# Lab 1: Strain Gauge

1. (2 Points) What types of amplifiers are used in interface circuit shown in Figure 1?

Op amp 1 - Differential
Op amp 2 - non-inverting amplifier

2. (5 Points) Derive a gain expression for each amplification stage. Then, calculate the gain values for each stage. What is the total gain of the circuit?

Op amp 1 - differential
$V_2 = (V_a - V_b)(\frac{R_6}{R_4})$, where $R_4 = R_5$ and $R_6 = R_7$
Gain G = $\frac{V_2}{(V_a - V_b)} = (\frac{R_6}{R_4}) = \frac{1\ M\Omega}{100\ k\Omega} = 10,$

Op amp 2 – non-inverting
$V_{out} = V_2\left(\frac{R_8+R_9}{R_8}\right) = (V_a - V_b)(\frac{R_6}{R_4})\left(\frac{R_8+R_9}{R_8}\right),$
Gain G = $\frac{V_{out}}{V_2} = \left(\frac{R_8+R_9}{R_8}\right) = \frac{1\ k\Omega + 20\ k\Omega}{1\ k\Omega} = 21$ ,

Total gain G = $\frac{V_{out}}{V_2} * \frac{V_2}{V_{ab}} = \frac{V_{out}}{(V_a - V_b)} = (\frac{R_6}{R_4})\left(\frac{R_8+R_9}{R_8}\right) = 10 * 21 = 210$

3. (2 Points) Measure the resistance of the strain gauge at rest and report it. Manually pull or bend the strain gage and report the new value (different groups may get different results). Your result should not be saturated.

Rest: 119.9 $\Omega$
Compressive: 120.4 $\Omega$
Bending: 120.1 $\Omega$

4. (2 Points) What is the relationship between the R$strain$ and $Vab$?

Wheatstone bridge $V_o = V_b - V_a = V_s \frac{R_1R_3 - R_2R_{strain}}{(R_1 + R_{strain})(R_2 + R_3)}$

$$V_{ab} = V_a - V_b = V_s \frac{R_2R_{strain} - R_1R_3}{(R_1 + R_{strain})(R_2 + R_3)}$$

5. (2 Points) Provide an expression which relates the $Vout$ to R$strain$?

$$V_{out} = V_{ab}\left(\frac{R_6}{R_4}\right)\left(\frac{R_8 + R_9}{R_8}\right) = V_s \frac{R_2R_{strain} - R_1R_3}{(R_1 + R_{strain})(R_2 + R_3)}\left(\frac{R_6}{R_4}\right)\left(\frac{R_8 + R_9}{R_8}\right)$$

6. (3 Points) Assume that the resistance of the strain gauge at rest position is 120 Ω and it shows ±1 Ω variation under tensile and compressive strain. Calculate the theoretical $Vout$ for the three states including rest, compressive- and tensile strain.

$$V_{out} = V_s \frac{R_2 R_{strain} - R_1 R_3}{(R_1 + R_{strain})(R_2 + R_3)} \left(\frac{R_6}{R_4}\right)\left(\frac{R_8 + R_9}{R_8}\right)$$

$R_1 = R_2 = R_3 = R_{strain} = 120\ \Omega,\ R_4 = R_5 = 100\ k\Omega,\ R_6 = R_7 = 1\ M\Omega,\ R_8 = 1\ k\Omega,\ R_9 = 20\ k\Omega$

$DC_{bias} = V_s = 5$ :

Rest: $V_{out} = (5)\left[\frac{(120*120)-(120*120)}{(120+120)(120+120)}\right]\left[\frac{1\ M}{100\ k}\right]\left[\frac{(1+20)\ k}{1\ k}\right] = 0\ V$

Compressive: $V_{out} = (5)\left[\frac{(120*(120-1))-(120*120)}{(120+120)(120+120)}\right]\left[\frac{1\ M}{100\ k}\right]\left[\frac{(1+20)\ k}{1\ k}\right] = -0.4375\ V$

Tensile: $V_{out} = (5)\left[\frac{(120*(120+1))-(120*120)}{(120+120)(120+120)}\right]\left[\frac{1\ M}{100\ k}\right]\left[\frac{(1+20)\ k}{1\ k}\right] = +0.4375\ V$

7. (4 Points) Provide your snapshots of your oscilloscope traces (camera photo is OK) at rest and under tensile strains. Full credit will be given for a clean looking signal with a well labeled plot and a picture of a carefully constructed circuit with nice short wires and everything tight to the breadboard.

