EE254: Electronic Instrumentation

Applications of Operational Amplifiers I

Group No.		Reg. No.	

Note 1 :: Objectives

The modern operational amplifier is a very useful and versatile building block for thousands of circuits in applications as diverse as audio, video, communications, process control, instrumentation, and biomedicine. This lab studies some of the basic uses of op amps. Because the main use of the op amp is as an amplifier, the three most common configurations will be studied. These include the inverting, non-inverting, and differential amplifier circuits.

Note 2 :: Materials and Equipment

- 741 Op-Amp
- Assorted Resistors
- DC dual power supply
- Function generator

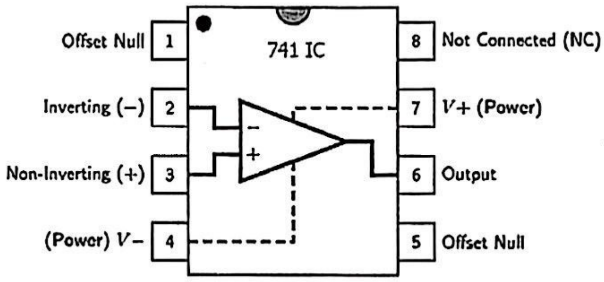

Fig. 1: 741 Op-Amp

Note 3 :: Theory

The primary uses of the operational amplifier is signal amplification and performing mathematical operations on signals, such as addition, subtraction, integration, differentiation etc. Based on three input modes of the op-amp we can create inverting, non-inverting and differential amplifier for signal amplification.

Any op-amp will act as a differential amplifier and amplify the voltage difference at its two inputs. The open-loop gain of an op-amps is very large, therefore, in its open loop configuration op-amp drives into either positive or negative saturation and act as a comparator. By using negative feedback, op-amps can be designed to have a much smaller and variable gains as required.

The op-amp draws very little current into its inputs which is assumed to be zero due to high input impedance. With negative feedback, we can show that the voltages at the inverting and the non-inverting terminals should be approximately the same (potential) at all the times. Based on these assumptions, a simple procedure for op-amp analysis can be formed. Once the op-amp is integrated into a circuit, it can be easily analyzed through the following steps:

– Write the node equation at the inverting terminal.
– Write the node equation at the non-inverting terminal.
– Set the voltage at the inverting terminal equal to the voltage at the non-inverting terminal.
– Solve for the gain.

Pre-Lab 1 :: Inverting Amplifier

One of the most common operational amplifier designs is the inverting amplifier (Fig. 2). Derive the equation for the inverting amplifier gain given below using circuit analysis procedure mentioned in Note 3. State all the assumptions you make.

$$A_v = \frac{v_O}{v_I} = -\frac{R_2}{R_1}$$

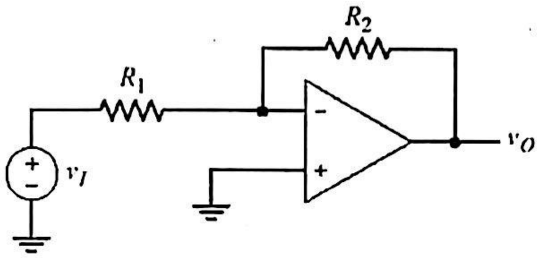

Fig. 2: Inverting Amplifier

Activity 1 :: Inverting Amplifier

1. Construct an inverting amplifier with R_I=2.2 kΩ, R_2=39 kΩ. Take Op-Amp supply voltage as $+v_s = 15\ V$ and $-v_s = -15\ V$.
2. Apply a 1Vp-p, 1kHz sinusoidal input signal to the amplifier.
3. Increase the input voltage until distortion occurs at the output.
3. Reduce the input voltage to a point where there is no distortion occurs at the output.
4. Display V_I and V_o at the same time on the oscilloscope using dual channel mode.
5. Measure the peak to peak voltages V_I and V_o.

V_I = ______________________________ V_O = ______________________________

6. Calculate the gain of the inverting amplifier using measured values.

7. Calculate numerically value of inverting amplifier gain using equation derived in Pre-Lab 1. Compare this value to value obtained in step 6.

8. Measure peak to peak voltages V_I and V_o for given frequencies.

Frequency/Hz	V_I/Volts	V_o/Volts	Voltage Gain
100			
200			
300			
400			
500			
1k			
2k			

8. Comment on the variation in voltage gain with frequency.

Pre-Lab 2 :: Non Inverting Amplifier

Another common op-amp configuration is the non-inverting amplifier (Fig. 3). This amplifier has a very high input impedance and does not invert the signal. Derive the equation for the non inverting amplifier gain given below. State all the assumptions you make.

$$A_v = \frac{v_O}{v_I} = 1 + \frac{R_2}{R_1}$$

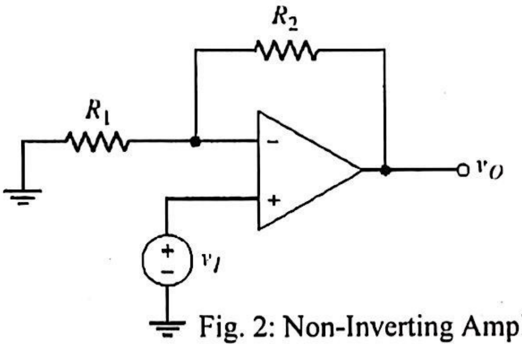

Fig. 2: Non-Inverting Amplifier

Activity 2 :: Non Inverting Amplifier

1. Construct a non-inverting amplifier with R_1=2.2 kΩ, R_2=39 kΩ. Take Op-Amp supply voltage as $+v_s = 15\ V$ and $-v_s = -15\ V$.
2. Apply a 1Vp-p, 1kHz sinusoidal input signal to the amplifier.
3. Increase the input voltage until distortion occurs at the output.
3. Reduce the input voltage to a point where there is no distortion occurs at the output.
4. Display V_I and V_o at the same time on the oscilloscope using dual channel mode.
5. Measure the peak to peak voltages V_I and V_o.

