Building the AMP—Amplifier

Introduction

For about 80 years it has been possible to amplify voltage differences and to increase the associated power, first with vacuum tubes using electrons from a hot filament; and, since about 1960, with solid state devices—transistors (like the 2N3055) and integrated circuits (like the LM317 and the LF411). *Amplify* means to make larger, and the ratio of the output voltage to the input voltage is called the "gain".

The voltages to be amplified are sometimes induced in antennas by fields from distant radio transmitters, or are the output of some 'transducer' that turns a physical phenomenon into a voltage; for example, a microphone turns a varying sound pressure into a varying voltage.

Operational amplifier integrated circuits are widely used nowadays. They have two inputs and one output. One input is called inverting—a plus voltage is turned into minus output; the other input is non-inverting—a plus voltage stays plus. Thus a voltage difference between the two inputs is obtained if the two input voltages are not equal. If the same voltage is applied to both inputs there is no output (ideally). This voltage difference between the two inputs is amplified by a large factor A, (open-loop gain). By using a negative feedback circuit, a much lower but stable ratio of output to input voltage, $G = V_{out}/V_{in}$, can be obtained (closed-loop gain). This also ensures a reduction of noise and gain variations.

You will construct a non-inverting dc amplifier with the integrated circuit op-amp, LF411. It has an amplification A of more than 10^5, which means that it can amplify voltages so that tens of microvolt differences between the two inputs can become volts at the output. We will use the LF411 op-amp in a negative-feedback circuit to give a gain, G, of about 90.

You will build your amplifier on the other half of the same circuit board that you used for the LVPS (low voltage power supply). The schematic circuit diagram for the amplifier is shown in Figure 1.

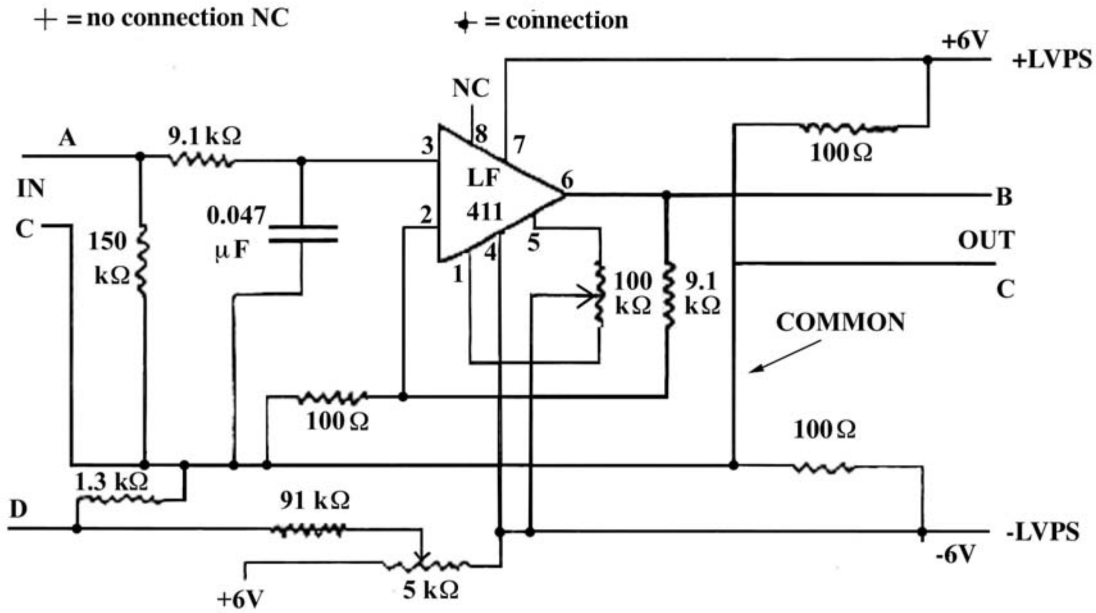


Figure 1: Amplifier Circuit Diagram

Voltage divider for the LVPS

The LF411 requires two equal plus and minus power supply outputs. We can make this from the LVPS by using the voltage divider shown in Figure 2 with the LVPS set at $12V$.

