Laboratory Project 1b: Electromyogram Circuit

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***Abstract*-You will build an electromyogram circuit consisting of electrodes, pre-amps, and a differential amplifier. After designing, constructing, and testing the circuit, you will connect electrodes to your biceps muscle and measure the small voltages generated by the activity of neurons terminating on muscle fibers. By recording these signals on an oscilloscope, you will create electromyograms that you will analyze to determine the rate of neural activity associated with lifting various weights.**

I. Preparation

For Lab 1b, which will last about four weeks, you will need the parts listed in Table I, (in addition to the parts from Lab 1a). You may purchase these parts from the stockroom next to the lab or purchase them elsewhere.

TABLE I
PARTS LIST FOR LAB 1B

Item	Qnty	Description
1	4	Resistors (values determined during lab)
2	2	LF353 Operational Amplifier
3	1	10 Ω Resistor
4	1	1 kΩ Resistor
5	1	1 MΩ Resistor
6	1	1 0.1 μF Capacitor
7	3	Electrodes

II. Learning Objectives

1) Learn about voltage dividers and understand why pre-amps are necessary to increase current drive of weak signals from electrodes.
2) Learn how to derive equations for op-amp circuits, such as pre-amps and a differential amplifier, using Kirchhoff's and Ohm's laws.
3) Understand how to design a differential amplifier to meet practical constraints.
4) Determine the relationship between neuromuscular activity and force applied by a muscle by measuring electromyograms.

III. Introduction

A. Overview

In Lab 1b you will build an amplifier circuit to measure electromyograms (EMG's) and view them on an oscilloscope. The EMG will be a plot showing the tiny voltages produced by your biceps muscle and picked up by electrodes, as shown in Fig. 1. You will attach the electrodes to your arm, and they will feed into pre-amp circuits that output the same voltage as is present on the electrode but with a higher current-drive capability. You will explore why this is necessary in the first part of this lab. After building and testing the pre-amps, you will add a differential amplifier to complete EMG circuit. You will measure EMG's while lifting different amounts of weight and complete a simple study of how weight affects the measured EMG signal.

B. Electromyograms

EMG studies in general are useful for assessing the health of the neuromuscular system, since certain diseases, such as multiple sclerosis, slow down or even suppress normal nerve and muscle firing. In addition, several research groups have recently studied the possibility of using EMG signals to control artificial limbs for patients who have lost an extremity; the EMG signal would be obtained from a surviving portion of the limb and would represent the patient's central nervous system's desire to move the limb in a certain direction with a certain force.

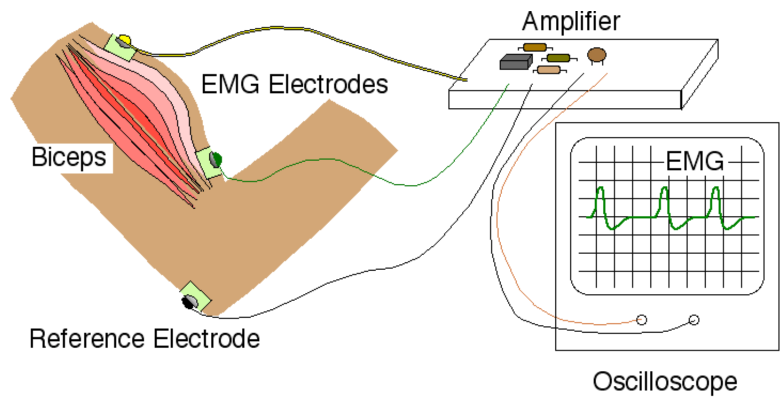


Figure 1. System for measuring an electromyogram.

C. Op-Amps

In Lab 1b, you will build and test amplifier circuits based on an op-amp (short for operational amplifier) integrated circuit (IC or "chip"). The op-amp IC comes in a small black plastic package with 8 pins. Inside the package are many transistors, which you will learn about in later courses. For Lab 1b, we may treat the op-amp as a basic circuit component whose function is to measure a voltage drop at its inputs and output a voltage that is about 100,000 (or 100k) times the input voltage drop. Fig. 2, below, illustrates the op-amp as it appears in a circuit diagram and how it is connected to the pins on the package. Note that the op-amp IC actually contains two op-amps, allowing us to build two amplifier circuits with one chip. Although we will omit the details of the circuitry inside the op-amp, (because it is beyond the score of the course), you may find this information by searching for "National LF353 data sheet" on the web.

Just as cell phones and mp3 players require batteries, an op-amp requires power supplies. We connect +9V and –9V to the pins labeled V+ (pin 8) and V– (pin 4), respectively. Power supplies in the lab can produce these voltages, allowing us to avoid wasting batteries.

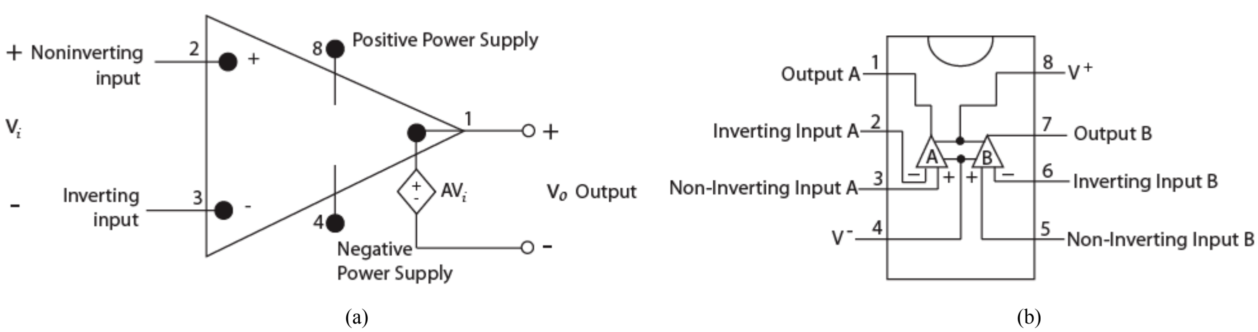


Figure 2. LF353 operational amplifier: (a) Model, (b) Pins on package.

D. Design Project Overview

You will complete the design and construction of an EMG circuit that receives input from three electrodes: two neighboring electrodes placed on the biceps of the upper arm, plus one reference electrode placed on the elbow. The objective of the circuit is to measure the small voltage drop between the electrodes on the biceps caused by neuromuscular activity. It turns out that a differential amplifier is useful for amplifying small voltage drops.

The power in the signals picked up by the electrodes, however, is minute. Attaching the electrodes directly to a differential amplifier would draw too much current from the electrodes, causing their voltage to drop to almost zero. Consequently, we use pre-amps to create higher-power signals. The pre-amps can output higher current at the same voltage as the electrodes while drawing virtually zero current. The outputs of the pre-amps can then drive a differential amplifier.

Fig. 3 shows a block diagram of the EMG circuit with the pre-amps and differential amplifier that you will build in this lab. You will connect the output voltage, v_3, to an oscilloscope to record an EMG.

