Amplifiers are a common occurrence in electronic circuits. An amplifier may consist of only one transistor (single transistor amplifier), or many transistors. Transistor amplifiers are used in high quality audio amplifiers. However, operational amplifier integrated circuits (op amps) are commonly used for simple voltage amplification in many applications. Op amps typically consist of tens of transistors. One of the least expensive and most common op amps is LM741, which consists of about 20 transistors. In this lab we will use the LM741 operational amplifier. Using a search engine look up the specification sheet and the pin diagram for this IC. For the details of structure, definitions, principles and applications of operational amplifiers visit the Wikipedia website at http://en.wikipedia.org/wiki/Operational_amplifier

To appreciate the wide usage of transistors, it is probably not too far-fetched to say that in our world the number of transistors exceed the number of insects! A single computer includes hundreds of millions of transistors.

Voltage amplifiers are of fundamental importance in electronics. An ideal voltage amplifier, in general, will have two inputs, \( v_1 \) and \( v_2 \), and one output \( v_o \). The relationship between the input and the output is given by \( v_o = A (v_2 - v_1) \), where \( A \) is the gain of the amplifier, which indicates the ratio of the output to the input of an amplifier. Ideally, the input impedance of the amplifier is infinity. A very large input impedance means that the device draws a negligible amount of current (close to zero). In practice, operational amplifiers are used for voltage and signal amplification. Various types of “op amps” are characterized based on their power consumption, frequency response, etc. The pin diagram for 741 op amp is illustrated below. The device has 8 pins. Note that the location of pin 1 is to the left of the small semi-circle etched in the bottom surface near the end of the device.
The important pins are the “input” pins (2, 3) and the “output” pin (6). Pins 1, 5 and 8 are unused in this experiment. This device requires two driving source voltages of $+V_{CC}$ and $-V_{CC}$. The device will operate for source voltages ranging from +/- 5 V to +/- 18 V. Let us use +/- 12 V for our experiment. Note that the Discovery Scope’s (DS) DC voltage output may not exceed +/- 5 V. Therefore, to power the op amp, it is recommended that you use a DC power supply (or a battery) capable of providing higher voltage outputs than the DS. Keep in mind that the amplified output signal may not exceed the voltages supplied by the power supply (+/- $V_{CC}$). For example, suppose you use a +/- 9 V power supply (battery) to power an op amp circuit designed to provide a gain of $A = 40$. Assume an input sinusoidal signal of 0.25 volts amplitude. Ideally one expects the amplitude of the output signal to be

$$V_{out} = A \times V_{in} = 40 \times 0.25 = 10 \text{ V}$$

But the maximum voltage in the circuit is limited by the voltage of the power supply. Therefore the output signal will be a sine wave clipped at +/- 9 V. In order to power such a circuit at home you can use two 9 V batteries. You can then use the wave generator and oscilloscope functions of your DS to make the measurements.

The following diagrams show simple “inverting” and a “non-inverting” amplifier circuits. The degree of amplification is determined by the values of resistors $R_1$ and $R_2$ (not specified in the diagrams). Note that in the case of the inverting amplifier the output signal is negative of the input signal amplified by a factor of - ($R_2/R_1$). The ratio of the output to input voltage (gain) is given by the following equation (without proof).

$$v_{out} / v_{in} = - (R_2/R_1)$$

The op amp can also be used as a difference amplifier, which will amplify $(v_b - v_a)$ and a summing (adder) amplifier, which will amplify $(v_b + v_a)$. The two voltages are connected to the op amp input through resistors. The difference or summing amplifiers are not shown here and will be treated in more advanced courses. Here is an inverting amplifier circuit:
A. Construct the inverting amplifier as shown above. In the event that your power supply does not simultaneously provide positive and negative voltages, reverse the red and black leads of a second power supply to create the necessary -12 V voltage. Connect a sine wave to R₁ (1 kΩ) with a peak-to-peak voltage of 400 mV, and choose 10 kΩ for R₂. Observe and measure $v_{\text{out}}$ using your oscilloscope, and experiment with the frequency response of the amplifier by ramping up the frequency. To measure the frequency response of the op amp, monitor the output voltage as you increase the signal frequency as explained in part B below. Carefully draw one cycle of the input and output signals with the correct scale.

B. Record the peak-to-peak voltage of $v_{\text{out}}$ for the input voltage frequencies of 1 KHz and confirm the inverting nature of this amplifier. Does $v_{\text{out}}$ decrease as the frequency increases? Increase the frequency and determine the frequency at which the output drops to the 0.707 of its maximum value at lower frequencies. This is the frequency at which the output has dropped by -3dB. Does the shape of the output voltage become distorted as the frequency increases? Your instructor will describe this section in more detail on the board.

C. Construct the non-inverting amplifier shown in the circuit below. Repeat part (A) for the same values of R₁ and R₂ at 1.0 kHz, and note that in this case

$$\frac{v_{\text{out}}}{v_{\text{in}}} = 1 + \left(\frac{R_2}{R_1}\right)$$

Carefully record the input and output signals to the scale in your lab book!

D. In this section examine the extent of voltage amplification that can be achieved with this simple amplifier. Clearly, $V_{\text{out}} = \left(\frac{R_2}{R_1}\right) V_{\text{in}}$. In order to increase the output voltage, we can increase R₂ or decrease R₁ (or both). Let us manipulate the size of R₁ by replacing it with a variable resistor (potentiometer). You can use the
potentiometer in your toolbox. Before doing so, measure the range of resistance of the potentiometer using a multimeter and set its value at 1 k. Replace R₁ with the 1 k potentiometer. Observe that the input and output signals remain unchanged. Now increase R₁ and observe the decrease in Vₜₐₐₜ. Next, decrease R₁ and observe that Vₜₐₐₜ increases. Continue decreasing R₁ and monitor the output voltage. At some point you should see that the peak-to-peak output voltage flattens at the peaks and does not increase anymore. This effect indicates that Vₜₐₐₜ has reached a saturation point. Measure the peak to peak voltage of the saturated Vₜₐₐₜ and explain why this saturation occurs. Draw two cycles of the saturated Vₜₐₐₜ in your lab book!

Finally note that the above inverting and non-inverting amplifier circuits both demonstrate negative feedback amplification in which the amplifier's output is fed back to the negative terminal of the op amp. Negative feedback is a critical concept employed in all electronic amplifiers. A positive feedback quickly leads to saturation and renders the amplifier useless. The concept of positive feedback is used in optoelectronic amplifiers such as lasers. Ask your instructor if you like to learn more about optoelectronic amplifiers and their associated positive feedback mechanisms. If curious about the concept of feedback, search the internet for more explanations!