

LESSON 17

SIGNAL CONDITIONERS

Now after covering all these topics we are in a position to discuss the methods used for modifying the transduced signal into a usable format for the final stage of the measurement system. For that we will now start our discussion on Signal conditioner. We will start with the help of block diagram representation.

2.16 Signal Conditioners

The measurand, which is basically a physical quantity as is detected by the first stage of the instrumentation or measurement system. The first stage, with which we have become familiar, is the "Detector Transducer stage". The quantity is detected and is transduced into an electrical form in most of the cases. The output of the first stage has to be modified before it becomes usable and satisfactory to drive the signal presentation stage which is the third and the last stage of a measurement system. The last stage of the measurement system may consist of indicating, recording, displaying, data processing elements or may consist of control elements.

In this chapter, methods used for modifying the transduced signal into a usable format for the final stage of the measurement system are described.

Measurement of dynamic physical quantities requires faithful representation of their analog or digital output obtained from the intermediate stage i.e. signal conditioning stage and this places a severe strain on the signal conditioning equipment. The signal conditioning equipment may be required to do linear processes like amplification, attenuation, integration, differentiation, addition and subtraction. They are also required to do non linear processes like modulation, demodulation, sampling, filtering, clipping and clamping, squaring, linearizing or multiplication by another function etc. These tasks are by no means simple. They require ingenuity in proper selection of components and the selection of most faithful methods of reproduction of output signals for the final data presentation stage.

The *signal conditioning or data acquisition equipment* in many situation is an excitation and amplification system for *passive transducers*. It may be an amplification system for active transducers. In both the applications, the transducer output is brought up to a sufficient level to make it useful for conversion, processing indicating and recording. Excitation is needed for passive transducers because these transducers do not generate their own voltage or current. Therefore, passive transducers like strain gauges, potentiometers, resistance thermometers, inductive and capacitive transducers require excitation from external sources. The active transducers like technogenerators, thermocouples, inductive pick ups and piezo electric crystals, on the other hand, do not require an external source of excitation since they produce their own electrical output on account of application of physical quantities. But

these signals usually have a low voltage level, and hence, need amplification.

The excitation sources may be an alternative or a d.c. voltage source. The d.c. system is comparatively simple as shown in Fig. 26.1.

The resistance transducers like strain gauges, constitute one arm or more than one arm of a wheatstone bridge which is excited by an isolated d. c. source. The bridge can be balanced by a potentiometer and can also be calibrated for unbalanced conditions.

The desirable characteristics of a d.c. amplifier are :

- (i) It may need balanced differential inputs giving a high Common mode rejection ratio (CMRR).

This is elaborated later on in this chapter.

- (ii) It should have an extremely good thermal and long term stability.

The advantages of a d.c. amplifier are that :

- (i) It is easy to calibrate at low frequencies,
- (ii) It is able to recover from an overload condition unlike it's a.c. counterpart.

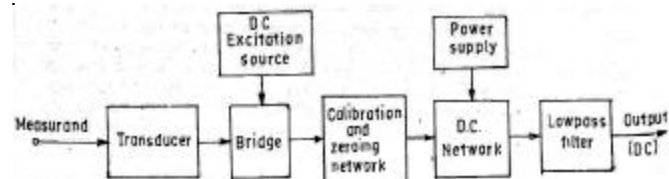


Fig. 26.1. D.C. Signal conditioning system.

But the greatest disadvantage of a d.c. amplifier is that it suffers from the problem of drift. Thus low frequency spurious signals come out as data information. For this reason special low drift d.c. amplifiers are used. The d.c. amplifier is followed by a lowpass filter which is used to eliminate high frequency components or noise from the data signal.

In order to overcome the problems that are encountered in d.c. systems, a.c. systems are used. In a.c. systems, the Carrier-type a.c. Signal Conditioning systems are used as shown in Fig. 26.2.

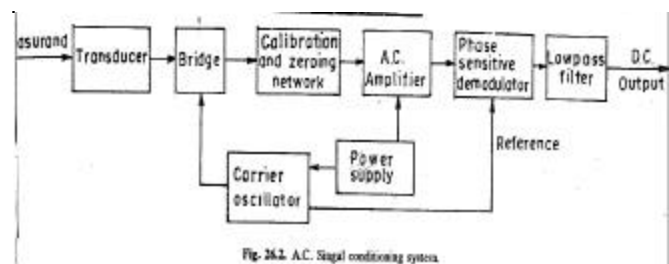


Fig. 26.2. A.C. Signal conditioning system.

