USER_MANUAL FOR OPERATIONAL AMPLIFIER FUNCTIONAL MODULE

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Introduction

It is often necessary in signal analysis to measure an output Voltage from a system. In many cases, this Voltage is too small to take an accurate measurement or use as a trigger to start another function. In these cases, an operational-amplifier (op-amp) can be used in order to boost the output signal to a level where it can be utilized. The amount that an input signal is amplified is determined by a relationship between external resistors. Resistors, capacitors, and transistors are all used to form an Integrated Circuit, which allows the op-amp to be used as a single component.

Theory

An op-amp is an active device, which means that it requires an external power source. In this experiment, a Voltage of ±15 was used. This power supply serves the purpose of allowing the output signal to be greater than the input signal. It also restricts the gain of the signal in that the maximum output Voltage can be no greater than the power supplied to the op-amp. In reality, the output will not reach the power source Voltage due to the amount of power required to run the op-amp and losses within the circuitry of the device.

Central to the performance of an op-amp is a loop from the output Voltage back to the inverting input Voltage. Known as feedback, this forms a closed-loop, which helps maintain stability and control gain of the op-amp. It is also used in the circuitry analysis to predict how the device will work.

An analysis of the inverting op-amp circuitry gives an expression for the expected gain and output Voltage. Using Kirchoff's Current Law with reference to node A (Figure 1),

$$i_s + i_f = i_{in} \tag{1}$$

where i_s is the source current, i_f is the feedback current, and i_{in} is the op-amp input current. The input current is considered to be zero; therefore, the feedback current is equal to the negative of the source current. Applying Ohm's Law to the above,

$$\frac{V_{in}}{R_1} = -\frac{V_{out}}{R_2} \tag{2}$$

Solving for the output Voltage yields,

$$V_{out} = -(\frac{R_2}{R_1})V_{in} \tag{3}$$

with the Gain being represented by the negative ratio of R_2 to R_1.

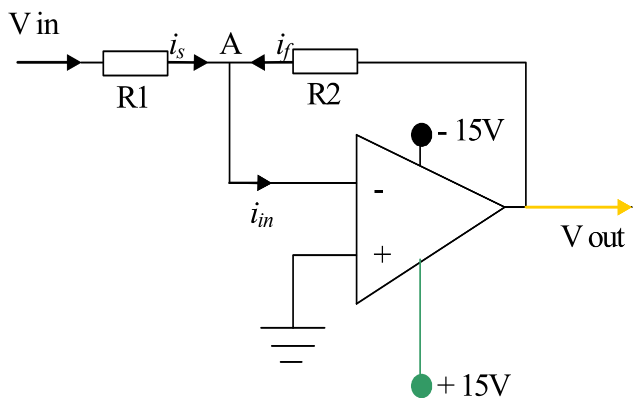

Figure 1-Inverting Op-Amp Circuit

Evaluating the Non-Inverting op-amp (Figure 2) about node B,

$$i_f = i_s + i_{in} \tag{4}$$

If it is once again assumed that the current into the op-amp is zero, then the source current is equal to the feedback current. Appling Ohm's Law to both sides of Equation 4,

$$\frac{V_{out} - V_{in}}{R_2} = \frac{V_{in}}{R_1} \tag{5}$$

Solving for V_{out},

$$V_{out} = (\frac{R_2}{R_1} + 1)V_{in} \tag{6}$$

with the Gain being represented the sum of one plus the ratio of R_2 to R_1.

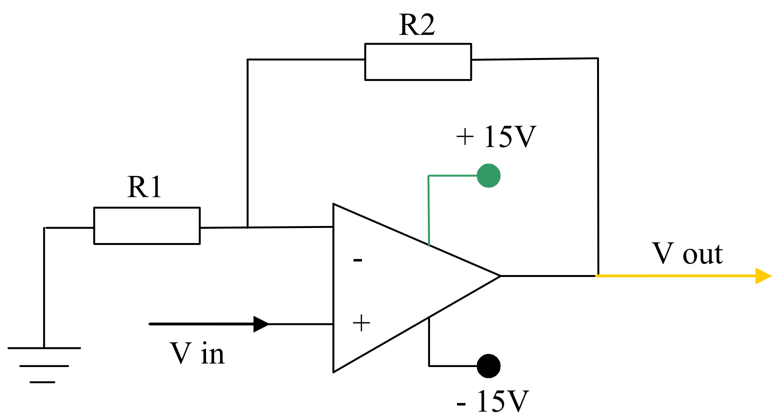

Figure 2-Non-Inverting Op-Amp Circuit

Functional Module Description

In this functional module, side A was arbitrarily determined to be Inverting and side B to be Non-Inverting. Figure (3) is a picture of the functional module used in the experiment. In this function module there are two circuits; the inverting op amp circuit and the non-inverting op- amp circuit. In figure (3) side A is the bottom half of the bread board and side B is the top half of the breadboard. The wiring description, with reference to Figure 3, is as follows:

Side A:

1. Ground to Non-Inverting Input A pin
2. R_1 to Inverting Input A
3. Input Voltage through Potentiometer to R_1
4. Signal wire from Output A pin
5. R_2 connected to Output signal wire and Inverting Input A
6. External Power Supply

