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قسم الفيزياء الطبية
المرحلة الرابعة/ اجهزة طبية

Chapter 3

Bioelectric Signal Acquisition

3.1 INTRODUCTION

Bioelectric signals are in the range of microvolts and low frequency region. Hence acquisition of bioelectric signals becomes difficult. Particularly for EEG signals, preamplifiers are required to detect signals as low as in microvolts. The bio-signals are subjected to high power supply frequency interferences. It is obvious that the preamplifier used in bio-signals processing should overcome these problems.

3.2 BIO-SIGNAL AMPLIFIERS

The quality of the output of the biomedical instruments depends upon the characteristics of the bioelectric signal amplifier. Hence the bioelectric signal amplifiers require the following characteristics:

(i) The voltage gain of the bioelectrical signal amplifier has to be above 100 dB so that it has to drive the recorder.

(ii) The bandwidth of the amplifier should be from zero to the maximum frequency available in the signal.

(iii) The gain should be linear throughout the range.

(iv) Frequency response should be uniform throughout the range.

(v) The amplifier should not have any drift.

(vi) The input impedance of the bioelectrical amplifier should be very high so as to avoid the over loading effect. For example, 10 mega ohms for ECG signals and 100 mega ohms for EEG signals.

(vii) The common mode rejection ratio should be very high (at least 80 dB) so as to eliminate the power supply noise.

Operational amplifiers have the above mentioned qualities. So, many of the bioelectrical signal amplifiers are made up of operational amplifiers. Therefore, it is important to have knowledge about the operational amplifiers.

3.2.1 Operational Amplifier

Operational amplifier (op-amp) is an electronic amplifier with very high input impedance and very high gain. Op-amp is generally used to amplify very small signals. Op-amp has two input terminals, one output terminal, two power supply terminals and a ground connection. In the schematic diagram shown in Figure 3.1, the input terminal denoted with positive sign is called non-inverting terminal and the one denoted with negative sign is called inverting terminal. The single terminal opposite to the input terminal is called output terminal. It has two additional terminals for the power supply.

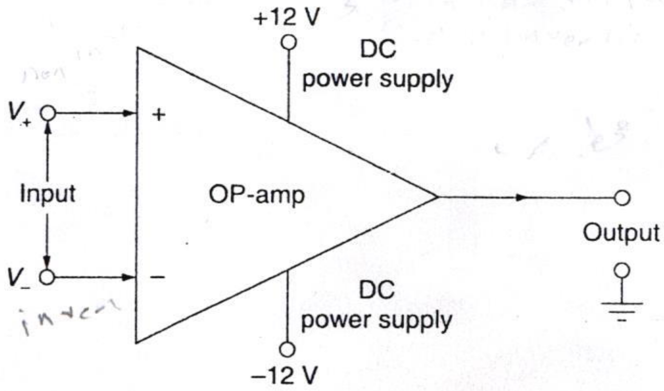

Figure 3.1 Schematic diagram of operational amplifier.

Internally op-amps can be modelled as a combination of resistors and dependent sources as shown in Figure 3.2. Dependent voltage source produces an output voltage proportional to the voltage across the input impedance R_{in}. The input impedance R_{in} is very large and it is in mega ohm. So, very small current is flowing into the op-amp. When R_{in} approaches infinity, the current approaches zero. In that case the op-amp is called ideal op-amp. The analysis can be simplified by using ideal op-amps. In an ideal op-amp, the input terminal voltages V_+ (non-inverting terminal voltage) and V_- (inverting terminal voltage) are equal and the current entering the op-amp is zero, that is, I_+ and I_- are zero. The following example will be useful to understand how an op-amp circuit can be analyzed. For an ideal op-amp, the inverting terminal V_- and the non-inverting terminal V_+ are at same potential, i.e., $V_- = V_+$. There is no current through V_+ and, therefore, $I_+ = 0$.

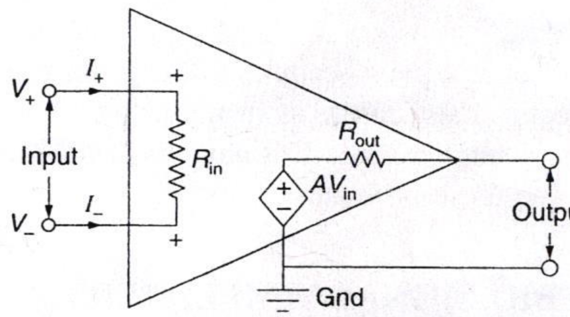

Figure 3.2 Functional diagram of operational amplifier.

3.2.2 Characteristics of an Ideal Operational Amplifier

Ideal operational amplifier has the following characteristics:

(i) The input impedance of the ideal operational amplifier is infinity.
(ii) The output impedance of the ideal operational amplifier is zero.
(iii) The static gain of the ideal operational is infinity.
(iv) Bandwidth of the ideal operation amplifier is infinity.

3.2.3 Operational Amplifier as Voltage Follower

Buffer or voltage follower, as shown in Figure 3.3, is one of the common applications of operational amplifier. Voltage follower has unity gain and works as isolation between circuits.

From Figure 3.3, one can write

$$V_+ = V_s \tag{3.1}$$

But for an ideal operational amplifier,

$$V_+ = V_- \tag{3.2}$$

On assuming that this practical operational amplifier has $V_+ = V_-$, we get

$$V_0 = V_- \tag{3.3}$$

From Eqs. (3.1) and (3.3), we have

$$V_0 = V_s$$

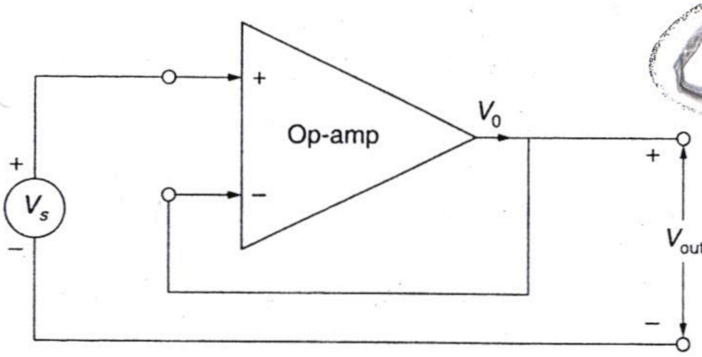

Figure 3.3 Voltage follower.