The transducers used are the variable resistance or variable inductance transducers. They are employed between carrier frequencies of 50 Hz to 200 kHz. The carrier frequencies are much higher, they are at least 5 to 10 times the signal frequencies.

Transducer parameter variations amplitude modulate the carrier frequencies at the bridge output and waveform is amplified and demodulated. The demodulation is Phase Sensitive so that the polarity of d.c. output indicates the direction of the parameter change in the bridge output.

In a carrier system amplifier drift and spurious signals are not of much importance unless they modulate the carrier. However, it is more difficult to achieve a stable carrier oscillator than a comparable d. c. stabilized source. In carrier systems, it is easy to obtain very high rejection of mains frequency pick up. Active filters can be used to reject this frequency and prevent overloading of a.c. amplifier. The phase-sensitive, demodulators filter out carrier frequency components of the data signal.

D.C. systems are generally used for common resistance transducers such as potentiometers and resistance strain gauges, A.C. systems have to be used for variable reactance transducers and for systems where signals have to be transmitted via long cables to connect the transducers to the signal conditioning equipment.

After the physical quantities like temperature, pressure, strain, acceleration etc. have been translated into their analogous electrical form and amplified to sufficient current or voltage levels (say 1 V to 10 V), they are further processed by electronic circuits. In some applications the signal does not need any further processing and the amplified signal may be directly applied to indicating or recording or control instruments. But many applications involve further processing of signals which involve linear and non-linear operations as mentioned earlier.

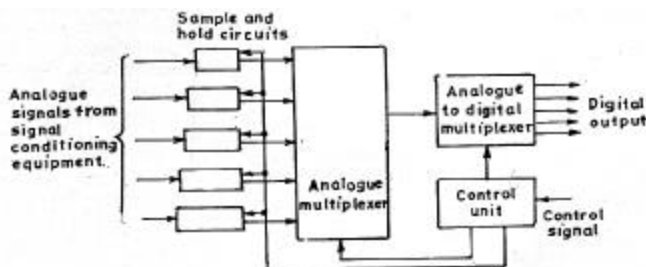


Fig. 26.3. Data acquisition and conversion system.

The signals may be applied to sample and hold (S/H) circuit as shown in Fig. 2.63. This may be fed to an analog multiplexer and analog to digital (A/D) converter. If the signal is in digital form it may be applied to a variety of digital systems like a digital computer, digital controller, digital data logger or a digital data transmitter.

The sample and hold units shown in Fig. 2.63 sample the different inputs at a specified time and then hold the voltage levels at their output while analog multiplexer performs the time division multiplexing (TDM) operation between different data inputs. Time Division Multiplexing means that each input channel is sequentially connected to the multiplexer for a certain specified time. (The input signals are not applied to the

multiplexer continuously but are connected in turn to the multiplexer thereby sharing time). The timing of the various input channels is controlled by a control unit. This unit controls the sample and hold (S/H) circuits, the multiplexer and the analog to digital (A/D) converter. The control unit may be controller itself.

In case time division multiplexing is not used, the frequency division multiplexer (FDM) may be used. In this case, the multiple data analog inputs can remain in analog form and are transmitted all at the same time, using frequency division multiplexing (FDM). The voltage input from the signal conditioning equipment is converted into frequency. Thus any change in voltage input of the measurand produces a corresponding change in frequency.

Earlier circuits comprising of discrete electronic components were used where impedance transformations, amplification, and other signal conditioning were required. The requirement to produce designs from discrete components has given way to easier and more reliable methods of signal conditioning which use integrated circuits (ICs). Many special circuits and general purpose amplifiers are now contained in IC packages producing a quick solution to signal conditioning problems, together with small size, low power consumption and low cost.

2.17 Operational Amplifier

The operational amplifier (OPAMP) manufactured with integrated circuit technology contains transistor's diodes, resistors and capacitors, is an extremely versatile device that does countless jobs in many electronic circuits. We limit our discussion regarding OPAMP to an external description and to those application, where it serves as a dependant source for important electronic circuits as well as a device for performing such important functions as isolation, inversion, addition, subtraction, multiplication and division. It can also be used for performing mathematical operations like integration and differentiation which together with its summing capabilities puts it in a position to model differential equations of physical systems.

