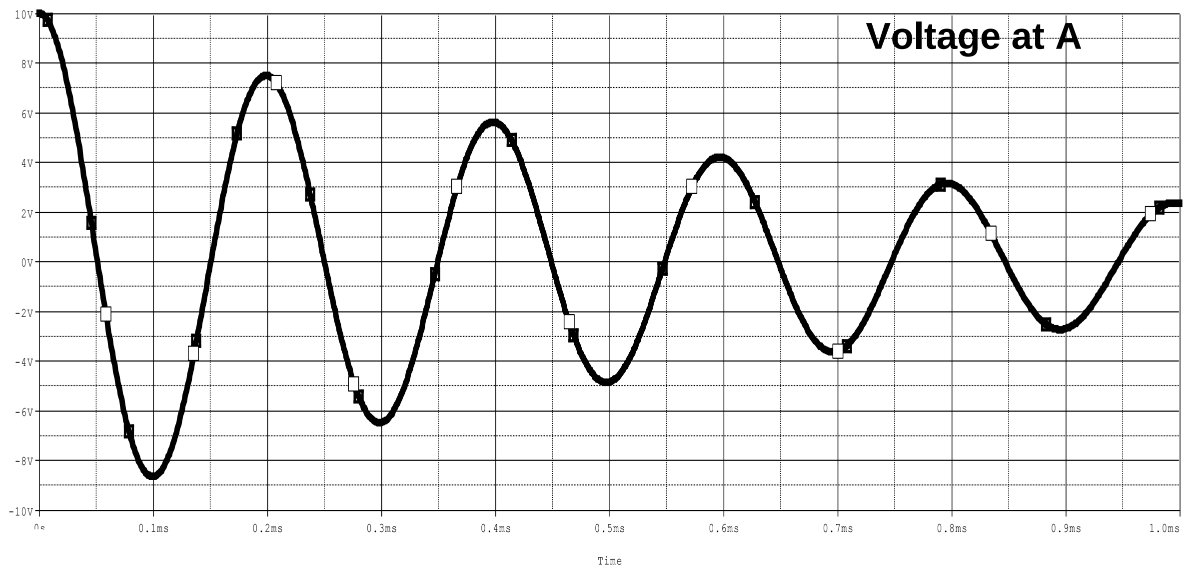
Concept: {2 pts} For what load resistance will the power delivered to the load be a maximum for Circuit 2?

Maximum power transfer occurs when the load is equal to the internal resistance of the source so RLOAD = 1.5kΩ

2. Harmonic Oscillators and Math



We encounter the harmonic oscillator in an unlimited number of circumstances in engineering and science. For example, you have likely done some kind of a pendulum experiment in Physics. As we have seen in class, physical oscillators (damped spring-mass systems like the cantilever beam) and RLC circuits behave the same way, although at different frequencies. The circuit shown here is made by connecting a 1mH inductor in parallel with a 1μF capacitor. The resistor in the circuit is the resistance of the inductor and is shown as a separate resistor here. That is, all circuit elements used to model the circuit are ideal, with the R and L used to represent the real inductor. The inductor is made by Bourns, located in Riverside, CA. The capacitor is made by Panasonic, probably at their manufacturing plant in Mexico. Capacitors are very low loss so there is no need to use a resistor to model them, under most conditions. The circuit is charged and then allowed to oscillate down, starting at t = 0sec, as shown. The figure shows the voltage as a function of time at point A (which is the voltage across the capacitor).



The horizontal scale is time (1ms full scale) and the vertical scale is V (-10V to +10V).

a. Find the decay constant α and the angular frequency ω for this data. {6 pts}

Frequency: 5 periods in 1ms or 5kHz. $\omega = 2\pi f = 31.4\text{k}$

Decay constant: Decays from 10V to about 4V in .6ms or $10e^{-\alpha(.0006)} = 4$ or $\alpha \approx 1450$

b. Write the mathematical expression for the voltage at A 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. Use real values for the constants and provide units where appropriate. {4 pts}

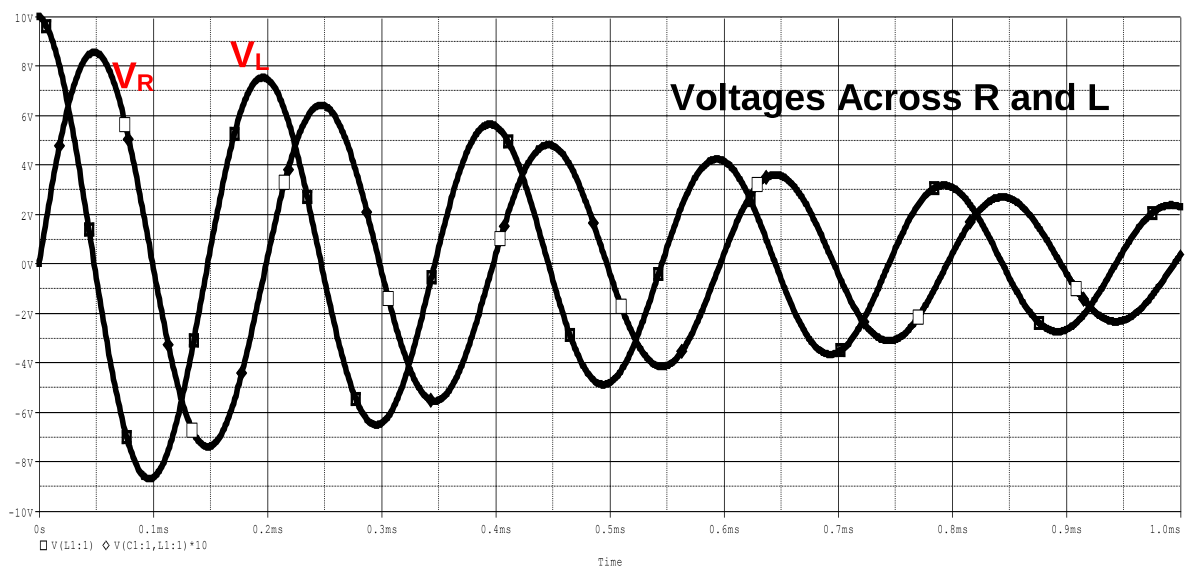
The cosine form fits better: $V(t) = 10e^{-1450t}\cos 31400t$ Volts The units of α are s^{-1} but there are no units in the exponent, so it is not necessary to include them.