Side B:

1. Input Voltage through Potentiometer to Non-Inverting B pin
2. R_1 to Inverting Input B
3. Ground to R_1
4. Signal wire from Output B pin
5. R_2 connected to Output signal wire and Inverting Input B
6. External Power Supply

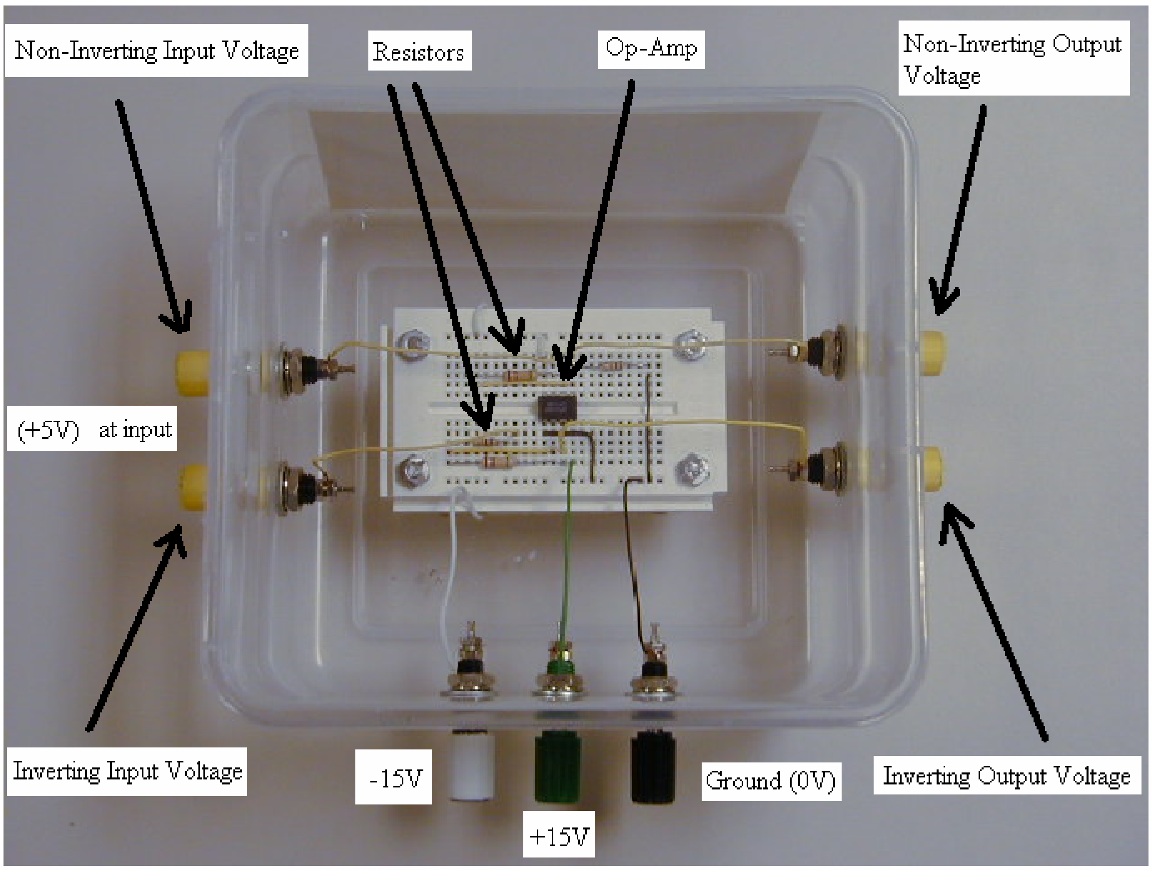

Figure 3-Op-Amp Average Gain

Table 1-Wiring Color Scheme

Ground	Black
Input Signal	Red
Signal	Yellow
External Power (+15)	Green
External Power (-15)	White

