EE283 Lab 7
Operational Amplifiers
Inverting and Noninverting

Objective:

To understand how operational amplifiers (op amps) work and the equations used in their operation.

Theory:

Figure 1 shows the symbol for an operational amplifier. The amplifier has two supply voltages. The positive supply voltage is called V_{CC} and is typically +15 V_{DC}. The negative supply voltage is called V_{EE} and is typically -15 V_{DC}. In some applications either V_{CC} or V_{EE} could be connected to ground so that the amplifier operates from a single supply voltage. The amplifier also has an output terminal and differential inputs.

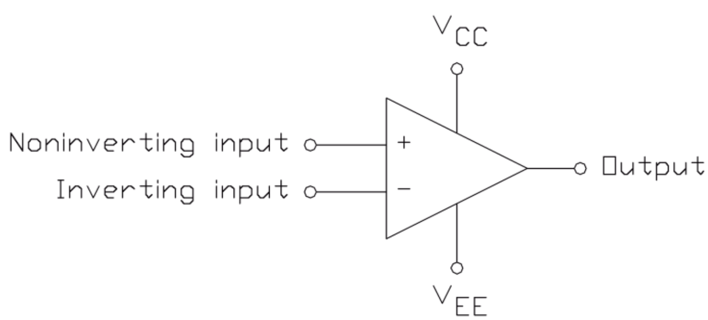


Figure 1
Operational Amplifier Symbol

Figure 2 shows the simplified equivalent circuit of the operational amplifier.

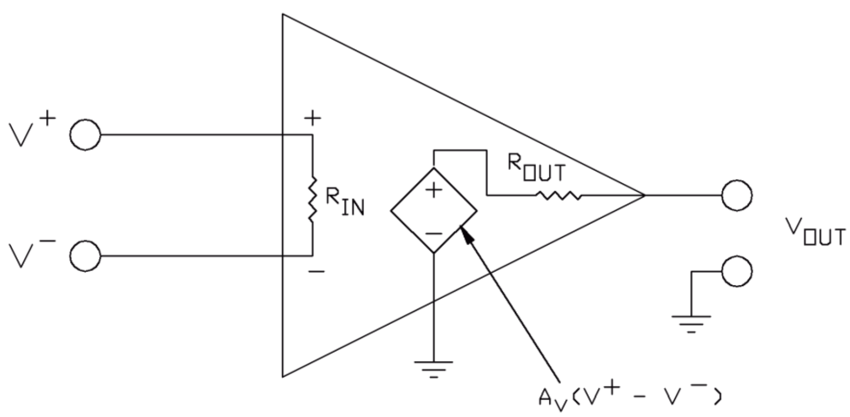


Figure 2
Simplified Equivalent Circuit

In an ideal amplifier the amplifier gain, A_V, and the input resistance, R_{IN}, are very large and can be considered infinite. The output resistance, R_{OUT}, is very small and can be considered zero ohms. Typical values of A_V, R_{IN} and R_{OUT} are 1 million, 2 megaohms and 75 ohms respectively. In a practical amplifier the output voltage cannot exceed the positive supply voltage, V_{CC}, or go below the negative supply voltage, V_{EE}. Using positive and negative supply voltages allows the amplifier to operate from single ended input voltages and have an output voltage which can swing both positive and negative. External components provide negative feedback to the amplifier inputs to keep the output voltage within its operating range. Let's say the amplifier output voltage is +10 volts and the amplifier gain, A_V, is 1 million. Since $V_{OUT} = A_V(V^+ - V^-)$ the differential input voltage, $V^+ - V^-$, is V_{OUT}/A_V or $10/1x10^6$ or 10µV. You can consider this voltage to be zero volts for all practical purposes.

There are only three simple rules in designing circuits using operational amplifiers:

- The inverting input (V^-) and the noninverting input (V^+) each have a very high impedance and can neither source or sink current.
- The high amplifier gain, A_V, forces (by means of negative feedback) the inverting input voltage to be equal to the noninverting input voltage. i.e. $V^- = V^+$.
- The amplifier output resistance (not R_{OUT}) is reduced to zero ohms by means of negative feedback.

Design Equation – Inverting Amplifier

Figure 3 shows a basic inverting amplifier using an operational amplifier. Resistor, R_F, provides the negative feedback.

