DIFFERENTIAL AMPLIFIER

Minster

ABSTRACT

Bioelectric signals are recorded routinely in modern clinical practice. Biomedical engineers generally have a good physical insight into the physical problems to solve biological problems. For example, ECG, ERG, and EEG deal with biological signals which called biopotentials and amplifiers are very important to get rid of noise, amplify small amplitude of signals, filtering, etc. Therefore this lab is focused on differential amplifier and analyzing data in terms of grain, CMRR (Common mode rejection ratio), and frequency response, which is a bode plot. Students will design the differential amplifier and one with capacitor to compare results. The results show that adding an external capacitor to the circuit indicated on the graphs moves one of the RC filter corner frequencies to a very low frequency. This compensates the uncompensated op amp, resulting in decrease slope and a maximal phase shift of -90 degrees. Also the band width at -3dB became much narrower with the external capacitor.

INTRODUCTION

Amplifiers are an important part of modern instrumentation systems for measuring biopotentials. Such measurements involve voltages that often are at low levels, have high source impedances, or both. Amplifiers are required to increase signal strength while maintaining high fidelity. For example, the ECG needs an op amp to amplify signals without frequency distortion, time shifting, ground loops, etc. Therefore, biomedical engineers should knowledge of amplifiers to handle physical problems, that may contribute to the solution of biological problems. Thus, the purpose of this lab is to understand how differential op amps contribute to the instrumentation and what op amps do to signals. Moreover, the objectives of this lab are to design and build a differential amplifier using the 741 op amp, and to characterize the differential amplifier and one with capacitor. Students can analyze data to get gain, CMRR (Common mode rejection ratio), and frequency response which is a bode plot.

The grounded signal is one in which a ground reference is established, for example, by connecting the signal low lead to a case. The signal low connection is tied to the instrument case ground. A measurement system can be a ground or a differential. In differential system, neither of the two signal connections is tied to ground. Therefore, a differential measurement system is well suited to measuring differences between two signal levels. Physiologic signals are differential because a lot of medical instruments measure the potentials which is differences between two signal levels.

Students are going to use equations:

$$V_{out} / V_{in} = V_o / (V3-V4) = - R4/R3$$

$$V_{out} / V_{in} = (V3- V4)/(V1-V2) = i(2R2 + R1) / iR1 = 2\,R2/R1 + 1$$

V2 / (V1-V2) = -R4 / R3 [(2 R2 / R1) + 1]

CMRR = Overall gain/common mode gain

Overall gain = V out (Vo) / Differential input voltage of V1 and V2 (V id)

Power (P) = current (I) voltage(V)

METHODS

There were two parts in this experiment. The first part was a designing and building the differential amplifier. Another part was a differential amplifier characterization. The main measurements were focused in part two.

1. Designing and building the differential amplifier.

Students designed the circuit which included a differential amplifier, potentiometer, resistors, ground, and voltage sources as the given circuit diagram, figure 1.

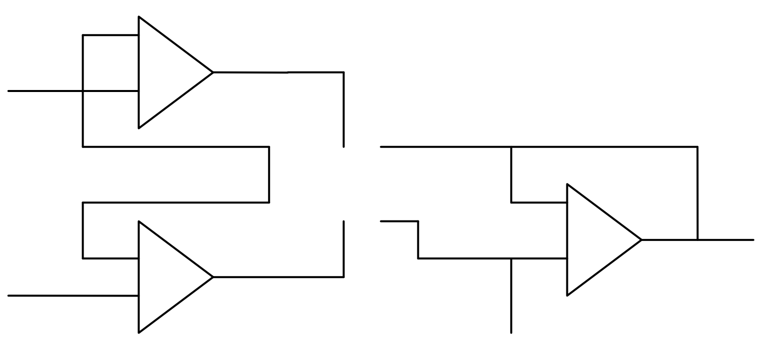

Figure 1. Circuit diagram of differential amplifier

This design a differential amplifier provided between plus minus 2 to 5 volts (V) output for a plus and minus 100 millivolts (mV) input. Students chose R1 as 0.363 Mega Ohms (MΩ), R2 as 2 Mega Ohms (MΩ), R3 as 1 Mega Ohms (MΩ), R4 as 3 Mega