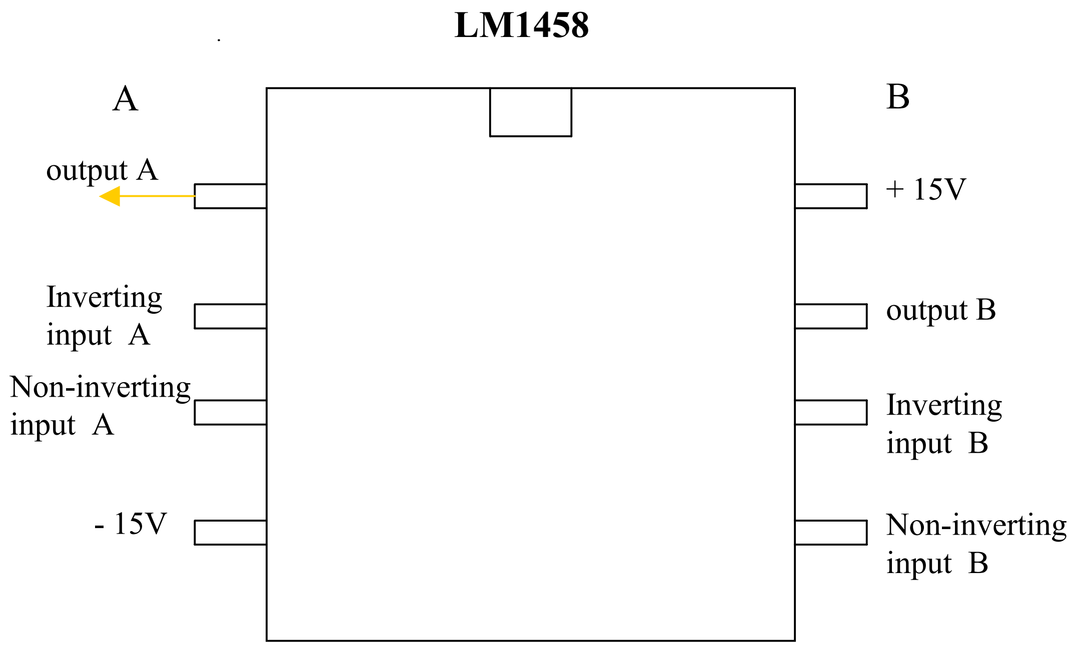

Figure 4-Op-Amp Schematic

The first experiment was conducted by altering the input Voltage by varying the resistance through a potentiometer. The input and output Voltages, as well as the actual resistance of all resistors, were measured using a multimeter. All values were recorded and analyzed. The graphs and data for this experiment can be found in Figures (4) through Figure (8), and Appendices A through Appendices B.

The second experiment was conducted by altering the resistance of the resistor R_2 through the use of a potentiometer or variable resistor. The input and output Voltages, as well as the actual resistance of all resistors, were measured using a multimeter. All values were recorded and analyzed. The graphs and data for this experiment can be found in Figure (9), and Appendix C.

In this functional module, side A was arbitrarily determined to be Inverting and side B to be Non-Inverting. Figure (5) is a picture of the functional module used in the experiment. In this function module there are two circuits; the inverting op amp circuit and the non-inverting op- amp circuit. In figure (5) side A is the bottom half of the bread board and side B is the top half of the breadboard. The wiring description, with reference to Figure 3, is as follows:

Side A:

7. Ground to Non-Inverting Input A pin
8. R_1 to Inverting Input A
9. Input Voltage to R_1
10. Signal wire from Output A pin
11. Potentiometer connected to Output signal wire and Inverting Input A
12. External Power Supply

Side B:

7. Input Voltage to Non-Inverting B pin
8. R_1 to Inverting Input B
9. Ground to R_1
10. Signal wire from Output B pin
11. Potentiometer connected to Output signal wire and Inverting Input B
12. External Power Supply