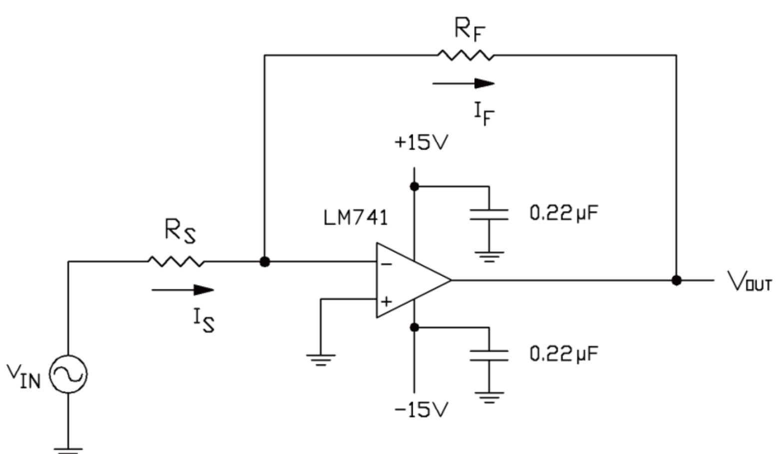


Figure 3
Inverting Amplifier

The design process is as follows:

- The noninverting amplifier input, V^+, is grounded.
- Since $V^- = V^+$ the inverting input, V^-, is also at zero volts (but not grounded).
- The input current, I_S, is therefore

$$I_S = \frac{V_{IN}}{R_S}$$

- Since no current flows into the inverting input terminal $I_F = I_S$.
- Therefore

$$I_S = I_F = \frac{V_{IN}}{R_S} = \frac{0 - V_{OUT}}{R_F}$$

And the voltage gain is

$$\text{Voltage Gain} = \frac{V_{OUT}}{V_{IN}} = -\frac{R_F}{R_{IN}}$$

The negative sign in this equation means that this is an inverting amplifier. If you put a positive voltage into the amplifier you will get a negative voltage at the amplifier output. The voltage gain is simply the ratio of two resistors. The operational amplifier gain, A_V, does not enter into this equation. The value of the 0.22µF capacitors also does not enter into the gain equation. The capacitors are present to prevent the amplifier from oscillating due to the long leads connecting the amplifier to the power supply.

Design Equation – Noninverting Amplifier

Figure 4 shows a basic noninverting amplifier using an operational amplifier. Resistor, R_F, provides the negative feedback.

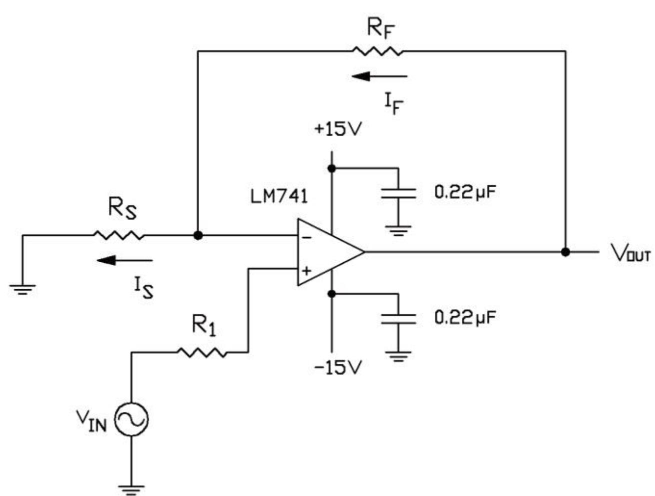


Figure 4
Noninverting Amplifier

The design process is as follows:

- Since no current flows into the noninverting input terminal $V^+ = V_{IN}$. It doesn't matter what the value of R_1 is – it could be zero ohms.
- Since $V^- = V^+$ the inverting input, V^-, also equals V_{IN}.
- The current, I_S, is therefore

$$I_S = \frac{V_{IN}}{R_S}$$

- Since no current flows into the inverting input terminal $I_F = I_S$.

- Therefore

$$I_S = I_F = \frac{V_{IN}}{R_S} = \frac{V_{OUT} - V_{IN}}{R_F}$$

  And the voltage gain is

$$\text{Voltage Gain} = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{R_{IN}}$$

There is no negative sign in this equation which means that this is a noninverting amplifier. If you put a positive voltage into the amplifier you will get a positive voltage at the amplifier output. The voltage gain is simply 1 plus the ratio of two resistors. The operational amplifier gain, A_V, does not enter into this equation.

Limitations:

- The output voltage of the op amp that we will be using for this exercise, a LM741, cannot swing up to the supply voltages. If ±15 V_{DC} power supplies are used the output voltage will be limited to about ±13 volts.
- The LM741 output cannot supply unlimited current. The maximum output current cannot exceed approximately 10mA before the op amp limits the output voltage and all of the above equations no longer apply.
- The LM741 op amp gain, A_V, begins to decrease at approximately 5 Hz. This means that for most circuits the maximum useable frequency will be less than 10 KHz.