One of the most popular OPAMPS is the 741 type, which has been produced by several manufacturers for many years. Also several improved versions have been developed having different internal circuitry to the original 741 OPAMPS.

The 741 is a plastic encapsulated device with dual inline (DIL) rows of pins as shown in Fig. 26.4 (a). Such devices are said to be directly pin compatible. The pin connections are shown in Fig. 26.4 (b). The 741 is an eight pin device. The operational amplifier has two types of connections :

(i) Inverting and (ii) Non-inverting. When a voltage is applied to inverting input pin 2, the output voltage has a sign which is opposite to that of the input. In case, the input voltage is applied to pin 3, which is designated as non-inverting, the output voltage has the same sign as the input.

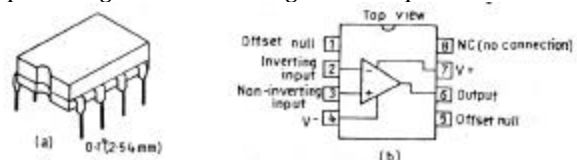


Fig. 26.4. Integrated circuit 741 OPAMP (a) DIL package (b) Pin connections.

The operational amplifier is shown by a triangular symbol with inverting and non-inverting inputs being connected at pins 2 and 3 respectively.

The OPAMP output appears at pin 6. Several other pins are labeled in the diagram. The most important of these are 7 and 4, where positive and negative constant supply voltages, V_+ and V_- are connected to supply energy to the integrated circuit. Usually this supply voltage is fixed at $\pm 15V$ with respect to ground reference. The OPAMP does not work without the supply voltage.

Two other pins (1 and 5) are provided on 741 and are labeled offset null. The offset effects are one of the several types of non-ideal behavior of OPAMPs and are explained later in this chapter.

2.17.1 Ideal Operational Amplifier

The properties of an ideal operational amplifier are :

- (i) It should have an infinite input impedance i.e. $Z_i = \infty$
- (ii) It should have a zero output impedance i.e. $Z_o = 0$.
- (iii) It should have an infinite open loop gain i.e. $A_{VOL} = -\infty$
- (iv) It should have a flat frequency response over a wide range of frequency i.e. its bandwidth $BW = \infty$

Fig. 26.5 shows the symbol for an operational amplifier, which is simply a triangle having two inputs and a single output the two inputs are labeled differently. One input terminal is designated by a -ve sign, it is called inverting end and is connected to pin 2 while the other input terminal is designated by a +ve sign, it is called non-inverting end and is connected to pin 3.

A negative voltage (v_-) applied to inverting end appears as a +ve output voltage v_o at pin 6 while a positive voltage (v_+) applied to the non-inverting end appears a +ve voltage at pin 6. Frequently, the non-inverting end is not used and some operational amplifiers do not have this terminal for use. When non-inverting end is not available, it is omitted from the schematic diagram and the input terminal shown is the inverting end (-ve) even though it may not be marked as such. The inverting input causes a reversal of polarity at the output. It should be understood that when one input is shown in the schematic diagram of an OPAMP, it is the inverting input. There is only one input terminal and the other terminal is the ground which may or may not be shown in the schematic diagram.

(v) For an ideal OPAMP, the output voltage $v_o = 0$, when equal voltages are applied to inverting and non-inverting ends of the amplifier i.e. the output voltage is zero i.e. $v_o = 0$ when (v_- input) - (v_+ input) = 0 where v_- and v_+ are the voltages applied to inverting and non-inverting ends of OPAMP.

The OPAMP can accommodate both positive and negative input signals simultaneously or one at a time. The schematic diagram showing the input signals and +ve and -ve power supplies is shown in Fig. 26.6 voltage appearing at pin 6 has the same polarity as that of the input signal. When a signal v_- is applied to pin 2, it gets inverted and we obtain a signal output of opposite polarity at pin 6. In the interest of simplicity the symbol most commonly used for an OPAMP is shown in Fig.