Here the output voltage follows the input voltage and hence it may be called voltage follower. It is a buffer circuit to isolate between two parts of the circuit. Another use of voltage follower is for impedance matching.

3.2.4 Operational Amplifier as an Inverting Amplifier

For this practical op-amp, another common application of op-amp is inverting amplifier. In this configuration, the amplifier gives a negative gain to the input voltage. Here $V_g = 0$ (Grounded). Therefore, $V_+ = V_- = 0$ (Both are at ground potential). Here the op-amp acts as amplifier, but its output is 180° out of phase with input voltage. The external circuit diagram of an inverting amplifier is shown in Figure 3.4. Z_1 and Z_2 are impedances connected in the external circuit. The non-inverting terminal is connected to the ground. Therefore, $V_+ = V_g = 0$. For an ideal operational amplifier, it is obvious that $V_+ = V_-$ and $I_+ = 0$. Let this practical amplifier be assumed to be an ideal operational amplifier. Therefore, we get

$$V_+ = V_- \quad \text{and} \quad I_+ = 0 \tag{3.4}$$

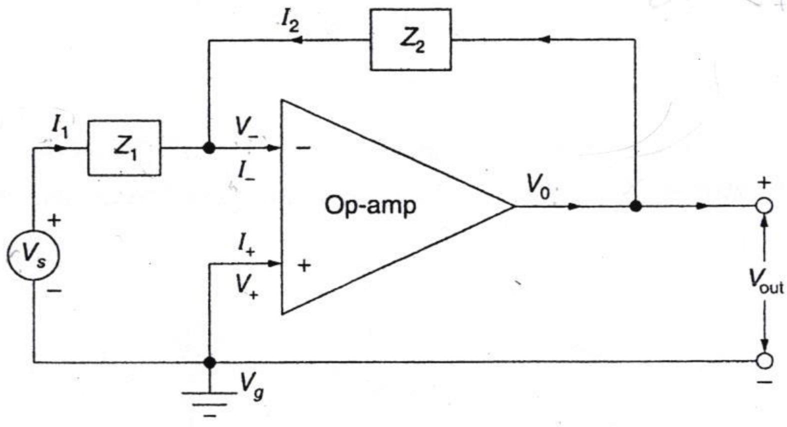

Figure 3.4 Inverting amplifier.

Let I_1 and I_2 be the current entering the junction V_-, and I_- be the current leaving V_-.

By using the Kirchhoff's current law,

$$I_1 + I_2 - I_- = 0 \tag{3.5}$$

$$\frac{V_s - V_-}{Z_1} + \frac{V_0 - V_-}{Z_2} - 0 = 0 \tag{3.6}$$

Since $I_- = 0$,

$$\frac{V_s}{Z_1} + \frac{V_0}{Z_2} - \frac{V_-}{Z_1} - \frac{V_-}{Z_2} = 0$$

But

$$\frac{V_-}{Z_1} = 0 \text{ and } \frac{V_-}{Z_2} = 0$$

$\therefore$

$$\frac{V_0}{Z_2} = -\frac{V_s}{Z_1}$$

$$V_0 = -\frac{Z_2}{Z_1} V_s$$

The gain of the amplifier is decided by Z_2/Z_1. By regulating appropriate value of Z_1 and Z_2, one can select the required gain.

3.2.5 Operational Amplifier as a Non-inverting Amplifier

A non-inverting amplifier is shown in Figure 3.5. Here $V_+ = V_s$. $V_- = V_1$. Let I_2 and I_1 be current through Z_2 and Z_1 respectively. By Kirchhoff's current law, we get

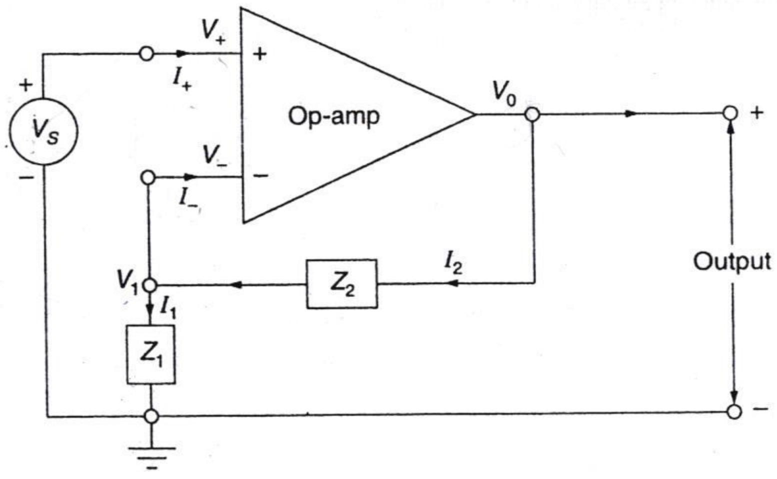

Figure 3.5 Non-inverting amplifier.

$$\frac{V_0 - V_1}{Z_2} - \frac{V_1}{Z_1} - I_- = 0$$

But
$$V_1 = V_- = V_s \text{ and } I_- = 0$$

$\therefore$
$$\frac{V_0}{Z_2} - \frac{V_s}{Z_2} - \frac{V_s}{Z_1} = 0$$

$$(V_0 - V_s)\frac{1}{Z_2} = \frac{V_s}{Z_1}$$

$$(V_0 - V_s) = \frac{Z_2}{Z_1} V_s$$

$$V_0 = \left(1 + \frac{Z_2}{Z_1}\right) V_s$$

The output is $\left(1 + \frac{Z_2}{Z_1}\right) V_s$. That is by selecting Z_1 and Z_2, one can get the appropriate gain.

