5. Operational Amplifier

Learning Objectives

Design, build, and characterize an operational amplifier.

Assignments Before the Laboratory Session

Operational amplifiers are used in amplifying signals. In the data sheet of µA741, the following information can be found. When the dual inline package (DIP) is placed on a prototype circuit board with the notch located at the left side, pin 1 is located at the lower left corner of the device. Pins are counted in the counter-clockwise direction. Pin 2 is the inverting input. Pin 3 is the non-inverting input. Pin 4 is the negative power supply. Pin 7 is the positive power supply. Pin 6 is the output. Pin 1 and pin 5 are for offset adjustment. The maximum output voltage swing is ±14.3 V with ±15 V power supply. The typical output short-circuit current is 25 mA. The typical slew rate, i.e., how fast the output voltage can change, is 0.5 V/µsec.

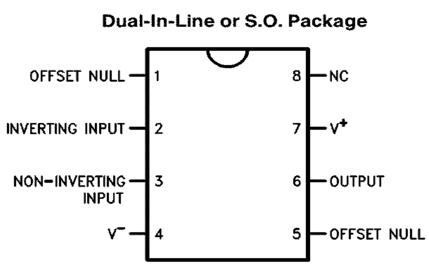

Fig. 1. The pin diagram of the 741 operational amplifier.

Following parts are required in this experiment:

1. A µA741 operational amplifier
2. A collection of resistors and a 10-kΩ potentiometer

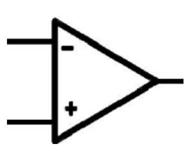

Fig. 2. The schematic symbol of an operational amplifier.

The schematic diagram of the operational amplifier is shown in Fig. 2. It has two input ports. One is the inverting input (V_-), i.e., the output signal is 180º out of phase with respect to the input signal. The other is the non-inverting input (V_+). The intrinsic open-loop gain, A, of a typical operational amplifier is very large, i.e., >10,000. It is internally compensated and short-circuit protected. It has an excellent stability in a closed loop, i.e., with feedback. For dc input, dual voltage power supply with both positive and negative voltages is needed. The common node of the dual voltage power supply should be connected to the ground bus on the prototype circuit board. For ac coupling and amplification, a single voltage power supply is sufficient.

The output voltage, V_o, is related to the input voltages by:

$$V_o = A \cdot (V_+ - V_-) \tag{1}$$

If there is no feedback loop in the circuit, because of the large open-loop gain, a very small input is sufficient to drive the operational amplifier into saturation, i.e., the nonlinear regime. For example, a small, sine wave input can produce a large, square wave output.

When a feedback loop is connected, the amplifier can operate as an oscillator with positive feedback or a linear amplifier with negative feedback. For positive feedback, a portion of the output signal is brought to the non-inverting input. For negative feedback, the output is connected to the inverting input via a resistor. A simple inverting amplifier is shown below.

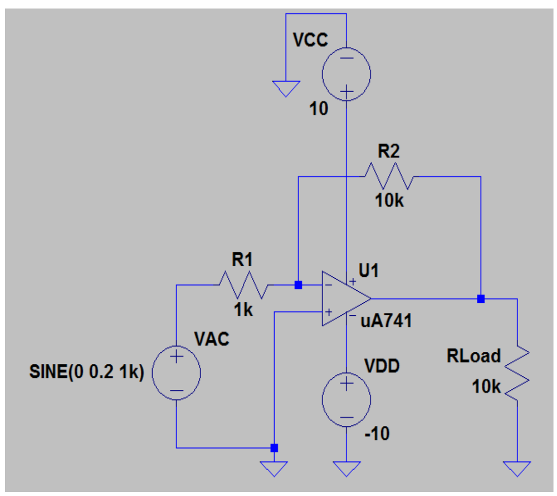

Fig. 3. A simple inverting operational amplifier circuit. Please note that pin 7 is the connected to 15 V; pin 4 to -15 V. Pins 1 and 5 are for offset adjustment. R_2/R_1 determines the gain. R_3 is the load resistor.