c. Using your expression for the voltage at A, determine the current through the capacitor as a function of time. {4 pts}

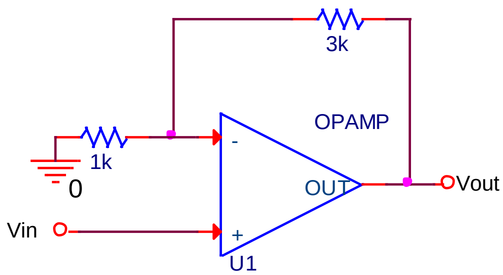
The current through the capacitor is determined from its current-voltage expression:

$$I = C\frac{dV}{dt} = -CA\omega\sin\omega t = -(0.000001)(10)(31400)\sin 31400t = -0.314\sin 31400t$$

d. Shown below are the voltages across the resistor and the inductor. Neither is labeled. Determine which is which and label them in the figure. Explain your answer. *No credit without an explanation.* {6 pts} Current tracks the resistor voltage (V=IR) so V_R is the one that looks like a sine function. V_L is the remaining curve. Note that the sign is wrong because the current in the resistor is in the opposite direction from the capacitor.



3. Operational Amplifier Applications



a. For the circuit shown at the right:

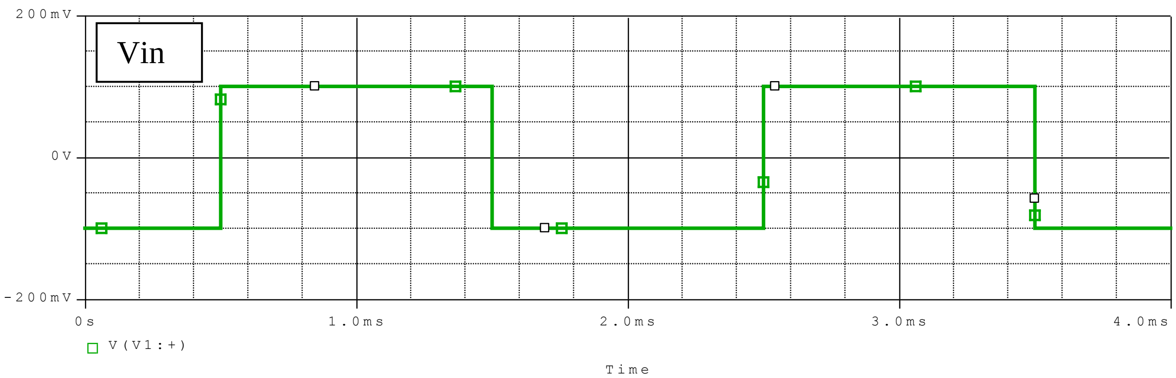
i. {1pt} What type of amplifier is this circuit?

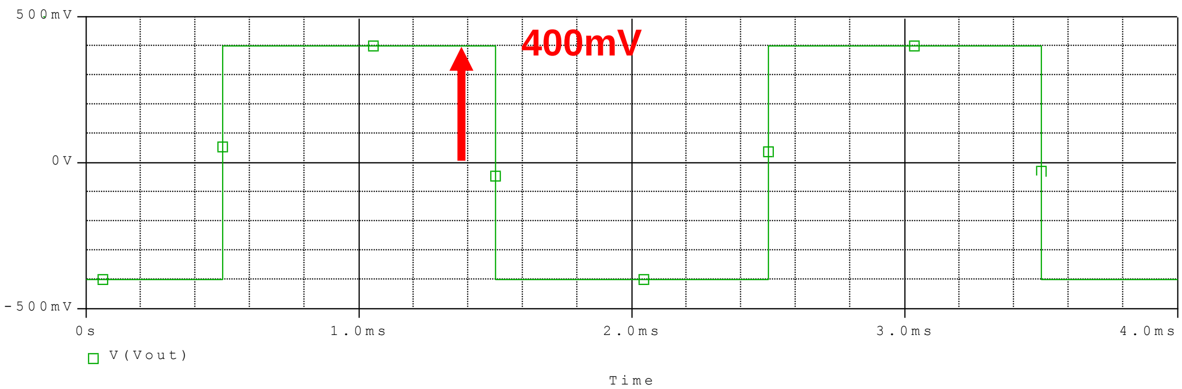
Non-Inverting

{1pt}Write and expression for Vout as a function of Vin.