3.2.6 Operational Amplifier as a Differentiator

The circuit diagram of a differentiator using op-amp is shown in Figure 3.6. It can be proved that the output voltage is the time derivative of the input voltage. Let I_1 and I_2 are currents through C_1 and R_2 respectively. Let I be the current entering into the non-inverting terminal. The current entering into the op-amp in an ideal case is zero. Now, let us assume that the negligible current is entering the op-amp, i.e., $I_- \approx 0$. By using Kirchhoff's current law, we get

$$I_1 + I_2 - I_- = 0$$

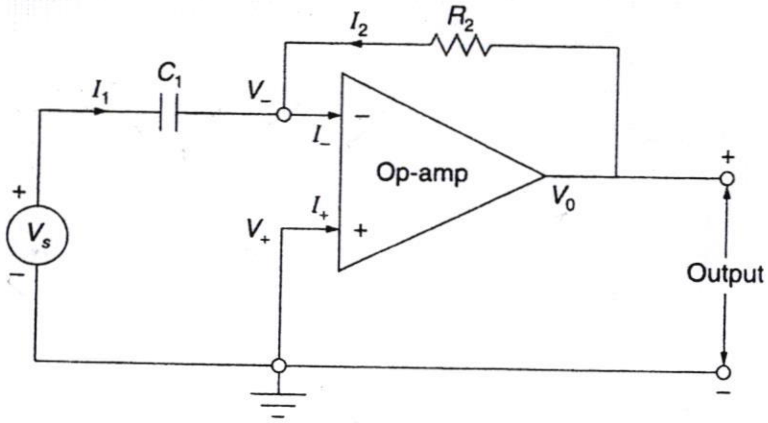

Figure 3.6 Op-amp as a differentiator.

$$C_1 \frac{dV_{c1}}{dt} + \frac{V_0 - V_-}{R_2} - 0 = 0$$

$$C_1 \frac{d(V_s - V_-)}{dt} + \frac{V_0 - V_-}{R_2} = 0$$

But for an ideal op-amp, $V_+ = V_- = 0$. Let us assume that for this practical op-amp, $V_- = 0$.

$\therefore$
$$C_1 \frac{d(V_s)}{dt} + \frac{V_0}{R_2} = 0$$

$\therefore$
$$V_0 = -R_2 C_1 \frac{dV_s}{dt}$$

The voltage V_0 is R_2C_1 times the derivate of input signal V_s.

3.2.7 Operational Amplifier as an Integrator

The circuit diagram of an integrator using op-amp is shown in Figure 3.7(a). It can be proved that the output voltage is the time integral of the input voltage. Let I_1 and I_2 be the current through R_1 and C_2 respectively. I_- be the current entering the inverting terminal. For an ideal op-amp, the current entering the inverting terminal is zero. Let us assume that the current entering this practical op-amp is also negligible, i.e., $I_- = 0$. By using Kirchhoff's current law, we get

$$I_1 + I_2 + I_- = 0$$

$$\frac{V_s - V_-}{R_1} + C_2 \frac{d(V_0 - V_-)}{dt} - 0 = 0$$

$$\frac{V_s}{R_1} - \frac{V_-}{R_1} + C_2 \frac{dV_0}{dt} - \frac{dV_-}{dt} = 0$$

But $V_- \approx 0$.

Therefore,
$$\frac{V_s}{R_1} + C_2 \frac{dV_0}{dt} = 0$$

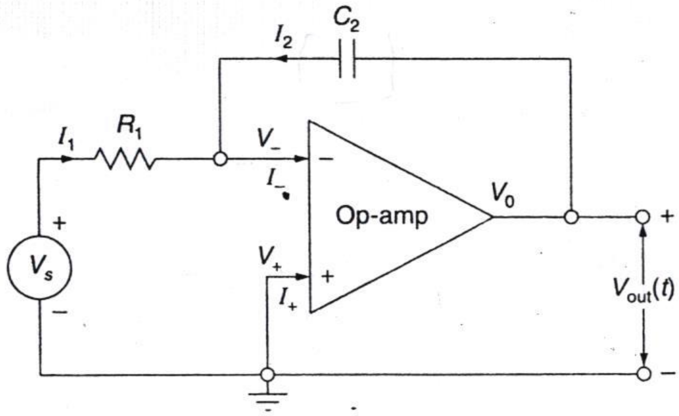

Figure 3.7(a) Op-amp as an integrator.

$$dV_0 = -\frac{1}{R_1C_2}V_s dt$$

$$\int dV_0 = -\frac{1}{R_1C_2}\int_{-\infty}^{t} V_s\, dt$$

$$V_0 = -\frac{1}{R_1C_2}\int_{0}^{t} V_s\, dt + V_c(0^+)$$

The output voltage V_0 is equal to $1/R_1C_2$ times the integral of input signal V_s and the initial voltage of the capacitor. A typical input signal and its output are shown in Figure 3.7(b).

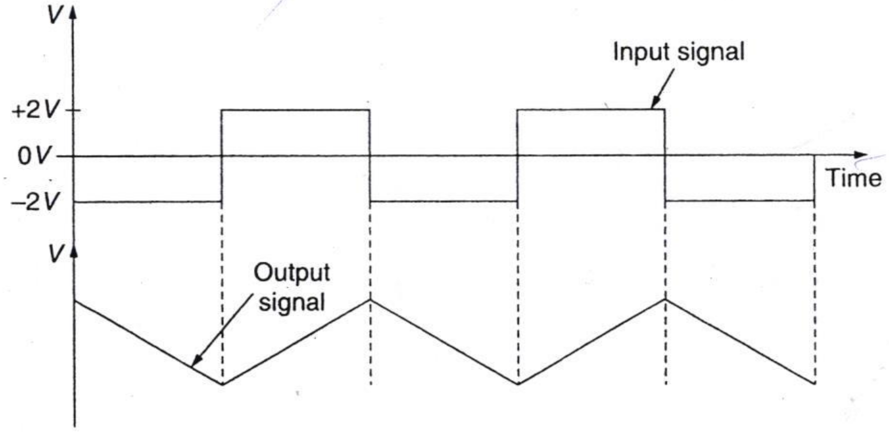

Figure 3.7(b) A typical input and output signals of an integrator.

