LESSON 18
SIGNAL CONDITIONERS

Signal conditioning involve modification of the signal and often include scaling (attenuation or amplification), conversion from current to voltage, integration and differentiation. In the current lecturer we will discuss a variety of circuits which are used for signal conditioning.

2.17.3 Voltage Follower (Isolation) Mode.

An interesting result is obtained when the feedback resistor R_f = 0 as shown in Fig. 26.10.

For such a circuit we have,

$v_0 = v_i$

In other words, the output of the OPAMP exactly tracts the input voltage in sign and magnitude. This is the reason why this circuit is called a voltage follower.

The result of Eqn. 26.11 can be found form direct application of Eqn. 26.1. Observe in Fig. 26.10 that by physical connection v_ is equal to v0. Therefore, from Eqn. 26.1,

$v_0 = A_{VOL}\, v_d = A_{VOL}\, (v_1 - v_0)$

$$\therefore \quad \frac{v_0}{v_1} = \frac{A_{VOL}}{1 + A_{VOL}} = 1$$

as $A_{VOL} >> 1$

The direct connection of the output voltage to the non-inverting terminal of the OPAMP represents the case when 100% negative feedback of the output to the input. In such cases the output to the input. In such cases the output quantity by the Eqn. 26.13. Of course when the open loop gain A_{VOL} is allowed to assume large values compared to unity the corresponding closed loop gain becomes approximately unity. However, a unity gain is not the only feature of the voltage follower. A more detailed analysis of the equivalent circuit of the OPAMP reveals that the resistance looking into the input terminals (i.e. pin 3 and ground) takes on the value of $A_{VOL} R_i$. It will be recalled that when OPAMP is used in open loop mode (i.e. without feedback connection from the output) R_i has already a value of 1 or 2 MΩ. Hence for a typical value of $A_{VOL} = 10^5$, it follows that the input resistance for voltage follower is 10^5 MΩ or more. This virtually means that the OPAMP has no effect on the input signal even if the latter is characterized by a high resistance.

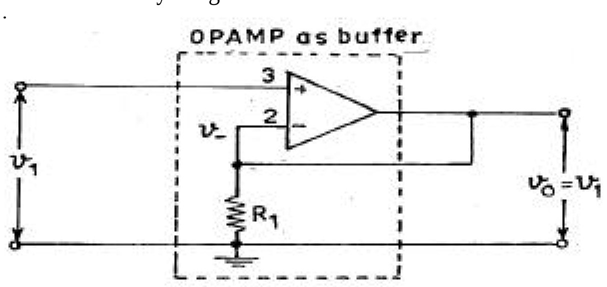

Fig. 26.10. Voltage follower.

Detailed analysis of the equivalent circuit of an OPAMP reveals that the output resistance, R_0, looking into the input terminals, which is just under 100W, is reduced to R_0 / A_{VOL} when 100% feedback, as in the case of voltage follower, is used. Consequently, the output impedance of the OPAMP has a value of 0.001W . This means that on the output side, the OPAMP connected in a voltage follower configuration behaves like a voltage source i.e. a source having a negligible output (internal) resistance.

The voltage follower, therefore, possesses the following important characteristics:

(i) It has large input resistance (impedance)

(ii) It has a unity gain

(iii) It has a small value of output resistance (impedance)

With high input impedance and a low output impedance this OPAMP when connected in the circuit will have negligible loading effects. Therefore, this circuit can serve as an ideal Buffer (or isolation circuit). In this way, it can be made to prevent the disturbance of one part of a circuit affecting another can be prevented.

2.18. Current To Voltage And Voltage To Current Converter.

A current to voltage converter is a circuit the provides an output voltage that is directly proportional to input current. Fig. 26.33 shows this type of converter with an OPAMP connected tin the inverting configuration and R_1 = 0.

Since the OPAMP input current id is essentially zero, the input current directly flows through R_f. Also, since v_ terminal is a virtual ground, the output voltage is

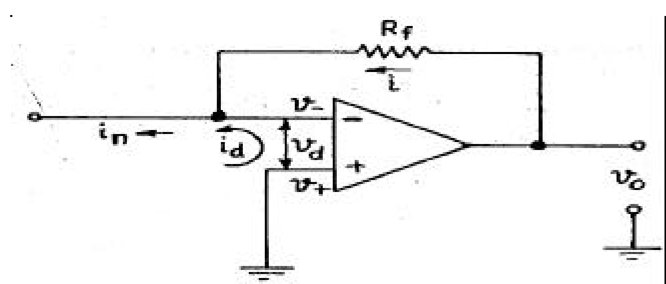

Fig. 26.33. Current to voltage converter.

