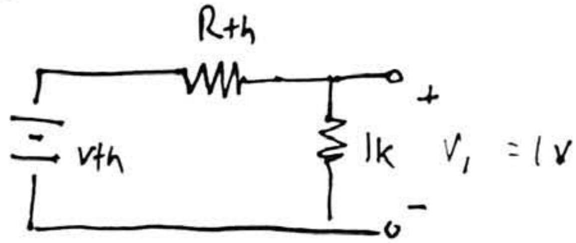
Quiz 2 Solutions

I. a.)

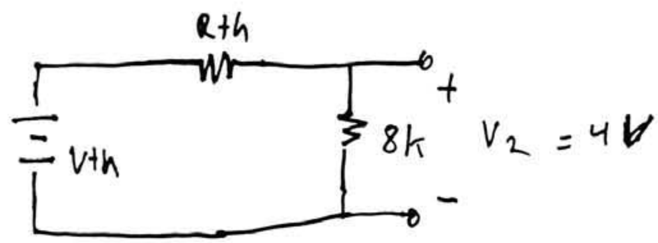


Using voltage division,

$$V_1 = 1 = V_{th}\left(\frac{1k}{1k + R_{th}}\right)$$

$$V_{th} \cdot 1k = R_{th} + 1k$$

$$V_{th} = \frac{R_{th}}{1k} + 1 \implies \text{Eqn. } \underline{1}$$



$$V_2 = 4 = V_{th}\left(\frac{8k}{8k + R_{th}}\right)$$

$$V_{th} \cdot 8k = 32k + 4R_{th}$$

$$V_{th} = \frac{R_{th}}{2k} + 4 \implies \text{Eqn. } 2$$

Solving eqn. 1 and eqn. 2,

eqn. 1 − eqn. 2 $\Longrightarrow$

$$\frac{R_{th}}{2k} - 3 = 0$$

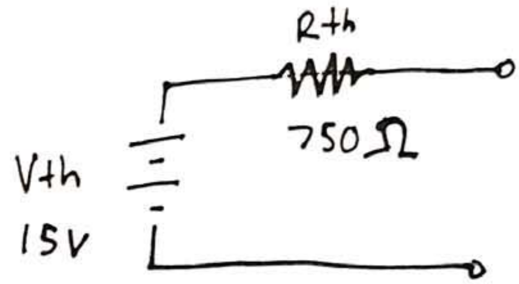
$$R_{th} = 6k\,\Omega$$

Using eqn. 1,

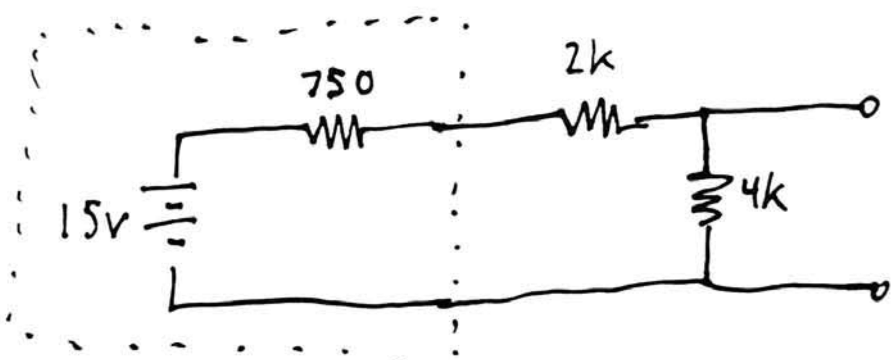
$$V_{th} = \frac{R_{th}}{1k} + 1 = \frac{6k}{1k} + 1 = 7.0\,V$$

b.) $V_{th} = V_1 \left(\frac{R_2}{R_1 + R_2} \right) = 20 \left(\frac{3k}{1k + 3k} \right) = 15\,V$