3.2.8 Limitations of Simple Operational Amplifier Circuit

Even though the simple circuit like inverting and non-inverting amplifiers works well, the quality of the signals like ECG is pretty poor. These inverting and non-inverting modes are called common modes. The following problems can be noticed in simple common mode circuits.

(i) There is still too much noise from power supply (ac hum). Although the QRS waves of ECG can be seen, the P and T waves of ECG are suppressed by noise. On the other hand, the filter used to filter out noise also reduces the amplitude of entire ECG signal.

(ii) There is a problem of drift. Due to static charge on the subject, a dc offset may superimpose on the signal. Due to motion artifact, frequency drift (base line wander) may occur. Sometime it may saturate the amplifier.

3.2.9 Differential Amplifier

In order to minimize the abovesaid drawbacks, a new improved circuit is required. The new improved design is differential amplifier. The name is because of its property of amplifying the difference between the two input voltages. A typical differential amplifier is shown in Figure 3.8. It can be easily proved that V_0 is proportional to the difference between two inputs i.e., $V_0 \propto (V_s^+ - V_s^-)$.

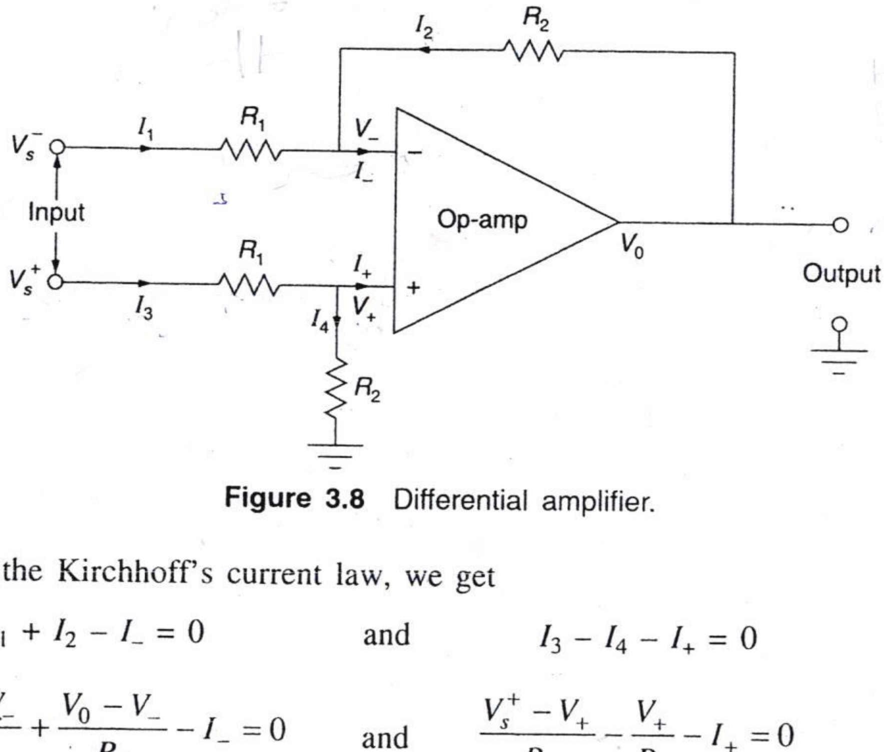

Figure 3.8 Differential amplifier.

By using the Kirchhoff's current law, we get

$$I_1 + I_2 - I_- = 0 \quad \text{and} \quad I_3 - I_4 - I_+ = 0$$

i.e.
$$\frac{V_s^- - V_-}{R_1} + \frac{V_0 - V_-}{R_2} - I_- = 0 \quad \text{and} \quad \frac{V_s^+ - V_+}{R_1} - \frac{V_+}{R_2} - I_+ = 0$$

i.e.
$$\frac{V_s^-}{R_1} + \frac{V_0}{R_2} = V_-\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \quad \text{and} \quad \frac{V_s^+}{R_1} = V_+\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \quad \text{since } I_- = I_+ \approx 0$$

But it is obvious that $V_+ = V_-$

$$\therefore \quad \frac{V_s^-}{R_1} + \frac{V_0}{R_2} = \frac{V_s^+}{R_1}$$

This equation can be written as:

$$V_0 = \frac{R_2}{R_1}(V_s^+ - V_s^-)$$

The output is proportional to R_2/R_1 times the difference between the two input signals V_s^+ and V_s^-.

3.2.10 Common Mode Rejection

The output of the differential amplifier is proportional to the difference between the inputs given on the two input terminals. If anything other than the signal (e.g. noise) is present on both inputs will be cancelled out. The ratio of the gain in differential mode to the gain in common mode is called common mode rejection ratio (CMRR).

$$\text{CMRR} = \frac{\text{Gain in differential mode}}{\text{Gain in common mode}}$$

Let a typical differential amplifier has a CMRR of about 30000. Suppose the constructed circuit has a differential gain of 1000, then the gain in common mode will be common mode gain.

$$\text{Gain in common mode} = \frac{\text{Gain in differential mode}}{\text{CMRR}}$$

A common mode gain of 1/30 indicates that the noise will be attenuated by 30 times instead of amplifying it.