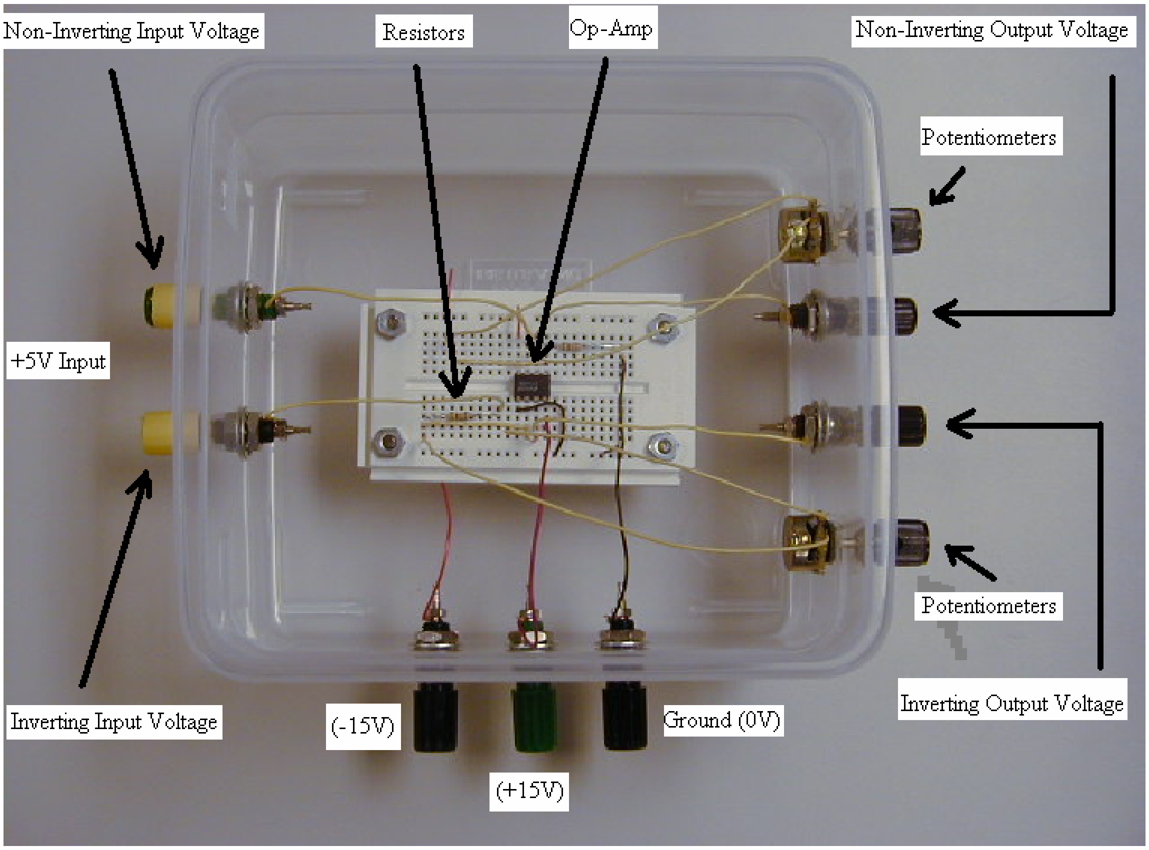

Figure 3- Op-Amp Function Module with Changeable Gain

Table 2-Wiring Color Scheme

Ground	Black
Input Signal	Red
Signal	Yellow
External Power (+15)	Green
External Power (-15)	Gold

Analysis of Results

The gain of an op-amp is solely dependent on the ratio of the resistors applied to the circuit, as was shown in the theory section of this paper. This experiment was performed in two parts: the inverting and non-inverting op-amps.

For the inverting op-amp, R_1 was equal to 9.93 kOhms and R_2 was equal to 216 kOhms, with the expected gain being -21.75. The Input Voltage versus the Output Voltage was graphed (Figure 6) in order to display the data obtained. The linear region of this graph represents the average gain that was observed, also represented in Figure 6, and the flat tail shows the saturation Voltage of the op-amp. The average gain for this particular configuration was -21.80. An Output Saturation Voltage of -12.8 was reached around 0.67 Volts. The average percent error, when very low and saturation Voltages are neglected, is 0.47%. The diagram of this function module is Figure 5.