$R_{th} = 3k \,||\, 1k = \frac{3k \cdot 1k}{3k + 1k} = 750\,\Omega$



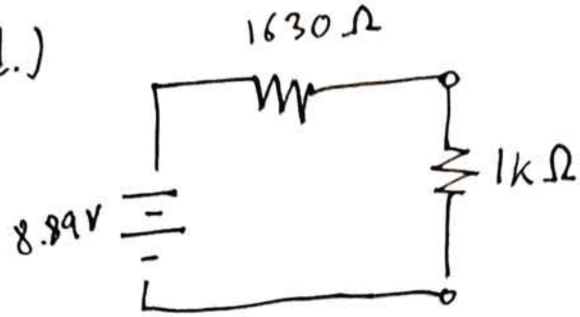
c.) Using our result from part b,



$V_{th} = 15 \left(\frac{4k}{750 + 2k + 4k} \right) = 8.89\,V$

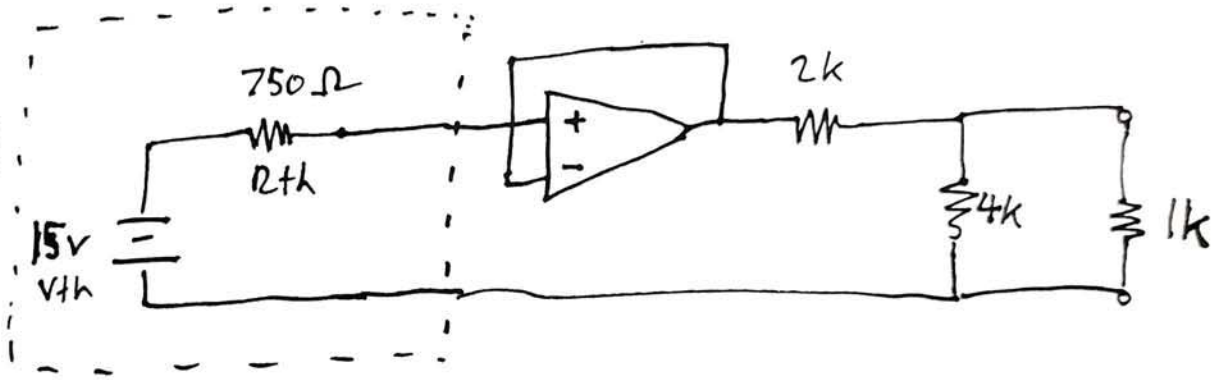
$R_{th} = (2k + 750) \,||\, 4k = \frac{(2750)(4000)}{2750 + 4000} = 1630\,\Omega$

d.)

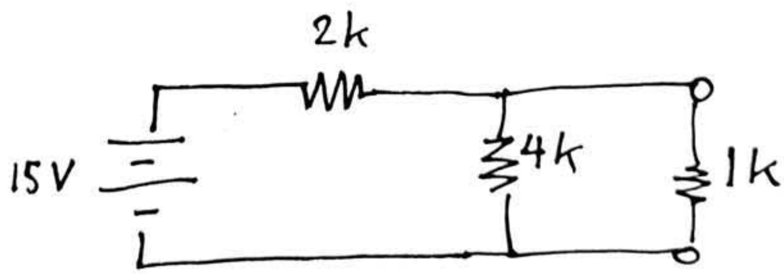


$$I_{load} = \frac{8.89V}{(1630 + 1000)\,\Omega} = 3.38\,mA$$

e.)



Since the voltage follower draws no current at its inputs, it will have an input voltage of $V_{th} = 15V$. Its output voltage will also be 15V. We can now represent the circuit as:



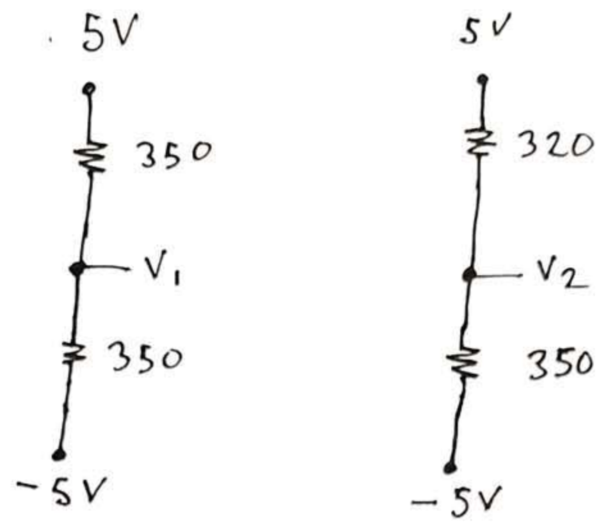
$$4k \,\|\, 1k = \frac{4k \cdot 1k}{4k + 1k} = 800\,\Omega$$

$$V_{load} = 15 \cdot \frac{800}{800 + 2k} = 4.29\,V$$

$$I_{load} = \frac{4.29\,V}{1k\Omega} = 4.29\,mA$$

II.