V_I = ______________________________ V_O = ______________________________

6. Calculate the gain of the non-inverting amplifier using measured values.

7. Calculate numerically value of non-inverting amplifier gain using equation derived in Pre-Lab 1. Compare this value to value obtained in step 6.

8. Measure peak to peak voltages V_I and V_o for given frequencies.

Frequency/Hz	V_I/Volts	V_o/Volts	Voltage Gain
100			
200			
300			
400			
500			
1k			
2k			

8. Comment on the variation in voltage gain with frequency.

Note 4 :: Differential Amplifier

The differential amplifier is designed to amplify the difference between the two input signals (Fig. 03). If the four resistors satisfy the relationship, $R_2/R_1 = R_4/R_3$, then the gain of this amplifier is given by:

$$v_O = \frac{R_2}{R_1}\left(v_{I2} - v_{I1}\right)$$

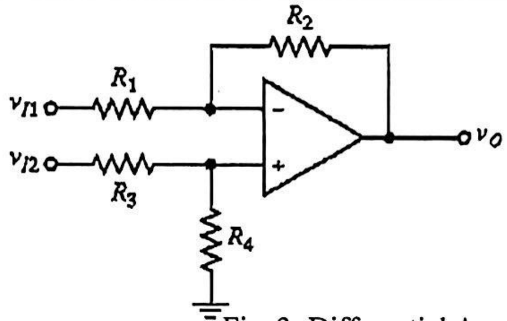

Fig. 3: Differential Amplifier

Note 5 :: Common Mode Rejection Ratio

Because the differential amplifier only amplifies the difference between the two input signals, it rejects common mode signals (signals which are common to the two inputs). Therefore, if common noise appears at both inputs, it will be rejected. For this reason, the differential amplifier is used in very noisy environments to reject noise.

An ideal differential amplifier only amplifies the voltage difference between its two inputs.

- ***Differential-mode input voltage*** is defined as the difference of applied inputs,

$$v_d = v_{I2} - v_{I1}$$

- Therefore, the output of the differential amplifier v_{od} is,

$$v_{od} = A_d v_d = A_d\,(v_{I2} - v_{I1})$$

- ***Differential-mode Gain*** is, therefore defined as,

$$A_d = \frac{v_{od}}{v_d} = \frac{v_{od}}{v_{I2} - v_{I1}}$$

However, the output of practical/real differential amplifier depends not only upon v_d. Input voltage that is simultaneously applied between both inputs (like noise, offset voltages etc.) will also be amplified.

- ***Common-mode input voltage*** is defined as the average of applied voltages.

$$v_{cm} = (v_{I2} + v_{I1}))/2$$

- Therefore, the output of the differential amplifier for the common mode signal is,

$$v_{ocm} = A_{cm} v_{cm} = A_{cm}\,(v_{I2} + v_{I1})/2$$

- ***Common-mode Gain*** is, therefore defined as,

$$A_{cm} = \frac{v_{ocm}}{v_{cm}} = \frac{2v_{ocm}}{v_{I2} + v_{I1}}$$

The generic output of a real op-amp differential amplifier is then given by,

$$v_o = A_d v_d + A_{cm} v_{cm}$$

In general, what we expect from the differential amplifier is to have a large A_d and smaller A_{cm} to eliminated common mode effects. To measure the common mode rejection capabilities of the differential amplifier, a measure called common mode rejection ratio is used.

- ***Common Mode Rejection Ratio*** is defined as,

$$CMRR = \frac{A_d}{A_{cm}}$$

$$CMRR_{dB} = 20\log_{10} CMRR$$

The performance of a real op-amp differential amplifier is most commonly measured in terms of CMRR. For LM 741 op-amp CMRR is 70dB or approx.3000. Because the common mode rejection ratio in a typical op-amp is so high, common-mode gain is usually not a great concern. A high CMRR is required when a differential signal must be amplified in the presence of a large common-mode input, such as EMI noise etc. For ideal case A_d is infinite and A_{cm} is zero.

Activity 3 :: Differential Amplifier

1. Build the differential amplifier in Figure 3. Take $R_2=R_4=39k\Omega$ and $R_1=R_3=2.2\ k\Omega$. Then, bias the amplifier with +15V or -15V. By applying a 1Vp-p, 200 Hz signal between two inputs connecting function generator output to v_{I2} and ground to v_{I1}.

Calculate the differential gain of this circuit,

A_D= ____

2. Apply a common mode signal to the amplifier (this is done by connecting the function generator simultaneously to both non-inverting and inverting inputs of the op-amp). Measure the common mode gain of this amplifier.

A_{cm}= ____

3. From steps above calculate the Common Mode Rejection Ratio CMRR.

$CMRR(1)$=

4. Make a web search and from the data sheet, specify the value of CMRR for 741 circuit.

$CMRR(2)$=

4. Compare the values and write down your comments on these values.

Homework1 :: Common Mode Rejection Ratio

Calculate V_o from a differential amplifier with differential gain equals to 100, when non-inverting terminal input, V_1= 1050μV and inverting terminal input, V_2= 950 μV,

a) If CMRR=100

b) If CMRR=10,000

c) If CMRR = ∞ (ideal opamp)

Homework2 :: Effect of Rise Time on Useful Bandwidth of a Op-Amp

Rise time indicates how fast an op-amp can respond to a change in the voltage signal. Explain how the rise time of an op-amp limit the useful operational bandwidth of an op-amp.