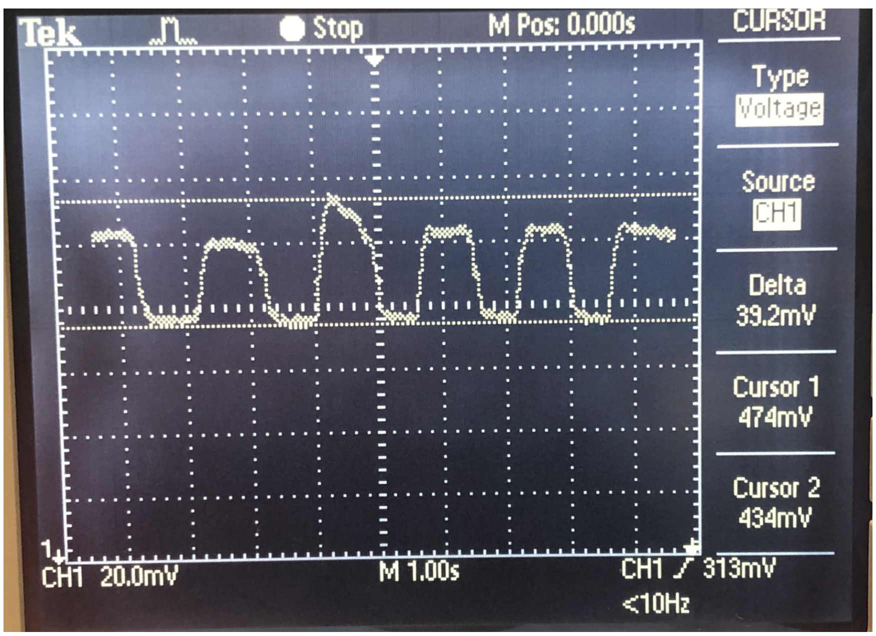



Figure 1) Strain Gauge under tensile strain

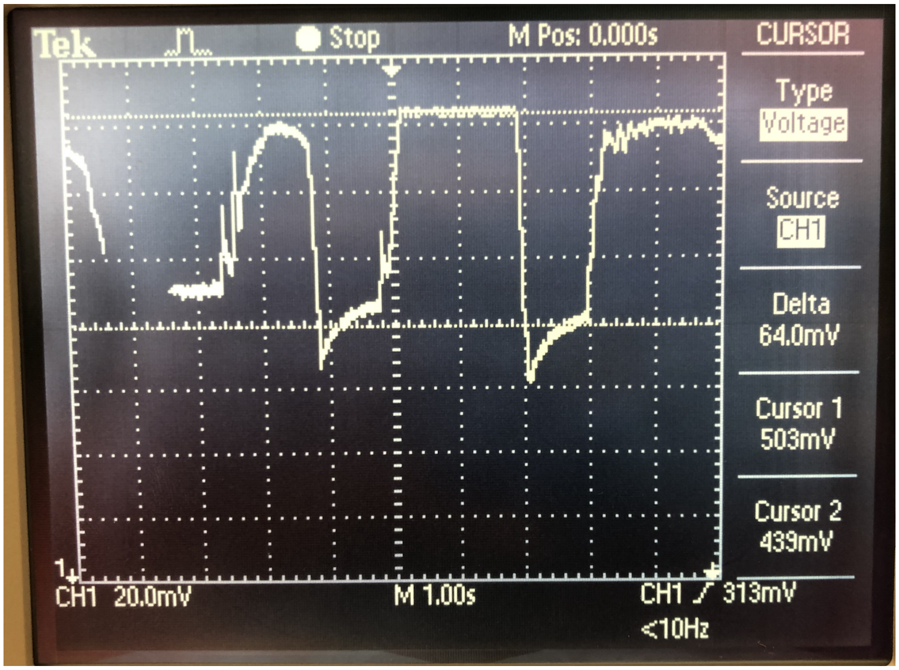


Figure 2) Strain Gauge under compressive strain

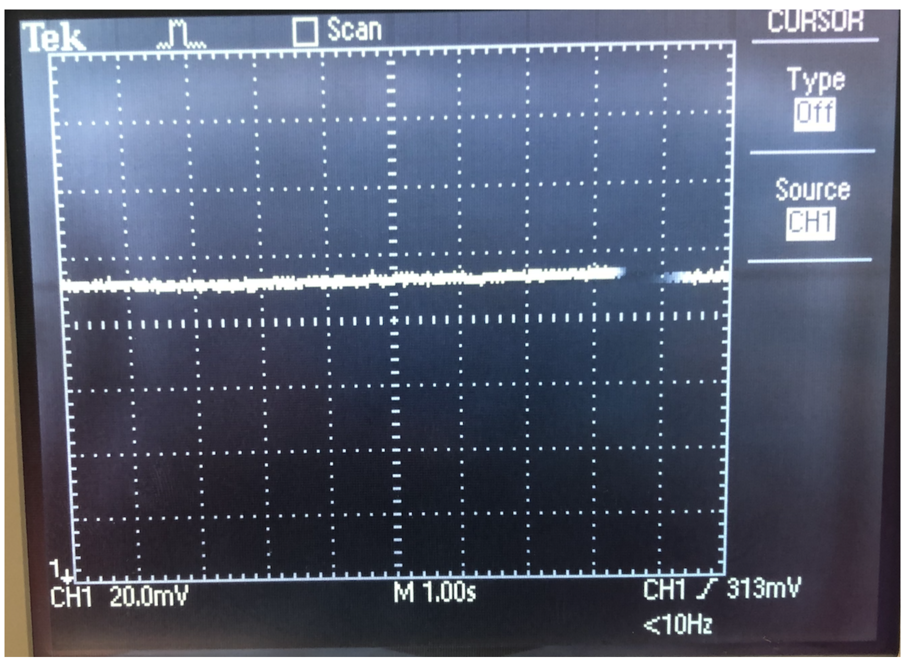


Figure 3) Strain Gauge at rest

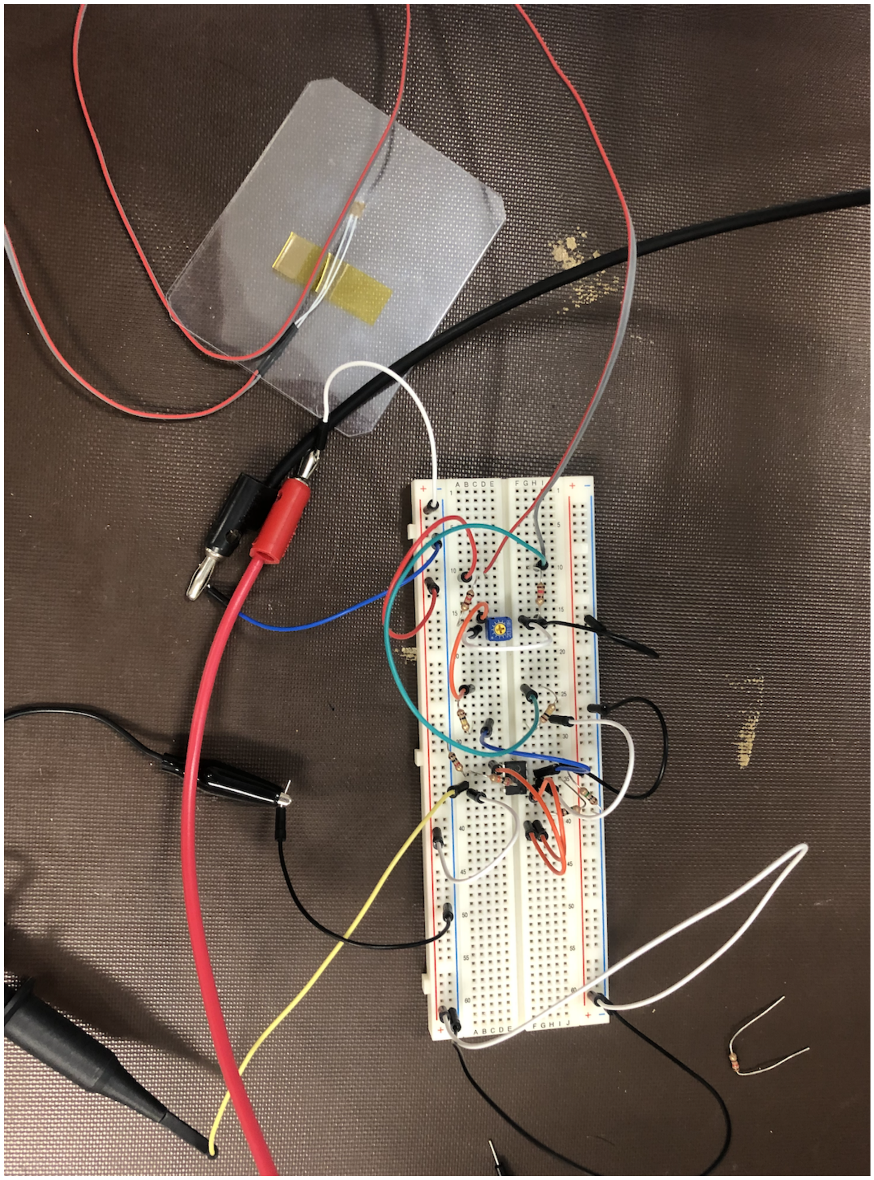


Figure 4) Strain Gauge circuit

# Lab 2: Electrocardiography (ECG/EKG)

1.(2 points) What are the reasons to use AD620 instrumentational amplifier instead of the circuit shown in Figure 3?

fewer circuit components (op-amps and resistors) -> less room for error in resistor tolerances

The instramentational amplifier in fig. 3 should act as a well balanced a diff-amp. The issue with getting this amplifier design to run correctly is it requires an extremely low offset voltage and very accurate resistor tolerance values. With slight changes in tolerance of the resisters you can see enough offset voltage enough to greatly affect the diff amp output. The AD620 bypasses a lot of these technical issues by being a very high accuracy instramentational amplifier, the resistor offsets are trimmed internally and so it makes for a very low noise, low input bias current amplifier suitable for picking up small biophysical signals that can normally be construed as noise.

2.. (5 points for circuit #1 + 3 points BONUS for circuit #2). Provide a picture of your obtained experimental ECG traces for circuit #1 and #2, separately. Compare two snapshots and interpret any possibly observed differences. Also provide a photo of your constructed circuits. Full credit will be given for a clean looking signal with a well labeled plot and a picture of a carefully constructed circuit.