$V_0 = i_n R_f$

Thus the desir4ed result is obtained.

Note that the input impedance of current to voltage converter of Fig. 26.33 is approximately zero since v_ terminal is virtual ground. The input impedance is R_f / A_{VOL}. The output impedance is quite small since R_1 = 0.

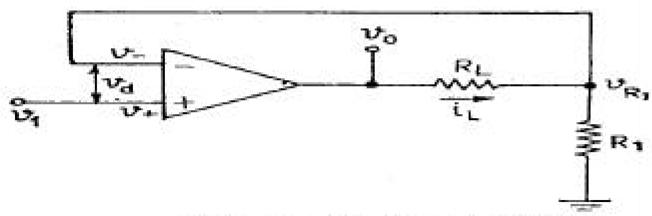

Fig. 26.34. Voltage to current converter.

$$i_L = i_{R1} = \frac{v_1}{R_1}$$

The circuit diagram of a voltage to current converter is shown in Fig. 26.34. Since v_d is quite small, the input voltage v_1 is applied directly across R_1 and hence $i_{R1} = V_1 / R_1$. However this current must be supplied by the output of OPAMP. Therefore, thus the circuit as voltage to current converter. It is clear form Eqn. 26.72 that the current through RL is independent of resistance RL. Hence, this circuit can be used as constant current source controlled by voltage. Note that the input impedance is quite large.

2.18.2 Buffer Amplifier.

The circuit of a unity gain buffer amplifier also called a voltage follower is shown in Fig. 26.35.

This circuit has a unity gain and a very high input impedance. The input impedance is essentially the input impedance of the operational amplifier itself which may be greater than 100 MΩ. The output voltage is equal to the input voltage. In fact, the output voltage tracks the input voltage from plus to negative saturation levels. Current output is limited to short circuit current of the operational amplifier and the output impedance is small, typically less than 100Ω. Many manufacturers market operational amplifiers with internally provide feedback. These are used as buffer amplifiers and have a very high input impedance.

The buffer amplifier is essentially an impedance transformer which converts a voltage at high impedance to the same voltage at low impedance. The use of unity gain buffer amplifiers greatly reduces the loading effects in measurement systems.

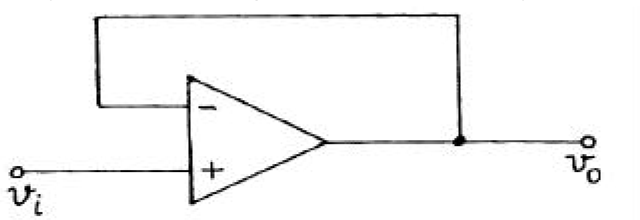

Fig. 26.35. Unity gain buffer amplifier (voltage follower).

2.19 Differential Amplifier

The operational amplifier which is very important in an instrumentation system is the differential amplifier. In its basic form it has two outputs. The signal available to the two outputs are identical except that the two are 180 out of phase with each other. The output voltage of the amplifier is proportional to the difference between the two input voltages.

Fig. 26.36 shows a differential amplifier. This amplifier produces an output voltage which is proportional to difference between the two input voltages.

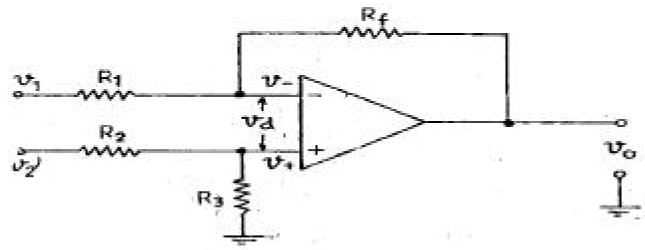

Fig. 26.36. Operational amplifier used as a differential amplifier.

$v_0 = A_d (v_+ - v\_)$

Where A_d = differential gain

The operational amplifier is designed to have a very high differential gain. This means $v_0/(v_+ - v\_) = 10^5$ or more. Also this high gain implies that $v_+ = v\_$. Since, the output voltage v_0 has a limited amplitude and therefore, the term, $v_0/(v_+ - v\_)$ is very large. The differential voltage $v_d = (v_+ - v\_)$ is very small and hence we can safely assume $v_+ = v\_$.

The input impedance of a differential amplifiers is quite large. For negative feedback, the path must be from output to v_. Now v_0, is shifted by 180° with respect to v_ and 0° with respect to v_+.