Ohms (MΩ). R1 is the potentiometer so students needed to calculate the value of potentiometer after they chose R2, R3, and R4. The equations to get the value of R1 is

$$V\ out / V\ in = Vo / (V3-V4) = - R4/R3$$

$$V\ out / V\ in = (V3- V4)/(V1-V2) = i(2R2 + R1) / iR1 = 2\ R2/R1 + 1$$

$$V2 / (V1-V2) = -R4 / R3\ [(2\ R2 / R1) + 1]$$

Students built breadboard for differential amplifier using the calculated resistor values and 741 op-amp. The 3M solderless breadboard is used for design the circuit. At the top, there are connections for power supply (Voltage), the circuit run across bread board is right below of connections for power supply, and the circuit run up and down breadboard is what students put parts to design circuit.

For example, to connect R3 and op-amp, one end of resistor 3 goes to the number 2 pin and another end of resistor 3 goes to the voltage source. Thus, one end of voltage sources, V1, V2, V out, and one ground should stick out from the breadboard.

The power supply (HP-E3616A) to apply the supply voltage (plus minus 12 V) to the 741 op-amps.

2. Differential amplifier characterization.

The first step is to connect the breadboard to the function generator (Agilent 33120A) for input voltage, V1, V2 to the differential amplifier. Connect the output terminals of the function generator to the inputs of the inputs of the differential amplifier on breadboard. Students used the oscilloscope (Agilent 54622A) to visualize the output (Vo) of the amplifier. Then they connect the output and ground of the circuit on the breadboard to the oscilloscope.

To observe different characterization, students tested the circuit with different gain, and different frequencies. Students used the function generator to create a plus minus 100 mV 1kHz sine wave. After students connect the oscilloscope probes to V1 and V2 and they can adjust amplitude as needed.

Students turn the power supply on to supply plus minus 12 V to the op amps. They adjusted the channel 1 volts/division knob on the oscilloscope to view fully view the sinusoidal output. They record the peak-to-peak voltage output. HP 973 multimeter is useful to record the current draw of a 741 op amp. The black probe on pin 6 and the red probe is on 3 and students turned off the power.

After students performed the previous part, they are going to test common mode gain. They use the same function generator to create a plus minus 100 mV 1Khz sine wave.

They connect both V1 and V2 to the high input of the function generator. Then the red probe of oscilloscope goes to the output of the instrumentation amplifier circuit. The black probe goes to the ground. Turn the power supply on then adjust the channel 1 volts/division knob on the oscilloscope to view fully view the output. Record the peak-to-peak voltage.

Finally, students perform the frequency response of the breadboard. Students connect the function generator as for B-1a, for a sine wave of 100Hz. When the plus minus 100 mV input amplitude was maintained, students increased the frequency from 100Hz to 1MHz. After that, students added a capacitor across R4 and repeat the procedure of changing frequency from 100Hz to 1MHz.

RESULTS

Resistors	Default Diff Amplitude part of experiment	Amplifier 2 w/0.15 microfarad capacitor part of experiment
R1	0.363 MegaOhms	10 kiloOhms
R2	2 MegaOhms	51 kiloOhms
R3	1 MegaOhm	10 kiloOhms
R4	3 MegaOhms	20 kiloOhms

Table 1. Resistors values of default differential amplitude part of experiment

Frequency (Hz)	Default Diff Ampl (V)	Amplifier 2 w/0.15 microfarad capacitor (V)
10	2.94	3.31
100	2.88	3.31
500	2.69	1.75
1000	2.69	1.60
5000	2.81	1.00
10,000	3.00	0.80
50,000	4.00	0.60
100,000	1.00	0.40
200,000	0.20	0.20
300,000	0.20	0.20
400,000	0.20	0.20
500,000	0.20	0.20
600,000	0.20	0.20
700,000	0.20	0.20
800,000	0.20	0.20