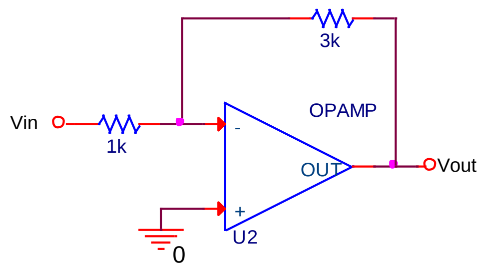
$$A_v = 1 + \frac{R_f}{R_g} = 1 + 3 = 4 \quad V_{out} = 4V_{in}$$

ii. {2pts} Given that Vin is as shown in the plot below, draw Vout on the blank plot. You must label both the y axis and also mark the signal amplitude. For both plots the horizontal scale goes from 0 to 4ms. For the top plot, the vertical scale goes from -200mV to +200mV.





b. For the circuit shown at the right:



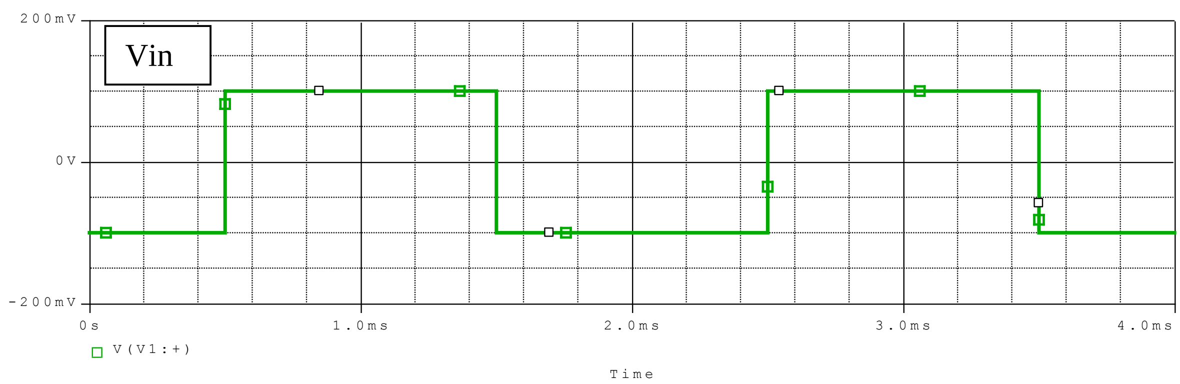
i. {1pt} What type of amplifier is this circuit?

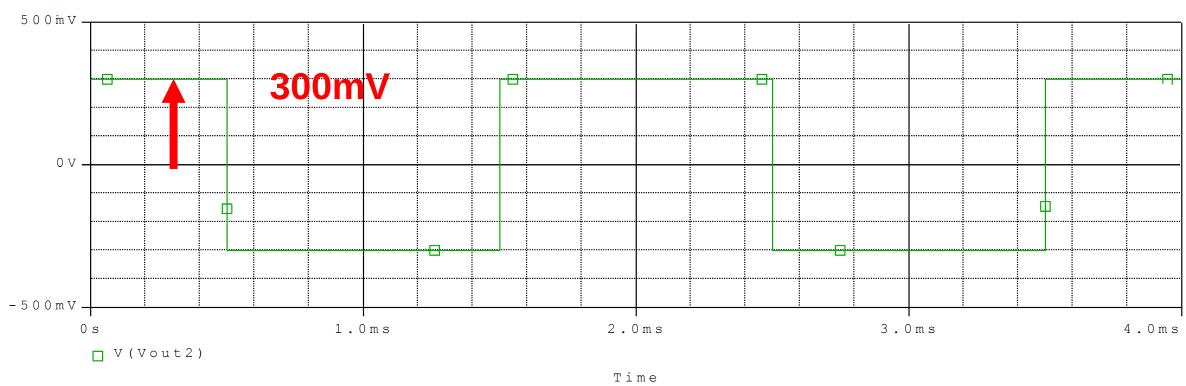
Inverting

ii. {1pt}Write and expression for Vout as a function of Vin.

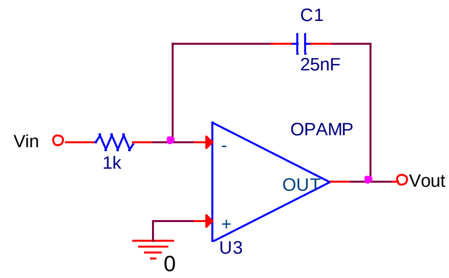
$$A_v = -\frac{R_f}{R_g} = -3 \quad V_{out} = -3V_{in}$$

{2pts} Given that Vin is as shown in the plot below, draw Vout on the blank plot. You must label both the y axis and also mark the signal amplitude. For both plots the horizontal scale goes from 0 to 4ms. For the top plot, the vertical scale goes from -200mV to +200mV.





c. For the circuit shown at the right:



i. {1pt} What type of amplifier is this circuit?