a.)



$$V_1 = -5V + (5-(-5))\frac{350}{350+350} = 0V$$

$$V_2 = -5V + (5-(-5))\frac{350}{320+350} = 0.22V$$

b.) $$V_{out} = \frac{R_8}{R_6}(V_2 - V_1) = \frac{R_7}{R_5}(V_2 - V_1)$$

$$V_1 = 0V$$

$$800mV = \frac{10k}{1k}(0 - V_1)$$

$$V_1 = -80mV = [(5-(-5))]\frac{R_4}{R_3+R_4} - 5$$

$$V_1 = 10\frac{500}{R_3+500} - 5 = -80mV$$

$$R_3 = 516.3\ \Omega$$

c.) Suppose that R_3 is $450\,\Omega$.

$V_1 = 0V$

$$V_2 = -5V + 10\,\frac{500}{450+500} = 0.26\ V$$

$$V_{out} = \frac{R_8}{R_6}(0 - 0.26\ V) = \frac{R_7}{R_5}(0 - 0.26\ V)$$

V_{out} will saturate at $-5\,V$. Therefore,

$$-5 = \frac{R_8}{R_6}(-0.26\ V)$$

$$\frac{R_8}{R_6} = \frac{R_7}{R_5} = 19.23$$

$R_5 = R_6 = 1k\,\Omega$

so

$R_8 = R_7 = 19.23\,k\Omega$

We can find the same answer by setting R_3 to $550\,\Omega$.

d.) Various physical factors, including beam and strain gauge deformation and small variations in resistor values, will cause each cantilever beam to produce a different output voltage when attached to the diff amp circuit at zero deflection. Changing beams mid-experiment would introduce measurement error.

e.) With two strain gauges, one will be subjected to tension while the other experiences compression and vice versa, and one resistance will decrease while the other increases and vice versa. This doubles the voltage response of the system for a given amount of deflection.

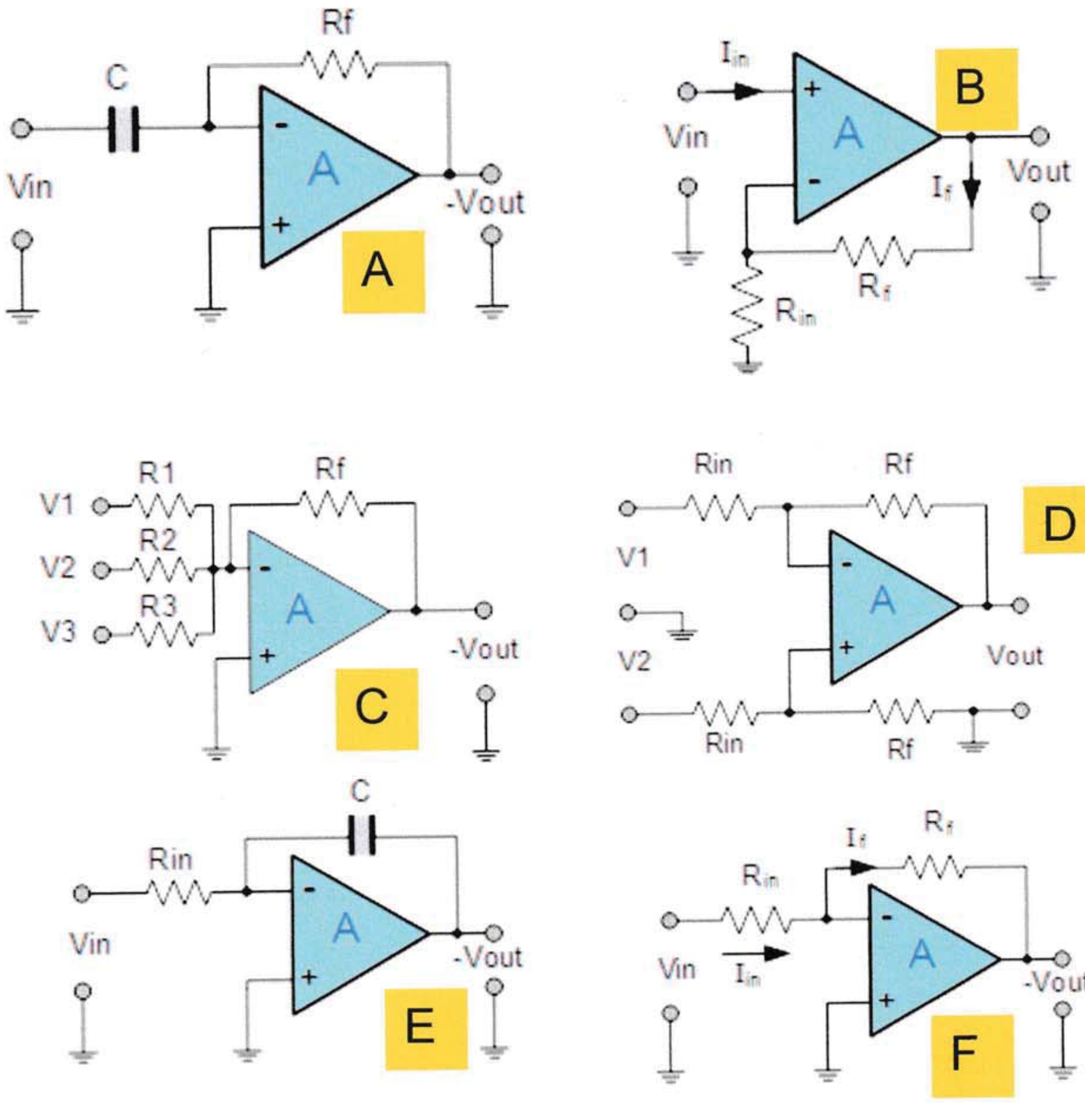
f.) The small positive voltage means that the value of R_3 is larger than $500\,\Omega$. We could re-zero the circuit by adding a small resistor in series with $R4$ or $R1$, or a large resistor in parallel with R_3.