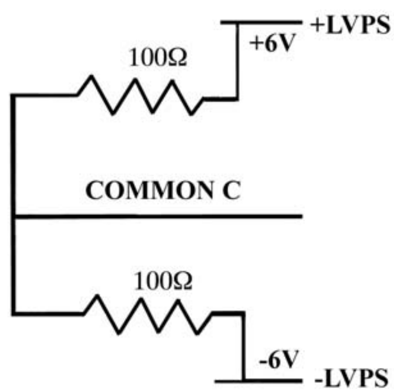


Figure 2: Voltage divider for LVPS

If the central connection between the two resistors is defined to be the zero-volt level, then we have two power supply outputs; one at $+6V$ and one at $-6V$ with respect to this common zero of voltage, called "common".

LF411 op-amp

The op-amp has eight pins: pins 1-4 on one side and pins 5-8 on the other side. Pin 1 is conventionally marked by a dot on the op-amp.

Figure 3: Op-amp

The various pin connections are as follows:

1) Pin 7 connects to the $+6V$ voltage output of the LVPS. Pin 4 connects to the $-6V$ voltage output of the LVPS.

2) Pin 6 is the **output voltage** with respect to common.

3) Pin 2 is the **inverting** input, so a voltage $+V_2$ with respect to common becomes $-AV_2$ at the output, where $A \approx 10^5$ is the open-loop amplification. Similarly, a voltage $-V_2$ with respect to common becomes $+AV_2$ at the output.

4) Pin 3 is the **non-inverting** input, so a voltage $+V_{in}$ with respect to common becomes $+AV_{in}$ at the output. Similarly, a voltage $-V_{in}$ with respect to common becomes $-AV_{in}$ at the output. So the two different input voltages input (pins 2 and 3) give an output voltage $+A(V_{in} - V_2)$. The op-amp amplifies the difference of voltage between its two inputs. If the two input voltages are the same voltage with respect to common, then there is no output voltage.

5) Most op-amps have some dc offset in the output. This can be eliminated by adjusting the potential difference between pin 1 and pin 5 with the $100\,k\Omega$ pot.

6) Pin 8 has no connection.

The input voltages to the amplifier go to the non-inverting input (pin 3) through a $9.1\,k\Omega$ resistor followed by a $0.047\,\mu F$ bypass capacitor between common and input (pin 3), to keep voltage spikes and surges out of the op-amp.

Negative Feedback

The negative feedback circuit is shown in Figure 4. **Study this schematic diagram carefully.** Notice that the feedback voltage divider consisting of a resistor $R_1 = 9.1\,k\Omega$ from the output (pin 6) to the inverting input of the op-amp (pin 2) and a resistor $R_2 = 100\,\Omega$ connected from the inverting input (pin 2) to the common. These resistors determine the gain of the circuit $G = V_{out}/V_{in}$, which is the ratio of the output voltage at pin 6 to the input voltage at pin 3.

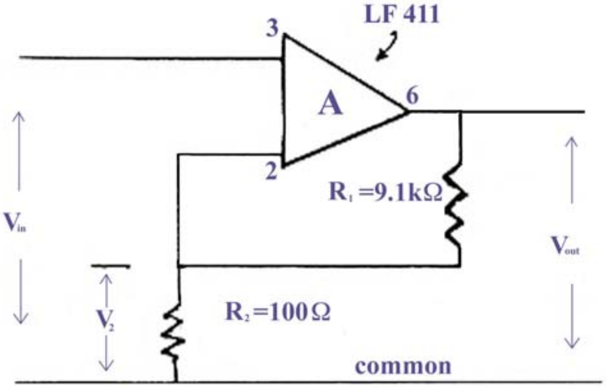


Figure 4: The negative feedback circuit

The resistors R_1 and R_2 form a voltage divider so the voltage at pin 2 is

$$V_2 = \frac{R_2}{R_1 + R_2} V_{out} \equiv \beta V_{out}$$

where

$$\beta = \frac{R_2}{R_1 + R_2} = \frac{100\Omega}{9.1k\Omega + 100\Omega} = \frac{1}{92}.$$

