Module II
BASIC BIOINSTRUMENTATION SYSTEM

- The quantity, property, or condition that is measured by an instrumentation system is called the measurand.
- This can be a bioelectric signal, such as those generated by muscles or the brain, or a chemical or mechanical signal that is converted to an electrical signal.
- The sensors are used to convert physical measurands into electric outputs.
- The outputs from these biosensors are analog signals—that is, continuous signals—that are sent to the analog processing and digital conversion block.
- Then the signals are amplified, filtered, conditioned, and converted to digital form.

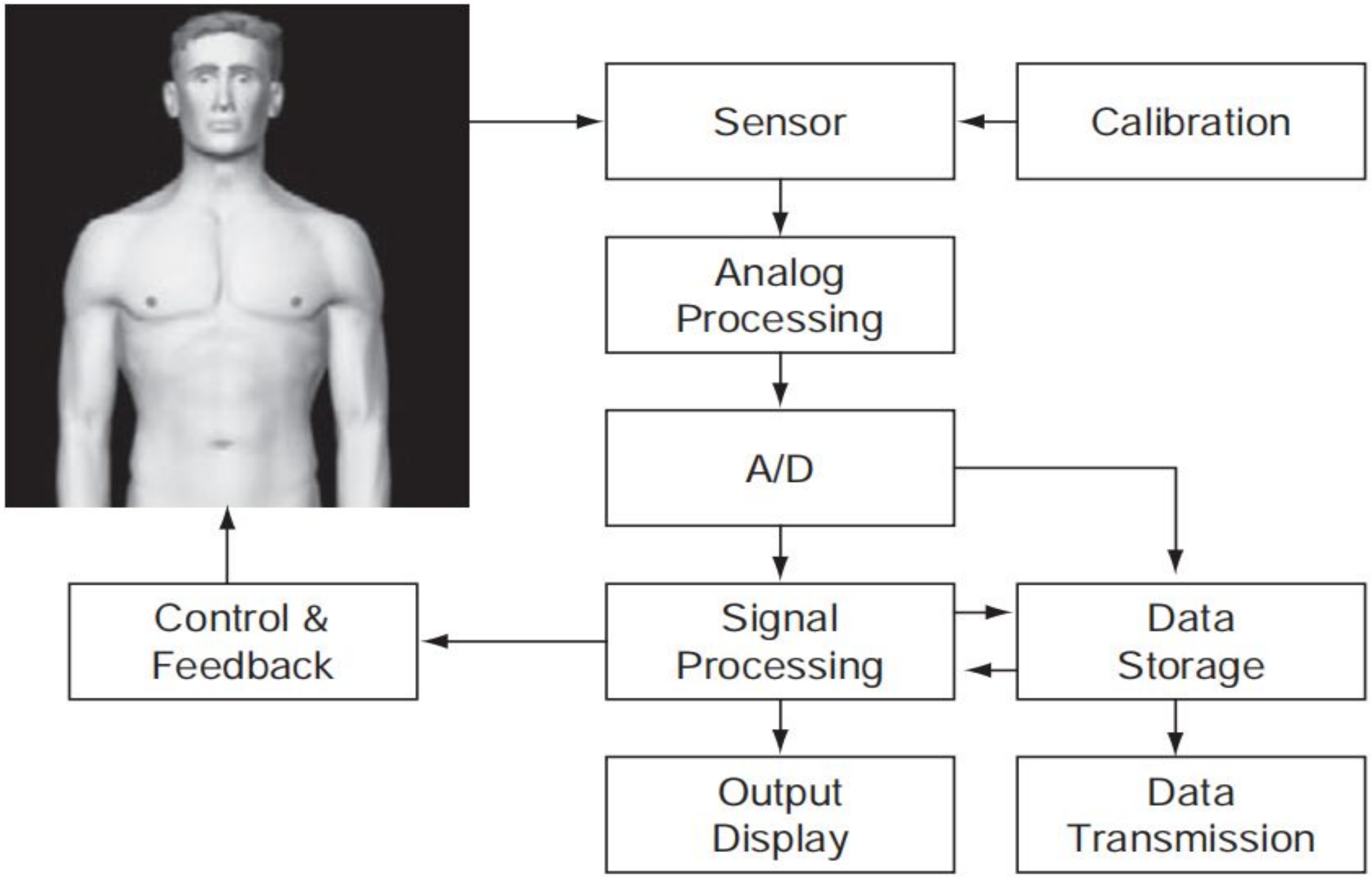


FIGURE 9.2 Basic instrumentation systems using sensors to measure a signal with data acquisition, storage, and display capabilities, along with control and feedback.

Man - Instrumentation System:

- The overall system including both the human body and the instrumentation required for its measurement is called the *man – instrumentation system*. The set of instruments and equipment utilized in the measurement of multiple characteristics plus the presentation of these information in a readable and interpretable manner is called an instrumentation system. In the man – instrumentation system, the human body is treated as the black box (the unknown system) within which several kinds of signals and systems are found, all interacting with each other.

Function:

- Man Instrument System: The overall system, which includes both the human organism and the instrumentation required for the measurement of a human.
- Component of Man Instrument System: Subject, Stimulus, Transducer, Signal Conditioning equipment, Display Equipment, 'Recording, Data Processing and Transmission Equipment' and Control Devices.
- Objective and Goal: Information gathering, Diagnosis, Evaluation, Monitoring, Control.
- The Goal is to make possible the measurement of information communicated by the various elements of the human body.

- Methods for modifying analog signals, such as amplifying and filtering an ECG signal
- Once the analog signals have been digitized and converted to a form that can be stored and processed by digital computers, many more methods of signal conditioning can be applied
- Basic instrumentation systems also include output display devices that enable human operators to view the signal in a format that is easy to understand.
- These displays may be numerical or graphical, discrete or continuous, and permanent or temporary.