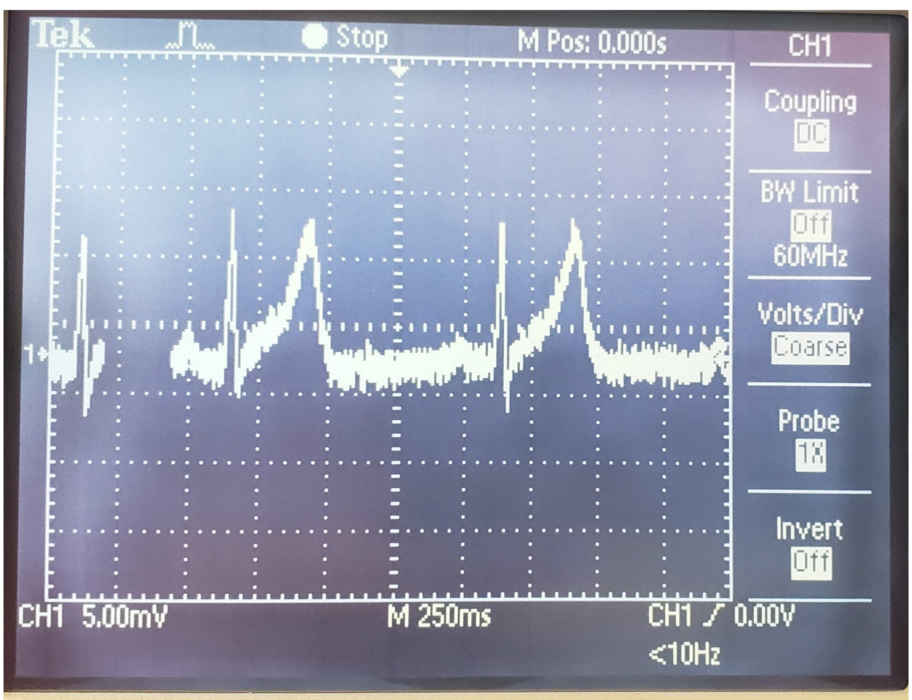


Figure 5) Circuit #1 ECG pulse signal

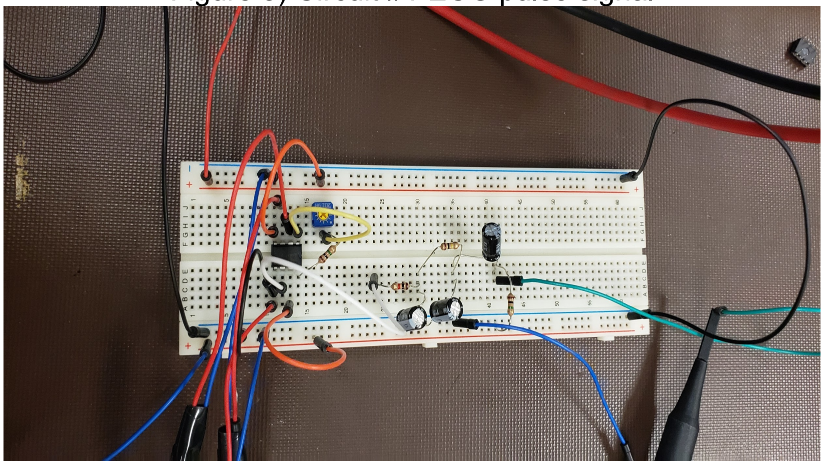


Figure 6) Constructed Circuit #1

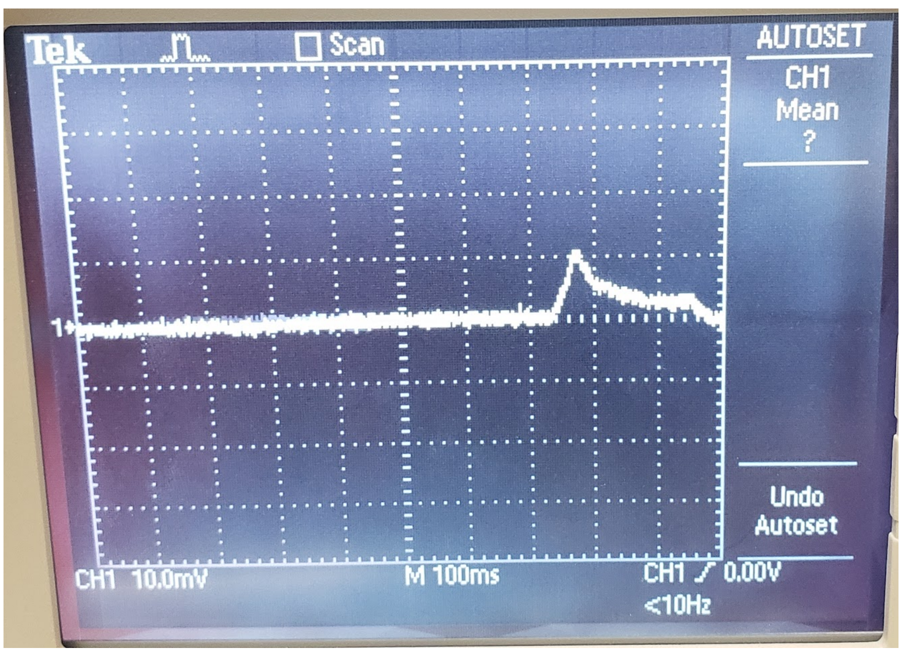



Figure 7) Circuit #2 ECG pulse signal (Attempt)