The LF411 op-amp inverts V_2 and then adds the inverted voltage to V_{in}. (This is essentially a voltage subtractor.) The difference between these input voltages is then amplified by a factor $A \approx 10^5$ to give the output voltage

$$V_{out} = A(V_{in} - V_2) = A(V_{in} - \beta V_{out}).$$

We can solve this equation for the gain G which is the ratio of the output voltage to the input voltage at pin 3

$$G = \frac{V_{out}}{V_{in}} = \frac{A}{1 + \beta A} \cong \frac{A}{\beta A} = \frac{1}{\beta} = 92$$

.

Notice that $1 + \beta A \cong \beta A >> 1$ since $\beta A \approx (10^{-2})(10^5) = 10^3$. The negative feedback circuit reduces the gain to 92. But the important point is that this gain is nearly independent of A, the amplification. The amplification may vary due to factors like temperature changes, dependence on voltage inputs, or noise, but the gain, determined by stable components (resistors), is stable. It can be changed by choosing different resistors.

Wiring the Amplifier

The best way to wire the amplifier is shown in the circuit diagram, (Figure 1), and the diagrams (Figures 5-8) showing the layout of the parts on the board. If you are not sure about the value of a resistor, measure it with your MMM!

You should start with the socket with eight legs. This will help get the wiring for the op-amp correct. The LF411 op-amp itself is a sensitive component, and can be damaged by static electricity. It should be the last item to be installed.

Figures 5-8 are guides to how the amplifier can be wired. Notice that the leads of the socket can be bent in directions that enable them to be connected to various components. Think where these should go and install them in the right place with wires heading toward where they will be connected.