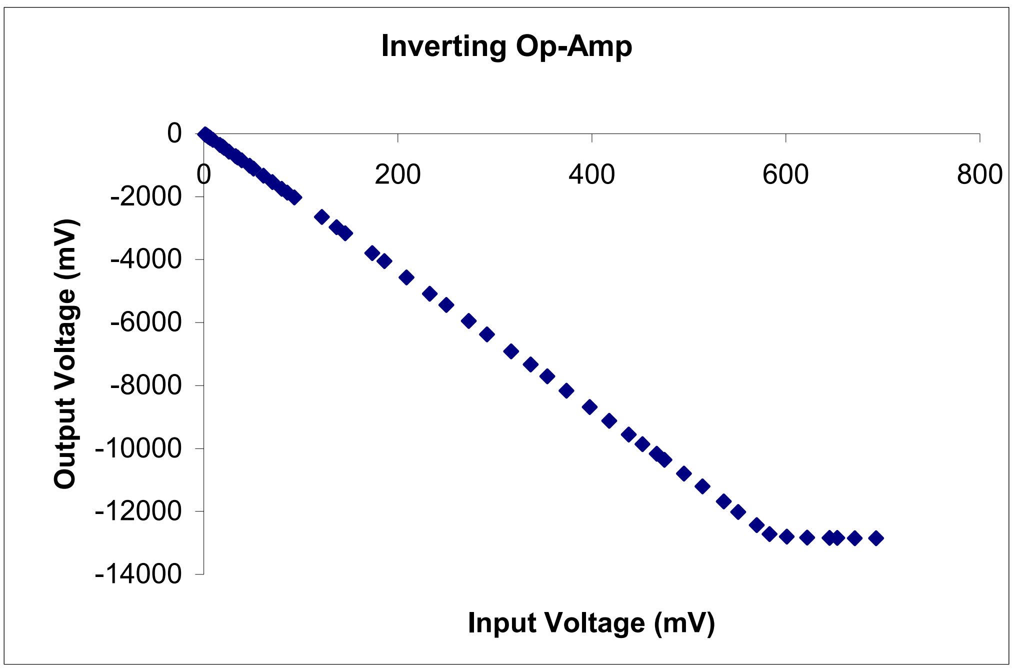

Figure 4-Inverting Op-Amp Data

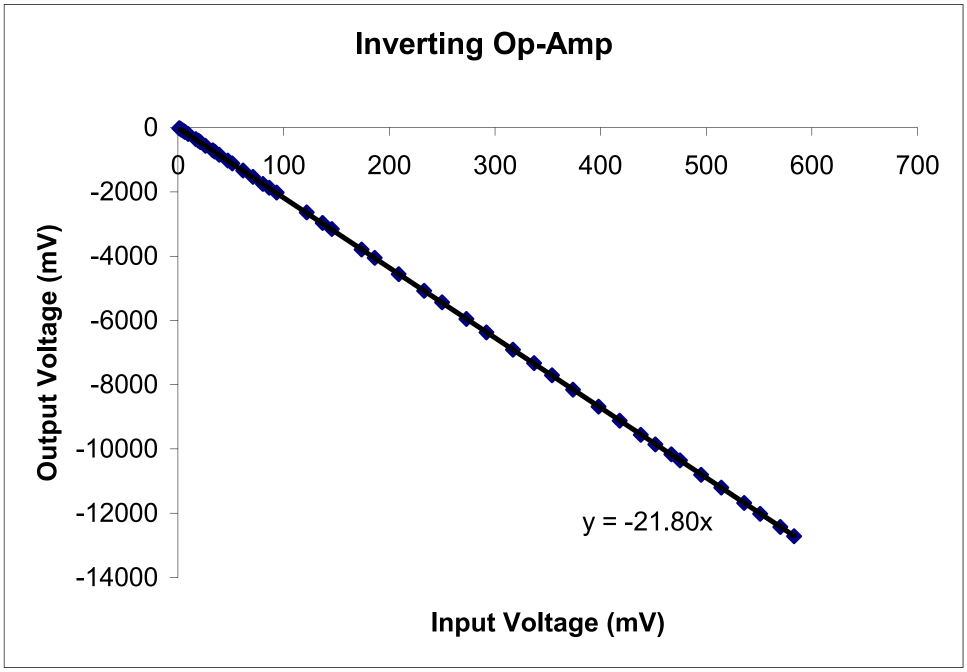

Figure 5-Inverting Op-Amp Average Gain

The non-inverting op-amp used an R_1 with a value of 9.83 kOhms and an R_2 of 217 kOhms. This gives an expected gain of 22.08 times the V_{in}. The Input Voltage versus the Output Voltage was graphed (Figure 8) in order to display the data obtained. The linear region of this graph represents the average gain that was observed, also represented in Figure 8, and the flat tail shows the saturation Voltage of the op-amp. The average gain for this particular configuration was 23.06. An Output Saturation Voltage of 14.2 was reached around 0.625Volts. The average percent error, when very low and saturation Voltages are neglected, is 0.46%.