Equipment:

- Tektronix TBS 1064 Oscilloscope
- Tektronix AFG 1022 Function Generator
- Keithley 2231A-30-3 Power Supply
- LM741 Operational Amplifier
- Breadboard

Procedure:

Figure 5 shows the top view of the 741 operational amplifier. The notch in the end of the package denotes the pin layout as shown in the figure. This amplifier has to be installed on the breadboard in the manner shown in the appendix – the leads on each side of the package must straddle each side of the "trench" in the breadboard. The figure in the appendix shows a 14 pin package but the LM741 has only 8 pins. The orientation is still the same. Make sure all of the pins are inserted into the breadboard holes properly. Do not use force to insert the op amp.

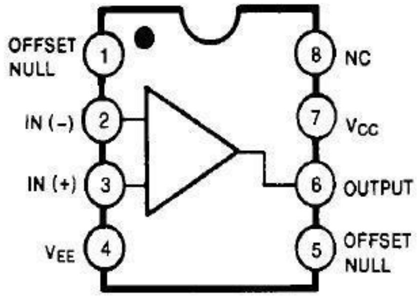


Figure 5
LM741 Pinout – Top View

To supply the ±15 V_{DC} voltages use the two variable power sources in the Keithley 2231A-30-3 Power Supply. They are to be connected as shown in Figure 6.

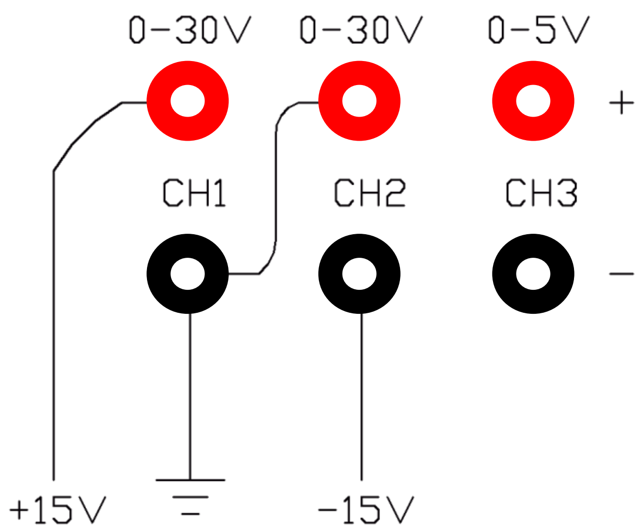


Figure 6
Power Supply Connections

Make sure the voltages are adjusted to 15 volts before connecting them to the breadboard. Set the power supply current limit to $0.1A_{DC}$

Inverting Amplifier:

Construct the circuit shown in Figure 3 on the breadboard. Use the Tektronix AFG 1022 Function Generator to provide the voltage source, V_{IN}. Set the magnitude of this voltage source to 1.0 V_{PEAK} and set the frequency, f, to 1000 Hz. Connect Channel 1 of the Tektronix TBS 1064 Oscilloscope to measure the voltage at V_{IN} (the output of the signal generator) with respect to ground. Connect Channel 2 of the Tektronix TBS 1064 Oscilloscope to V_{OUT}. You are to design an amplifier with the following characteristics:

- The gain V_{OUT}/V_{IN} is to be -2.7
- The input impedance is to be 1K

A copy of Figure 3 with all component values shown must be included in the report. The report should also contain your design equations and a figure showing the input and output waveforms. The figure must be properly annotated which means a title, axis labels and scales. The waveforms must be identified (i.e. V_{OUT} and V_{IN}). Just Ch 1 and Ch 2 is not sufficient. Calculate the actual gain from the voltages in your figure and include this calculation in your report.

Increase the output of the Tektronix AFG 1022 Function Generator to 6.0 V_{PEAK}. Include in your report a figure showing the input and output voltage waveforms. Calculate the actual gain from the voltages in your figure and include this calculation in your report.

Noninverting Amplifier:

Construct the circuit shown in Figure 4 on the breadboard. Use the Tektronix AFG 1022 Function Generator to provide the voltage source, V_{IN}. Set the magnitude of this voltage source to 1.0 V_{PEAK} and set the frequency, f, to 1000 Hz. Connect Channel 1 of the Tektronix TBS 1064 Oscilloscope to measure the voltage at V_{IN} (the output of the signal generator) with respect to ground. Connect Channel 2 of the Tektronix TBS 1064 Oscilloscope to V_{OUT}. You are to design an amplifier with the following characteristics:

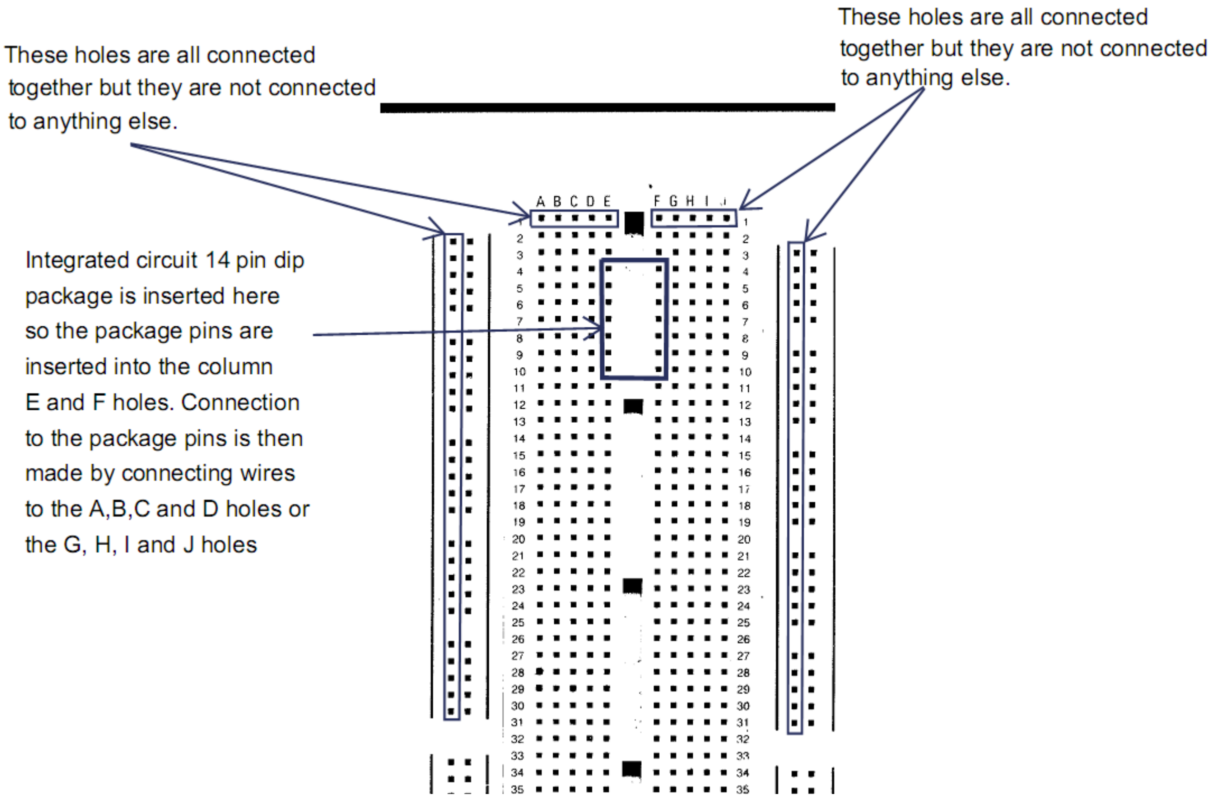
- The gain V_{OUT}/V_{IN} is to be +3.7
- The value of R_1 is to be 1K

A copy of Figure 4 with all component values shown must be included in the report. The report should also contain your design equations and a figure showing the input and output waveforms. The figure must be properly annotated which means a title, axis labels and scales. The waveforms must be identified (i.e. V_{OUT} and V_{IN}). Just Ch 1 and Ch 2 is not sufficient. Calculate the actual gain from the voltages in your figure and include this calculation in your report.

Change the value of R_1 in Figure 4 to 10K. Keep the magnitude of the Tektronix AFG 1022 Function Generator voltage source set to 1.0 V_{PEAK}. Include in your report a figure showing the input and output voltage waveforms. Calculate the actual gain from the voltages in your figure and include this calculation in your report. Compare the voltage gains with R_1 set to 1K and 10K. Are they different? If so why are they different. If they are the same, why are they the same?

Appendix A

Breadboard Connections



EE283 Laboratory Exercise 7 Form Report

Name:_______________________ Section:_____ Station:_____ Date:___________

Show Figure 3 with component values here

Show inverting amplifier design equations here

Show inverting amplifier input and output waveforms for V_{IN}=1 volt here

Show inverting amplifier gain and calculations from waveforms (V_{IN}=1 volt) here

Show inverting amplifier input and output waveforms for V_{IN}=6 volts here

Show inverting amplifier gain and calculations from waveforms(V_{IN}=6 volts) here

Show Figure 4 with component values here

Show noninverting amplifier design equations here

Show noninverting amplifier input and output waveforms for V_{IN}=1 volt (R1=1K) here

Show noninverting amplifier gain and calculations from waveforms (V_{IN}=1 volt R1=1K) here

Show noninverting amplifier input and output waveforms for V_{IN}=1 volt (R1=10K) here

Show noninverting amplifier gain and calculations from waveforms (V_{IN}=1 volt R1=10K) here

Comparison of noninverting amplifier gain between R1=1k and R1=10K