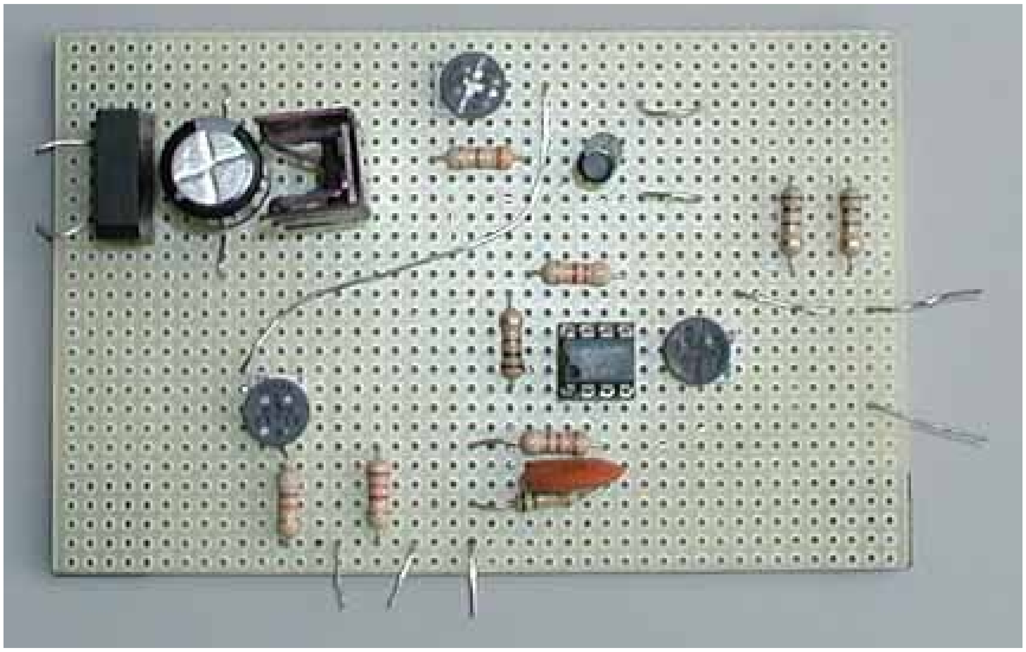


Figure 5a: Parts Layout, Topview

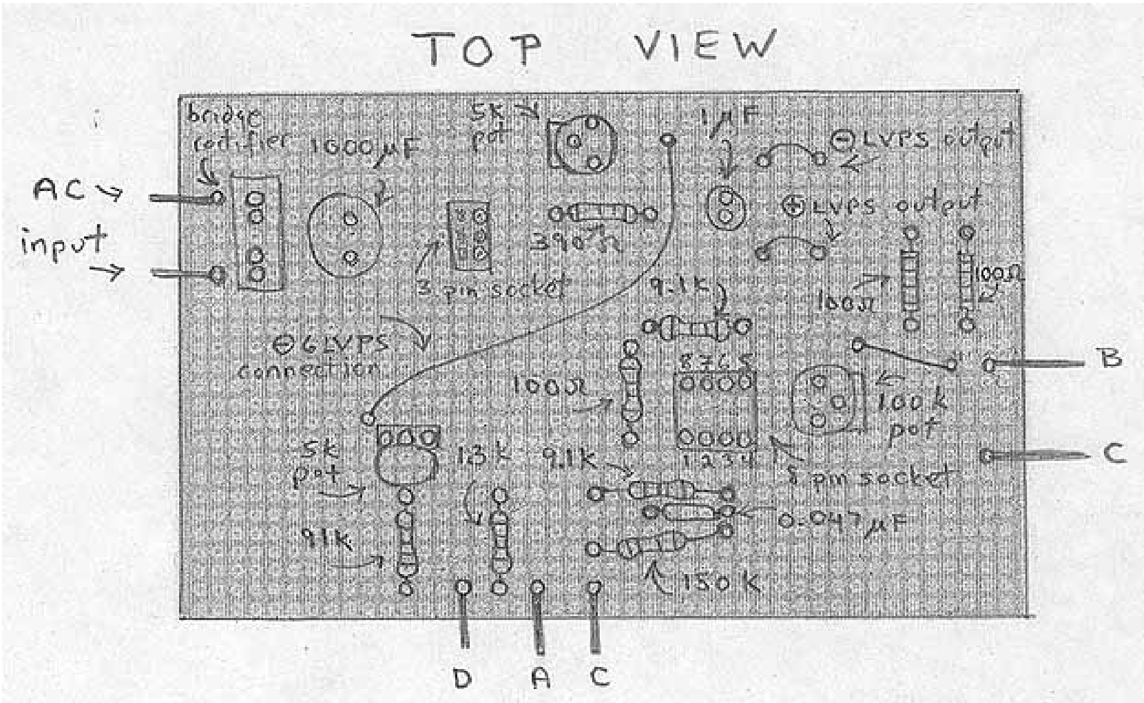


Figure 5b: Schematic Parts Layout, Topview

Note: In figure 5a and 5b, there is two bare wires on the topside of the board. The first connects the $-6V$ line from the LVPS to one leg of the $5k\Omega$ pot of the amplifier. The second connects pin 6 to the output B.