III. Operational Amplifier Applications (20 points)

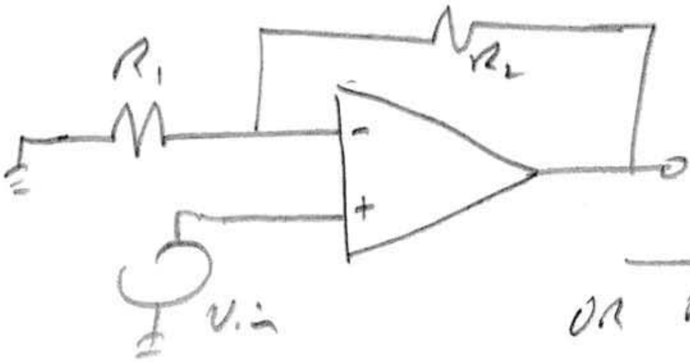
B

a. {3 pts} What type of amplifier is each circuit?

A differentiator	B non inverting Amp
C summer (OR) Inverting summer	D Different Amp
E Integrator	F inverting amp



b. (6 psts) Design a non-inverting amplifier circuit with a **gain of 20, specify resistor values, the resistors must have values of ≥1kΩ. Draw the circuit schematic. Be sure to label the input and the output.** You can assume any resistor value is available. (6 pts)



Value such that

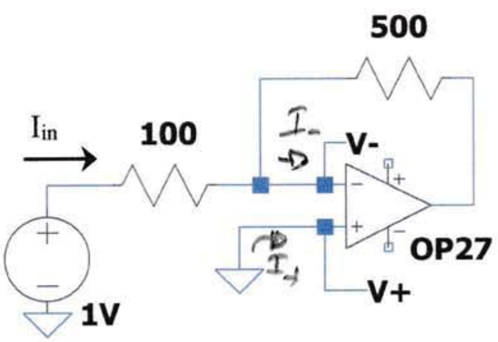
$1 + \frac{R_2}{R_1} = 20 \Rightarrow \frac{R_2}{R_1} = 19$

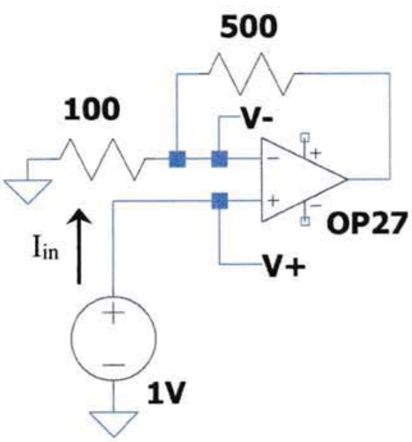
example let $R_1 = 1k$
$R_2 = 19k$

OR $R_1 = 2k$, $R_2 = 38k$

OR $R_2 = 20k$, $R_1 = 1.05k$

c. (6 pts) Using the ideal op amp rules, "Op Amp Analysis Rules", determine for each circuit below the values for V_+, V_-, and Iin. These circuits aren't connected to each other in any way. As with all problems, include units.





