26

Signal Conditioning

26.1 SIGNAL CONDITIONING

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 a 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 alternating or a d.c. voltage source. The d.c. system is comparatively simple as shown in Fig. 26.1.

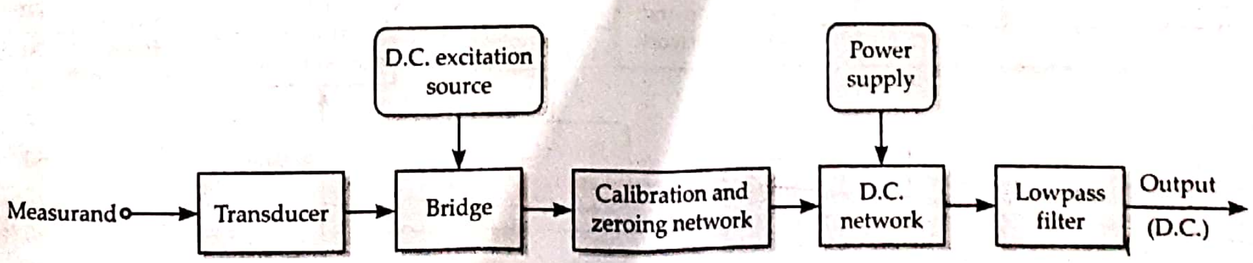

Fig. 26.1 D.C. Signal conditioning system.

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 its a.c. counterpart.

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.

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 transduced 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.

The signal may be applied to **sample and hold (S/H) circuit** as shown in Fig. 26.3. 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. 26.3 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

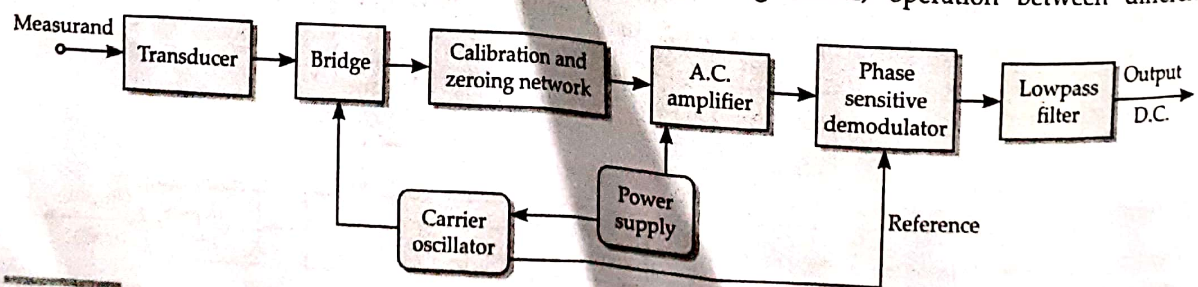

Fig. 26.2 A.C. Signal conditioning system

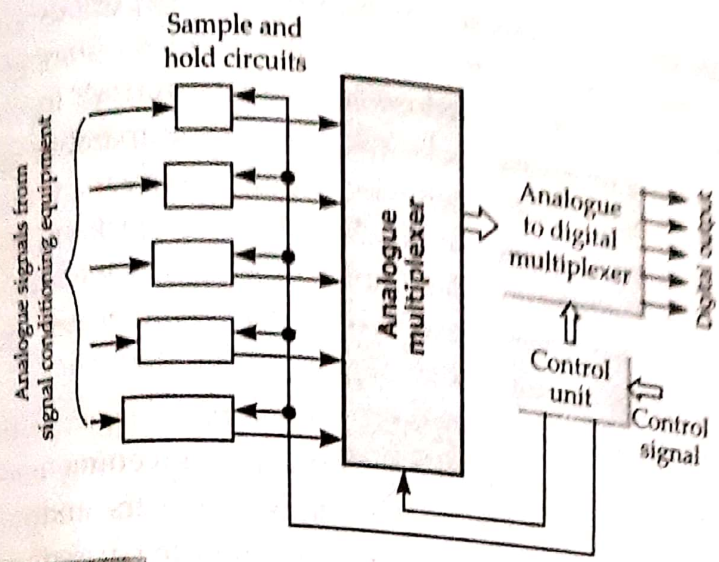

Fig. 26.3 Data acquisition and conversion system.

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.

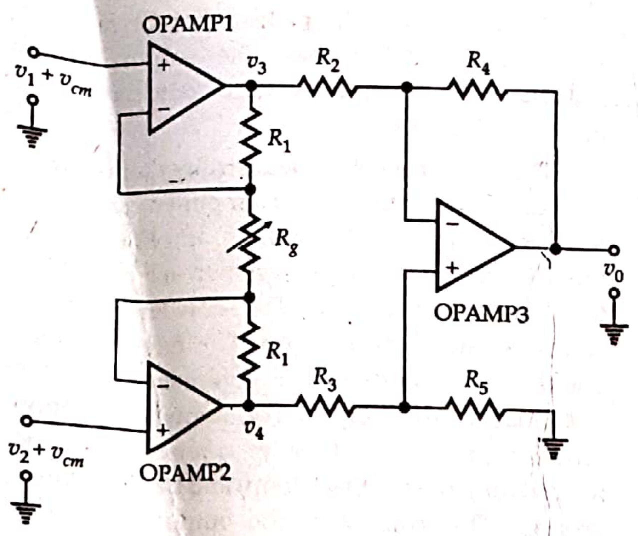

Fig. 26.49 Three amplifier configuration.