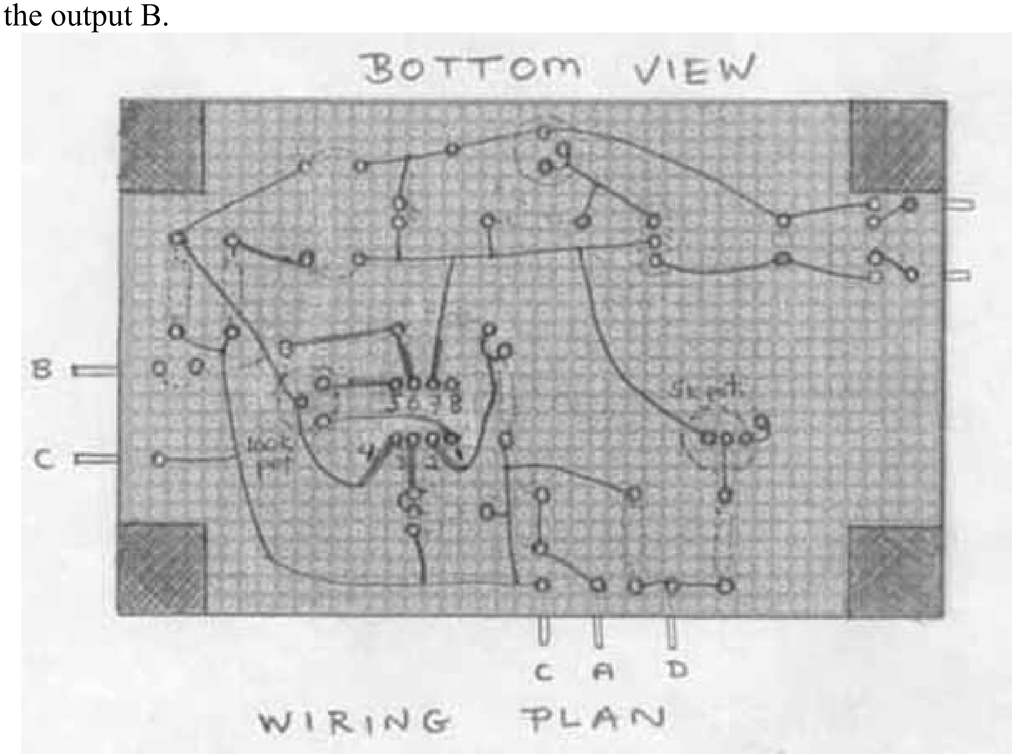


Figure 6: Wiring Plan, Bottom View

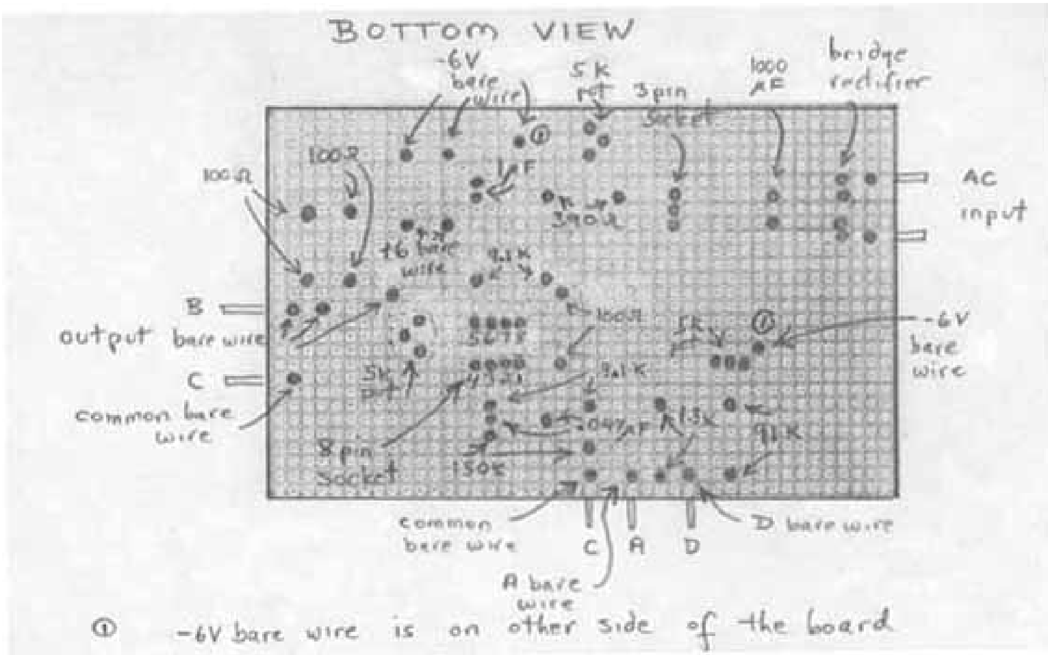


Figure 7: Schematic Parts Layout, Bottom View

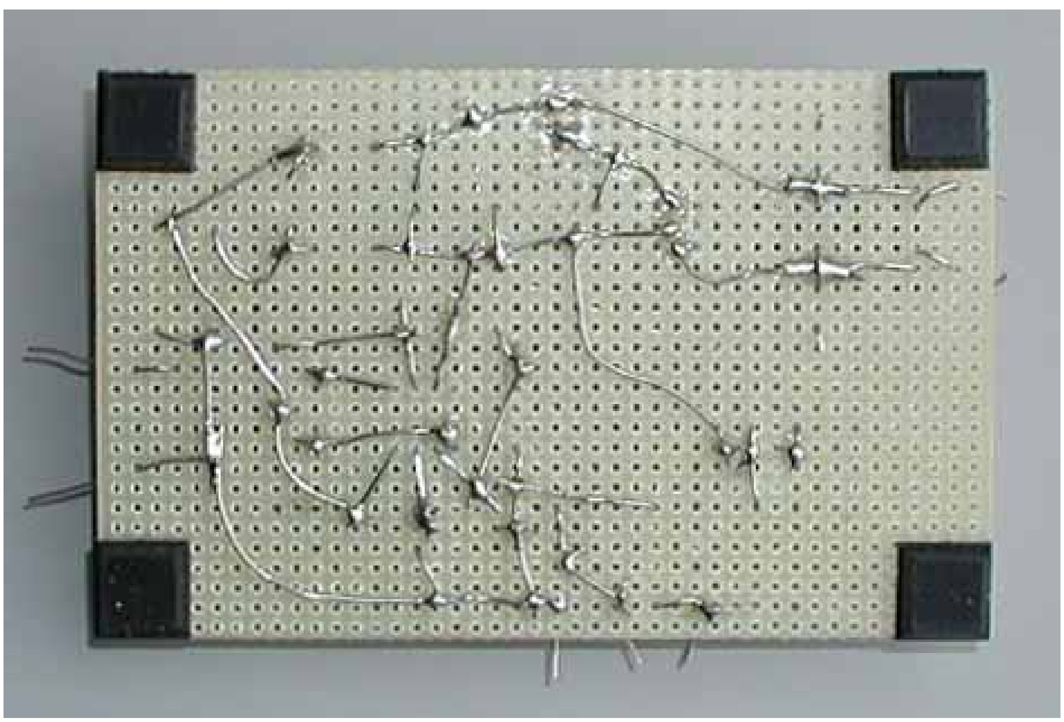


Figure 8: Wiring Plan, Bottom View

Installing the Op-Amp

When you have finished the wiring and checked everything; the circuit, the solder joints, no shorts, you can install the op-amp in its socket. Take precautions against static charges. Hold it so your fingers touch its pins and touch part of the wiring on your board with your other hand to bring it to the same potential. Then push the op-amp into place, being sure to match the notched end of the socket and that of the LF411 op-amp. (If you need to remove the op-amp for rewiring, remember to go through this procedure for both the removal and the reinstallation.)

Preparing and Adjusting the Amplifier

1. Setting the LVPS:

The LVPS should be set to give an output of $12V$. Once you have made that adjustment, the voltage divider made from the two $100\,\Omega$ resistors will supply you with $+6V$ and $-6V$ for the op-amp, and a zero common.

2. Zeroing the Amplifier:

Most op-amps have some dc offset in the output. Adjusting the potential difference between pin 1 and pin 5 with the $100\,k\Omega$ pot can eliminate this.

Set the MMM to the 5V range. Connect the negative side of your MMM to the ground of the amplifier (common, labeled 'C' in Figures 4-7). Connect the positive side of your MMM to the output, labeled 'B' in Figures 4-7. The input of the amplifier is labeled 'A' in Figures 4-7. Disconnect the ac input to the LVPS.