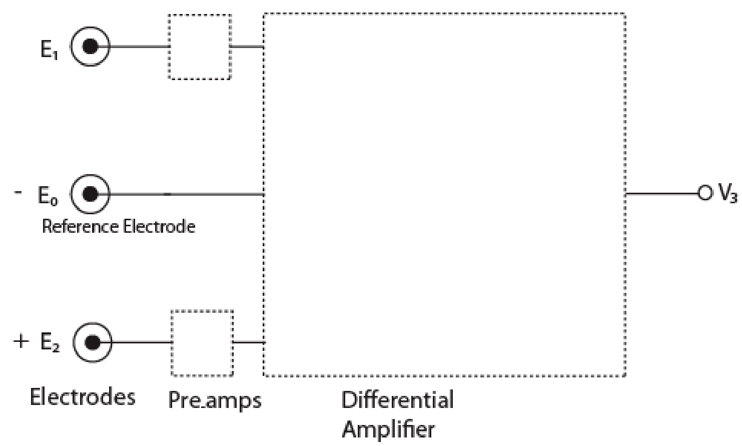


Figure 3. Block diagram of electromyogram circuit.

IV. Modeling Electrodes With and Without Pre-amps

A. Overview

In this part of the lab, you will demonstrate that using the electrodes to directly drive the differential amplifier would result in signals too small to be accurately measured. This scenario is similar to considering what would happen if we tried to use a 12V camera battery instead of a 12V car battery to start a car: the smaller battery would be unable to supply enough current to the starter motor, and the output voltage of the small battery would drop to almost 0V. You will also show that a solution to this dilemma is to use a pre-amp that reproduces the electrode voltage but with higher current drive capability.

B. Model of Electrode Driving Differential Amplifier Without Pre-amp

Each electrode is a metal pad with conductive gel that contacts the skin to pick up voltages on the order of 90 mV, (only a fraction of which is detected by the finite-sized electrode), generated by neuromuscular activity. The voltage sources are inside muscles, well below the skin and so are separated from the skin by the resistance of the muscle, other tissues, and skin. The resistance of the skin, being dry on the surface, is quite high. An approximate model of the resistance is a 1 MΩ resistor. Thus, we may model an electrode (and muscle) as a voltage source in series with a 1 MΩ resistor.

It would be convenient if we could connect electrodes directly to a differential amplifier that would magnify the voltage drop between electrodes. We now explore what would happen if we tried to do this.

It would be convenient if we could connect electrodes directly to a differential amplifier that would magnify the voltage drop between electrodes. We may model what would happen in such a situation by treating the input to the differential amplifier as approximately a 1 kΩ resistor. This value is obtained by dividing the voltage at the input of the differential amplifier by the current that flows into the differential amplifier. In other words, we use Ohm's law. Attaching this resistor to the electrode model yields the circuit, shown in Fig. 4, that we will use to simulate the electrode driving the differential amplifier directly.

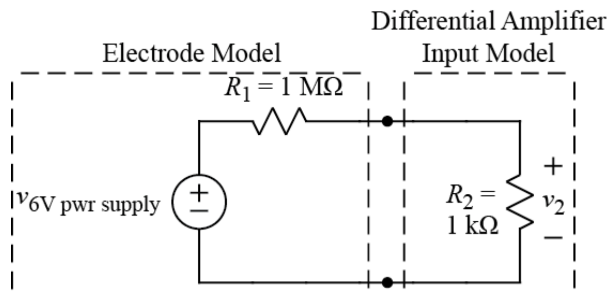


Figure 4. Circuit model of an electrode driving differential amplifier: schematic.

C. Procedure

1) Build the circuit shown in Fig. 5. In place of the electrode, use the 6V power supply, which is part of the same power supply used to power the LED's. (The 6V power supply is the third of three voltage sources in the power supply. To see its value it, press the 6V button on the front of the power supply. Use the gray knob to adjust its value. The 6V outputs are the two leftmost banana plugs on the front panel of the power supply.) Use long wires coming off the breadboard and banana-to-alligator clips to connect to the 6V power supply.

2) Adjust the 6V power supply to the values shown in Table II and use the multimeter probes to measure the voltage drop across R_2. (Use the DCV button on the multimeter so the meter is reading voltage.) Record the measured voltage drops across R_2 in the second column of Table II. When you have completed the second column of Table II,

3) Use the voltage-divider formula from class to fill in the third column of Table II in your laboratory notebook. Be sure to record what you are doing, including the voltage-divider formula, in your notebook.

TABLE II

MODEL OF ELECTRODE DRIVING DIFFERENTIAL AMPLIFIER

Power Supply Voltage	measured R_2 Voltage	calculated R_2 Voltage
0 V		
2 V		
4 V		
6 V		

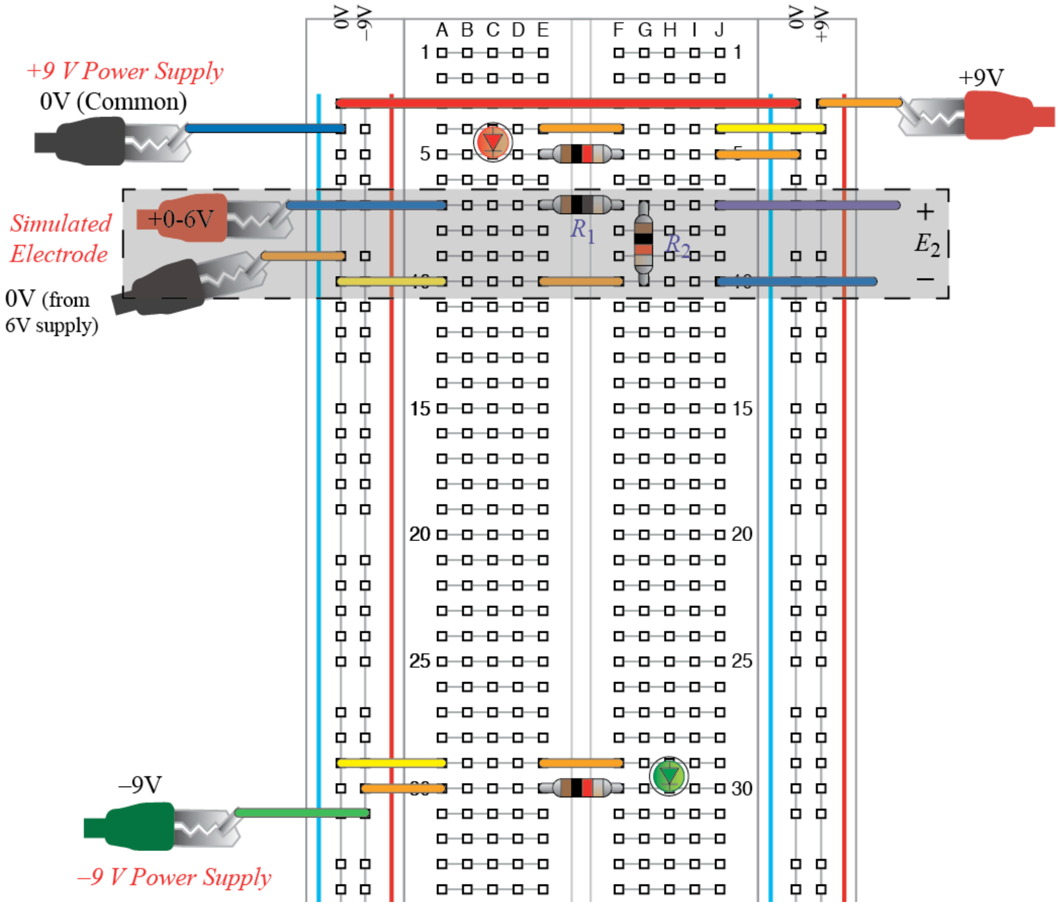


Figure 5. Circuit model of an electrode driving differential amplifier: breadboard layout.