OPAMP 1 and OPAMP 2 act as buffers with unity gain for the common mode signal and with a gain of $(1+2R_g / R_1)$ for the differential inputs v_1 and v_2. The circuit has a high input impedance since the OPAMPs 1 and 2 operate in non-inverting mode for common mode signal.

It is clear from Eqn. 26.95 that there is no output corresponding to the common mode input signal. This is because OPAMP 3 acts as a difference amplifier with a high value of CMRR. The gain off course can be changed by changing resistance R_g.

26.8 ATTENUATORS

The term attenuator is often loosely used to denote a device which reduces the voltage and/or power conducted between the circuits connected to its input and output terminals. Such an interpretation of the term may be applied to all the potential dividers, shunts, current and voltage transformers. A purer interpretation restricts the use of the term to apply only to those dividers which are constructed so that in addition to providing the reduction in voltage or power, the impedance of the divider is matched to the input and output circuits, and for a multiratio attenuator these impedances are constant irrespective of ratio setting.

26.8.1 Resistance Attenuator

Figure 26.50 shows a simple form of resistance attenuation pad for which $R_S = R_i$, $R_L = R_0$ and V_i is the input voltage and V_0 the output voltage.

It should be noted that the attenuation (A) is normally quoted as a power ratio in terms of decibels, that is :

$$A = 10 \log_{10} (P_S / P_L) \quad ...(26.97)$$

$$A = 20 \log_{10} (V_i / V_0) \text{ db}$$

$$\text{(provided } R_S = R_L) \quad ...(26.98)$$

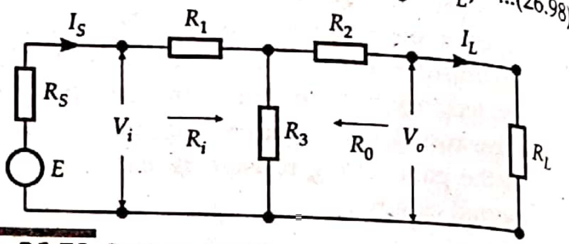

Fig. 26.50 Resistance attenuator pad.

Alternatively, the attenuation may be expressed in nepers (N_p) when

$$A = \log_e (I_S / I_L) N_p \quad ...(26.99)$$

Thus latter expression is commonly used in theoretical work. Now if $R_s = R_L$, then the attenuation in db is,

$$A = 20 \log_{10} (I_S / I_L) \text{ db} = [8.686 \times (\text{attenuation in } N_p)]$$

Conversely attenuation in

$$N_p = 0.1151 \times (\text{attenuation in db})$$

For the attenuator pad shown in Fig. 26.50 let the attenuation be $20 \log_{10} k$, where

$$k = \left(\frac{P_S}{P_L}\right)^{\frac{1}{2}} = \left(\frac{I_S^2 . R_S}{I_L^2 R_L}\right)^{\frac{1}{2}} \quad ...(26.100)$$

Now $$R_i = R_S = R_1 + \frac{R_3 (R_2 + R_L)}{R_2 + R_3 + R_L} \quad ...(26.101)$$

and $$R_c = R_L = R_2 + \frac{R_3 (R_1 + R_S)}{R_1 + R_3 + R_S} \quad (26.102)$$

also $$\frac{I_S}{I_L} = \frac{R_2 + R_L + R_3}{R_3} \quad ...(26.103)$$

From equations 26.100 to 26.102 it can be shown that,

$$R_1 = R_S \left\{\frac{k^2+1}{k^2-1}\right\} - 2(R_S R_L)^{\frac{1}{2}} \left\{\frac{k}{k^2-1}\right\} \quad ...(26.104)$$

$$R_2 = R_L \left\{\frac{k^2+1}{k^2-1}\right\} - 2(R_S R_L)^{\frac{1}{2}} \left\{\frac{k}{k^2-1}\right\} \quad ...(26.105)$$

$$R_3 = 2(R_S R_L)^{\frac{1}{2}} \left\{\frac{k}{k^2-1}\right\} \quad ...(26.106)$$