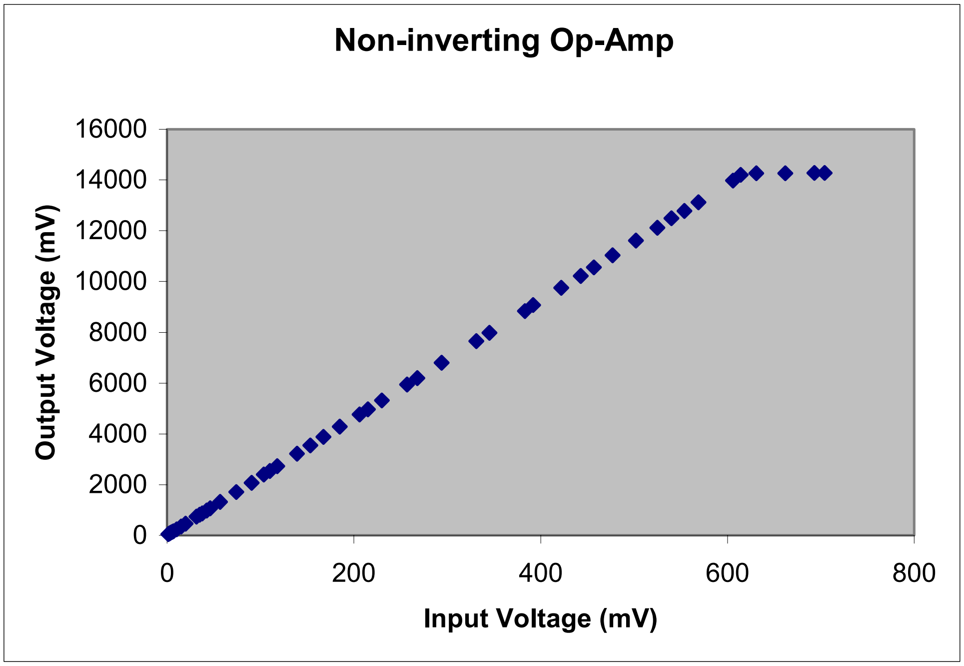

Figure 6-Non-Inverting Op-Amp Data

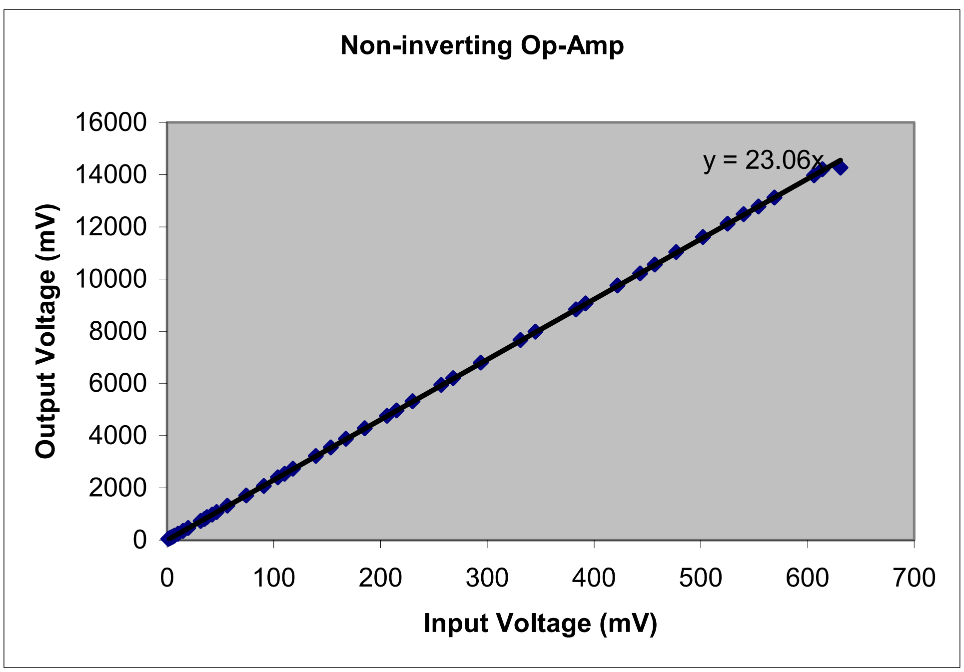

Figure 7-Non-Inverting Op-Amp Average Gain

Another useful configuration with an operational amplifier is to have a changeable gain. In order to achieve this, a variable resistor is connected to the op amp as one of the resistors that affects the gain. For example, in figure 10 a variable resistor is used as resistor R_2 instead of a fixed resistor as in Figure 2.

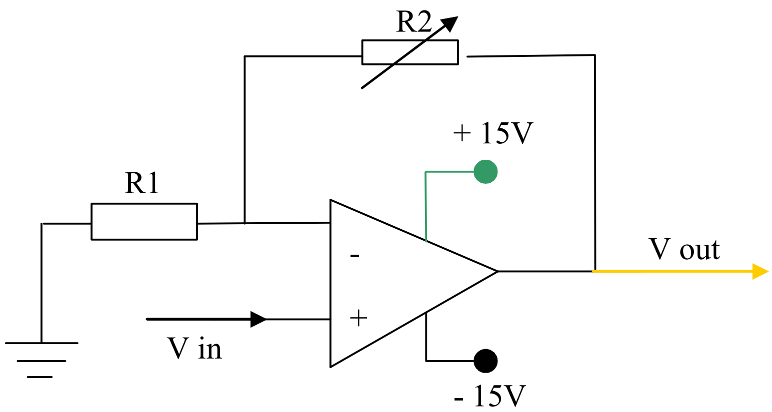

Figure 8-Non-Inverting Op-Amp Circuit with variable resistor as R_2

The change in resistance of R_2 affects the value of the gain that the op amp produces. Equation (6) shows that if the resistance R_2 is increased then the value of the gain will increase, whereas if the resistance R_2 is decreased then the value of the gain will decrease. When the op amp gain is graphed as a function of the variable resistance R_2 the following data is obtained in Figure (11).

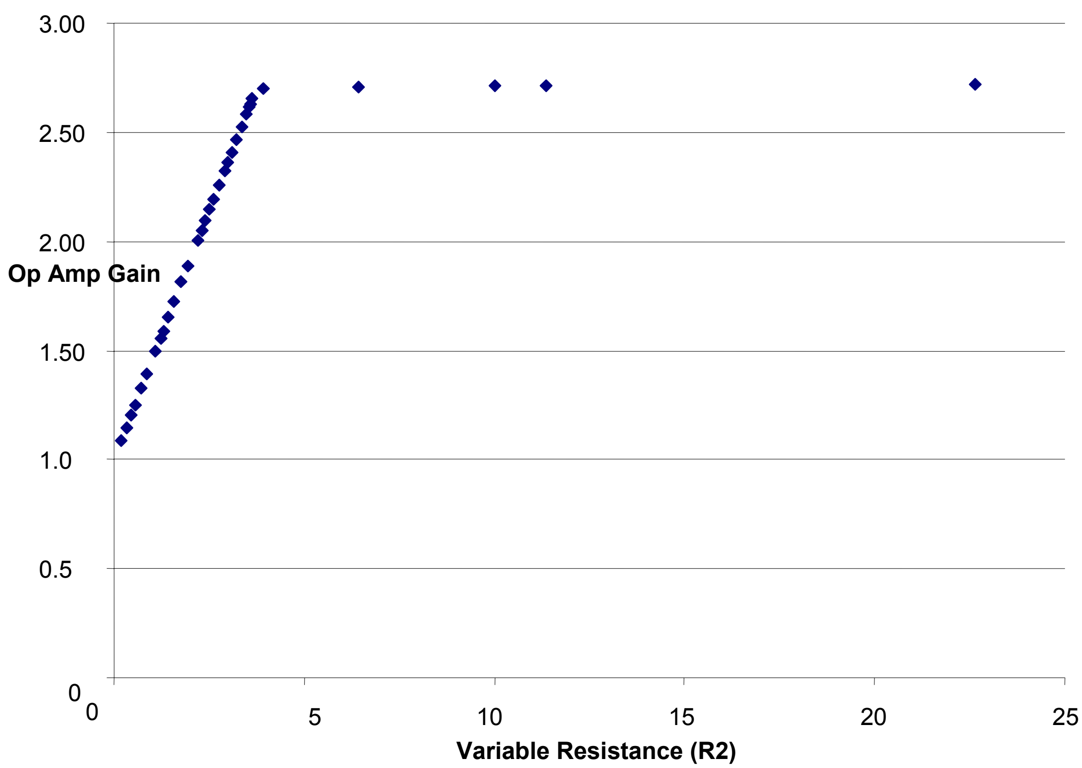

Figure 9- Data for Non-Inverting Op-Amp Circuit with variable resistor as R_2

This graph shows that there exists a linear relationship between the op amp gain and the variable resistance R_2. The op amp gain increases linearly as the variable resistance increases, however, at a certain value of the variable resistance, the gain does not increase. This is the case because the output saturation voltage of the op amp is reached at this point, and any further increase in variable resistance would not yield an increase in the op amp gain. The value of the variable resistance in which the op amp gain stopped increasing was found to be 3.91kΩ. The maximum gain the op amp could achieve was found to be 2.72. As the gain of the op amp increases the amplification of the output voltage signal increases proportionally. Appendix C contains the raw data.