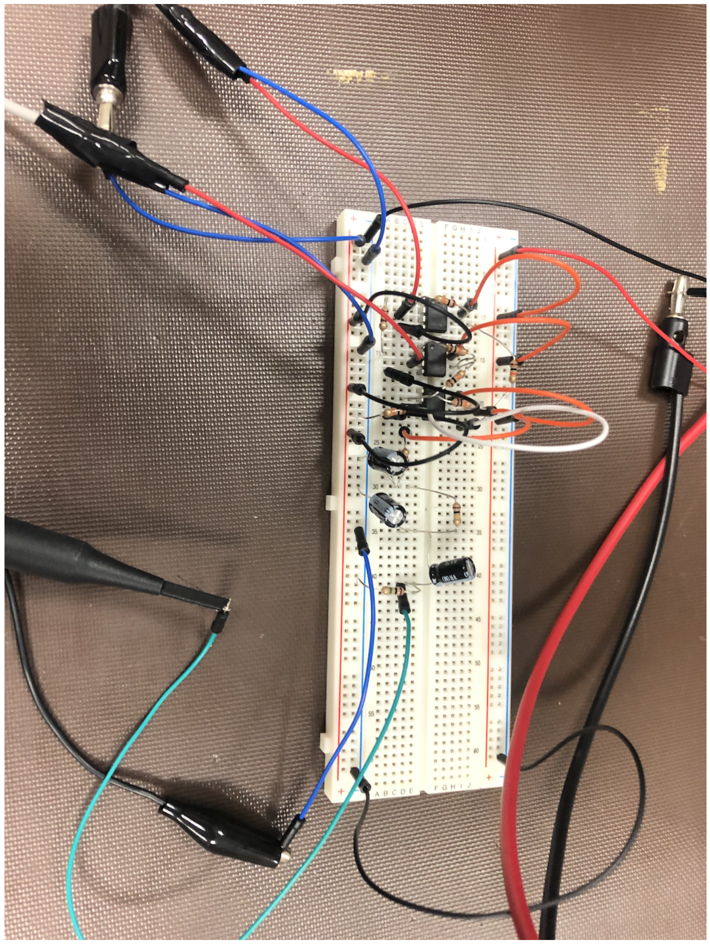


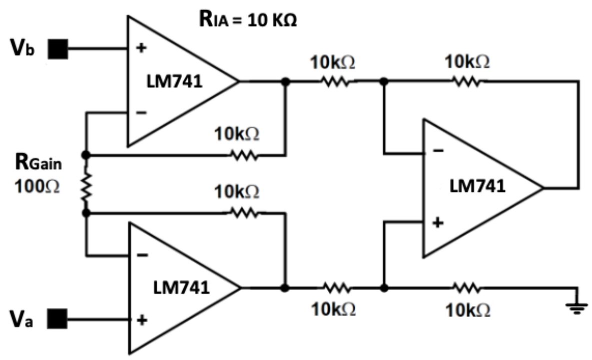
Figure 8) Constructed Circuit #2

3. (1 point) What happens if you bypass or remove the filters?

Low-pass filters in ECGs are used to eliminate muscle artifact and external interference readings which occur at high frequencies. High-pass filters remove motion artifact, respiratory variation and baseline wander occurring at low frequencies. If filters are removed the ECG will read a lot more noise which will make it more difficult to isolate the pulse we intend to get a reading on. You are dealing with such a small signal that any amount of noise can nearly always be picked up by mistake as a signal from the muscles. The filters are absolutely needed to ensure that the narrow voltage gain can be accurately read on the oscilloscope.

4. (4 points) Calculate the gain of the instrumentation amplifier shown in Figure 3.

output of op amp with input $V_b = V_1$
output of op amp with input $V_a = V_2$
inputs of final op amp $= V_+ = V_- = V_3$




1 - $\frac{V_1-V_b}{10k} = \frac{V_b-V_a}{R_{Gain}} = \frac{V_a-V_2}{10k}$
2 - $\frac{V_2-V_3}{10k} = \frac{V_3-0}{10k}$
3 - $\frac{V_1-V_3}{10k} = \frac{V_3-V_o}{10k}$
4 - $V_o = \frac{-10k}{10k}V_1 + \left[1+\frac{-10k}{10k}\right]\left[\frac{10k}{10k+10k}\right]V_2$ (differential amplifier)

Using (1) – solve $V_1$ & $V_2$ to input into (4)

$$V_1 = \left(\frac{V_b-V_a}{R_{Gain}}\right)10k + V_b = V_b(1+\frac{10k}{100}) - V_a(\frac{10k}{100})$$

$$V_2 = -\left(\frac{V_b-V_a}{R_{Gain}}\right)10k + V_a$$

$$V_o = \frac{-10k}{10k}\left[\left(\frac{V_b-V_a}{R_{Gain}}\right)10k + V_b\right] - \left[1+\frac{-10k}{10k}\right]\left[\frac{10k}{10k+10k}\right]\left[\left(\frac{V_b-V_a}{R_{Gain}}\right)10k + V_a\right]$$

$$= \frac{-10k}{10k}\left[\left(\frac{V_b-V_a}{R_{Gain}}\right)10k + V_b\right] - [0]\left[\frac{10k}{10k+10k}\right]\left[\left(\frac{V_b-V_a}{R_{Gain}}\right)10k + V_a\right] \text{ , } (G_c = 0)$$

$$= \frac{-10k}{10k}\ [V_b(1+\frac{10k}{100}) - V_a(\frac{10k}{100})]$$

$$G_d E_d = G_d(V_a - V_b)$$

$V_o$=-$E_d[\frac{1+10k/10k}{1+10k/10k}(\frac{10k}{100}+0.5)+\frac{10k}{10k}(0.5+\frac{10k}{100})]$

$G_d$=201

# Biophysical Measurement and Instrumentation (ECE 405)

## Lab#1: Strain Gauge

## Due 10 Dec 2018 at 4pm

## One Report Per Person is Required

In this lab, you are proposed to design and build an op-amp amplifier circuit for a strain gauge. The strain gauge is a kind of sensor whose output resistance varies with applied force or strain on it and is used to measure the strain on an object. This sensor has a wide application in mechanical measurements such as the measurement of the deflection and displacement. As you know strain consists of tensile and compressive strains, distinguished by a positive or negative sign. The basic background about the strain gauge can be found in [1].

### The Schematic of the Strain Gauge Circuit:

To make an op-amp amplifier circuit for a strain gauge, first we make a Wheatstone bridge network using a strain gauge and three discrete resistors. This circuit is then connected to LMC6482 op-amp. Figure 1 shows the schematic of the sensor interface circuit which contains two amplifiers followed by a Wheatstone bridge network.