26.6 (b). The design of the OPAMP is such that the output voltage is related to two input voltages as,

$$V_o = A_{vol} v_+ - v_- = A_{vol} v_d \quad (26.1)$$

Where v_d = net input differential voltage = $v_+ - v_-$

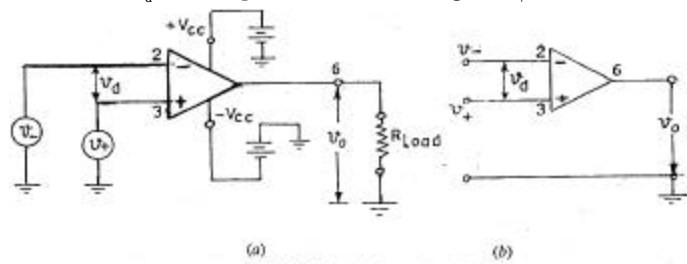


Fig. 26.6 Schematic diagram of an OPAMP.
(a) model showing supply voltages and signal inputs with connection to ground reference.
(b) commonly used simplified symbol for modeling an OPAMP.

Three notable features characterize the OPAMP model shown in Fig. 26.6. In the interest of stressing a simplified strategy for analysis, the idealized versions of these features are specified.

These are :

- (i) Input impedance Z_i should be infinite. The actual value may be of the order of several megohms, but this is tantamount to infinity.
- (ii) Output impedance Z_o should ideally be zero. In actual amplifiers, the output resistance is below 100 Ω , but for the level of the load resistors generally used across the output terminals of the OPAMP in applications, this value can be considered as negligible.
- (iii) Open loop gain A_{VOL} which is the ratio of v_o to v_d is considered to be infinity.

Although we know this gain to be finite and in the vicinity of 1,00,000, this figure is high enough so that the practical results obtained with finite gain are the same as if the OPAMP was treated with an infinite gain.

V_d is the net input differential voltage. A_{VOL} is the open loop gain which is about 1,00,000. This means that the net differential voltage is increased at the output terminals (pin 6) by this factor. Clearly, then if overloads are to be avoided, it is necessary to restrict v_d to those values that will keep v_o at least below the magnitude of supply voltage.

Accordingly, for the case where $A_{vol} = 100,000$, it follows that v_d must be limited to,

$$V_d = 15/100,000 = 150 \text{ mV where } 15 \text{ V is the supply voltage}$$

Which is obviously a small quantity. Fortunately, there are techniques available for increasing this limit to more practical values. These are considered as below.

One of the characteristics of OPAMP is that saturation of the output voltage sets in rapidly once the differential input voltage reaches a threshold value such as 150 V as calculated above. This feature is illustrated in Fig. 26.7.

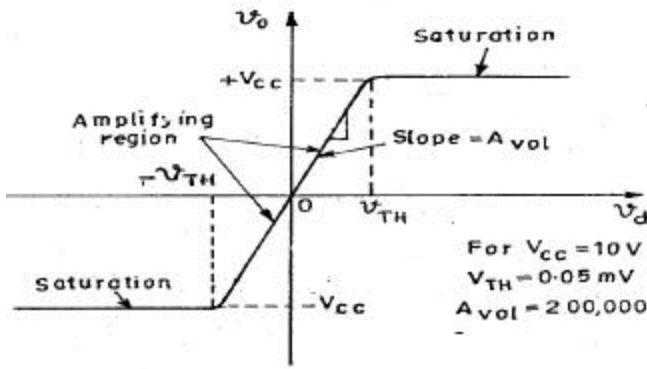


Fig. 26.7. Transfer characteristics of an OPAMP.

Fig. 26.7 shows the transfer characteristics of an OPAMP. Here V_{TH} represents the threshold value of v_d beyond which saturation sets in.

The saturation value is approximately taken to be supply voltage V_{CC} for convenience. Actually the threshold voltage is less than V_{CC} . The slope of the curve represents the open loop gain A_{VOL} .

The transfer characteristics indicate that the amplifier region for the OPAMP in which $v_o = A_{VOL} v_d$ is restricted to an output voltage range of $v_{o\ min} \leq v_o \leq v_{o\ max}$. In this region, each stage of OPAMP is restricted to amplifier operation. If the signal level drives the output stage (or any stage) into saturation or cut off, the output voltage of OPAMP gets fixed as shown in Fig. 26.8 (b) outside the amplifier region. Furthermore, positive saturation of OPAMP occurs when $v_o = v_{o\ max}$ and the negative saturation occurs when $v_o = v_{o\ min}$.