CMRR in dB

The CMRR is usually expressed in dB.

$$\text{CMRR in dB} = 20 \log\left[\frac{\text{Differential mode gain}}{\text{Common mode gain}}\right]$$

In this case,

$$\begin{aligned}\text{CMRR in dB} &= 20 \log 30000 \\ &= 90 \text{ dB}\end{aligned}$$

3.2.11 Instrumentation Amplifier

Even though the differential amplifier rejects common mode signals like noises, it has low input impedance. The input impedance can be improved by designing instrumentation amplifiers. Addition of two bootstrapped buffer amplifier in the input side of differential amplifier is an instrumentation amplifier as shown in Figure 3.9. Bootstrapped buffer amplifiers are just op-amps with unity gain.

At the differential amplifier stage (Second stage) there is a gain of R_4/R_3 (in this case $47k/10k \approx 4.7$). Therefore, the output is $V_{out} = R_4/R_3\,(V_2 - V_1)$. This relation has a common mode gain of approximately 0 provided R_3 resistors are identical. This can be achieved by selecting larger values. Now, look at the buffer stage. The current has to be the same through $R_2 - R_1 - R_2$ (voltage divider) because non-inverting input draws little current.

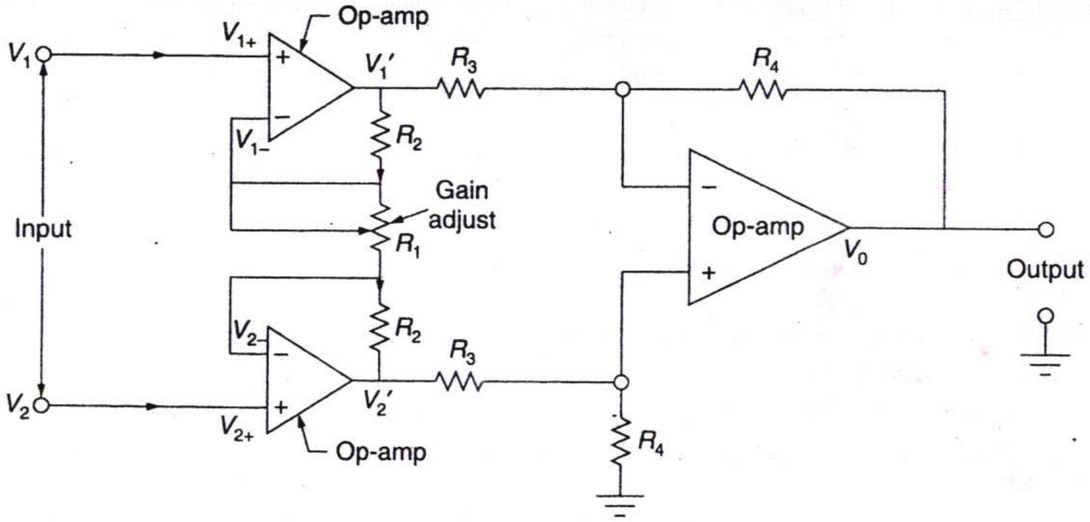

Figure 3.9 Instrumentation amplifier.

$$\text{The current through } R_2 - R_1 - R_2 = \frac{V_1' - V_{1-}}{R_2} = \frac{V_1 - V_{2-}}{R_1} = \frac{V_2 - V_2'}{R_2}$$

If one solve the above equation it can be easily seen that the common mode gain is only 1, while the differential gain is $A_{\text{diff}} = 1 + 2R_2/R_1$. The gain of the complete circuit is given by the product of the separate gains giving an ideal CMRR of infinity. However, the common mode gain of the second stage is small, but non zero in practice. Let us assume that the common mode gain is 1/10, then the CMRR used to be CMRR $= 10\left[1 + \dfrac{2R_2}{R_1}\right]\dfrac{R_4}{R_3}$ by selecting R_2 large enough one can get a large CMRR. The purpose of instrumentation amplifier is to have high input impedance noises, particularly 50 Hz ac power and to eliminate noise due to unshielded connecting wires.

band stop filter

3.2.12 Carrier Amplifiers

high

In a direct-current amplifier, the dc input signal is filtered by a low-pass filter, then used to modulate a carrier so that it can be amplified conventionally as an alternating-current signal; the amplified dc output is obtained by rectifying and filtering the rectified carrier signal. Alternatively, many transducers based on changes in inductances or capacitances require sinusoidal ac excitation for working. In some cases, strain gauges are also operated with ac for its effectiveness. Hence to measure dc or slowly changing biological variables transducers with ac excitation are necessary and desirable. Carrier amplifiers can be used to amplify the dc signals superimposed on a static ac signal. The advantage of carrier amplifier is that it can be operated on a narrow band frequency range so that the noises can be easily averted by selecting the narrow band frequency suitably. Hence the CMRR ratio is very high.

The carrier amplifier amplifies the modulated dc or modulated low frequency signal, and hence it demodulates the amplified signal to get the amplified modulating dc signal (or modulating low frequency signal). The function of carrier amplifier as employed with strain gauge transducers arranged as a Wheatstone bridge configuration is shown in Figure 3.10.