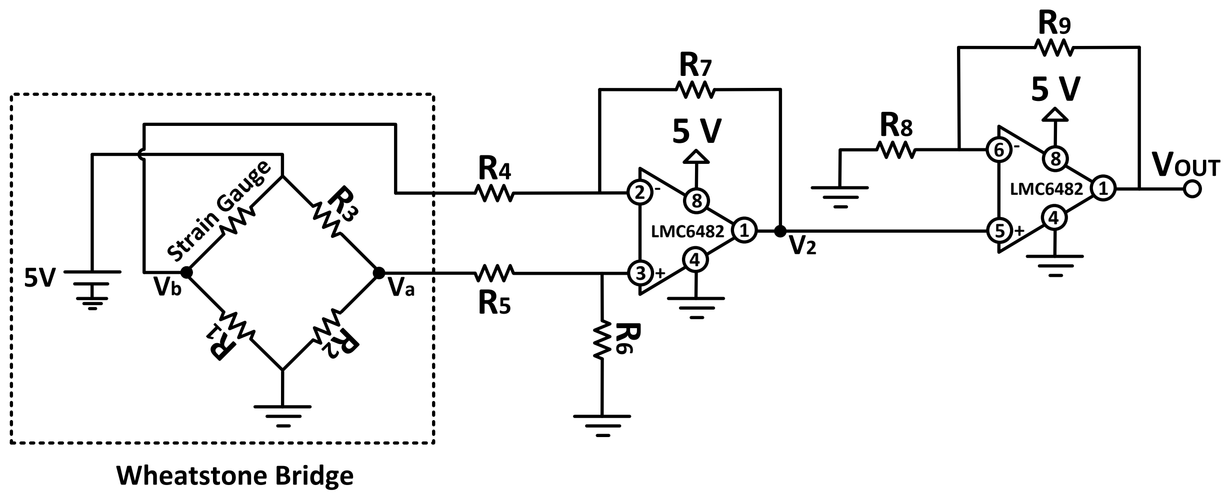



Fig. 1. Schematic of a strain gauge interface circuit.

By deflecting the strain gauge, the resistance across the sensor changes by a very small amount and causes a very small variation in $V_{ab}$. This voltage difference should be amplified in order to observe the effect of the strain on the sensor. Table I summarized the required components for building the strain gauge interface circuit.



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Electrical and Computer Engineering Department, University of Alberta, 2017

Table I. Required components for making the strain gauge interface circuit.

| Case | Component | Value | Case | Component | Value |
|---|---|---|---|---|---|
| 1 | strain gauge | NA | 7 | Resistor ($R_5$) | 100 KΩ |
| 2 | Operational Amplifier | LMC6482 | 8 | Resistor ($R_6$) | 1 MΩ |
| 3 | Resistor ($R_1$) | 120 Ω | 9 | Resistor ($R_7$) | 1 MΩ |
| 4 | Resistor ($R_2$) | 120 Ω | 10 | Resistor ($R_8$) | 1 KΩ |
| 5 | Resistor ($R_3$) | 120 Ω | 11 | Resistor ($R_9$) | 20 KΩ |
| 6 | Resistor ($R_4$) | 100 KΩ | 12 | DC Bias | 5 V |

The provided interface circuit in Figure 1, can be built with only one LMC6482 op-amp because it contains two separated amplifiers which can be connected in series to obtain more gains. LMC6482 op-amp has a good CMRR (common mode rejection ratio), ultralow input current and high voltage gains. Moreover, it can be used for applications such as data acquisition systems, transducer amplifiers, medical instrumentation and etc. The full datasheet of LMC6482 can be found in [4]. For convenience, the connection diagram of the LMC6482 amplifier is shown in Figure 2.

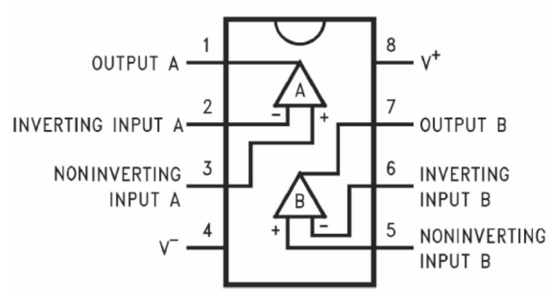


Fig.2. Connection diagram of the LMC6482 operational amplifier.

## Testing the Strain Gauge Circuit:

After building the circuit using Figure 1 on the breadboard, connect the output of the circuit to the oscilloscope. Try to adjust the signal level at X-axis of the oscilloscope so that you can see the voltage variations after applying strain on the sensor. Try to see the effect of tensile and compressive strain on the sensor. You will need to include clean snapshots of your results under



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tensile and compressive strains in your lab report. So, make sure that you saved your results before leaving your desk. You will also need a photo of your working circuit on the breadboard.

## Grading (Attendance: 50%, Lab Report: 50%):

1. (2 Points) What types of amplifiers are used in interface circuit shown in Figure 1?
2. (5 Points) Derive a gain expression for each amplification stage. Then, calculate the gain values for each stage. What is the total gain of the circuit?
3. (2 Points) Measure the resistance of the strain gauge at rest and report it. Manually pull or bend the strain gage and report the new value (different groups may get different results). Your result should not be saturated.
4. (2 Points) What is the relationship between the $\mathrm{R}_{strain}$ and $V_{ab}$?
5. (2 Points) Provide an expression which relates the $V_{OUT}$ to $\mathrm{R}_{strain}$?
6. (3 Points) Assume that the resistance of the strain gauge at rest position is 120 Ω and it shows ±1 Ω variation under tensile and compressive strain. Calculate the theoretical $V_{OUT}$ for the three states including rest, compressive- and tensile strain.
7. (4 Points) Provide your snapshots of your oscilloscope traces (camera photo is OK) at rest and under tensile strains. Full credit will be given for a clean looking signal with a well labeled plot and a picture of a carefully constructed circuit with nice short wires and everything tight to the breadboard.