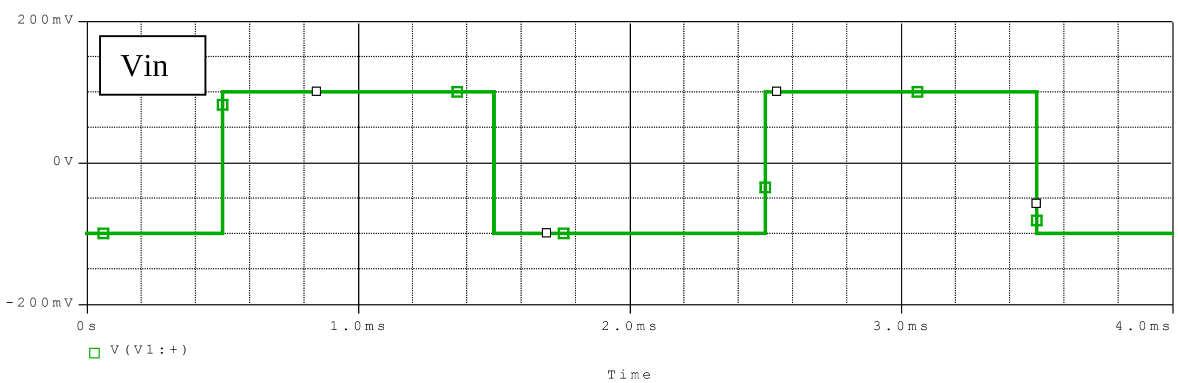
Integrator or Active Integrator

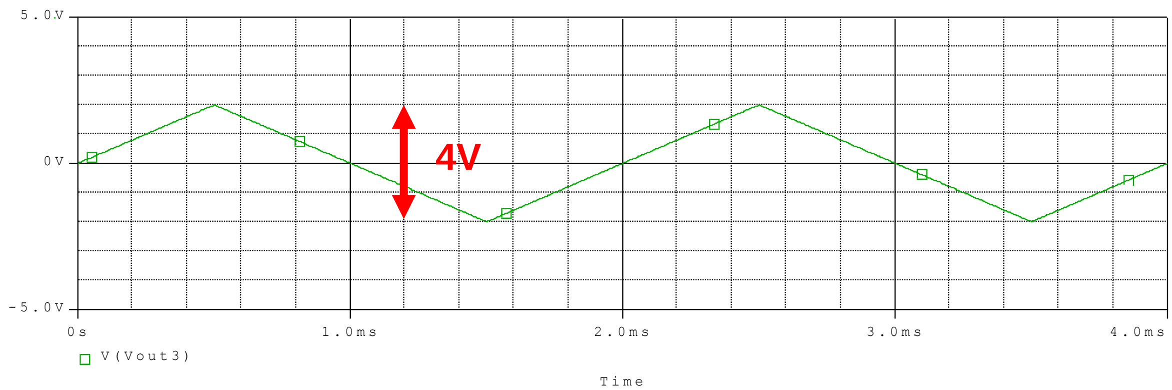
{2pt}Write and expression for Vout as a function of Vin.

$$V_{out} = -\frac{1}{R_{in}C_f}\int V_{in}(t)dt \qquad V_{out} = -4x10^4\int V_{in}(t)dt$$

{2pts} Given that Vin is as shown in the plot below, draw Vout on the blank plot. You must label both the y axis and also mark the signal amplitude.
At t=0, set Vout to 0V. For both plots the horizontal scale goes from 0 to 4ms. For the top plot, the vertical scale goes from -200mV to +200mV.

$V_{out} = -4x10^4 \int_0^{.001} 0.1dt = -4x10^4(0.1)(0.001) = -4$ so while the voltage is high (0.1V) the integration drops 4V. It goes up 4V when the voltage is low (-0.1V).



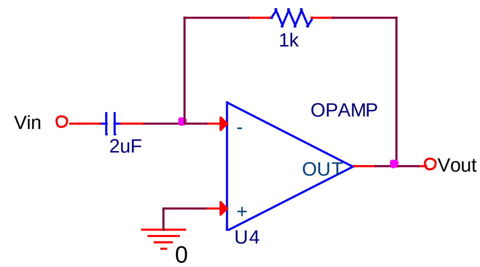


d. For the circuit shown at the right:

i. {1pt} What type of amplifier is this circuit?

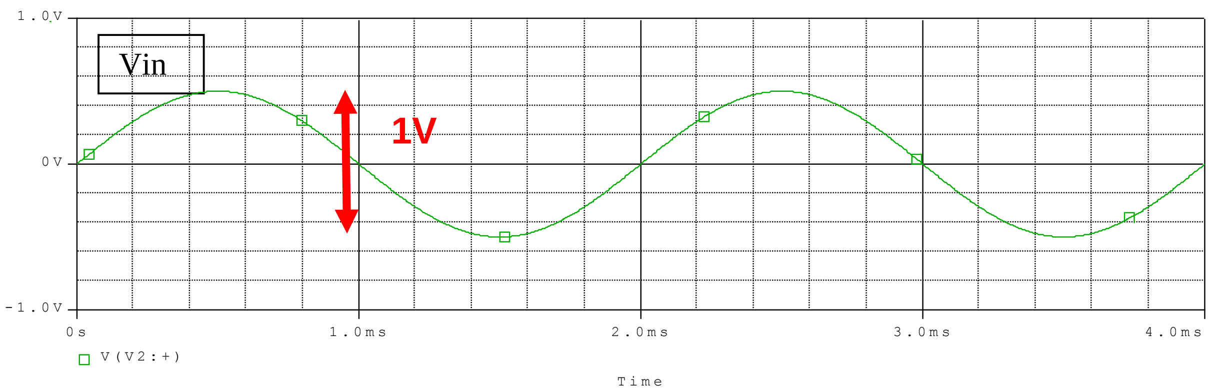
Differentiator or Active Differentiator

{2pt}Write and expression for Vout as a function of Vin.