Plug in the LF411 op-amp and turn on the LVPS. There may be a deflection of the MMM needle, plus or minus. Short the input of the amplifier by using one of your clip leads to connect the lead labeled 'A' in the figures to common C. With the input of the amplifier still shorted, set your MMM to the $250\,mV$ range. Using a screwdriver on the amplifier's $100\,k\Omega$ pot, adjust the MMM to read zero and leave the pot at this position. This is called nulling or zeroing the amplifier; that is, adjusting the circuit to give a zero reading when there is no input. Once you have finished this step; disconnect the clip lead that shorted the input A to the common C.

3. Calibrating the Amplifier

Normally the input of the amplifier will be a signal from a microphone, etc. In Experiment MW (Microwaves), the signal will come from a coil or antenna. Now calibrate the amplifier by measuring input voltages and output voltages.
Determine the gain of the amplifier. Use as an input signal a dc voltage obtained from a $5\,k\Omega$ pot across the $12V$ LVPS output, followed by a voltage divider made up of $91\,k\Omega$ and $1.3\,k\Omega$ resistors. The calibration circuit is shown in Figure 8.

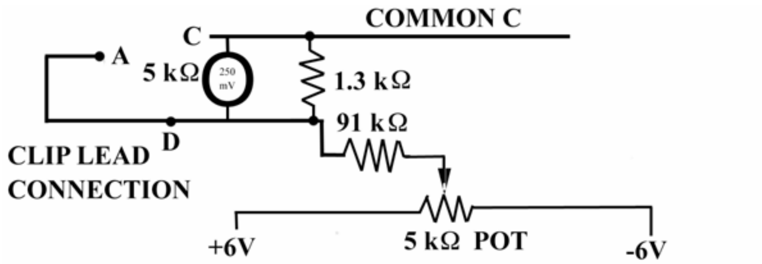


Figure 8: Calibration Circuit

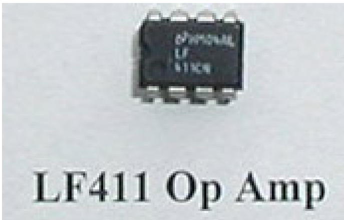
Connect your second MMM, set on 250mV DC, across the $1.3k\Omega$ resistor, that is, from the lead labeled 'D' in the Figure 8 to common C.

Connect lead D to the input A (use your clip lead), and vary the input by turning the $5k\Omega$ pot in both directions so as to make $10\,mV$ steps. Turning the $5k\Omega$ pot in one direction will make the input voltage minus so you will need to reverse the leads of the MMM in order to read the voltage. You will measure the output voltage with your first MMM set on 5DCV (as you did when you were adjusting the offset voltage). Again you may need to reverse the polarity of the MMM as needed. You will only be able to reach a maximum input voltage of $67\,mV$ in either direction. Tabulate your measurements of input and output voltages.

AMP Parts

1	op amp, LF411
1	socket, IC 8 pin dual inline
1	potentiometer, $100\,k\Omega$
1	potentiometer, $5k\Omega$
3	resistors, $100\,\Omega$ $1/2W$
2	resistors, $9.1k\Omega$ $1/2W$
1	resistor, $91k\Omega$ $1/2W$
1	resistor, $1.3k\Omega$ $1/2W$
1	resistor, $150\,k\Omega$ $1/2W$
1	capacitor, $0.05\,\mu F$
1 *ft*	wire, #22 red insulated solid
1 *ft*	wire, #22 bare solid