References:

[1] https://en.wikipedia.org/wiki/Strain_gauge.

[2] http://www.ti.com/general/docs/lit/getliterature.tsp?genericPartNumber=lmc6482&fileType=pdf.

[3] https://inst.eecs.berkeley.edu/~ee100/archives.html.



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# Biophysical Measurement and Instrumentation (ECE 405)

# Lab#2: Electrocardiography (ECG/EKG)

# Due 9 Dec 2019 at 4pm

# One Report Per Group is Required

In this lab, you will design a fully-operational 3-wire electrocardiography (ECG) instrument. These 3-wires are connected to both elbow joints and one of the ankles. The basic background about the ECG can be found in [1]. Please consider that WE ARE NOT ECG EXPERTS OR DOCTORS, hence do not try to interpret anything from your ECG signals other than possibly your heart rate.

## The Schematic of the ECG Circuit:

We will design two quite simple ECG circuits. First, we will use an 8-lead low-cost and low-power instrumentational amplifier [3] which is designed and built as a single IC chip for applications such as weigh scales, ECG and medical instrumentation, transducer interface, data acquisition systems, industrial process controls and battery-powered and portable equipment. In next step (BONUS), we will design and make our own instrumentation amplifier using three LM741 op-amps.

### A) ECG Circuit #1:

Figure 1 shows the entire schematic of a 3-wires ECG circuit using AD620 instrumentational amplifier. The circuit consists of ECG probe connectors, an instrumentational amplifier which is followed by two low-pass (LP) and one high-pass (HP) filters. Finally, the last stage of the circuit consists of another amplifier. Since people have various voltage differences between their arms, two stage of amplification can make the circuit flexible to adjust the total gain of the ECG circuit and avoid the amplifier to enter the saturation mode. Table I summarized the required components for building the first ECG circuit.

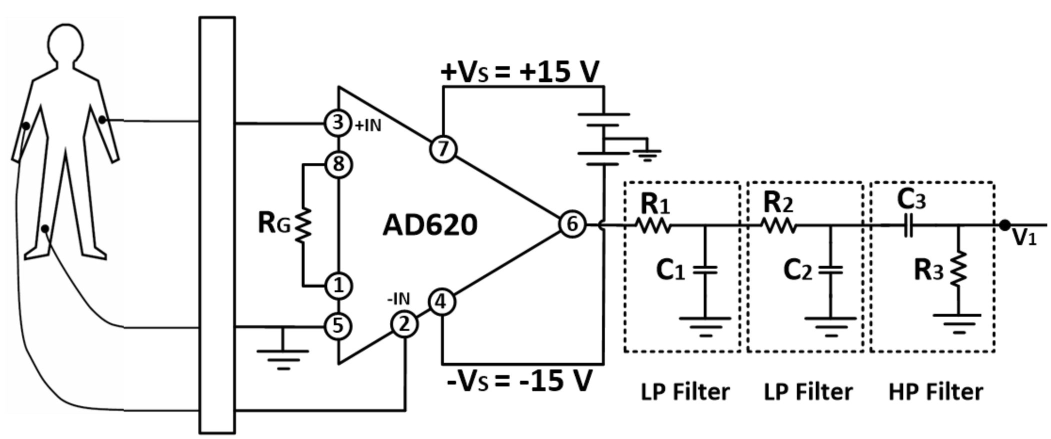


Fig. 1. Schematic of a fully operational 3-wires electrocardiography (ECG) instrument.



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Table I. Required components for making the ECG circuit.

| Case | Component | Value | Case | Component | Value |
|---|---|---|---|---|---|
| 1 | Three ECG probes | NA | 7 | Resistor ($R_3$) | 1 MΩ |
| 2 | Instrumentational Amplifier | AD620 | 8 | Capacitor ($C_1$) | 1 µF |
| 3 | Operational Amplifier | LMC6484 | 9 | Capacitor ($C_2$) | 0.1 µF |
| 4 | Resistor/Potentiometer ($R_G$) | 0-1 KΩ | 10 | Capacitor ($C_3$) | 1 µF |
| 5 | Resistor ($R_1$) | 10 KΩ | 11 | | |
| 6 | Resistor ($R_2$) | 100 KΩ | 12 | | |

## AD620 Instrumentational Amplifier:

The AD620 is a low-cost, low-power and high accurate instrumentational amplifier that requires only one external resistor ($R_G$) between its 1 and 8 pins to adjust gains of 1 to 10,000. This amplifier is made by Analog Devices and really suitable for this project because it is easy to use, it has excellent DC performance, low noise and excellent AC specifications. The full datasheet of AD620 can be found in [4]. For convenience, the connection diagram of the AD620 amplifier is shown in Figure 2.

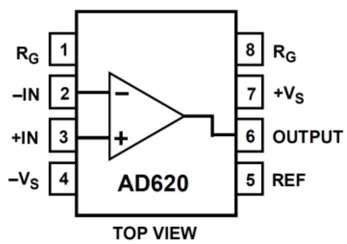


Fig.2. Connection diagram of the AD620 instrumentational amplifier.