4) Repeat the above process using the circuit shown in Figs. 6 and 7, and fill out Table III in your laboratory notebook. In this circuit, the 6V power supply and the 10 Ω resistor simulate the output of a pre-amp that is between an electrode and a differential amplifier. As before, R_2 simulates the input of the differential amplifier.

TABLE III
MODEL OF PRE-AMP DRIVING DIFFERENTIAL AMPLIFIER

Power Supply Voltage	measured R_2 Voltage	calculated R_2 Voltage
0 V		
2 V		
4 V		
6 V		

5) When you have filled out Tables II and III, determine which circuit gives an output that is closer to the value of the input voltage from the 6V power supply. That is, comment on which circuit more faithfully preserves the input voltage representing the voltage picked up by an electrode.

6) Comment in your lab notebook on the results and explain why the pre-amps are needed in the EMG circuit. Note that, when used for an actual EMG, the input signal to the circuit will only be a few millivolts instead of the higher values used here. If the signals get much smaller, they sink below the measurement noise.

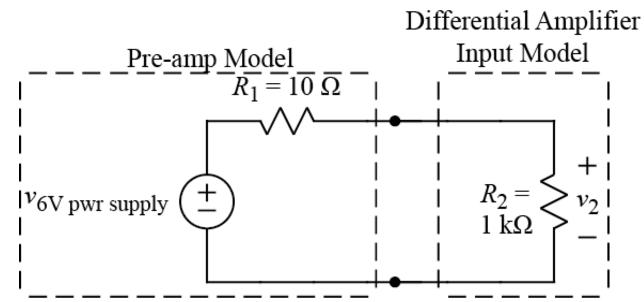


Figure 6. Circuit model of a pre-amp driving differential amplifier: schematic.

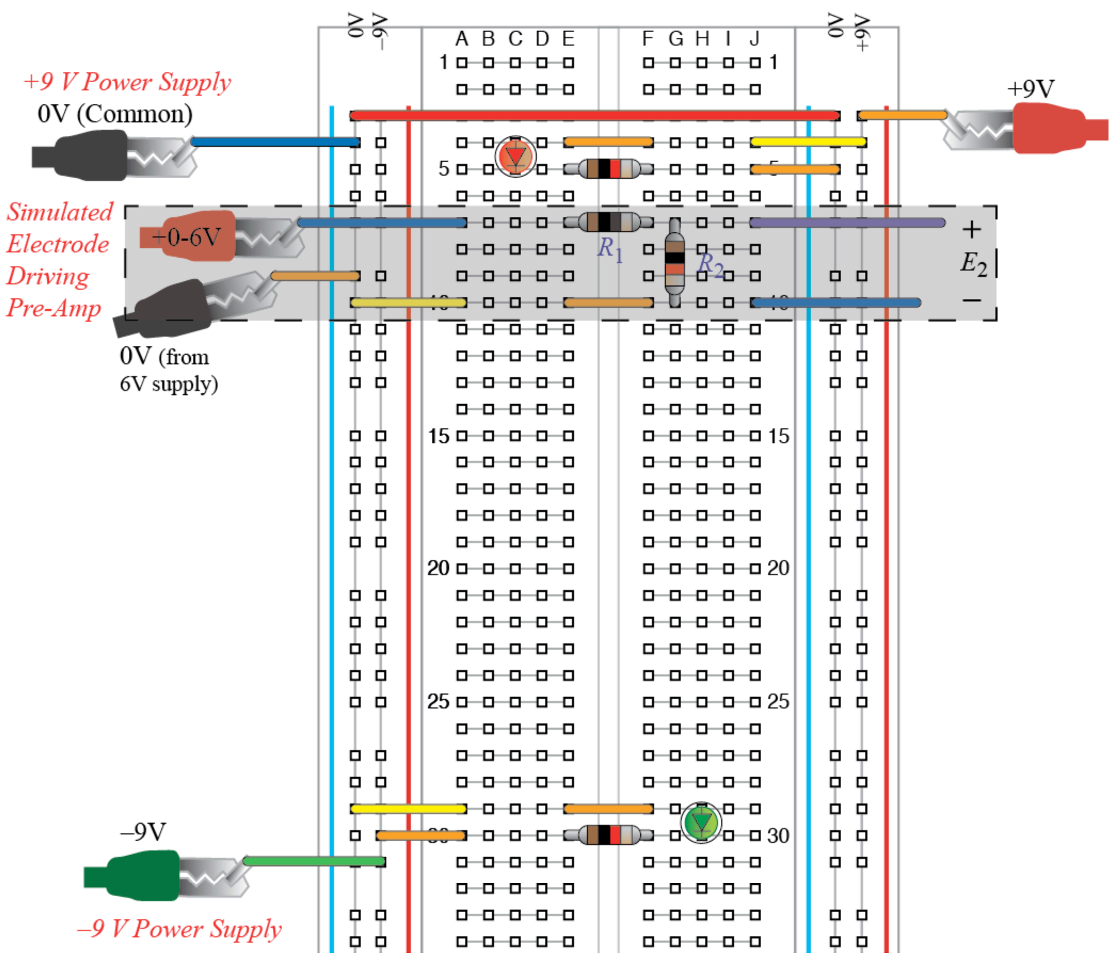


Figure 7. Circuit model of a pre-amp driving differential amplifier: breadboard layout.

V. Construction and Testing of Pre-Amps

A. Overview

In this part of the lab, you will build and test the pre-amp circuits. Fig. 8 shows a schematic diagram of the pre-amp circuits that the models in the previous section simulated. The pre-amps draw very little current from the electrodes and output the same voltage as the electrodes but with a much higher ability to supply current. As shown in the previous section, the output voltage of the pre-amp is largely immune to loading effects resulting from driving a differential amplifier. Thus, the pre-amps allow us to build a working EMG circuit.

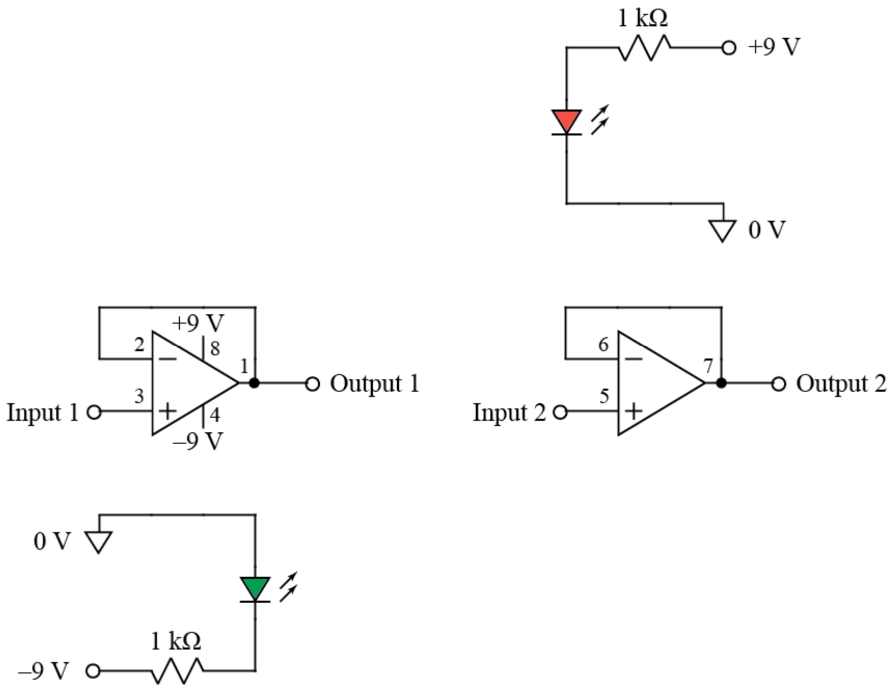


Figure 8. Pre-amp circuits: schematic. (LED power indicators also shown.)