AMP PARTS


LF411 Op Amp


IC Socket, 8 pin

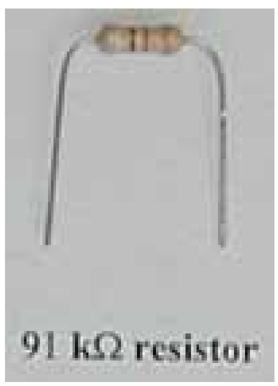

potentiometer 100kΩ


potentiometer 5kΩ


0.05 μF capacitor

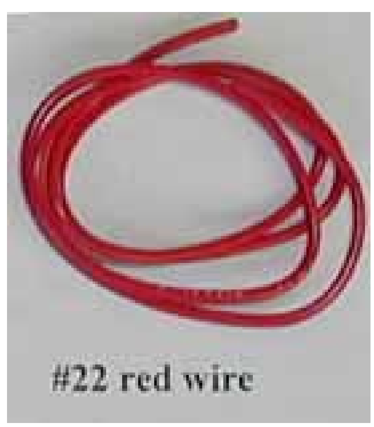

100 Ω resistor


9.1 kΩ resistor


91 kΩ resistor


150 kΩ resistor


#22 black wire


#22 red wire


#22 bare solid wire


1.3 kΩ resistor

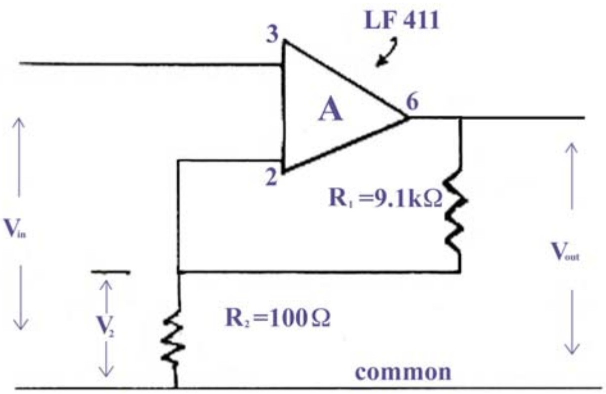
Building the AMP (Amplifier)

Report:

After you have made and tabulated your measurements of input and output voltages for the amplifier, plot the output voltage as a function of input voltage. Determine the gain of the amplifier in the region where the response is linear and compare your value with the theoretical expectation. Does the gain remain constant over the whole range of input voltages?

Problem 1: ***Amplification***

A negative feedback circuit in an amplifier circuit is shown in the figure below. In this circuit, the resistors have the values $R_1 = 9.1k\Omega$, $R_2 = 100\Omega$, and the open loop amplification is $A \approx 10^5$. Pin 3 is non-inverting and pin 2 is inverting.



a) What is the output voltage V_{out} of the op-amp in terms of the input voltage V_{in} to pin 3, and the voltage at pin 2, V_2, and the amplification A? (Note: all voltages are with respect to common).

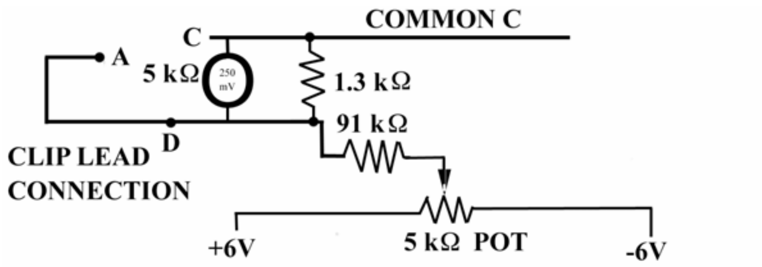
b) Derive an expression for the voltage at pin 2, in terms of R_1 and R_2.

c) Derive an expression for the closed loop gain $G = V_{out}/V_{in}$ in terms of R_1, R_2, and A.

d) Calculate the value of the gain G, clearly indicating any approximations you have made.

Problem 2: ***Calibration***

The calibration circuit for the amplifier is shown in the figure below. When the multimeter is set on the 250 mV scale the multimeter has a resistance of $5k\Omega$.



a) When the $5k\Omega$ pot is turned 2/3 of the way in the direction of the $+6V$ line from the $-6V$ end, what is the voltage difference between common C and the $5k\Omega$ pot slider?

b) When the $5k\Omega$ pot is set as in part a), calculate the voltage difference between the common C and point D which is connected via a clip lead to the input A?

c) What ouput voltage did you read when your pot was set as in part a) while you were calibrating your amplifier?