Table 2. Default differential amplitude with different frequency

	Actual	Theoretical
Differential gain	26.9	30
Common mode gain	1.09	0

Table 3. Actual and theoretical values for differential and common mode gain

In differential amplifiers, current flows from V4 through R3 and R4 to ground. By the rule, no current flows into either input terminal of the op amp, no current flows into the positive input of the op amp. Also R3 and R4 act as a simple voltage divider attenuator that is unaffected by having the op amp attached or by any other changes in the circuit. By the rule, when the op amp output is in its linear range, the two input terminals are at the same voltage, whatever voltage appears at the positive input also appears at the negative input. After this voltage is fixed, the top half of the circuit behaves like an inverting amplifier.

The theoretical gain of common mode voltage is zero. If the two inputs are hooked together and driven by a common source, with respect to ground, then the common mode voltage is V3 = V4. Vo = (V4 – V3)R4/R3 shows that the output is zero. That is why common mode gain is zero. No matter how the inputs are varied, Vo is zero. No differential amplifier perfectly rejects the common mode voltage. To quantify this imperfection, we use the term common mode rejection ratio (CMRR), which is CMMR (Common Mode Rejection Ratio) = 24.68 in the lab. This factor is less than 100 for oscilloscope differential amplifiers.

To calculate the power required to drive the amplifier, students need to know the value of the current. Because of the rules, no current flows into either input terminal of the op amp, or no current flows into the positive input of the op amp when the op amp output is in its linear range. The equation can be set as current (I) = (V3-V5)/R3 = (V5-Vo)/R4, V3, R3, and R4 are known values. Therefore, (12V – V5)/1MΩ = (V5-2.69V)/3MΩ. V5 = 9.67V. Thus, plug the value of V5 back to the equation for I to calculate I. Thus, I is 2.33A. Power is voltage times current and voltage is 12V from power source, P = VI = 2.33 A X 12V = 27.96W.

Bode plots of gain vs. frequency for both differential amplifier and the added capacitance C4 across R4. X axis is frequency with log scale and y axis is gain with unit of dB. The 3-dB point and the amplifier band width are on figure 4.

DISCUSSION

1. Measured gain was less than theoretical gain for differential gain and measured gain of common was bigger than the theoretical gain. When the left and right halves of figure 1 are combined, the resulting three op amp amplifier circuit is frequently called an instrumentation amplifier. It has high input impedance, a high CMRR and a gain that can be changed by adjusting R1. This circuit finds wide use in measuring biopotentials because it rejects the large 60-Hz common mode voltage that exists on electronics that students used in the lab. This lab report will discuss about biopotentials later.

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2. The differential amplifier is fine for low resistance sources, for instance, strain gage. However, the input resistance is too low for high resistance sources. Students obtained gain from buffering amplifiers by using a noninverting amplifier. However, this solution amplifies the common mode voltage as well as the differential voltage sot there is no improvement in CMRR. That is why the actual common mode gain is 1.09.

CMRR is very important for investigating physiologic signals. Common mode voltages can be responsible for the interference in biopotential amplifers, for instance, CMRR is higher than 10000 for a high quality biopotential amplifier. Although having an amplifier with a high CMRR minimizes the effects of common mode voltages, a better to discover the source of the voltage and try to eliminate it.

3. Given the battery rated at 10A/hour, then the differential amplifier will be powered for 4.3 hours. Power is equal to multiplication of current and voltage. The current of battery is 10A/ hour and the calculated power is 27.96 Watt. Thus, power divided by the current of battery is 2.796 Volt Hour. The battery is 12V so voltage of battery divided by 2.796 volt hour is the hours that differential amplifier be powered by the battery, which is 4.3 hours.