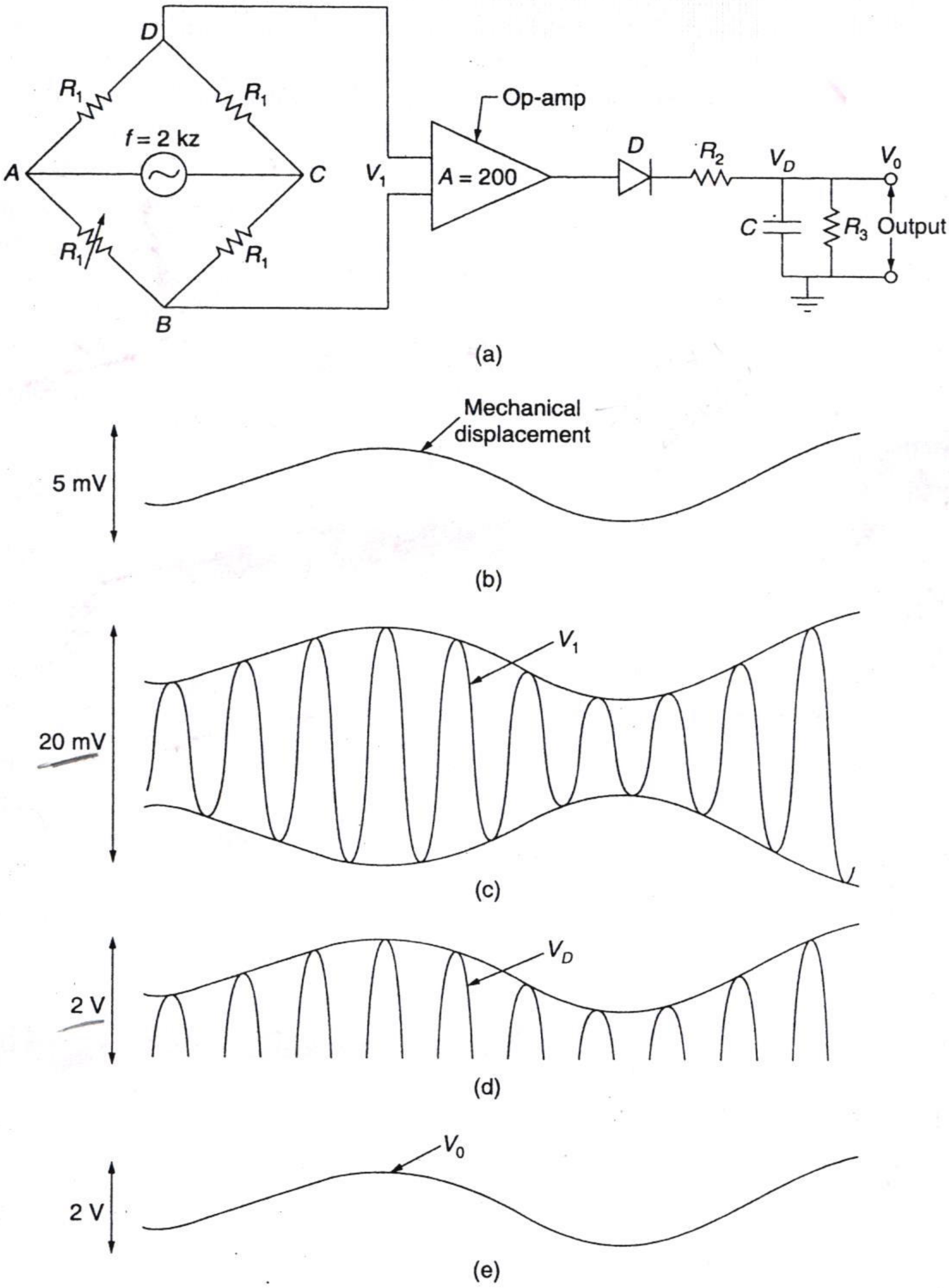

Figure 3.10 Carrier amplifier for a strain gauge transducer.

The Wheatstone bridge is made up of strain gauge in the arm AB and dummy gauge in the arm CB. Other two arms DA and DC are made up of equal resistances. Let us assume that the bridge is excited from 2000 Hz sinusoidal source and is not balanced to zero volts, but is rather slightly offset to provide a 2000 Hz 10 mV peak-to-peak voltage when there is no strain on the strain gauge.

Let us further assume that the mechanical strain of the strain gauge is sinusoidal low frequency of 1 Hz. Then the change in resistance AB will be sinusoidal. The output BD of the bridge is a sinusoidal signal of 2000 Hz. According to the variation of strain gauge resistance, the carrier signal of 2000 Hz is amplitude modulated signal with respect to 1 Hz. Note that the input impedance of the amplifier should be high enough so that no over loading takes place. The amplitude modulated 2000 Hz signal varies above and below 10 mV according to the variation of resistance of the strain gauge. Let us assume that the variation of the signal between 20 mV and 10 mV for maximum strain in the two opposite extreme resistance changes. If there is no change in the resistance then the out of the bridge remains 10 mV. Let the gain of the amplifier be 200 then the variation of the output voltage is 200 times larger than the bridge voltage. The signal can be demodulated by using a diode and resistor–capacitor combination as shown in Figure 3.10. The time constant of the demodulator circuit should be sufficient to suppress the unidirectional pulses and hence converts them in to dc and smooth slowly varying component according to resistance variation. For faithful carrier amplification, the carrier frequency must be at least 10 times the maximum frequency component in the input signal (Frequency of strain gage resistance variation in this case). Hence the carrier amplifier gives the same amplification as if it is a dc amplifier.

3.2.13 Chopper Amplifiers

DC amplifiers may exhibit drift, which is the shift or sudden peaks of output even though the input is maintained constant or zero. Chopper amplifier is one of the solutions to the problem of drift in dc amplifiers used for amplifying slowly varying or low-level dc biological variables.

The schematic diagram of a typical chopper amplifier is shown in Figure 3.11. The first block is a chopper to convert the dc signal to an ac signal. The second block is an ac amplifier to amplify the chopped signal. The third block converts the amplified chopped signal into an amplified dc signal.

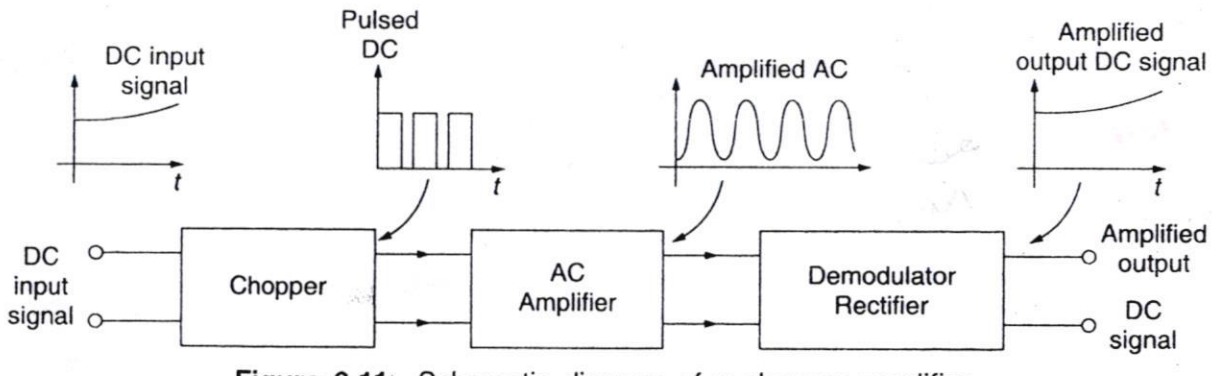

Figure 3.11 Schematic diagram of a chopper amplifier.

