In this lab we will be exploring the use of integrated circuit operational amplifiers to make a wide variety of electronic devices. For each device, you will need to choose appropriate values of resistances and capacitances to produce the desired function. You will then test the circuit with a variety of signals to check its performance. Once you have each circuit working and tested, check in with the instructor who will ask you some questions about the circuit and its behavior.

Data Sheets for the op amps we will be using are attached to the end of this write-up. The data sheets indicate the correspondence between the pin connections on the integrated circuit and the functional connections to the op amp.

Trouble-shooting: You may find that your circuit does not perform as expected. Here are some hints to help you pin-point the difficulties.

1. Check all resistors and capacitors with a multimeter before assembling your circuit.
2. Check all your circuit connections for loose wires or incorrectly connected wires.
3. Using a digital multimeter or an oscilloscope, check that the power supply voltages are reaching the desired pins on the integrated circuit.
4. Check that the signal voltage is reaching the op amp circuit.
5. Check that the voltages at the noninverting input and the inverting input are nearly the same. A deviation of more than a few millivolts can lead to trouble.

I. The Inverting Amplifier

![Inverting Amplifier Diagram]

Figure 1
A. Design and construct an inverting amplifier with a voltage gain of about ten. Choose resistance values for \( R_1 \) and \( R_2 \) that are neither too large nor too small (somewhere between 100 ohms and a few hundred thousand ohms).

Take data to produce a graph of the frequency dependence of the gain and also the frequency dependence of the phase difference between \( v_{in} \) and \( v_{out} \). N.B. - Include DC (frequency = 0) as one of the points at which you measure the gain; for \( v_{in} \), you can just use the DC offset from the function generator with the Amplitude control set fully counter-clockwise.

Then increase both \( R_1 \) and \( R_2 \) by a factor of ten (keeping the ratio the same) and take a few measurements to see how the gain and phase shift (as a function of frequency) have changed. Hint: you will see a difference, if any, at high frequencies.

B. Consider the amplifier you have constructed as a “black box”. That is, the black box is the op-amp itself together with the two resistors, \( R_1 \) and \( R_2 \). Measure the input impedance of this black box for a 1 kHz sine wave signal. Compare your result with what you expect for the input impedance.

C. Now investigate the output properties of this black box, that is, the way in which \( v_{out} \) varies when a “load” resistor (\( R_L \)) of adjustable size is connected across the output terminals. Be careful - if this were a perfectly linear amplifier, it would appear from the output terminals to be a voltage source (an amplified version of \( v_{in} \)) in series with an output impedance (preferably small); then \( v_{out} \) would slowly decrease as \( R_L \) is reduced. You may well find, though, that the behavior is not quite so simple. Nevertheless, see what you can determine about the output capability of the amplifier - an important thing to know about. How does \( v_{out} \) vary as \( R_L \) is reduced? Does this behavior depend on how large \( v_{out} \) is? That is, set the input so that \( v_{out} \) has some specific value with \( R_L = \infty \), and study the output behavior as \( R_L \) is reduced. Then try it again with a different input amplitude \( v_{in} \). Try to figure out what the op amp is doing.
II. The Non-Inverting Amplifier

A. Design and construct a non-inverting amplifier with a gain of about 20 and investigate its voltage gain and phase shift as you did for the inverting amplifier.

B. Measure the gain of the non-inverting amplifier in which $R_1 = \infty$ and $R_2 = 0$. Note: This circuit is referred to as a “Voltage Follower” and is used in circuits where you want a high input impedance “buffer” between one part of a circuit and another.

III. An Integrator

Design and construct an op amp integrator that will convert a 1 kHz square wave with an amplitude of 0.1 volt into a triangular wave with an amplitude of 1 volt. Test the circuit. NOTE: You may need to use the DC OFFSET control of the function generator to guarantee that the square wave is exactly symmetrical around zero.
IV. A High-Pass Amplifier

Design and construct a high-pass amplifier that has a gain of about 10 for high frequencies and a “-3dB” frequency of 100 Hz. **Reminder:** $2\pi \neq 1$. Measure the voltage gain and phase shift as a function of frequency and see if they match the predictions derived in class. Produce a graph to compare your measurements to the theoretical predictions.

V. An Oscillator

With appropriate connections, the op amp can become an oscillator, producing a time-varying $v_{out}$. from P35 lab

VI. A Design Problem

Your **formal report** for the lab will be based on this section of work only. The report should be addressed to someone who knows about op amps but who is unfamiliar with this particular circuit. The report should explain your design considerations and should include a circuit diagram of your final circuit, an estimate of the costs of the components (catalogs will be available in lab) and a description of your test results, including voltage gain and phase shift as a function of frequency and input and output resistances for a 1 kHz sine wave signal. You should also describe and explain the response of your circuit to a square wave of various frequencies.

You should attach to the report a cost estimate for your amplifier, including itemized costs of the op amps, a power supply, the resistors and capacitors. Note: for the resistors you will need to decide what “power rating” you need. For the capacitors you need to specify a maximum voltage rating. Electronics catalogs will be available to help you find the appropriate items.

**The design problem:**

We require a **band-pass** amplifier that will provide a voltage gain of 15 ($\pm 2$) for a 1 kHz frequency sine-wave signal and has -3 dB frequencies of 100 Hz and 10 kHz ($\pm 10\%$ in each case.) It should be able to produce a 10 volt amplitude signal across a 1 kOhm load.
resistance. The input impedance must be 100 (±10) kOhm. Your design should include specification of the power ratings of the resistors you use and the voltage rating of the capacitors. **HINT:** Use two op amps, one for the low-pass part, one for the high-pass part.