Ideal Op Amp $V_+ = V_-$
$I_- = 0$, $I_+ = 0$

Left Circuit:

V+ = 0V

V- = 0V

$I_{in} = (V_{in} - V_-)/100$
$= 1/100 = 0.01\,A$
or $10\,mA$

Right Circuit:

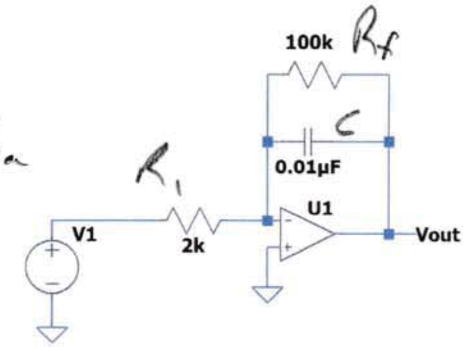
V+ = $V_{in} = 1V$

V- = $V_+ = 1V$

$I_{in} = I_+ = 0$

d) (5 pts) For the circuit shown on the right:

i) (1pt) For what range of frequencies will this behave as an integrator? Provide the answer in Hertz.



$\omega >> \frac{1}{R_f C}$ $\frac{1}{R_f C} = 10^3$ radians/sec

$f >> \frac{1}{2\pi R_f C}$ $\boxed{f >> 159\ Hz}$

ii) (1pt) Will it be a reasonable intergrator if V1 is a sinewave at 2kHz?

~~2kH~~ 2kHz is >> than 159 Hz, Yes

iii) (3pt)For this part assume it is a good integrator. If V1 is a sinewave with an amplitude of 0.5V and a frequency of 2kHz and a phase angle at t=0 or 0 degrees, what is Vout in the form of Vout=$V_{amp}\sin(\omega t+\theta)$. In other words: Give V_{amp}, ω, and θ of the output.

$\omega = 2\pi f = 12{,}600$

$H(j\omega) = \frac{-1}{j\omega R_1 C} = \frac{-1}{(j)(12{,}600)(2000)\,10^{-8}}$

$|H(j\omega)| = \frac{1}{(12600)(2000)\,10^{-8}} =$ 4

$|V_{out}| = |V_{in}| \cdot$ 4

$|V_{out}| =$ 2

$\angle H(j\omega) = \frac{-1}{j} = j \Rightarrow 90°$ or $\pi/2$

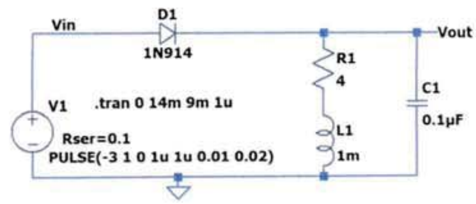
~~Vout(t)=~~ $V_{amp} =$ 2V

$\omega = 12{,}600$

$\theta = 90°$ or $\pi/2$ radians

IV – Concepts, Troubleshooting and Data Analysis (20 points)

a. (7 pts) Real components compared to ideal: In Experiment 5 you built and modeled the circuit on the right.



i. For the LTspice model you included R1. But you didn't put a resistor there when you built the circuit. Why not? {1pt}

R1 is the resistance of the coil. ~~It is part of the~~

OR R1 is part of the coil model.

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} Either say R1 or the coil.

