EE 1202 Experiment #7 – Signal Amplification

1. <u>Introduction and Goal</u>: Amplifiers <u>increase the power (amplitude) of an electrical signal</u>. They are used in audio and video systems and appliances. Amplifiers are designed to amplify signals within a <u>frequency range</u>. Today, we study an <u>operational amplifier</u> and use it to amplify a sinusoidal signal.

2. <u>Equipment List</u>: Required instruments and components are shown below.

• **Power Supply, HP Model E3630A.**	• **Electronic prototyping board.**
• **Multimeter, HP Model 34401A.**	• **Resistors, 5%, ¼ Watt: 1KΩ and others, as needed.**
• **Signal Generator HP Model 33220A.**	• **Fairchild Model 741 operational amplifier.**
• **Oscilloscope, Agilent Model 54622D.**	• **Oscilloscope probes and connecting leads: banana plug, coaxial, coaxial-to-hook-end.**

3. <u>Experimental Theory</u>: Amplifiers increase signal strength (Fig. 1) due to power from an external source, unlike the passive circuit elements that we have studied so far. We won't cover amplifier internals but instead concentrate on the <u>fundamentals of operation</u>.

Fig. 1. Amplifier Operation

Figure 2. Basic "op amp."
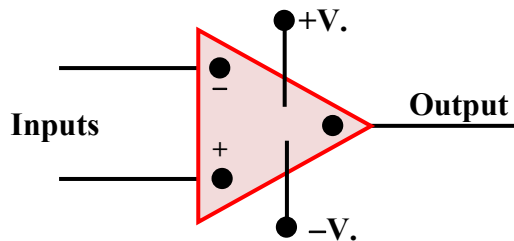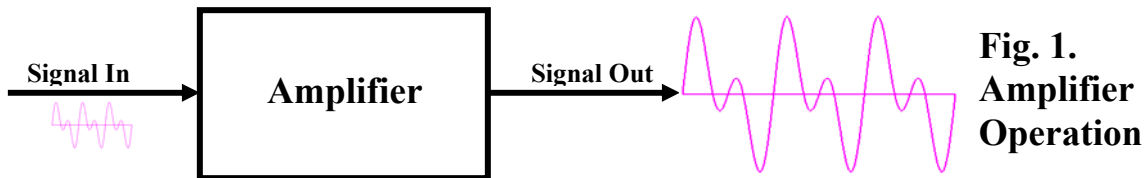
3.1. **Theory of the operational amplifier: Fig. 2 shows a basic "op amp."**

3.1.1. **The op amp has inverting and non-inverting inputs (─ and +), an output, and two power inputs, +V and ─V (DC voltages). It has no ground (or 0 V) input, but you can use power supply ground to attach to the ground lead of the oscilloscope probe.**

3.1.2. **An op amp cannot have an output larger than its power supply voltages. If the positive DC voltage is, for example, +15V., then the output cannot possibly exceed +15V. If the output would have a**

swing of more than ±15 V or more, the output voltage swing will be <u>clipped</u> (Fig. 3). In practice, clipping occurs when the output of the op amp is <u>much less</u> than the ± supply voltage. <u>A good rule of thumb is that the op amp output should limited to about 60-70% of the supply voltage limits</u>.

Figure 3. Clipped Output.

3.1.3. The amount of amplification of an op amp is called <u>gain</u>. The maximum gain of most operational amplifiers is <u>very large</u> (usually > 100,000). Op amp gain can be reduced to a useful range by "negative feedback," which is discussed below.

Figure 4. Linear Amplifier Gain

3.1.4. If op amp output is between ±0.6V, (± V = the DC power levels), it is operating in its "linear gain region." Thus, amplification is <u>constant</u> and <u>linear</u>. Output is <u>K</u> times the input, K a constant (Fig. 4).

3.1.5. Important op amp characteristics: (1) high input resistance, (~ 1 MegΩ), and (2) low output impedance (~ a few hundred Ω or less).

3.1.6. With its high gain, low output resistance and high input impedance, the op amp is easy to analyze if we assume: (1) Input impedance is <u>infinite</u> ($\rightarrow\infty$), (2) output impedance $\rightarrow 0$, (3) gain $\rightarrow\infty$.

3.2. Negative Feedback: With such high K, the op amp would be useful to amplify only tiny inputs. We can use <u>negative feedback</u> to lower K.

3.2.1. In Fig. 5, the input is $v_i(t)$ and the output signal is $v_0(t)$. The circuit resistors are R_i (input resistor), R_f (feedback resistor), and R_L (load resistor). Input voltages are ±V.