Since the input impedance of the operational amplifier is very large, any current provided by the signal source must flow through the feedback resistor, R_2. In addition, the open-loop gain is very large. Therefore, the voltage difference between the two input ports must be nearly zero. Since the non-inverting input is connected to ground, the inverting input port is virtually grounded, i.e., at zero volt. One can easily find the voltage gain, which is the ratio of the output voltage to that of the input, V_o/V_{in}, from these two conditions. The negative sign simply means that the phase of the output signal is 180^o from that of the input signal, or, a positive input voltage is amplified to become a negative output voltage.

$$A_v = -\frac{R_2}{R_1} \tag{2}$$

The negative sign simply means that the phase of the output signal is 180^o from that of the input signal, or, a positive input voltage is amplified to become a negative output voltage. The input impedance of operational amplifier is large but not infinite. The output impedance is low but non-zero. Therefore, resistors in the range of kΩ to a few hundred kΩ should be used in constructing the amplifier circuit. Otherwise, the assumptions used in deriving the voltage gain become invalid. The measured gain would, therefore, deviate from what the simple equation predicts.

Simulations of operational amplifier circuits can be performed easily by using any one of the circuit simulation programs. You can explore characteristics of the operational amplifier, such as relation between voltage gain and the bandwidth.

Activities During the Laboratory Session

Verify the integrity of the oscilloscope probe by connecting it to the internal square wave source. Verify the integrity of the multimeter test lead by measuring its resistance.

Build an inverting operational amplifier with a gain of -10X. Do not attach any load resistor. Review Exp. 1 on how to connect the dual voltage power supply. Don't forget to set the current limit. Connect the common ground of the power supply to the ground bus on the prototype circuit board. To prevent oscillation from happening, place a 0.1 µF capacitor between the positive power supply bus (rail) on the prototype circuit board to ground. Do the same for the negative power supply. After all circuit connections are verified, push the output button on the power supply to activate its output.

Examine the gain of the amplifier at 1 kHz with an input voltage of 1 V peak-to-peak. Both the input and output waveforms should be sinusoidal. Increase the input signal gradually towards 3 V. The output waveform saturates and becomes clipped. Record the saturation voltage which should be near the power supply voltage. Reduce the input voltage back to 1 V. Record the peak-to-peak voltage of the sinusoidal waveform. Attach a load resistor. Start with a large resistance, e.g., 1 kΩ. Reduce load resistance gradually. Eventually, the output voltage starts to decrease as waveform becomes clipped indicating that the load current has reached the limit of the current driving capability of the operational amplifier. Record the current driving capability by dividing the measured peak voltage by the resistance of the load when waveform clipping just starts to appear. Remove the load resistor.

Measure the frequency response of the amplifier from 20 Hz to 200 kHz. Mark the -3dB frequency. Is there any roll off on the low frequency side? Can the operational amplifier operate at dc? Replace R_2 with a resistor of ten times the resistance. What is the gain? Measure the frequency response again. Mark the -3dB frequency. As the gain increases, the bandwidth is reduced.

If high gain and large bandwidth are required at the same time, one must cascade two or more amplifier stages, each with a moderate gain. Because the gain is moderate, the bandwidth remains large. Using multiple amplifier stages, the overall gain can become quite large. While cascading operational amplifiers, one must adjust the offset. When the input signal is zero, the output should also be zero. If this is not the case, there is an offset. Attach a potentiometer around 15 k between pin 1 and pin 5. The center wiper pin is connected to the negative power supply bus. Ground the input signal. Adjust the potentiometer until the output offset is nearly zero.

At the end of laboratory session, turn off all equipment. Instead of logging out, shut down the computer. Turn off the monitor. Why? We would like everybody to put energy conservation into practice. The only drawback is the stress put on the hard drive when it spins up.

Activities After the Laboratory Session

Prepare a short summary with interpretation of data or conclusion. Do not simply copy the circuit diagram in the laboratory manual. Draw your own circuit diagrams and perform simulations. Copy the circuit diagram that you have simulated and paste it into the report.

Read http://focus.ti.com/lit/an/sloa093/sloa093.pdf for more filter circuits and how to design them.

Self Study

1. Can you draw an operational amplifier circuit with a gain of –10? How is the gain determined?
2. You need to memorize pins of 741 operational amplifier without looking at the data sheet.
3. What is the relationship between gain and bandwidth? Can you get high gain and high bandwidth at the same time?
4. How do you build an operational amplifier with an output in phase with the input signal? Look for information on “non-inverting amplifier.”

Cover and Score Sheet
Experiment 5 – Operational Amplifier

Author:______________________________ Partner:_________________________

Score

Item	Credit	Score
Data - Operational Amplifier	4	
Circuit Diagram		
Saturation Voltage		
Measured Bode Plot of -10X Amplifier; -3dB frequency		
Measured Bode Plot of -100X Amplifier; -3dB frequency		
Conclusion	1	
Total	**5**	

TA Signature:________________________ Date:______________________________