CONCLUSION

Op-amps are extremely important electronic devices that facilitate the use of output signals. By using a ratio of two resistors to achieve a desired gain, an output Voltage proportionate to the input Voltage can be determined and measured. The tests done for this experiment show the accuracy and preferred output that can be attained through the use of an op-amp.

Bibliography

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2. Soper, Jon A., “Electrical Engineering Basics” in Principles and Practice of Electrical Engineering, Merle C. Potter, ed., Great Lakes Press, Inc., Ann Arbor, Michigan, 1998.

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Appendix A

Raw Data for Inverting Op-Amp

Input (mV)	Output (mV)	Gain	Theoretical Output	Percent error
1.3	-17.3	-13.30769231	-28.27794562	38.8215812
2	-32.4	-16.2	-43.50453172	25.525
3.1	-55.2	-17.80645161	-67.43202417	18.13978495
4.2	-80.5	-19.16666667	-91.35951662	11.88657407
5	-98.3	-19.66	-108.7613293	9.618611111
6.3	-125.6	-19.93650794	-137.0392749	8.347442681
7	-141.3	-20.18571429	-152.265861	7.201785714
9.6	-196.2	-20.4375	-208.8217523	6.044270833
16.9	-356	-21.06508876	-367.6132931	3.159105851
19.3	-411	-21.29533679	-419.8187311	2.100604491
21.1	-446	-21.13744076	-458.9728097	2.826487625
26	-568	-21.84615385	-565.5589124	0.431623932
32.8	-708	-21.58536585	-713.4743202	0.767276423
34.8	-750	-21.55172414	-756.978852	0.921934866
39	-844	-21.64102564	-848.3383686	0.511396011
47.3	-1021	-21.58562368	-1028.882175	0.766091144
51.3	-1112	-21.67641326	-1115.891239	0.348711284
61.7	-1331	-21.57212318	-1342.114804	0.828155952
70.9	-1534	-21.63610719	-1542.23565	0.534007209
80.3	-1748	-21.76836862	-1746.706949	0.074027951
86.3	-1875	-21.72653534	-1877.220544	0.118288915
93.3	-2020	-21.6505895	-2029.486405	0.467428844
121.7	-2640	-21.69268694	-2647.250755	0.273897562
136.8	-2970	-21.71052632	-2975.70997	0.191885965
145.8	-3160	-21.67352538	-3171.480363	0.361987502
173.9	-3790	-21.79413456	-3782.719033	0.192479714
186.1	-4050	-21.76249328	-4048.096677	0.047017732
209	-4560	-21.81818182	-4546.223565	0.303030303
233	-5080	-21.80257511	-5068.277946	0.231282785
250	-5440	-21.76	-5438.066465	0.035555556
273	-5950	-21.79487179	-5938.36858	0.195868946
292	-6370	-21.81506849	-6351.661631	0.288717656
317	-6910	-21.79810726	-6895.468278	0.210743077
337	-7330	-21.75074184	-7330.513595	0.007006264
354	-7710	-21.77966102	-7700.302115	0.12594162
374	-8160	-21.81818182	-8135.347432	0.303030303
398	-8680	-21.80904523	-8657.401813	0.261027359
418	-9120	-21.81818182	-9092.44713	0.303030303
438	-9560	-21.82648402	-9527.492447	0.341197362
452	-9860	-21.81415929	-9832.024169	0.284537856
467	-10170	-21.77730193	-10158.30816	0.11509636
475	-10360	-21.81052632	-10332.32628	0.267836257
495	-10800	-21.81818182	-10767.3716	0.303030303
514	-11200	-21.78988327	-11180.66465	0.172935581
536	-11680	-21.79104478	-11659.2145	0.17827529
551	-12020	-21.81488203	-11985.49849	0.287860456
570	-12430	-21.80701754	-12398.79154	0.251705653
583	-12720	-21.81818182	-12681.571	0.303030303
601	-12800	-21.29783694	-13073.11178	2.089110741
622	-12830	-20.62700965	-13529.90937	5.173052876
645	-12840	-19.90697674	-14030.21148	8.483204134
653	-12840	-19.66309342	-14204.22961	9.604389995
671	-12850	-19.15052161	-14595.77039	11.96079649
693	-12850	-18.54256854	-15074.32024	14.75569184