It is the coil resistance ~~to~~ that causes the energy loss.
(The effective resistance of the cap is very small)

iii. Continuing with the energy loss question, will the energy loss be most rapid when the current in the inductor is at the maximum, or at 0A or energy loss doesn't depend on which part of the oscillation? Circle one. {2pts} $P_{power\ loss} = I^2 R_{coil}$

peak energy loss at:

I_L is at a peak $I_L=0$ doesn't depend on which part of an oscillation (circle one)

iv. The inductor used for this circuit was a 1mH inductor. If by mistake your partner used a 10mH inductor, would the resonant frequency go up or down, and by what percentage would the frequency change, to the nearest 1%? {3pts}

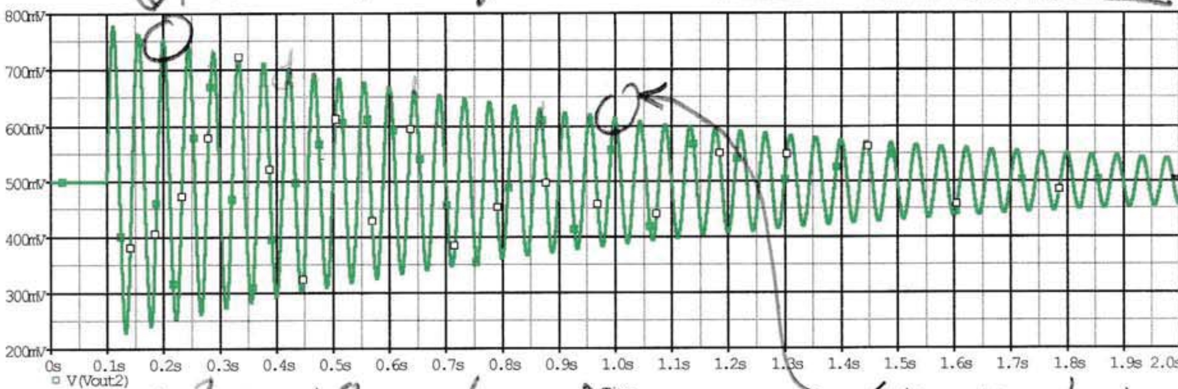
$$\omega_0 \simeq \frac{1}{\sqrt{LC}} \qquad \omega_{error} \approx \frac{1}{\sqrt{10LC}} = \left(\frac{1}{\sqrt{10}}\right)\underbrace{\left(\frac{1}{\sqrt{LC}}\right)}_{\omega_0}$$

$$\omega_{err} = 0.316\,\omega_0$$

Drop by 68.4% ⇒ 68%

750mV at 0.2 sec

Pick any 2 points, Must substract V_{avg}



$V_{avg} = 0.5V$

| ← 18 cycles → T

610mV at 1sec

b. (4 pts) The plot shown above represents data taken from the accelerometer on a beam after it has been integrated by an op-amp circuit. Note that there is a dc offset, typical of integration. Find the decay constant α and the angular frequency ω for this data. **You must mark the data points on the plot that you use for your answer**.

18 cycles in 0.8 sec

$f = 22.5\ Hz$

$\boxed{\omega = 90\ rad/sec}$

at 0.2 sec $V_{amp} = 750 - 500 = 250mV = V_1$

1.0 sec $V_{amp} = 610 - 500 = 110mV = V_2$

$$\frac{V(t_2)}{V(t_1)} = \frac{110}{250} = e^{-\alpha(t_2 - t_1)} = e^{-\alpha(0.8)}$$

$$\ln\frac{100}{250} = (-\alpha)(0.8)$$

$$\alpha = 1.03 \simeq 1\ sec^{-1}$$

c. (4 pts) Classroom Knowledge and Tasks: **True or False, circle one.**

i. 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 or False

ii. The velocity of the beam can be measured by using a differentiator op amp circuit with the accelerometer.

True or False

iii. When asking for a signature on a check off page you show the instructor a live simulation or instrumentation board measurement. Live refers to it running on your computer it the time of the check off.

True or False

iv. You don't need to have done hand-drawn schematics for the first checkoff of an experiment.

True or False

$V_S = \pm 15$ V, $T_A = 25$°C, unless otherwise noted.

Table 1.