3.2.2. Using assumptions of 3.1.6: Since amplifier input impedance is large, we assume input current is negligible: $i_n \approx 0$. Since $v_p = 0$ (ground = 0V), and since i_n is 0, then $v_n = v_p = 0$. These are approximations, but they are close enough for our analysis.

3.2.3. By Kirchoff's current node law $\Sigma i_{node} = 0$ at "Node n" (Fig. 6).

Then $i_i + i_f = i_n$. Since $i_n = 0$, then $i_i + i_f = 0$. From the diagram,

$i_f = (v_0 - v_n)/R_f$ and $i_i = (v_i - v_n)/R_s$. But $v_n = v_p = 0$, so that

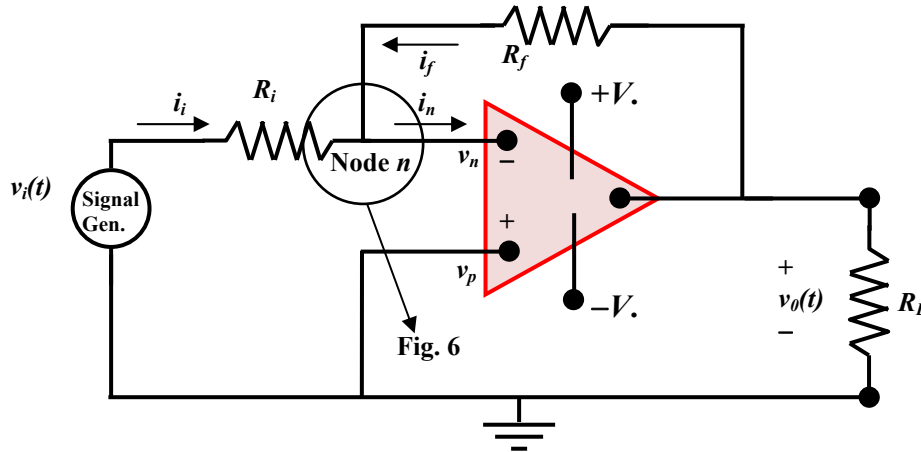$i_f = v_0/R_f$, and $i_i = v_i/R_s$.

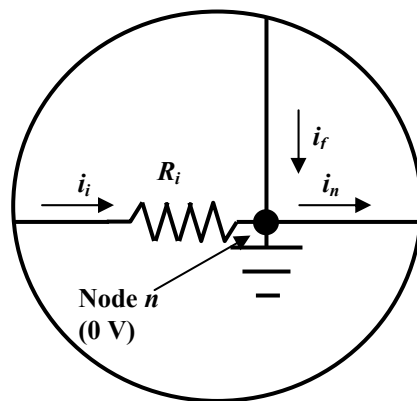**Figure 5. Op amp negative feedback circuit.**

Figure 6. Current Relationships.

3.3. Discovery Exercise: In your worksheet, use the information above to develop a formula for the gain, which you will use in the exercises below.

4. <u>Pre-Work</u>: Prior to lab, review exercise and complete Worksheet #7.

5. <u>Experimental Procedure</u>:

5.1. Negative Feedback Amplifier: In the exercises below, record the <u>measured value</u> of the selected resistors and enter in the data sheet.

5.1.1. (See op amp diagram on last page of this exercise). Plug a 741 op amp into the circuit board. Connect ± 20V DC power to the two power inputs. Connect the negative signal input to a 1K resistor, and the other side of the resistor to the signal generator (Fig. 7). The positive terminal of the op amp, DC power supply ground, and the low side of the oscilloscope probes should be connected together.