The restriction on output voltage of the OPAMP indicates that the input voltage difference of voltage (v_d) of OPAMP has similar restrictions. In fact, the range of v_d that provides amplifier operation is easily determined if we realize that the slope of transfer characteristics is A_{VOL} . Thus the range for amplifier region is given by :

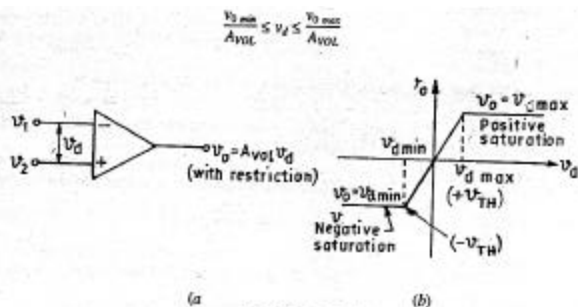


Fig. 26.8. The OPAMP. (a) Circuit symbol (b) Voltage transfer characteristics.

Typically the saturation sets in with $V_{CC} = 10\text{ V}$ and $V_d = 0.005\text{ mV}$. This means that the OPAMP has an open loop gain

$$A_{VOL} = \frac{10}{0.05 \times 10^{-3}} = 200,000$$

2.17.2 Non-Inverting Mode

The circuit configuration of an OPAMP working in the non-inverting mode is shown in Fig. 26.9. There is a single external input signal $v_1 = v_+$ that is applied to the + ve pin of OPAMP.

A signal is also made to appear at the - ve input terminal, but this is derived from resistors R_f and R_1 .

In order to determine the value of v_- , we must note that when an output voltage v_o appears at the output at the output terminals OPAMP, we have, from ohm's law.

$$V_o = I_f (R_f + R_1)$$

The connection of junction point of R_f and R_1 to the negative input pin causes no effect in the circuit involving R_f and R_1 because of the assumption of infinite resistance for OPAMP.

For this very reason current produced by input voltage $v_1 = v_+$ which I_p is zero.

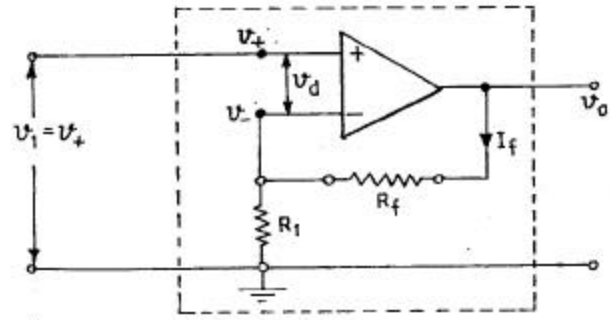


Fig. 26.9. OPAMP used in non-inverting mode.

The potential of v_- respect to ground is,

$$v_- = I_f R_1$$

$$= \frac{R_1}{R_f + R_1} v_o$$

Thus, $v_o = A_{vol} v_d$

Where $v_d = (v_+ - v_-)$

And $A_{VOL} =$ open loop gain of OPAMP,

$$v_o = v_d A_{VOL}$$

$$= \left(v_+ - \frac{R_1}{R_1 + R_f} v_o \right) A_{VOL}$$

Dividing by A_{VOL} on both sides of Eqn. 26.6, we get,

$$= \left(v_+ - \frac{R_1}{R_1 + R_f} v_o \right) = \frac{v_o}{A_{VOL}}$$

Next we introduce characteristic information about OPAMP.

The output voltage v_o is a finite quantity and is often less than 15V. The open loop gain A_{VOL} is very large and may be taken as infinite.

$$\left(v_+ - \frac{R_1}{R_1 + R_f} v_o \right) = 0$$

$$\text{or } v_o = \frac{R_1 + R_f}{R_1} v_1$$

Hence, the closed loop gain of the amplifier is ,

$$A = \frac{v_0}{v_1} = \frac{R_1 + R_f}{R_1} = \left(1 + \frac{R_f}{R_1} \right) \quad \dots\dots\dots(26.9)$$

Eqn. 26.9 makes it obvious that the magnitude of the output voltage can be controlled by properly selecting the values for resistors R_f and R_1 .

In case, impedances are used, closed loop gain is,

$$A = \left(1 + \frac{Z_f}{Z_1} \right)$$

Where Z_f and Z_1 are the feedback and input resistances respectively.

Review Questions

1. Draw the block diagram of a DC signal conditioner and explain the function of each block
2. Draw the pin diagram of an IC used as an operational amplifier. Explain the function of different pin connection.
3. Explain the characteristics of an ideal operational amplifier. Explain the function of its two input terminals.
4. What is non-inverting mode of an operational amplifier.