4. Biopotential amplifiers are specially designed for low level voltages and high source impedance. There are three common problems that may be encountered with the design and application of biopotential amplifiers, such as frequency distortion, ground loops, artifact from large electric transients. The ECG does not always meet the frequency response so that when this happens, frequency distortion is shown in ECG. When high frequency distortion is occurred, it rounds off the sharp corners of the waveforms and diminishes the amplitude of the QRS complex. When low frequency distortion is occurred, the ECG is no longer horizontal, especially immediately following any event in the tracing. There is also saturation or cutoff distortion which can greatly modify the appearance of the ECG.

Ground loops occur due to many pieces of electric apparatus. Each electric device has its own ground connection either through the power line or through a heavy ground wire attached to some ground point in the room. The ground loop can exist when a ground electrode attached to the patient and the ECG is grounded through the power line at a particular socket. The machine is also grounded through the power line but it is plugged into an entirely different outlet across the room which has a different ground. Then two different grounds make a circuit which can produce common mode voltages on the ECG. If the ECG has a poor CMRR, then it can increase the amount of interference seen.

Final frequent problem is an artifact from large electric transients. Due to the saturation of the amplifiers in the electrocardiograph caused b the relatively high amplitude pulse or step at its input. This pulse is sufficiently large to cause the buildup of charge on coupling capacitances in the amplifier, resulting in its remaining saturated for a finite period of time and slowly drifting by the low corner frequency of the amplifier.

Part number	Package type	pins	Gain bandwidth	Slew rate	Input output type	Supply current per channel	Supply Max	Supply Min	Offset voltage
LM725CN	MDIP	8	1MHz	0.2 Vs/usec	Nor rail to rail	1mA	44V	6V	2.5 mV
LM741CN	MDIP	8	1 MHz	0.5 Vs/usec	Not Rail to Rail	1.7 mA	36 V	10 V	6 mV

Table 4. Comparisons of LM725CN and LM 741CN.

5. The purpose of the offset null pin on 741 op-amp is to provide a simple way to balance out the internal variations and zero out the output offset which might be apparent with zero input voltage. Adjustment of this nulling increases emitter current through one fo the input transistors and lowers it through the other. This alters the base to emitter voltage of the two transistors until the offset voltage is reduced to zero (Webster).

6. Adding an external capacitor to the circuit indicated on the graphs moves one of the RC filter corner frequencies to a very low frequency. This compensates the uncompensated op amp, resulting in decrease slope and a maximal phase shift of -90 degrees. Also the band width at -3dB became much narrower with the external capacitor. This is done with an internal capacity. This op amp shows results as students expected which are narrow bandwidth, slender slope, and doing RC filter.

CONCLUSION

The resistance values (R1 ~ R4) of differential op amp are R1 equals 0.363 MegaOhms, R2 equals 2 MegaOhms, R3 equals 1 MegaOhm, and R4 equals 3 MegaOhms. The resistance values (R1 ~ R4) of differential op amp with 0.15 microfarad capacitor are R1 equals 10 KiloOhms, R2 equals 51 KiloOhms, R3 equals 10 kiloOhm, and R4 equals 20 KiloOhms. Measured differential gain, 26.9 was less than theoretical gain 30 and measured gain of common mode, 1.09 was bigger than the theoretical gain, zero. If the two inputs are hooked together and driven by a common source, with respect to ground, then the common mode voltage is V3 = V4. Vo = (V4 – V3)R4/R3 shows that the output is zero. That is why common mode gain is zero. CMRR is very important for investigating physiologic signals. Common mode voltages can be responsible for the interference in biopotential amplifiers. Adding an external capacitor to the circuit indicated on the graphs moves one of the RC filter corner frequencies to a very low frequency. This compensates the uncompensated op amp, resulting in decrease slope and a maximal phase shift of -90 degrees. Also the band width at -3dB became much narrower with the external capacitor. Biopotential amplifiers are specially designed for low level voltages and high source impedance. There are three common problems that may be encountered with the design and application of biopotential amplifiers, such as frequency distortion, ground loops, artifact from large electric transients. This lab was satisfactory because not all groups got the results from their own circuits. However, students learned how to calculated gain, design the op amp circuit with breadboard, bode plots, and biopotentials.

References

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Appendix

Spec sheets of LM 741
Spec sheets of LM725