B. Explanation of Pre-Amp Circuit

The pre-amps have negative feedback, which means the output signals are connected back to an input that in turn affects the output. The result is that, if there were a significant voltage drop across the + and – inputs, the output signal of the op-amp would try to become extremely large, (because the op-amp outputs a voltage that is about 100,000 times the voltage drop across the + and – inputs). If the output of the op-amp began to rise, however, the voltage at the – input would become more positive, which would reduce the voltage drop across the + and – inputs. That, in turn would reduce the output voltage. Following this logic around the loop again and again, we would find that the circuit would eventually reach an equilibrium with a very small voltage drop across the + and – inputs, meaning the output voltage must be nearly equal to the input voltage.

B. Procedure

1) Using the diagram in Fig. 9, construct the two pre-amp circuits whose schematic diagram is shown in Fig. 8. The LF353 is an op-amp IC that you may purchase in the stockroom (or elsewhere). Note that all points in the circuit marked with a triangle, meaning they are at 0V, are connected together. Note also that there are two very short vertical wires near the op-amp chip. These wires connect the outputs of the op-amps back to the – inputs of the op-amps.

2) Test the op-amp circuit using a function generator and an oscilloscope. Fig. 10 shows how to connect leads to the function generator and oscilloscope in preparation for making measurements. After making the connections shown in Fig. 10, connect all the black leads to 0V, which is running all the way down the leftmost column of the breadboard. Add wires for connections as needed. Connect the function generator output (red alligator clip) to “Input 1” on the breadboard. Also, connect the red alligator clip for input 1 on the oscilloscope to “Input 1” on the breadboard. Input 1 of the oscilloscope will show the waveform from the function generator. Connect the red alligator clip for input 2 on the oscilloscope to "Output 1" on the breadboard. Input 2 of the oscilloscope will show the waveform coming out of the pre-amp.

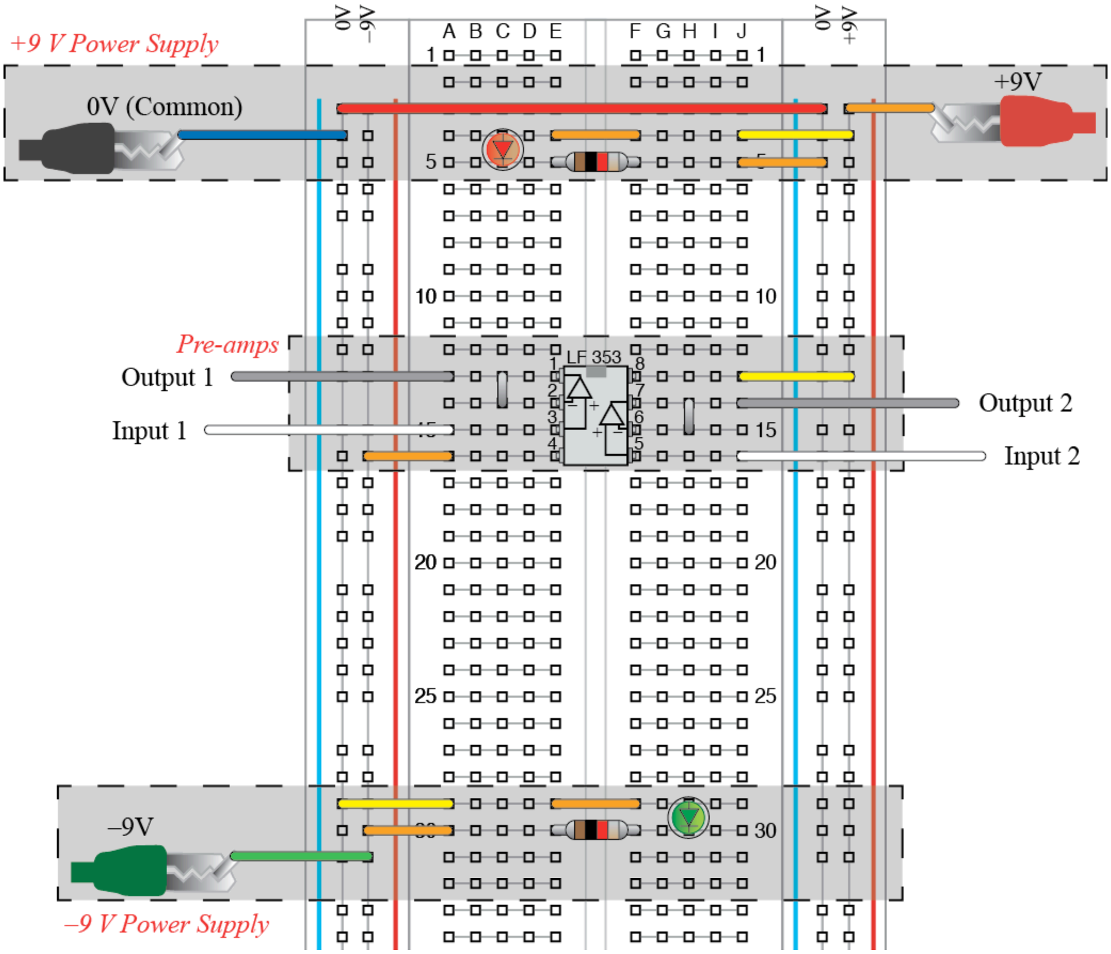


Figure 9. Pre-amp circuits: breadboard layout.

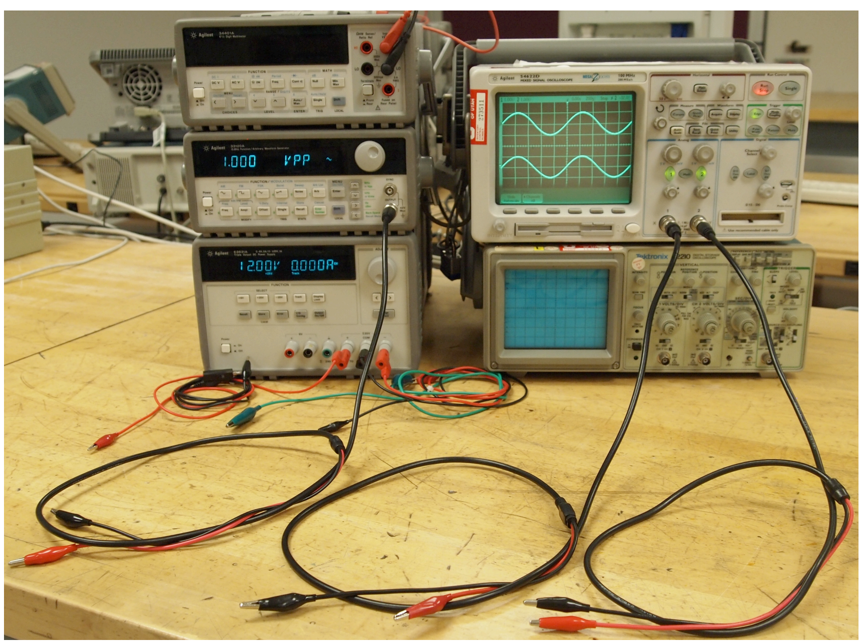


Figure 10. Waveform generator and oscilloscope connections.