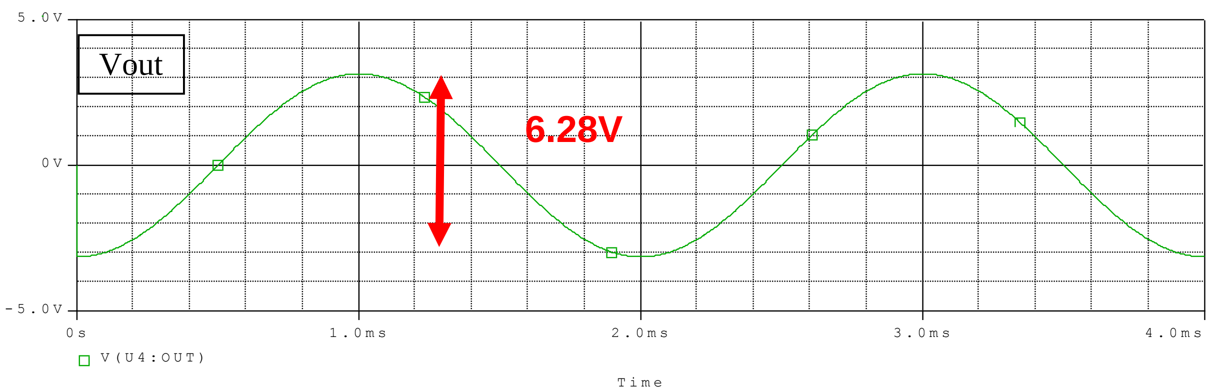
$$V_{out} = -C_{in} R_f \frac{dV_{in}(t)}{dt} = -2x10^{-3} \frac{dV_{in}(t)}{dt} \text{ or phasor form } V_{out} = -j2x10^{-3} \omega V_{in}$$

ii. {2pts} Given that Vin is a sinewave with amplitude = 0.5V and frequency = 500Hz, draw Vin(t) on the plot below, draw Vout on the blank plot. You must label both the y axis and also mark the signal amplitude. Same time scale as previous plots.



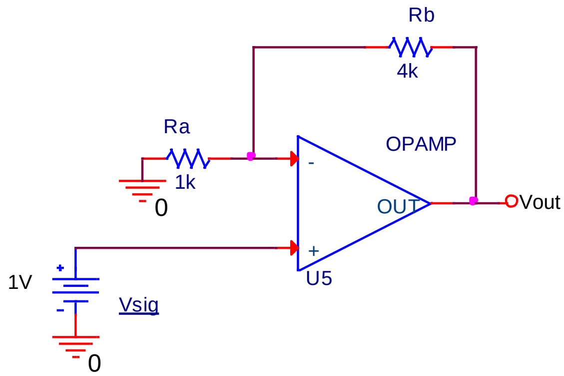
iii. {2pts} Draw Vout on the plot below. You must label both the y axis and also mark the signal amplitude. Same time scale as previous plots.

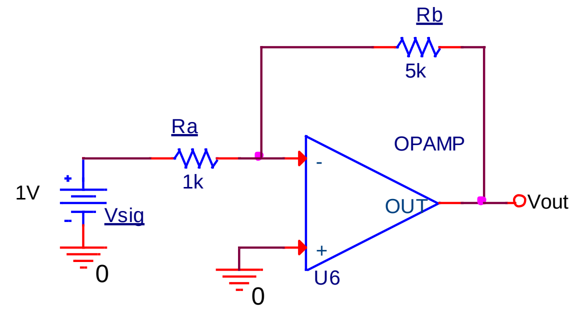
$$V_{out} = -2x10^{-3} \omega (0.5) \cos \omega t = -3.14 \cos(1000\pi t)$$



4. Operational Amplifier and Circuit Fundamentals

a. {6pts} Power draw, related to loading, varies with the op-amp configuration. This can be demonstrated by setting a signal source to a constant voltage and determining where the power is lost (converted to heat.) Analyze the 2 circuits shown and complete the table.





	Left Circuit	Right Circuit
Gain of circuit	5	-5
Vout	5V	-5V
Power from Vsig	0	1mW
Power into Ra	1mW	1mW
Power into Rb	4mW	5mW
Power from the op-amp output	5mW	5mW

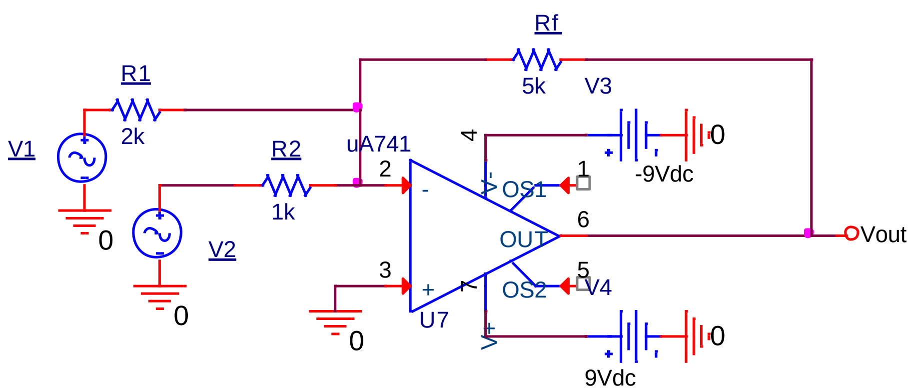
No current from V_{sig} on left so no power from $V_{sig.}$ On right $P_{sig} = \frac{1^2}{1000} = 1mW$