Voltage between v_0 and ground $= \dfrac{v_0 R_1}{R_f + R_1}$

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By superposition, we get,

$$v\_ = \frac{v_0 R_1}{R_f + R_1} + \frac{v_1 R_1}{R_f + R_1}$$

Now $\quad v_+ = \dfrac{v_2 \quad R_3}{R_2 + R_3}$

Since $\quad v\_ = v_+$, we have,

$$\frac{v_0 R_1}{R_f + R_1} + \frac{v_1 R_1}{R_f + R_1} = \frac{v_2 \quad R_3}{R_2 + R_3}$$

$$\text{or, } v_0 = v_2 \frac{R_3 (R_f + R_1)}{R_1 (R_2 + R_3)} - v1 \frac{R_f}{R_1}$$

Putting $R_f / R_1 = R_3 / R_2 = A_d$, we get,

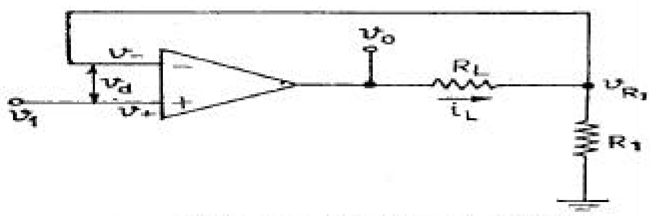
$v_0 = v_2 A_d - v_1 = A_d (v_2 - v_1)$

A_d is called Difference Mode Gain. The signal $v_d = (v_+ - v\_)$ is called the Difference Mode Signal or simply Difference Signal,

$A_d = v_0/(v_+ - v\_) = v_0/v_d$

2.19.1 Use Of Operational Amplifier With Capacitive Displacement Transducers.

Suppose a capacitive transducer is used for measurement of displacement. The principle involved is change of capacitance with change of distance between plates. The capacitor has air as dielectric medium. The capacitance is given by : $C_x = e_0 A / x$ where A is the area of the plates and x is the distance between plates.



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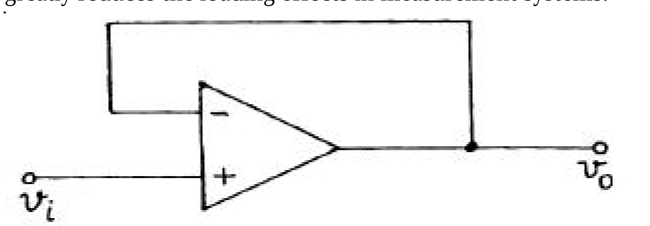

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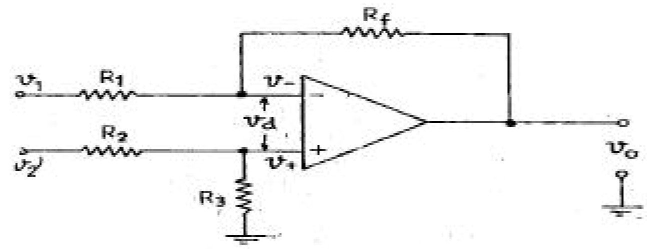

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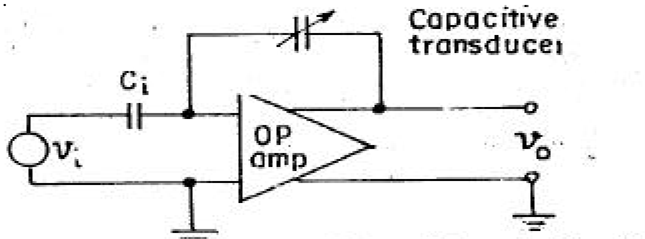

Fig. 26.37. Operational amplifier used in conjunction with capacitive transducers.

This represents a non-linear relationship between output i.e., output capacitance and the input displacement, x. A linear relationship between output and input can be obtained, by using an operational amplifier as shown in fig. 26.38.

This is done by connecting the operational amplifier in the feedback loop. Therefore, we have :

$$\frac{v_0}{v_i} = -\frac{Z_f}{Z_i} = -\frac{1}{jwC_x} \times jwC_i = -\frac{C_i}{e_0A/x}$$

Output voltage

$$v_0 = \left(-\frac{C_i \quad v_i}{e_0A}\right)x = kx$$

Where sensitivity

$$k = \left(-\frac{C_i}{e_0A}v_i\right)V/m.$$

Thus a linear relationship is obtained between input and output. In commercial instruments the input voltage vi is a 50 kHz sine wave which is connected to rectifiers to obtain a d.c. output that is read by d.c. instruments. This system is used for measurement of static displacements. For dynamic displacements, the signal v0 is a modulated wave and is fed to demodulators and low pass filters to recover the true output voltage.