Appendix B

Raw Data for Non-Inverting Op-Amp

Input (mV)	Output (mV)	Gain	Theoretical Output	Percent error
1.3	48.1	37	29.99786368	60.34475158
2.3	70.8	30.7826087	53.07314344	33.4008039
3.1	86.4	27.87096774	71.53336724	20.78279456
4.1	107.9	26.31707317	94.608647	14.04877189
5.5	135.9	24.70909091	126.9140387	7.080352527
6.8	165.5	24.33823529	156.9119023	5.473197082
10.2	242	23.7254902	235.3678535	2.81777923
15.1	354	23.44370861	348.4367243	1.596638729
19.8	464	23.43434343	456.8905392	1.556053414
31.5	736	23.36507937	726.8713123	1.255887739
34.9	811	23.23782235	805.3272635	0.7044014
37.5	873	23.28	865.3229908	0.887184235
42.3	981	23.19148936	976.0843337	0.503610821
46.2	1070	23.16017316	1066.077925	0.367897617
56.6	1318	23.28621908	1306.060834	0.914135506
74.3	1714	23.06864065	1714.493286	0.028771525
90.6	2080	22.9580574	2090.620346	0.507999738
103.7	2400	23.1436837	2392.906511	0.296438214
110	2540	23.09090909	2538.280773	0.067731942
117.9	2730	23.15521628	2720.575483	0.346416295
139.2	3220	23.13218391	3212.078942	0.24660222
153.4	3550	23.14211213	3539.747915	0.289627558
167.5	3880	23.1641791	3865.109359	0.385257945
185	4280	23.13513514	4268.926755	0.259391782
206	4760	23.10679612	4753.50763	0.136580622
215	4970	23.11627907	4961.185148	0.177676346
230	5320	23.13043478	5307.314344	0.239022137
257	5940	23.11284047	5930.346897	0.162774673
268	6200	23.13432836	6184.174975	0.255895499
294	6800	23.1292517	6784.132248	0.233895083
331	7660	23.14199396	7637.917599	0.289115463
345	7980	23.13043478	7960.971516	0.239022137
383	8840	23.08093995	8837.832146	0.024529245
392	9070	23.1377551	9045.509664	0.27074578
422	9750	23.1042654	9737.768057	0.125613415
443	10220	23.06997743	10222.34893	0.022978396
457	10560	23.10722101	10545.40285	0.138421944
477	11030	23.12368973	11006.90844	0.209791483
502	11610	23.12749004	11583.79044	0.226260676
525	12120	23.08571429	12114.52187	0.045219516
540	12490	23.12962963	12460.65107	0.235532892
554	12780	23.06859206	12783.70498	0.028982089
569	13120	23.05799649	13129.83418	0.074899507
606	13980	23.06930693	13983.61953	0.025884086
614	14200	23.12703583	14168.22177	0.224292296
631	14270	22.61489699	14560.50153	1.995134065
662	14270	21.55589124	15275.8352	6.584485793
693	14280	20.60606061	15991.16887	10.70071165
704	14280	20.28409091	16244.99695	12.09601303

Appendix C

Raw Data for Non-Inverting Op-Amp with variable resistor R_2.

Data Points	Vout	Variable Resistor	Theoretical Gain	Experimental Vin	Actual Gain	Percent Error Gain
1.000	14.080	22.650	11.295	1.247	2.720	75.918
2.000	14.050	11.370	6.168	2.278	2.714	55.994
3.000	14.040	10.010	5.550	2.530	2.712	51.127
4.000	14.020	6.410	3.914	3.582	2.709	30.791
5.000	13.990	3.910	2.777	5.037	2.703	2.681
6.000	13.750	3.635	2.652	5.184	2.656	0.157
7.000	13.600	3.575	2.625	5.181	2.627	0.094
8.000	13.540	3.551	2.614	5.180	2.616	0.068
9.000	13.380	3.479	2.581	5.183	2.585	0.139
10.000	13.060	3.347	2.521	5.180	2.523	0.070
11.000	12.780	3.228	2.467	5.180	2.469	0.072
12.000	12.470	3.093	2.406	5.183	2.409	0.135
13.000	12.220	2.987	2.358	5.183	2.361	0.132
14.000	12.030	2.908	2.322	5.181	2.324	0.100
15.000	11.680	2.763	2.256	5.178	2.257	0.027
16.000	11.340	2.610	2.186	5.187	2.191	0.205
17.000	11.100	2.518	2.145	5.176	2.144	0.003
18.000	10.840	2.402	2.092	5.182	2.094	0.116
19.000	10.610	2.306	2.048	5.180	2.050	0.079
20.000	10.380	2.201	2.000	5.189	2.005	0.246
21.000	9.780	1.949	1.886	5.186	1.889	0.188
22.000	9.390	1.771	1.805	5.202	1.814	0.505
23.000	8.910	1.566	1.712	5.205	1.721	0.558
24.000	8.570	1.438	1.654	5.183	1.656	0.124
25.000	8.230	1.293	1.588	5.184	1.590	0.143
26.000	8.060	1.218	1.554	5.188	1.557	0.227
27.000	7.750	1.084	1.493	5.192	1.497	0.304
28.000	7.200	0.854	1.388	5.187	1.391	0.204
29.000	6.880	0.722	1.328	5.180	1.329	0.076
30.000	6.480	0.554	1.252	5.176	1.252	0.007
31.000	6.240	0.445	1.202	5.190	1.206	0.272
32.000	5.930	0.318	1.145	5.181	1.146	0.097
33.000	5.620	0.182	1.083	5.191	1.086	0.280
34.000	5.190	0.001	1.000	5.188	1.003	0.223