Parameter	Symbol	Test Conditions	OP27A/OP27E Min	OP27A/OP27E Typ	OP27A/OP27E Max	OP27G Min	OP27G Typ	OP27G Max	Unit
INPUT OFFSET VOLTAGE[1]	V_{OS}			10	25		30	100	µV
LONG-TERM V_{OS} STABILITY[2, 3]	V_{OS}/Time			0.2	1.0		0.4	2.0	µV/Mo
INPUT OFFSET CURRENT	I_{OS}			7	35		12	75	nA
INPUT BIAS CURRENT	I_B			±10	±40		±15	±80	nA
INPUT NOISE VOLTAGE[1, 4]	$e_{n\,p\text{-}p}$	0.1 Hz to 10 Hz		0.08	0.18		0.09	0.25	µV p-p
INPUT NOISE	e_n	f_O = 10 Hz		3.5	5.5		3.8	8.0	nV/√Hz
Voltage Density[1]		f_O = 30 Hz		3.1	4.5		3.3	5.6	nV/√Hz
		f_O = 1000 Hz		3.0	3.8		3.2	4.5	nV/√Hz
INPUT NOISE	i_n	f_O = 10 Hz		1.7	4.0		1.7		pA/√Hz
Current Density[1]		f_O = 30 Hz		1.0	2.3		1.0		pA/√Hz
		f_O = 1000 Hz		0.4	0.6		0.4	0.6	pA/√Hz
INPUT RESISTANCE									
Differential Mode[5]	R_{IN}		1.3	6		0.7	4		MΩ
Common Mode	R_{INCM}			3			2		GΩ
INPUT VOLTAGE RANGE	IVR		±11.0	±12.3		±11.0	±12.3		V
COMMON-MODE REJECTION RATIO	CMRR	V_{CM} = ±11 V	114	126		100	120		dB
POWER SUPPLY REJECTION RATIO	PSRR	V_S = ±4 V to ±18 V		1	10		2	20	µV/V
LARGE SIGNAL VOLTAGE GAIN	A_{VO}	$R_L \ge 2$ kΩ, V_O = ±10 V	1000	1800		700	1500		V/mV
		$R_L \ge 600$ Ω, V_O = ±10 V	800	1500		600	1500		V/mV
OUTPUT VOLTAGE SWING	V_O	$R_L \ge 2$ kΩ	±12.0	±13.8		±11.5	±13.5		V
		$R_L \ge 600$ Ω	±10.0	±11.5		±10.0	±11.5		V
SLEW RATE[6]	SR	$R_L \ge 2$ kΩ	1.7	2.8		1.7	2.8		V/µs
GAIN BANDWIDTH PRODUCT[6]	GBW		5.0	8.0		5.0	8.0		MHz
OPEN-LOOP OUTPUT RESISTANCE	R_O	$V_O = 0$, $I_O = 0$		70			70		Ω
POWER CONSUMPTION	P_d	V_O		90	140		100	170	mW
OFFSET ADJUSTMENT RANGE		R_P = 10 kΩ		±4.0			±4.0		mV

$R_L > 2k$

$R_L < 2k$ but $\ge 600\,\Omega$

d. (5 pts) Part of the data sheet for the OP27 is shown. Use this to answer the following questions. Look at typical values for the G version, OP27G.

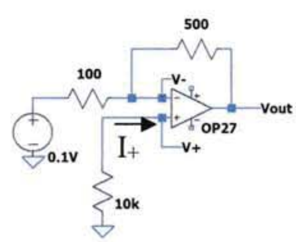
i. If the OP27G is powered by ±15V supplies and has a 10kΩ load, what are the expected maximum and minimum output voltages you can expect to achieve? (1pt)

$R_L > 2k\Omega$ so $\pm 13.5V$

ii. If the load is changed to 600Ω, what is the expected max and min output voltages? (1pt)

$R_L < 2k$ so use 600Ω values $\pm 11.5V$

iii. For the ideal op amp model what are the value of I_+ and V_+ as shown in the figure on the right?(1pt)



$V_+ = 0$, $I_+ = 0$

iv. The data sheet lists the actual expected values of I_+ as something called INPUT BIAS CURRENT. Using the largest typical value of the INPUT BIAS CURRENT, what would be the value of V+ for this circuit? (2pt)

typical $I_{Bias} = \pm 15nA$, use $15nA$ $\quad$ $15nA$ through $10k$

$= -15 \times 10^{-9} \times 10^4$

$= -150\mu V$ or $-0.15mV$

v. (2pt) Extra credit: Given your answer above, what would be the error in Vout due to the INPUT Bias Current?

$-0.15mV$ at V_+ $\Rightarrow$ gain of non-inverting amp is 6

$V_{out}(I_{bias}) = (6)(-0.15mV) = -0.9mV$