Power into Ra for both circuits

$P_{Ra} = \frac{1^2}{1000} = 1mW$ Voltage at neg input on left is 1V $P_{Rb} = \frac{4^2}{4000} = 4mW$ and on the right the voltage at neg input is 0V so $P_{Rb} = \frac{5^2}{5000} = 5mW$ Op amp has to make up remaining power so it must provide 5mW for both circuits.

b. The circuit shown has 2 input signals.

i. {2pts}Write an expression for Vout in terms of V1 and V2.



$$V_{out} = -\frac{R_f}{R_1}V_1 - \frac{R_f}{R_2}V_2$$

$$= -2.5V_1 - 5V_2$$

c. {4pts}If V1 is a dc voltage of 2V, V1=2Vdc, and V2 is a sinewave, V2=Asinωt what is the largest value of A for which the op-amp can follow your equation in part i. above? State any assumptions you made to calculate this number.

Assume output can go to plus or minus 9V (will be less in most real op-amps).

Input V1 has a gain of 2.5 so the output will be -5V. That leaves 4V for V2. With a gain of 5, A must be < 0.8V. If assume that output can go to a smaller number, V2 will be smaller. For output limited by 7V, A <0.4V

The circuit shown is a practical integrator.

i. {4pts}Assume ω is large. What is the magnitude and phase of the output if the input has a magnitude of 0.2V, a phase of 0 degrees, and a frequency of 10kHz?

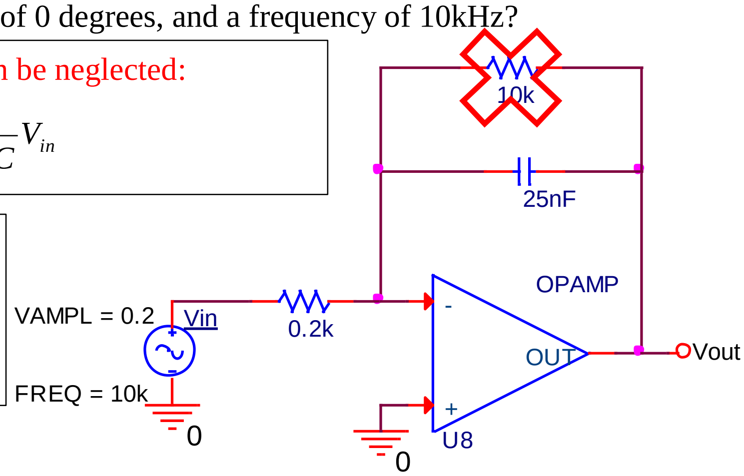
For ω large, the feedback resistor can be neglected:

$$H(j\omega) = -\frac{1}{j\omega RC} \quad \& \quad V_{out} = -\frac{1}{j\omega RC}V_{in}$$

$$V_{out} = \frac{1}{j(2\pi 10^4)(200)(25x10^{-9})}0.2$$

$$= j0.64$$

Magnitude is 0.64 and phase is 90°



ii. {2pts}For what range of frequency (in Hz) is it valid to make the assumption that ω is large?

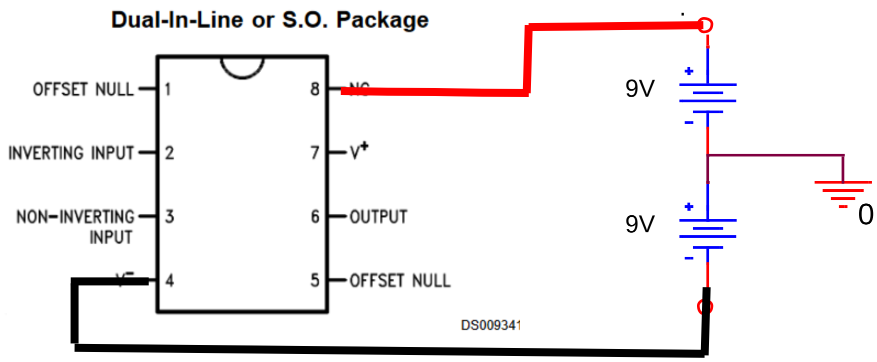
$\omega = 2\pi f >> 1/R_fC_f = 1/(10^4)(25x10^{-9})$ or f >> 640Hz. Note that this calculation finds the condition when the feedback capacitor impedance is much smaller than the feedback resistor.

{2pts} Give an expression for Vout of this circuit in terms of Vin if the frequency is very very low.