3) Turn on the function generator and oscilloscope and use the Ampl *button on the waveform generator and the knob and* < *and* > *buttons to change the output voltage to 1V.* Then press the "Auto Scale" button on the oscilloscope to see the waveform. If all goes well, you will see a two sinusoids that are the same size.

4) Make a careful drawing of the oscilloscope screen, showing the scale for the horizontal axis (time) and the vertical axis (voltage). The time and voltage represented by one box is displayed on oscilloscope screen. Be careful to include the value of each in your drawing.

VI. Deriving an Expression for the Differential Amplifier Output

A. Overview

In this part of the lab, you will use the voltage-divider formula to derive an expression for the output voltage of the differential amplifier circuit shown in Fig. 11. Note that the power supplies for the op-amp are omitted from the schematic, but there are positive and negative power supplies that supply current that flows into or out of the op-amp's output.

The differential amplifier magnifies the difference between the voltages coming out of the pre-amps. As was the case with the pre-amps, the differential amplifier has negative feedback that causes the voltage drop across the input of the op-amp to be very small. The output voltage that makes this happen is an amplified version of the voltage difference of the pre-amp outputs. You will show that the amplification is determined by resistor values.

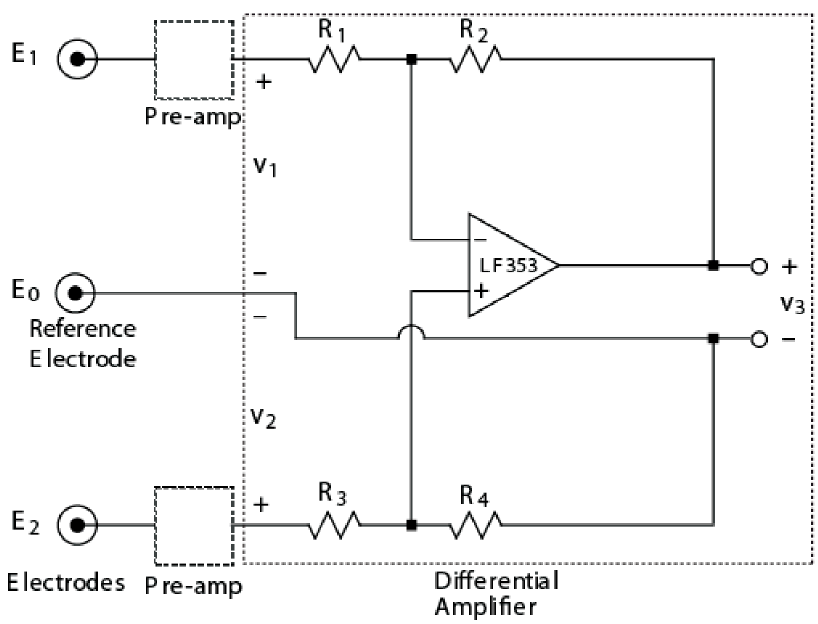


Figure 11. Schematic diagram of differential amplifier.

B. Differential Amplifier Analysis

When the output of an op-amp is connected back to the "–" input via a resistor, the op-amp output effectively adjusts to make the voltage drop across the + and – inputs zero. That is, with negative feedback, we may assume that the voltage drop across the + and – inputs is zero. Using this assumption, we can find an expression for the output voltage of the op-amp, (i.e., v_3), as a function of electrode voltages, v_1 and v_2. Thus, rather than modeling the op-amp as a dependent voltage source, we treat it as an independent but variable voltage source, and we determine how it must be adjusted to cause a zero volt drop across the + and – inputs.

The op-amp has a second convenient property: almost no current flows into the op-amp inputs. (Note that this applies only to the op-amp input, not the op-amp output). Because no current flows into the op-amp, we may think of the op-amp inputs and wires connected to them as equivalent to a voltmeter and probe wires.

Taking the above information into account, we may erase the op-amp and treat the inputs as a voltage measurement and the output as an independent source labeled v_3. Following this line of reasoning, our differential amplifier reduces to two simple circuits from which we may derive a formula for v_3 in terms of v_1 and v_2, as follows.

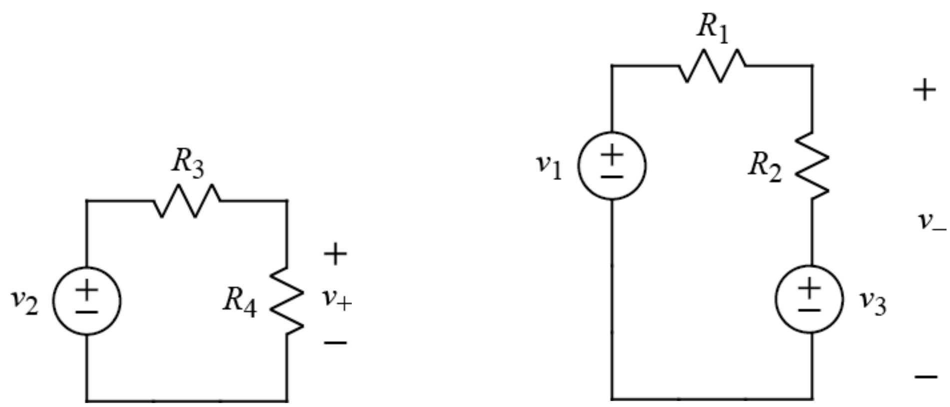
C. Procedure for Deriving Formula for v_3

1) Use the circuit model in Fig. 12 and the voltage-divider formula to find voltage drop v_+ *across* R_4.

2) Use the circuit model in Fig. 12 and Kirchhoff's and Ohm's law to find voltage drop v_- *across* R_2 *and* v_3. In other words, v_- is the sum of the voltage drops across R_2 and v_3.

3) Use a voltage loop to show that, if voltage drop across the + and – inputs equals 0 V, then $v_+ = v_-$.

4) Set $v_+ = v_-$ *and solve for* v_3 *in terms of* v_1 *and* v_2.



(a) (b)

Figure 12. Sub-circuits for analyzing differential amplifier: (a) v_+ value, (b) v_- value.

Armed with the expression for v_3, we can now show that the differential amplifier may be designed to amplify only the difference in voltages v_1 and v_2, thus reducing noise in the EMG measurements.

D. Differential and Common Mode Voltages

As you will discover when you build the differential amplifier, op-amps are less ideal that the models we use for them. One challenge with real op-amps is that they produce zero output when there is a small voltage drop called the "offset voltage" across the + and – inputs rather than when the voltage drop across the + and – inputs is exactly zero. The offset voltage is only a few millivolts, but it is amplified by the op-amp.

An offset voltage may also appear in the electrode voltages relative to the power supply of the differential amplifier. That is, the electrode voltages may float up or down together while maintaining the same voltage drop from one electrode to the other. If properly designed, the differential amplifier can eliminate this so called "common mode voltage" and amplify only the voltage drop or so called "differential mode voltage".

Adding a reference electrode connected to the common terminal of the power supply, (or the point between the two 9V batteries), helps to reduce the drift of the common mode voltage and creates a reference point for measuring electrode voltages. The electrode voltages, v_1 and v_2, are measured as voltage drops from electrodes on the bicep muscle to a reference electrode placed on the elbow.