The gain of the single IC chip can be simply adjusted by placing an external resistor between pins 1 and 8. According to device datasheet, the gain resistor, $R_G$, is related to the amplifier gain, $G$, through the following expression

$$R_G = 49.4k\Omega/(G-1)$$

and the chip produces an output voltage on pin 6 through

$$V_{OUT} = G(V_{+IN} - V_{-IN}) + V_{REF}$$

where $V_{REF}$ is the reference voltage applied to pin 5. If there is no difference between input signals applied to pins 2 and 3, the output pin will be equal to the reference voltage.

### B) ECG Circuit #2 (BONUS):

In this part of the lab, we rebuild the ECG circuit by making an instrumentational amplifier using three op-amps and seven external resistors (Figure 3) and then replacing it with AD620 amplifier. The biasing of the circuit is exactly the same as the ECG circuit #1 between the pins 7 and 4 of IC LM741. For convenience, the connection diagram of the LM741 amplifier is shown in Figure 3 (right).

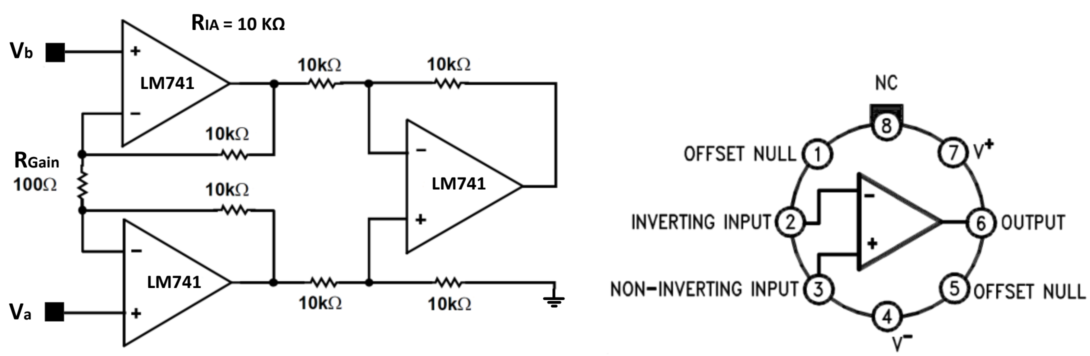


Fig. 3. (Left) A custom instrumentational Amplifier using three op-amps and external resistors. (Right) Connection diagram of the LM741 operational amplifier.

## Risks

You will have the option of measuring ECG signals from yourself or your lab group members. There could be some remote risks of minor electrical shock if there are problems with your design. Before attempting any human subject measurements on yourselves or your classmates, or to be measured, you must sign your informed consent to participate below. By signing below you understand and agree to the following:

-Submitted human subject data should be treated as confidential and will be treated as confidential by instructors and not be used for medical purposes

-Your circuit should be checked by an instructor before measuring signals from any participant

-Participation is voluntary. You may withdraw from the study at any time.

-Questions can be addressed to Dr. Roger Zemp at rzemp@ualberta.ca

-You will hold harmless and indemnify course instructors and teaching assistants as well as the University of Alberta for any adverse consequences of participation.

## Consent Statement

I have read the above and the lab study has been explained to me. I have been given the opportunity to ask questions and my questions have been answered. If I have additional questions, I have been told whom to contact. I agree to participate in the research study described above and will receive a copy of this consent form if requested after I sign it.

____________________________________________ _______________

Participant's Name (printed) and Signature Date

____________________________________________ _______________

Name (printed) and Signature of Person Obtaining Consent Date

## Testing the ECG Circuits:

We will test both of the ECG circuits and then record the ECG traces separately.

The circuit is connected using three adhesive electrode pads to the patient before applying the power supply of the circuit. Two of the pads are placed inside of your elbow and the third one should be placed on your ankle. The other side of the electrodes are connected to the ECG circuit as shown previously. Please notice that your ankle is connected to the common ground of the circuit. Then, the output of the circuit goes to the oscilloscope to observe the ECG trace. Now, turn the power supply on and try to show the ECG signals on the oscilloscope. Repeat the experiment using the ECG circuit #2 and record your results.

You will need to include a clean ECG snapshot in your lab report without identifying the patients. So, make sure that you saved your results before leaving your desk. You will also need a photo of your working circuit on the breadboard.

## Grading:

1. (2 points) What are the reasons to use AD620 instrumentational amplifier instead of the circuit shown in Figure 3?
2. (5 points for circuit #1 + 3 points BONUS for circuit #2). Provide a picture of your obtained experimental ECG traces for circuit #1 and #2, separately. Compare two snapshots and interpret any possibly observed differences. Also provide a photo of your constructed circuits. Full credit will be given for a clean looking signal with a well labeled plot and a picture of a carefully constructed circuit.
3. (1 point) What happens if you bypass or remove the filters?
4. (4 points) Calculate the gain of the instrumentation amplifier shown in Figure 3.

References:

[1] https://en.wikipedia.org/wiki/Electrocardiography.

[2] http://rwm.olin.edu/index.shtml.

[3] https://en.wikipedia.org/wiki/Instrumentation_amplifier.

[4] www.analog.com/media/en/technical-documentation/data-sheets/AD620.pdf

[5] http://rwm.olin.edu/index.shtml.



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