A typical functional diagram of a chopper is shown in Figure 3.12. The basic operation can be easily understood from the block diagram shown in Figure 3.11. The chopper allows the input signal periodically. Therefore, the input of the amplifier alternatively varied between zero volts and input voltage. The frequency of variation depends upon the switching speed of the

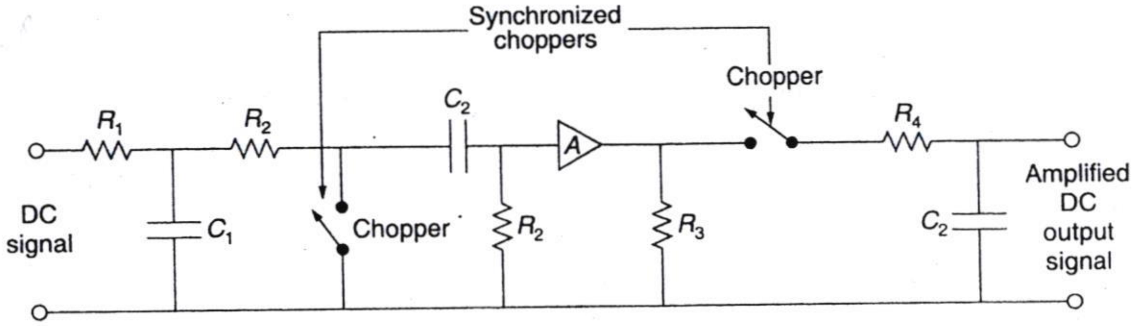

Figure 3.12 Functional diagram of a chopper amplifier.

chopper. The switch may be operated either by means of mechanical device or electronically. In olden days, mechanical switches were used. The speed of mechanical switching is limited up to 400 Hz. On the other hand, electronic switches can be operated at kilo hertz. The output of the chopper is an ac signal with amplitude equal to input signal and frequency equal to switching speed. This chopped signal is amplified using ac amplifier. A rectifier along with RC circuit demodulates the signal to get the amplified DC signal. The amplification part and demodulation part are identical to the carrier amplifier.

3.3 INTRODUCTION TO MICROPROCESSOR

A microprocessor based system or a computer is analogous to human body. The characteristics and mechanism of human body and microprocessor based system are identical except intelligence level. Intelligence level of the microprocessor is limited by the software, whereas the intelligent level of a human being is unlimited. In other words, intelligent level of a microprocessor based system is in par with the intelligent level of the person who develops the software for the particular system.

The human body consists of a brain, input devices like eyes, skin sensors, nose as smell sensors, and output devices like mouth, hands and legs. Similarly, microprocessor device consists of input devices like keyboards, joy sticks, etc., and output devices like monitor (display unit). In a human body, brain acts as a central processing unit (CPU) and takes appropriate action depending on the input from the input devices and executes the desired action through output devices. Similarly, in a microprocessor based device, microprocessor acts as a central processing unit (CPU). Comparison between a human system and a microprocessor based system is given in Table 3.1.

Figure 3.13 shows block diagram of a microprocessor based system. Here the system consists of input devices, and output devices, and memory (ROM, RAM). Input and output devices are connected by unidirectional data busses. Similarly, ROM is connected by unidirectional bus, whereas RAM (Readable and writable) memory is connected by bidirectional bus. The input devices, output devices and memory devices are commonly called peripheral devices. In addition to bus, the peripherals are connected by control bus and address bus. Address bus is to identify a particular device by the microprocessor, and control bus is acting as hand shaking signals. In the human body, nervous system acts as address bus, data bus and control bus.

Table 3.1 Comparison between Human Body and Microprocessor

S. No.	*Human body*	*Microprocessor based system*
1	Part of brain acts as decision making system.	Microprocessor makes decisions.
2	Part of brain acts as memory.	RAM, ROM are electronic memories attached to the microprocessor.
3	Eyes, ears, skin, etc., act as input devices.	Keyboard, mouse, joystick, switches etc., act as input devices.
4	Mouth, hands, legs, etc., act as output devices.	Monitor, motor, lamp, etc. act as output devices.
5	Nerves act as communication links.	Bus (group of wires) act as communication links.
6	Knowledge helps to take decisions.	Software helps to take decisions.
7	Intelligence is unlimited, but as a function of individual capacity and inborn characteristics.	Limited intelligence. Limited by software. It has artificial intelligent par with person who develops the software.