2.19.2 Charge Amplifiers.

Piezo-electric transducers are extensively used in accelerometers, pressure pick-ups, and load cells. The output of a piezo-electric transducers is charge. The charge is converted to voltage. This has led to development of a special kind of an amplifier, called a charge amplifier. The charge amplifier offers some advantages over the usual voltage amplifiers in these applications.

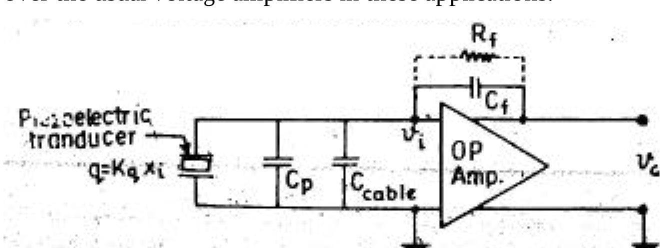

Fig. 26.39. Charge Amplifier.

A charge amplifier can be described by considering it as on operational amplifier with capacitive feedback. A block diagram of the charge amplifier is shown in Fig. 26.39.

Now,

$$\frac{v_0}{v_i} = -\frac{Cp + Ccable}{C_f}$$

Where

Cp = capacitance of cystal ; F, C_{cable} = capacitance of cable ; F.

Let $\quad C = Cp + C_{cable} \quad \therefore \ \frac{v_0}{v_1} = -\frac{C}{C_f}$

But $\quad$ vi = q/C where q is the charge generated.

$$\therefore \quad v_o = -\frac{C}{Cf}vi = -\frac{C}{Cf} \times \frac{q}{C} = -\frac{q}{Cf}$$

Let $\quad$ Kq = charge sensitivity ; C/m, and x_i = input displacement ; m

$$\therefore \quad v_o = -\frac{q}{C_f} = -\frac{K_q x_i}{C_f}$$

Eqn. 26.89 indicates that the output voltage v_0 is linearly related to input displacement, x_i. It also indicates that the output changes instantaneously with input without loss in the steady state response. But unfortunately in practice, it is not so. This is because the operational amplifier does not have an infinite input resistance as is assumed, but has finite input resistance though very high. The input resistance and the leakage resistance of C_p, exhibit a steady charging or C_f by the leakage current till the amplifier is saturated. To overcome this problem, a resistance R_f is connected across capacitor C_f in the feedback path. This prevents the small leakage current to charge the capacitor heavily. The connection of R_f is shown by a dotted line. The output-input relationship is now:

$$\frac{E_0(s)}{X_i(s)} = \frac{Kts}{1+ts}$$

where $\quad$ K = voltage sensitivity = Kq/C_f ; V/m, and t = time constant = $R_f C_f$:s.

The amplitude ratio is $M = \frac{1}{K}\left|\left(\frac{v_0(jw)}{x_i(jw)}\right)\right| = \frac{1}{\sqrt{1+1/w^2t^2}}$

Therefore, the frequency response of a charge amplifier is similar to that of a piezo-electric transducer. The amplifier exhibits attenuation of output at low frequencies. This response it shown in Fig. 26.40.

The advantages of a charge amplifier are :

(i) The output voltage is proportional to the charge produced by the piezo-electric transducer.

(ii) The amount of charge present is not affected by the cable capacitance. Since the amplifier detects charge rather than voltage, the system is completely independent of shunt capacitances and the changes in their value. This is important because of the fact that the output is not influenced by cable capacitance and hence large cable lengths can be used without any distortion of the input signal. Also the system temperature characteristics are dependent only on the charge versus temperature characteristics of the transducer and are not affected by changes in the capacitance of transducer or the cable.

(iii) The sensitivity, K, as well as the time constant are independent of the capacitance of the crystal and also that of connecting cables. These advantages are not available in ordinary voltage amplifiers.

There are certain disadvantages of charge amplifiers which may be present in certain applications. These disadvantages may be :

(i) The signal to noise ratio (S/N) tends to be small.

(ii) The natural frequency of the transducer it reduced due to loss of stiffness caused by what amounts to a sort circuit across the crystal.

In practical piezo-electric transducers, the value of C_f varies from 10 to 1,00,000 pF. The value of R_f used in between 10^{10} and 10^{14} . The high value of time constant results in almost a d.c. response.

In addition to above applications amplifiers are used in Sample Hold Circuits, voltage to current converters, current to voltage converters and digital to analog (D/A) converters.

Review Questions

1. Explain the functioning of a buffer amplifier.
2. Derive the expression for output voltage of a differential amplifier.
3. Describe the functioning of charge amplifier.
4. How operational amplifier works as a voltage follower.