The electrode voltages may be defined in terms of the common mode and differential mode voltages, and vice versa. The common mode voltage is defined as the voltage that is halfway between v_1 and v_2,

$$v_{\mathrm{cm}} \equiv \frac{(v_2 + v_1)}{2}, \tag{1}$$

and the differential mode voltage is the voltage drop across the electrodes on the biceps:

$$v_{\mathrm{dm}} \equiv v_2 - v_1 \tag{2}$$

Fig. 13 illustrates how the electrode voltages may now be defined as variations around the common mode voltage. The corresponding equations for the electrode voltages are as follows:

$$v_1 = v_{\mathrm{cm}} - \frac{v_{\mathrm{dm}}}{2} \tag{3}$$

$$v_2 = v_{\mathrm{cm}} + \frac{v_{\mathrm{dm}}}{2} \tag{4}$$

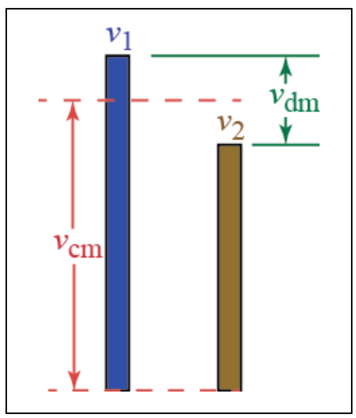


Figure 13. Electrode voltages represented in terms of common mode and differential mode voltages.

If we consider the sources that give rise to the electrode voltages, we will have neuromuscular activity and noise sources such as power lines, lights, motors, and wireless transmitters. The sun even creates electromagnetic disturbances, and there is more noise when there are more sunspots. Each source that contributes to the electrode voltages, affects both the common mode and differential mode voltages. The sources of noise external to the body, however, tend to affect both electrodes approximately the same amount, whereas at least some of neuromuscular activity (arising between the electrodes) will have a greater effect on the differential mode voltage. Thus, we design the differential amplifier to eliminate the common mode voltage and amplify the differential mode voltage.

The key to eliminating the differential mode voltage is making the ratio of resistor values R_1 to R_2 the same as R_3 to R_4. We define this ratio to be $\Re$:

$$\Re = \frac{R_1}{R_2} = \frac{R_3}{R_4} \tag{5}$$

You will now use this definition and constraint on resistor values to derive a formula for v_3 in terms of $\Re$.

E. Procedure for Deriving Formula for v_3 in terms of $\Re$

1) Write the formula for v_3 derived earlier in terms of $\Re$ as defined in (5). Note that it may be helpful to consider the reciprocals of expressions in order to express them in terms of $\Re$.

2) Rewrite the formula for v_3 in terms of the common-mode signal, v_{cm}, and the differential-mode signal, v_{dm}, defined in (1) and (2). In other words, substitute for v_1 and v_2 using (3) and (4).

3) Show that v_3 is a function of only v_{dm}. That is, show that v_{cm} disappears.

VII. Designing, Building, and Testing the Differential Amplifier

A. Procedure for Choosing Resistor Values for a Gain of 500

Now that you have derived the expression for v_3, you are ready to design the differential amplifier. That is, you are ready to find the values of R_1 through R_4. Having found those values, you will build the circuit. Keeping the preceding analysis in mind, design the differential amplifier for the electromyogram circuit to meet the following design objectives:

i) The differential gain of the circuit is to be 500. The differential gain is the term multiplying v_{dm} in the equation for v_3 derived above. This makes the output as large as possible without causing the output to "saturate" by reaching the op-amp power supply voltages. (The output is limited by the power-supply voltages, resulting in clipping distortion of the output waveform if the voltage reaches the level of the power supply.)

ii) The common mode gain of the circuit is to be zero.

iii) The input resistances, R_1 and R_3, are to be the same for both inputs. This will help cancel out less than ideal output characteristics of the pre-amps that might be amplified by any asymmetry in the differential amplifier's inputs.

iv) The input resistances, R_1 and R_3, must be high enough that the input current never exceeds the maximum current, (10 mA), that the op-amps in the pre-amps can supply. Use worst-case pre-amp output voltage $v_1 = +8$ V across R_1 to determine the minimum R allowed. (Note that actual voltages out of our pre-amps will be small, and exact values are unknown.)

v) The maximum resistor values used in your circuit (R_1, R_2, R_3, and R_4) should be limited to about 1 MΩ. This is because even a small noise current in our circuit can create a significant voltage across a high-valued resistor. Thus, we limit the resistor size in order to limit the voltage that small noise-currents will create.

List the values of R_1, R_2, R_3, and R_4 prominently in your lab notebook.

B. Procedure for Building and Testing the Differential Amplifier

1) Using the layout in Fig. 14, draw a schematic diagram of the complete EMG circuit. The complete EMG circuit layout is shown in Fig. 14 but with resistor values missing. Compare your result with Fig. 11 to determine which resistor is which in the differential amplifier. Also, include the circuit for the unused fourth op-amp on your schematic. What does this circuit do?

2) Build the differential amplifier. Note that the power supplies for the op-amp are omitted from the schematic, but +9 V must be connected to pin 8 and –9V must be connected to pin 4 of a second LF-353 op-amp chip used for the differential amplifier. Also, the wire to the reference electrode must be connected to the reference in your circuit, which is connected to the "common" output for the +25V and –25V power supplies. (The reference is also where the black leads for oscilloscope probes and the function generator are connected.)

3) Measure the differential-amplifier output voltage for several different input voltages for input 1. Then repeat the process for input 2. Fill out Tables IV and V in your lab notebook. Because the circuit has a high gain, you will test the circuit with small input voltages. Fig. 15 shows how voltage dividers like the simulated electrodes used earlier could be used to create small input voltages from power supply voltages of several volts. If enough power supplies were available, it would be possible to use the circuit shown in Fig. 15 to test both inputs at once. Since only one extra supply, (the 6V supply), is available, however, you will test your circuit using one simulated electrode driving only one pre-amp input at a time. To do so, connect the + wire for simulated output E_2 to Input 1 and later to Input 2. The other pre-amp input will be left unconnected, which is effectively like connecting that input to reference. As when testing simulated electrodes earlier, use the 6V power supply to drive the input of the simulated electrode voltage divider. Note that E_2, v_1, and v_2 will be very small but may be measured with the voltmeters in the lab. You should find that v_3 is several hundred times larger than v_1 and v_2. Also, when using input 1, v_2 should be relatively constant, and vice versa.

TABLE IV
MEASUREMENTS OF DIFFERENTIAL AMPLIFIER OUTPUT FOR INPUT 1

Power Supply Voltage	E_2 Voltage	v_1 Voltage	v_2 Voltage	$v_2 - v_1$ Voltage	v_3 Voltage
0 V					
2 V					
4 V					
6 V					

TABLE V
MEASUREMENTS OF DIFFERENTIAL AMPLIFIER OUTPUT FOR INPUT 2

Power Supply Voltage	E_2 Voltage	v_1 Voltage	v_2 Voltage	$v_2 - v_1$ Voltage	v_3 Voltage
0 V					
2 V					
4 V					
6 V					