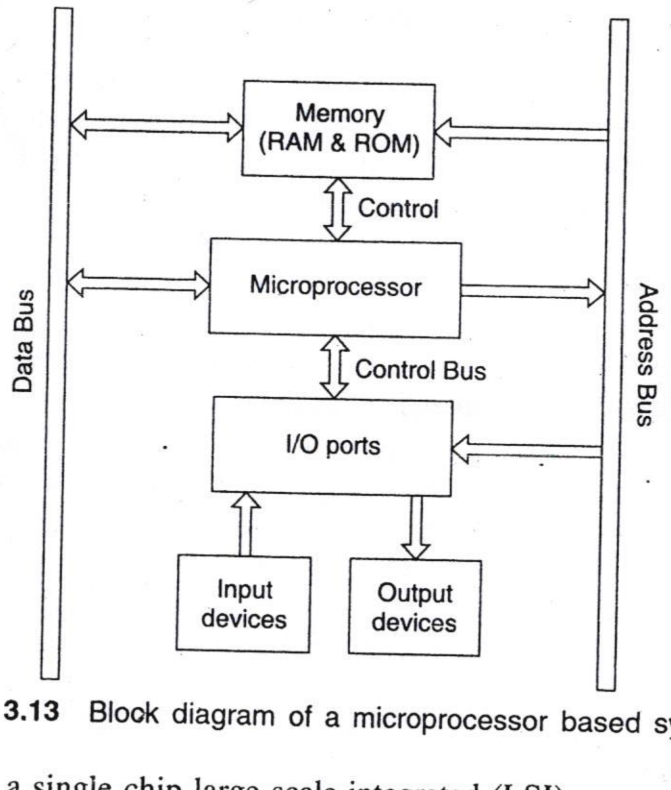

Figure 3.13 Block diagram of a microprocessor based system.

Microprocessor is a single chip large scale integrated (LSI) or very large scale integrated (VLSI) circuit. It has arithmetic, logic and control circuitry including memory registers for general purpose processing, control and computing. The microprocessor usually fabricated as a single chip forms the central processing unit (CPU) of the system. A microprocessor acts like human brain; it accepts data from input devices, fetches instructions from memory, decodes and execute them, performs logic and arithmetic operations on the data from the input devices. The results are sent to the output devices. A microprocessor based system has the following characteristics. It performs a pre-specified task for a single system. Nowadays it is part of many systems like cell phone, DVD, TV, Xerox copier, medical instrument, traffic controller, factory machine, etc. The set of instructions to be performed by the microprocessor is called a program. The microprocessor based system has a fixed program that is rarely changed. Programs are used to store on a permanent medium like read only memory (ROM). The microcomputers often perform real time tasks like cell phone, DVD, TV, biomedical telemetry systems, biomedical systems in general. Microcomputers have numerous applications in the form of smart biomedical instruments, control systems and calculators. Other applications include industrial process control and measurement system, control of automobile performance (mileage improvement, exhaust gas emission control, control of safety devices, etc.), information processing in the office (accounting, word processors, e-mail, etc.), inventory control, banking (ATM, net banking, credit card, etc.), control of kitchen ware (control of micro oven), and control of space vehicle (satellite, missile, radar, etc.).

An important advantage of a microprocessor based system is that the same hardware can be used for many applications simply by modifying the software (program) written on the read only memory (ROM). It is identical to human being. All human beings have the same structure, but their skill (software) level is different.

Figure 3.13 shows the block diagram of a simple microprocessor based system. It consists of the following blocks:

(i) Microprocessor
(ii) Memory
(iii) Input devices
(iv) Output devices
(v) Input/Output ports (I/O ports)
(vi) Data/Address/Control busses

Microprocessor

The microprocessor is the central processing unit (CPU) and consists of arithmetic and logic unit (ALU) to perform logic and arithmetic operations. It also has some registers to store instructions and data. In addition to this it has control circuitry to control the data transfer between memory, input devices, output devices with microprocessor. To perform all these tasks in a sequence manner, the user writes a sequence of instructions known as program. The program is stored in the memory. The microprocessor fetches the instructions one by one from memory and executes it. The input devices supply the required data. The results obtained while executing the instructions on the data are sent to the desired output device. The microprocessor also controls the various devices that perform the input–output operations.

Memory

Memory section usually consists of semiconductor memories such as RAM, ROM and EPROM. Read only memory (ROM) is the part of microprocessor based system to retain the set of instructions (program) when the system is switched off. Random access memory (RAM) is the part of microprocessor based system to store and retrieve the intermediate results during operation.

Input devices

The input devices convert the input signals into proper binary form so that the microprocessor can read and understand the meaning and magnitude of the signal. The typical input devices are keyboard, toggle switches, analog to digital converters, cassette tapes, hard disks, pen drive, CD-ROM, etc.

Output devices

The output devices convert the binary output from the microprocessor into a useful form. Examples of these devices include printers, cathode ray tube displays (Monitors), digital to analog converters, 7-segment displays, etc.

Input/Output ports

A country communicates with outside world through airports and seaports. Similarly, a microprocessor communicates with outside devices through input/output ports simply, called I/O ports. Through these ports the microprocessor sends and receives data to and from the peripheral devices respectively.

Busses (Data/Address/Control busses)

Busses are nothing but group of wires through which data are transferred and electrical communications are established. The busses through which the microprocessors communicate with outside devices can be classified into three types. They are address bus, data bus ad control bus. These busses link the CPU, memory and I/O ports.

The address bus is used by the CPU to send the address of the device or memory location to which the microprocessor desires to communicate. Address is similar to a cell phone number assigned to each cell phone. If one wants to communicate with the person who holds the particular cell phone, then as a first step, the address of the cell (cell number) is placed on the communication link. Once the communication link is established, then the other data like voice are placed over the communication link. The data bus is used to transfer data to and from the microprocessor. Address bus is unidirectional (from the microprocessor to devices), whereas data bus is bidirectional (both to and from microprocessor to and from devices). The control bus carries signals needed for synchronization and controls the entire system. Few examples of control signals are read, write, hold, reset, etc.

3.3.1 Introduction to Microcontroller

A microcontroller (also called MCU or μC) is a functional microprocessor based system-on-a-chip. In contrast to a microprocessor which only contains a CPU, microcontrollers consist of an integrated CPU, memory (a small amount of RAM, ROM, or both) and peripherals capable of input and output. In addition to arithmetic and logical operating units of a general purpose microprocessor, the microcontroller integrates additional operating units such as read–write memory for data storage, read-only memory for program storage, flash memory for permanent data storage, and input/output/pheripheral interfaces. Microcontrollers operate at very low speed compared to microprocessors, but this is adequate for typical applications. It consumes power in milliwatts or even microwatts, and will generally have the ability to retain functionality while