5.1.2. Turn on power supply. Set outputs to ± 15V. Note that when the "tracking ratio" knob is in the fixed position (max CCW), the ± 20 V voltage control knob sets the ± voltages to be equal and opposite.
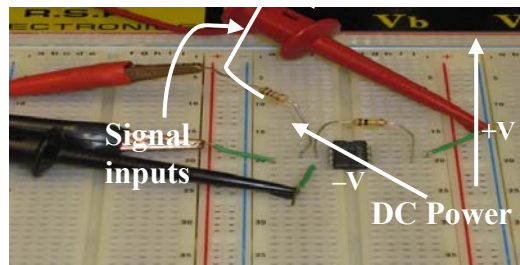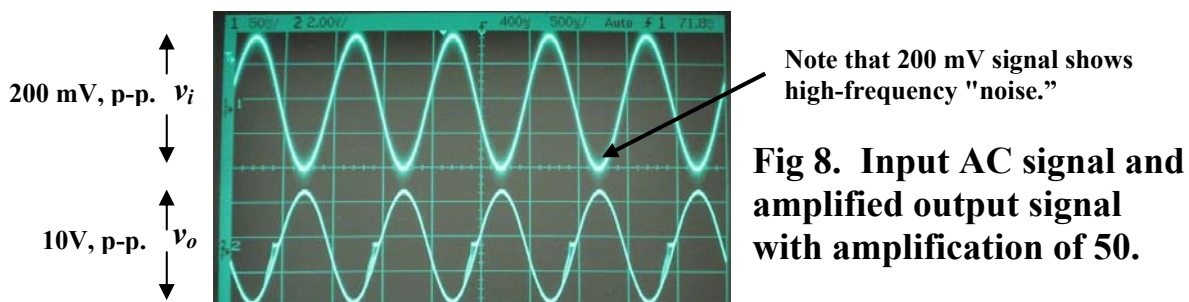

Fig. 7. Op amp basic hookup (ground lines and oscilloscope probes not shown).

5.1.3. **Connect oscilloscope channel 1 to the 1K input resistor and channel 2 to the output.**

5.1.4. **Set up the feedback resistor for an amplification of 10 (technically −10). Based on the 1K value of R_i, use your formula for K to select the feedback resistor, R_f, and connect it between the negative op amp input node and output terminal (you may have to chose an approximate value – be sure to measure the exact resistance).**

5.1.5. **Turn on signal generator. Using oscilloscope channel 1, set AC input to 1 V p-p at 1000 Hz. "Autoscale" channel 2 sensitivity to see the output AC signal. If resistor selection is correct, the output should be ~ 10 V, p-p. Is your output that value? Note input and output peak-to-peak voltages on your data sheet.**

5.1.6. **Calculate gain using measured resistor values. Are they close?**

5.1.7. **Turn off power supply. Change feedback resistor for a gain of ~ 50 (again, you may have to use an approximate value). Set signal generator at 200 mV, p-p. Turn on power supply; check the output channel. Record second resistor value calculated for K=50.**

5.1.8. **In both cases, the output voltage should look as shown in Fig. 8.**

5.1.9. **Note on high-frequency "noise:" You may see high-frequency noise on the display at higher oscilloscope sensitivities. This is <u>not</u> an equipment flaw. It is due to detecting "environmental" noise, radio or other signals due to sources in or near the lab. This may increase measurement difficulty, but does not affect circuit performance.**

200 mV, p-p. v_i

10V, p-p. v_o

Note that 200 mV signal shows high-frequency "noise."

Fig 8. Input AC signal and amplified output signal with amplification of 50.

5.1.10. **The op amp is an <u>inverting amplifier</u> in negative-feedback mode. Looking at Fig. 8, or the oscilloscope traces, you can see that**

the phase of the output is 180 degrees from the input, (it might be slightly off). Based on knowledge of AC circuits from earlier experiments, what can you speculate might cause any slight offset from a perfect 180 degree phase shift? Discuss this in your report.

5.2. Design Exercise – a Non-Inverting Amplifier: What if you need a non-inverting amplifier (one that does not reverse the phase)?

   5.2.1. Design a non-inverting op amp circuit with a gain of 100, using resistors from your parts kit and a second op amp chip. You can still use the equation that you developed for the earlier design. Note: to preserve the condition that the op amp output voltage be no more than about 60-70% of the power supply maximum input voltages, the input should be no more than 100 mV, peak-to-peak. Hints: (1) When amplifiers are cascaded (put in series), their gain <u>multiplies</u>; (2) Each negative-feedback op amp <u>inverts</u> the signal.

   5.2.2. After demonstrating amplifier circuit, the experiment is complete. Make sure you include the circuit schematic on your data sheet.

6. <u>Laboratory Area Cleanup</u>: Return parts kit to equipment cabinet. <u>Make sure work area is clean</u>.