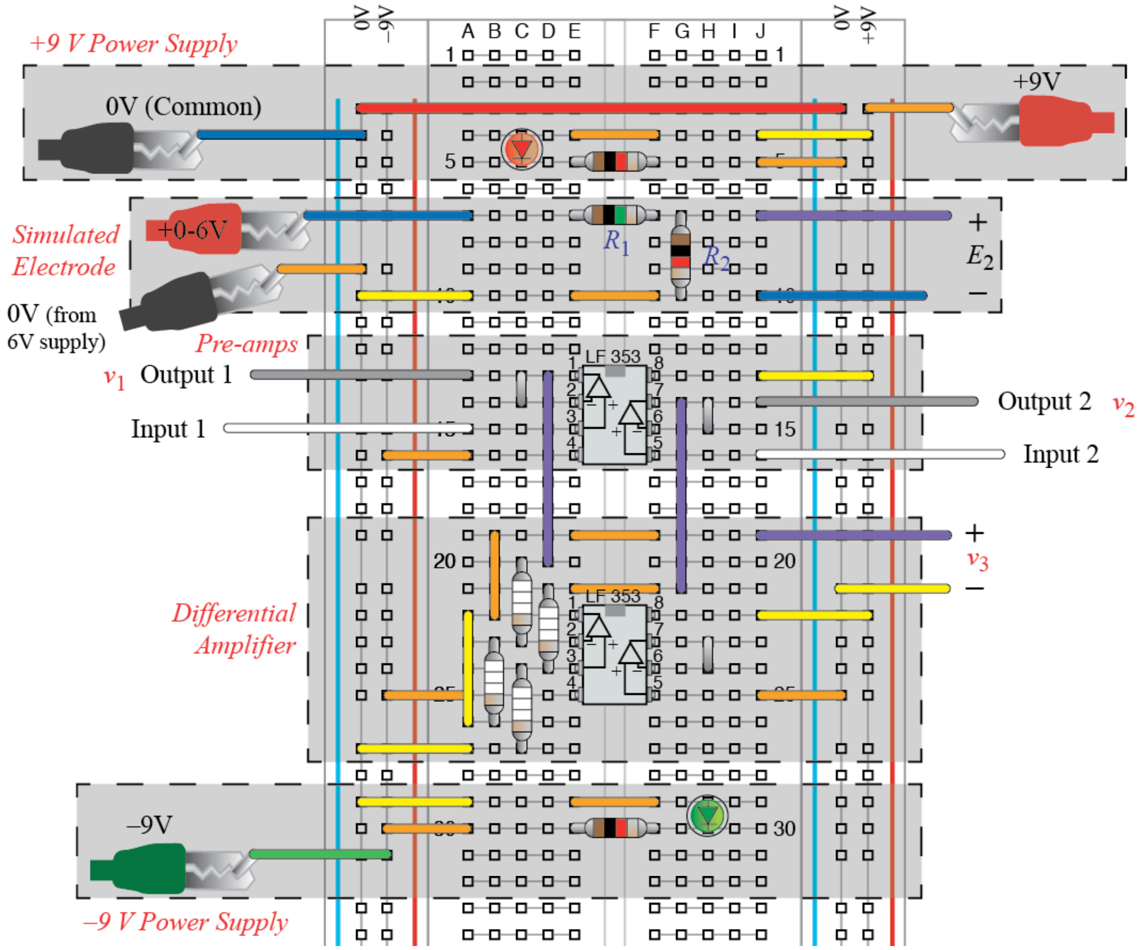


Figure 14. Complete EMG circuit.

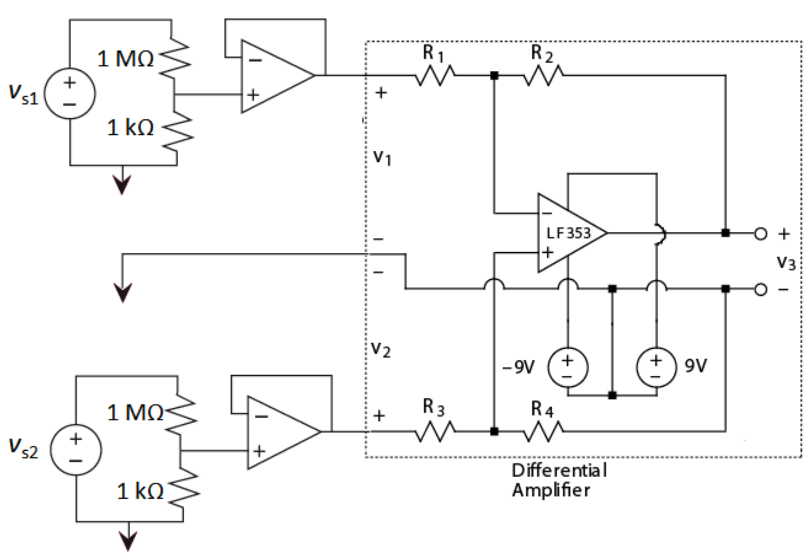


Figure 15. Testing differential amplifier using voltage dividers. (Arrow represents reference.)

C. Procedure for Calculating the Gain of the Differential Amplifier

1) Using your data from Tables IV and V, make a plot of v_3 versus $v_2 - v_1$.

The following code is an example of plotting the data.

```
% Example of plotting data.
x = [-1.1, 0.2, 1.3];   % All x values of three data pts go in one array.
y = [ 0.8, 2.3, 3.8];   % All y values of three data pts go in one array.
plot(x,y,'r+')          % Plot data pts as red + signs.
```

2) *Find the offset of the differential amplifier.* Using the `polyfit` function in Matlab®, draw a straight line through the data in your plot and find the *y*-intercept of the line. The *y*-intercept is the offset of the circuit. This offset is significant and arises as an artifact arising from non-ideal characteristics of the op-amps. In particular, there is a small offset in the voltage across the + and – inputs that the op-amp interprets as 0V. This offset voltage is only a few millivolts and in many applications may be neglected. In the differential amplifier circuit, however, the offset voltage is similar in size to the input signals and also gets multiplied by 500, causing a significant output voltage even when the two signals driving the differential amplifier are zero. A capacitor is used to eliminate this undesirable offset when measuring the EMG.

The following code is an example of using the `polyfit` function.

```
% Example of polyfit function.
x = [-1.1, 0.2, 1.3];   % All x values of three data pts go in one array.
y = [ 0.8, 2.3, 3.8];   % All y values of three data pts go in one array.
a = polyfit(x,y,1);     % a = [slope, yintercept], 1 means 1st-order fit
                        %  or straight line least-squares fit.
hold on                 % Keep the data plot.
yest = a(1)*x + a(2);   % Create values on straight line approx for plot.
plot(x, yest, 'k-')     % Plot straight-line fit as black line.
```

3) *Find the gain of the differential amplifier.* The slope of the line through your data is the gain of the circuit. (Use the exact numerical value returned by the `polyfit` function.)

4) Verify that the gain of the differential amplifier is close to 500. Note that calculation of the gain requires two data points since it is the slope of the line. If only one data point is used, the value of *y* divided by *x* is unequal to the slope. Fig. 16 illustrates the discrepancy between the true gain and *y/x*.

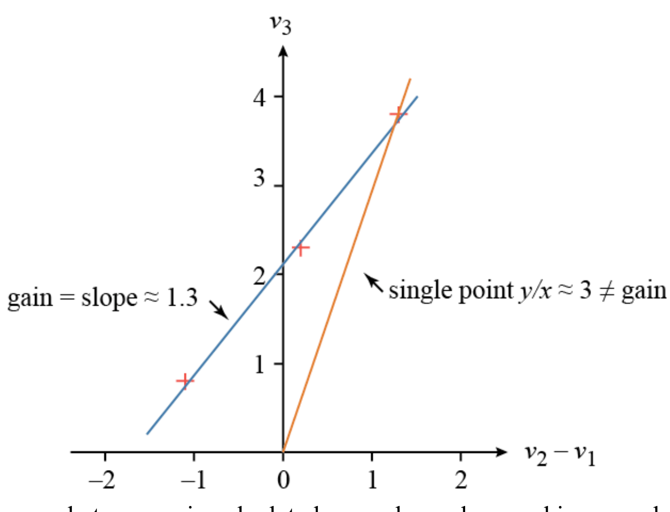


Figure 16. The difference between gain calculated properly as slope and improperly as *y/x* for one point.