When the frequency is very low, we have the opposite condition from the one above. The feedback resistor is smaller than the capacitor impedance. Then we neglect the capacitor and we have a simple inverting amplifier with $V_{out} = -\frac{10^4}{200}V_{in} = -50V_{in}$

5. Concepts, Troubleshooting and Data Analysis

a. Draw lines to connect the batteries to the 741 op-amp package shown below {2 pts}:



b. The following is from the 741 data sheet:

Electrical Characteristics (Note 5) (Continued) — LM741

Parameter	Conditions	LM741A Min	LM741A Typ	LM741A Max	LM741 Min	LM741 Typ	LM741 Max	LM741C Min	LM741C Typ	LM741C Max	Units
Large Signal Voltage Gain	T_A = 25°C, $R_L \geq 2$ kΩ										
	V_S = ±20V, V_O = ±15V	50									V/mV
	V_S = ±15V, V_O = ±10V				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $R_L \geq 2$ kΩ,										
	V_S = ±20V, V_O = ±15V	32									V/mV
	V_S = ±15V, V_O = ±10V				25			15			V/mV
	V_S = ±5V, V_O = ±2V	10									V/mV
Output Voltage Swing	V_S = ±20V										
	$R_L \geq 10$ kΩ	±16									V
	$R_L \geq 2$ kΩ	±15									V
	V_S = ±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

Using this data sheet answer the following {2 pts}:

i. If a 100Ω load is put on the output of a LM741 op-amp, what is the maximum output voltage that one would typically expect to be able to achieve?

Current limit of 25mA. V = IR = 0.025(100) = 2.5V

For a current limit of 40mA, the max voltage is 4V.

Remember – This was part of an Experiment

ii. If LM741 op-amp is power 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?

Max output voltage is 13V (from spec sheet, as long as the load is at least 2kΩ)

c. Which of the following op-amp configurations works best to amplify the signal from a strain gauge bridge circuit? Circle one. {2 pts}

Voltage Follower Inverting Non-Inverting Differential

Adder Integrator Differentiator

This is a good example of looking elsewhere in the quiz … see the strain gauge circuit on the next page!

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

Voltage Follower Inverting Non-Inverting Differential

Adder Integrator Differentiator

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) {2 pts}

True False

f. The voltage follower op-amp configuration has a gain of 1. Why bother to use this configuration if your signal voltage is already the desired value? In other words, why not just connect the signal to the load? (20 word limit) {2 pts}

Use voltage follower if the load would cause the input voltage to drop if directly coupled. For example, in a voltage divider, if the load resistor is similar in size to the lower divider resistor, the divider will no longer work as designed.

g. In Experiment 5, the strain gauge circuit is configured as shown below:

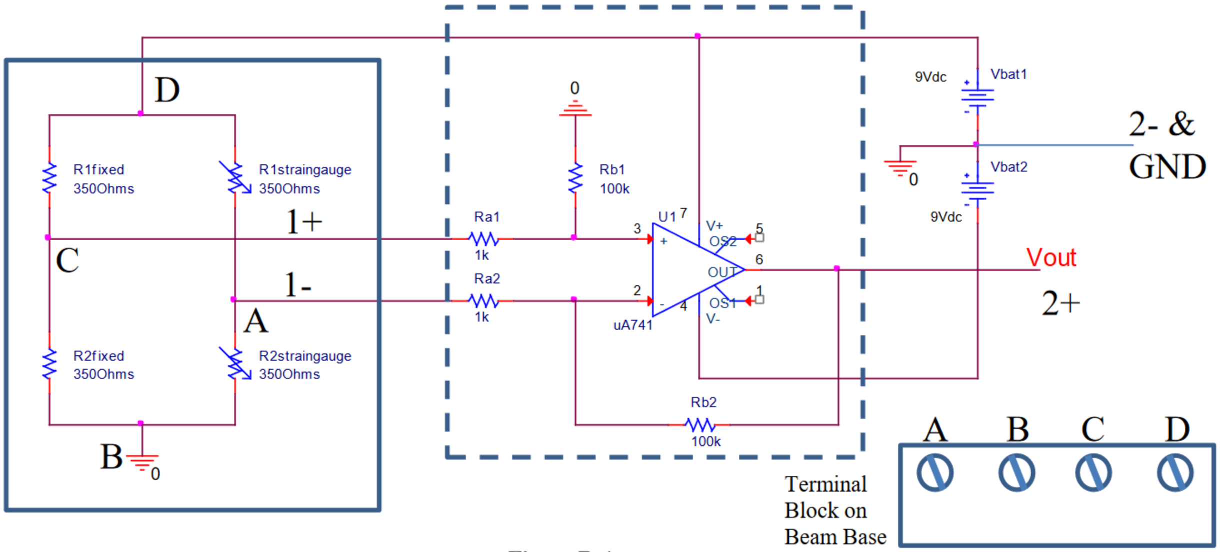


Figure B-4.

If the +5V and -5V power supplies of the Analog Discovery Board were used instead of the two 9V batteries, would the sensitivity of the system increase, remain the same or decrease? Explain your answer. (20 word max.) (Sensitivity in this case is the amount Vout would change for a given change in the deflection of the beam.) {2 pts}

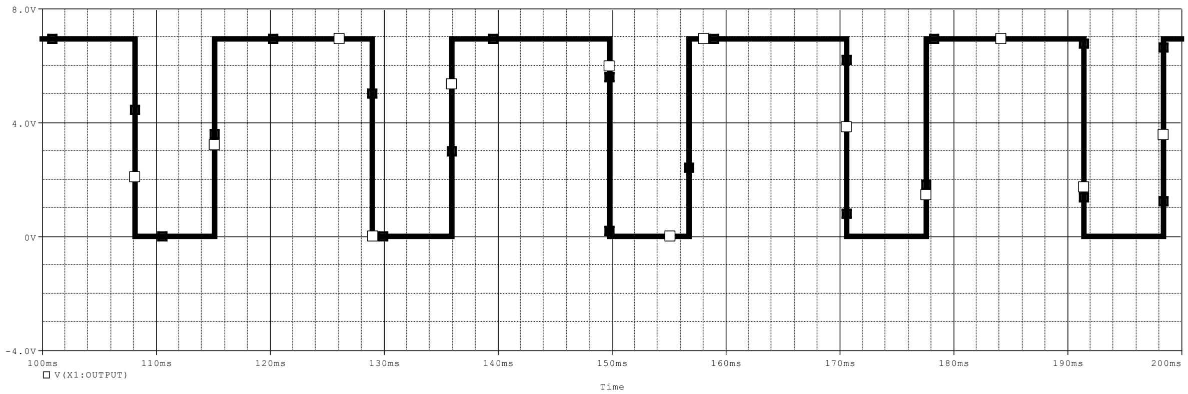
Decrease. From the formula (crib) sheet, the voltage from the strain gauge is proportional to the voltage source that powers it.