26.8.2 Symmetrical *T* Attenuator

Referring to Fig. 26.51. If the load and source impedance are equal the *T* attenuator will become symmetrical and

$$R_1 = R_2 = R_L \left(\frac{k-1}{k+1}\right) \quad ...(26.107)$$

and $$R_3 = \frac{2 R_L k}{k^2 - 1} \quad ...(26.108)$$

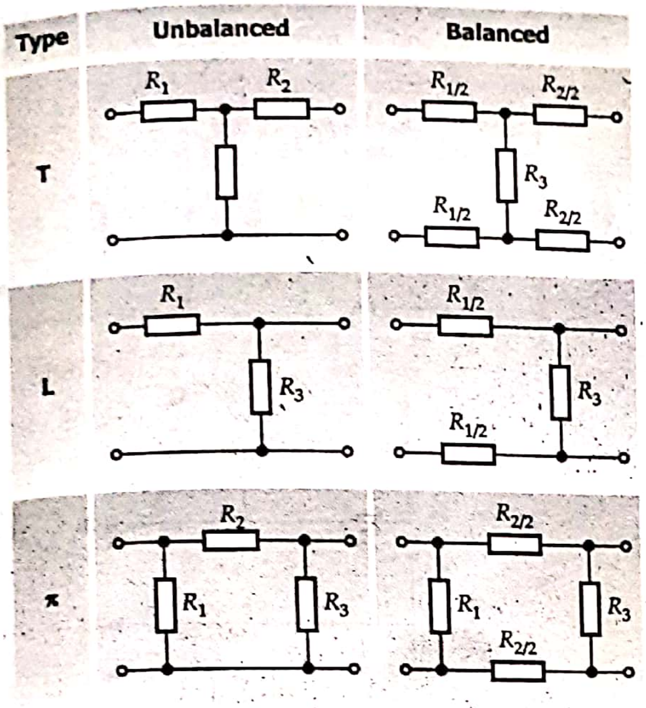

Fig.26.51 Balanced and unbalanced attenuators.

26.8.3 L-type Attenuator

If the attenuator/pad is required only for matching purposes it will be arranged to have minimum attenuation and under these conditions $R_2 = 0$ resulting in an L type attenuator (26.51) for which,

$$R_1 = [R_S(R_S - R_L)]^{\frac{1}{2}} \qquad \text{...(26.109)}$$

and

$$R_3 = \left(\frac{R_S R_L}{R_S - R_L}\right) \qquad \text{...(26.110)}$$

26.8.4 π Attenuator

Another common form of attenuator is the π type (Fig. 26.51) which, when used for matching, requires

$$R_1 = R_S \left\{ \frac{k^2 - 1}{k^2 - 2k\left(\frac{R_S}{R_L}\right)^{\frac{1}{2}} + 1} \right\} \qquad \text{...(26.111)}$$

$$R_2 = \frac{(R_S R_L)^{\frac{1}{2}}}{2} \left\{ \frac{k^2 - 1}{k} \right\} \qquad \text{...(26.112)}$$

$$R_3 = R_L \left\{ \frac{k^2 - 1}{k^2 - 2k\left(\frac{R_S}{R_L}\right)^{\frac{1}{2}} + 1} \right\} \qquad \text{...(26.113)}$$

and for attenuation alone, that is when $R_S = R_L$

$$R_1 = R_3 = R\left[\frac{k+1}{k-1}\right] \qquad \text{...(26.114)}$$

and

$$R_2 = R\left[\frac{k^2+1}{2k}\right] \qquad \text{...(26.115)}$$

The above attenuator have all been unbalanced and in some applications it is desirable that the legs of the circuit should be balanced. This is simply arranged by dividing the series arm in half and placing the equal halves in each leg (See Fig. 26.51).

Resistance attenuators of this form may be used from d.c. to several hundreds of MHz. For higher frequencies wave guide devices are used.

26.9 AMPLITUDE MODULATION

The term **Modulation** means "to change" or "to modify".

The interest in amplitude modulation signals in measurement systems is on account of *two* reasons :

1. Physical data that are to be measured, processed and interpreted are, many a times, amplitude modulated.
2. When carrying out dynamic measurements, the measurement system are intentionally designed to introduce amplitude modulation on account of various advantages.

There are, invariably, two parts to any method of modulation :

(*i*) **Carrier.** This is the medium that carries the information or intelligence, and

(*ii*) **Signal.** The signal is the information or intelligence to be carried.

In **amplitude modulation (AM),** the signal or the information modulates the amplitude of the carrier. Qualitatively, amplitude modulation may be defined as the modification of the amplitude of the carrier in proportion to the amplitude of the modulating signals. In general, the signal that modulates the amplitude of a carrier wave may be of any form, it may be a single sine wave, a periodic function, a random wave or a transient phenomenon. Similarly, the carrier may also be of different forms *i.e.*, it may be a sine wave or a square wave etc.

In order to understand the concept of amplitude modulation, the simplest form is a sinusoidal signal modulating the amplitude of a sinusoidal carrier wave. The modulation process, fundamentally, is the

1. Draw a block diagram of a d.c. signal conditioning system and explain the functions of each block.
2. Draw a block diagram of an a.c. signal conditioning system and the functions of each block. Explain the carrier type a.c. signal conditioning system and its advantages.
3. Explain the characteristics and an ideal operational