VIII. Measuring and Analyzing EMG's

In this part of the lab, you will complete the following tasks:

1) Connect electrodes to your biceps and measure EMG's while you are lifting various weights.

2) Plot and comment on the power in the EMG signal as a function of the weight lifted.

A. Procedure for Measuring EMG's

Fig. 17 shows the final EMG circuit. As a safety precaution, use two 9 V batteries as the power supplies for your electromyogram circuit when measuring EMG's with actual electrodes. That is, replace the +9V and –9V power supplies with batteries. One battery will have its positive side connected where the +9V alligator clip is shown and its negative side connected where the 0V alligator clip is shown. The other battery will have its positive side connected where the 0V alligator clip is shown and its negative side connected where the -9V alligator clip is shown.

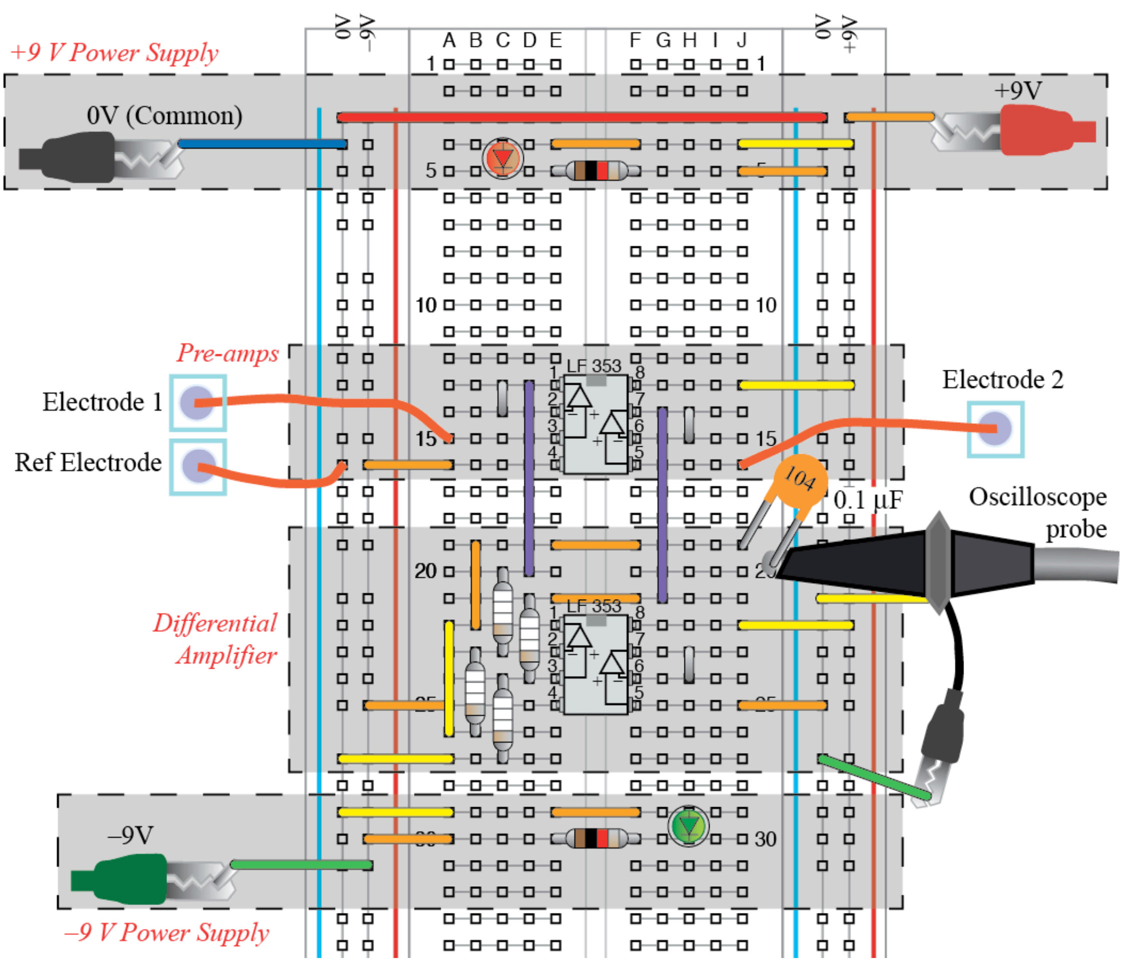


Figure 17. Final EMG circuit.

Connect electrodes to your biceps—the muscle on the top of the upper arm that bulges when showing off your strength. Place two electrodes, measuring the voltages going into the preamps, about three inches apart, on the upper and lower end of the biceps slightly toward the outside of the muscle, (see Fig. 1). Place the third, reference electrode, on the elbow. (Avoid placing the reference electrode on muscle.)

Connect the output of the electromyogram circuit to an oscilloscope. To eliminate the large constant vertical (DC) offset of the waveform, place a 0.1 μF capacitor between the differential amplifier output and the oscilloscope probe. That is, attach the oscilloscope probe to one side of the capacitor and connect the other side of the capacitor to the differential amplifier output. Observe the waveform on the oscilloscope and capture an example of the waveform that you can plot in Matlab® on a computer. (See instructions for capturing a waveform from the oscilloscope under Matlab® on the course website.) Print out a copy of the waveform for your lab notebook, and save the the Matlab® file of the waveform to create a plot for your report.

B. Procedure for Calculating Signal Power versus Weight for EMG Signals

By mimicking an example provided by your TA, write Matlab® code to calculate the average "power" of the recorded waveform by calculating the average value of voltage squared:

$$p = \frac{1}{N}\sum_{i=1}^{N} v_{3i}^2 \tag{6}$$

where

- p is the average "power" of the EMG circuit output signal
- N is the number of sample points
- v_{3i} is the ith sample of the EMG circuit output voltage

(Note that p actually has units of voltage squared rather than power, but p is equal to the power we would have if we connected a 1 Ω resistor to the output of the circuit.) This calculation of the average power is obtained from points spaced equally in time on the EMG waveform. The digital oscilloscope actually stores the measured waveform as a series of numbers representing the value of v_3 at closely spaced moments in time. The waveform shown on the oscilloscope is drawn as a smooth curve passing through these discrete points. (Digital music and videos are stored in a similar fashion as a series of numbers.) When we save the waveform for Matlab®, we are saving only these discrete values.

C. Procedure for Exploring EMG Signal Power versus Weight

Measure the average circuit output power, p, while holding the lower arm horizontal with no weight, one unit of weight, two units of weight, and three units of weight. Choose weights such that the three-unit weight requires significant but comfortable effort when held with the lower arm horizontal. When performing the tests with weights, keep your joints in a constant position as much as possible.

Using Matlab®, make a plot of p versus weight.

Comment on the shape of this plot.

IX. Notebook and Report

Turn in a copy of your laboratory notebook pages and a separate formal report. Refer to the grading information on the course website for the section numbering to use while writing the formal report. Use the IEEE format for typesetting. Information about the IEEE format, including a template file, is available on the course website. Additional information about writing the report and keeping a notebook is listed in the *Course Procedure* on the course website. Note that all Matlab® plots must appear in the laboratory notebook, and Matlab® plots required in the formal report must appear in both the laboratory notebook and the formal report.