h. Using the general harmonic oscillator equation below, determine its natural frequency ω. {2 pts}

$$a\frac{d^2H}{dt^2} + bH = 0$$

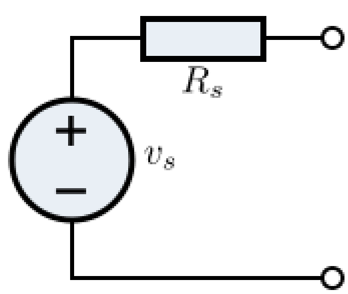
Assume that the solution is written as $H = A\cos\omega t$. Then $\ddot{H} = -\omega^2 A\cos\omega t = -\omega^2 H$. Plug this into the equation and solve for $\omega = \sqrt{\frac{b}{a}}$ This is something you should have seen in Differential Equations and Dynamics.

i. A very interesting and useful device we will be studying in Experiment 7 is the 555 timer chip. Timer chips make it easy to create sequences of pulses at almost any frequency. Shown below is a typical output for a pulsing circuit made with the 555 timer. The load in this case is R_L = 1kΩ. Note that the voltage pulses between V_{LOW} = 0V and $V_{HIGH} \approx$ 7V. A series of measurements are made of the high output voltage for load resistors varying from 10Ω to 1MΩ. Use this data to determine the Thevenin Equivalent Voltage (for the high voltage) and Resistance for this circuit. As usual, be sure to show all work. *Note that, since you are only addressing the high voltage and not the actual time variation of the output signal, you can solve the problem as if it was a DC source.* {4 pts}



R_L (Ω)	V_{HIGH} (V)	V_{HIGH} Calc
1000	6.9215	6.92307
1000000	8.995	8.99730
100000	8.97	8.97308
10000	8.735	8.73786
100	2.25	2.25
10	0.29	0.29032
300	4.5	4.5
3000	8.18	8.18181
30000	8.9	8.91089

Peak voltage is about 9V at 1MΩ so that is the source voltage. Half of that voltage is 4.5, so the resistance is 300Ω. One can check this answer by calculating the load voltage using $V_L = 9\frac{R_L}{300+R_L}$, filling in the additional column & comparing the results to the measured voltages.

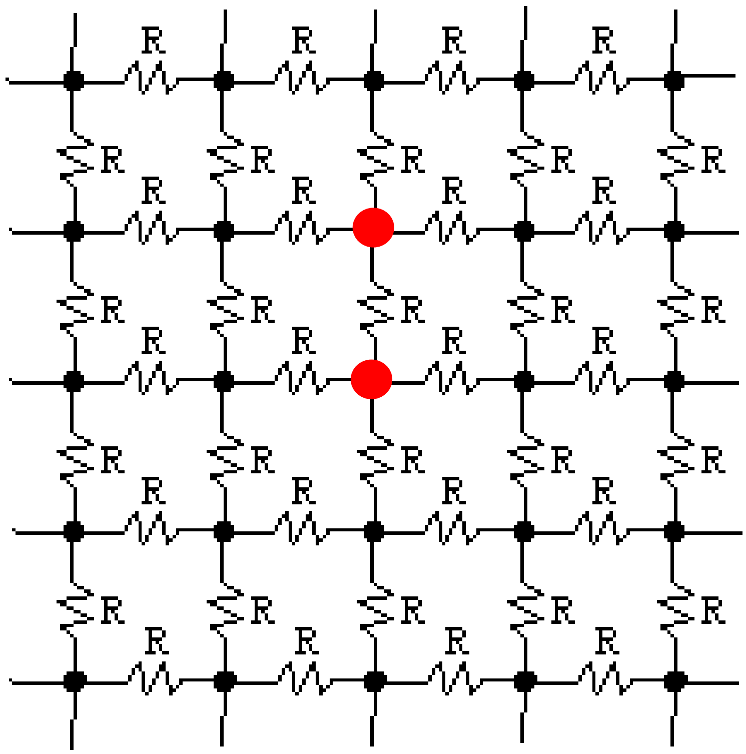


j. A classic puzzle involves an infinite 2D array of resistors (continues out to infinity in both directions), as shown below. All resistors have the same value R. If the resistance is measured at the two points with the large circles, will the resistance measured be {2 pts}

i. Greater than R?

ii. Less than R? Since R is in parallel with the other resistors, the combination must be smaller. It is, in fact R/2. This is essentially the same puzzle as in the Nerd Sniping cartoon.

iii. About equal to R?



Extra Credit: Solve this puzzle exactly {Up to 4 pts}

Check the puzzle out online.