7. <u>Writing the Laboratory Report</u>: In your report, do the following:

   7.1. Discuss gain characteristics of the op amp. Did your amplification formula work?

   7.2. How did the calculated gain and actual gain compare?

   7.3. How accurate was the amplification in your non-inverting circuit?

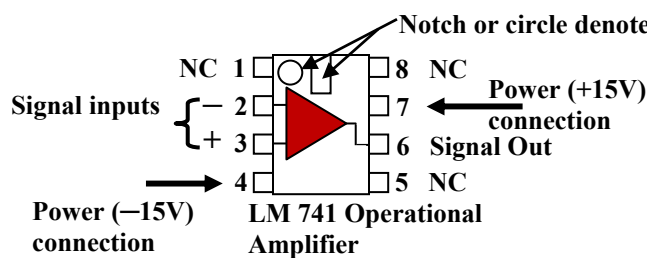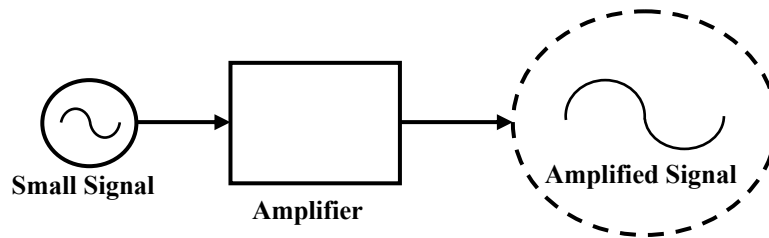   7.4. What problems did you encounter?

Fig. 9. Amplifier Circuit Information and Pin-outs.

Experiment #7 Data Sheet

1. **In the worksheet, you developed an equation for the gain *K* of an op amp operated in negative-feedback mode. Write that formula below:**

$$K = (v_O / v_i) = \underline{\hspace{3cm}}$$

2. **Measured value of 1K input resistor:** $\underline{\hspace{3cm}}$

   and feedback resistor that you chose in 5.1.4: $\underline{\hspace{2.5cm}}$

3. **Measured value of input AC signal (p-p):** $\underline{\hspace{2.5cm}}$

   and amplifier output voltage (p-p) in 5.1.5: $\underline{\hspace{2.5cm}}$

4. **Gain $(= v_0 / v_i)$ using measured values in #3 above:** $\underline{\hspace{2.5cm}}$

5. **Op amp calculated gain using your formula
   and the measured resistor values in #2 above:** $\underline{\hspace{2.5cm}}$

6. **Resistor value of for gain of 50 (section 5.1.7):** $\underline{\hspace{2.5cm}}$

7. **Amplitude of input AC signal (p-p):** $\underline{\hspace{2.5cm}}$

   and amplifier output from section 6.1.7: $\underline{\hspace{2.5cm}}$

8. **Gain $(= v_0 / v_i)$ using measured values in #7 above:** $\underline{\hspace{2.5cm}}$

9. **Calculated gain using measured value of 1K
   resistor (#2 above) and resistor for 50 gain (#6):** $\underline{\hspace{2.5cm}}$

10. **Non-inverting amplifier design: State below how you did this. What were the resistor values for your circuit? $\underline{\hspace{6cm}}$**

   $\underline{\hspace{12cm}}$

11. **Did you use both op amps in the non-inverting amplifier? If so, show the circuit below (like Fig. 5). Label all components.**

Experiment #7 Worksheet

Small Signal   Amplifier   Amplified Signal

1. The <u>gain</u> of an amplifier is a measure of its ability to add power to a signal. Based on information in the text, write down a simple gain formula

   in terms of input signal and output voltage: _____
2. Operational amplifiers have several basic characteristics, including high input impedance (~ 1 Meg Ω), low output impedance (typically < 500 Ω), and a specific gain range. What is a typical gain of an op amp?

   _____

3. Exercise: We developed some basic relationships for the negative-feedback operational amplifier circuit described in 3.2.2 and 3.2.3 (Figs. 5 and 6).
   a. Use the relations $i_i + i_f = 0$, or $i_i = -i_f$ and the definitions of i_i and i_f

      developed in 3.2.3 to find a value of the output voltage, v_0, in terms of the input signal, v_i. When you find this formula, the multiplier of the input signal v_i in the equation is the <u>gain</u> *K*, as discussed above.
   b. The formula you develop above gives the <u>gain of the negative feedback amplifier</u>, allowing you to set the amount of gain that it will provide.
   c. Using negative feedback, output voltage has the opposite sign of the input voltage (i.e., *K* is negative). If the input is positive, the op amp output voltage will be negative. If the input is negative, the output will be positive. For AC signals, the output will be <u>180 degrees out of phase with the input</u>. If AC input is changing in a range below 0, the output will change at a rate *K* times that of the input, but above 0. If the input is a sinusoid, then output and input will have 0 crossings at approximately identical times, but the output will be maximum when the input is a minimum and vice-versa.
   d. Suppose you have two inverting amplifiers with gains of -10 and -20, and you connect the output of the first to the input of the second. What is the overall gain of this "cascaded" set of two amplifiers?

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