- Most output display devices are intended to be observed visually, but some also provide audible output—for example, a beeping sound with each heartbeat.

- In addition to displaying data, many instrumentation systems have the capability of storing data so further processing / examine the data is possible.
- Holter monitors, for example, acquire 24 hours of ECG data that is later processed to determine arrhythmic activity and other important diagnostic characteristics.
- Now with the Internet, signals can be acquired with a device in one location and transmitted to another device for processing and/or storage.
- Useful to provide quick diagnostic feedback if a patient has an unusual heart rhythm while at home.
- It has also allowed medical facilities in rural areas to transmit diagnostic images to tertiary care hospitals so that specialized physicians can help general practitioners arrive at more accurate diagnoses.

- Two components play important roles in instrumentation systems.

- The first is the calibration signal. A signal with known amplitude and frequency content is applied to the instrumentation system at the sensor’s input.

- The calibration signal allows the components of the system to be adjusted so that the output and input have a known, measured relationship.

- Another important component, a feedback element, is not a part of all instrumentation systems.
- Devices include pacemakers and ventilators that stimulate the heart or the lungs.

- Some feedback devices collect physiological data and stimulate a response—a heart beat or breath-when needed , such as blood pressure, and uses conscious control to change the physiological response.

MAN-INSTRUMENT SYSTEM

- **Conventional Instrumentation system**
- **Inherent systems in human body**
- **Basic(general) Block diagram of-**

  Medical (Man)instrumentation system
- **Classification of Instrumentation system**
- **Objectives of Medical instrumentation system**
- **Factors to be considered while measurement**

❖ The system comprising both the Human being and the instruments used for measurement is termed as MAN INSTRUMENT SYSTEM.

Basic objectives

Basic objectives of
Medical or Man Instrumentation system-

- Information gathering
- Diagnosis
- Evaluation
- Monitoring
- control

Block diagram ……..:

- Basic(General) block diagram of Medical or Man Instrumentation system.
- Functional components
  - Measurand (subject)- stimulus
  - Sensors/Transducers
  - Signal conditioner-pre amplifier, signal processing
  - Output devices - Alarams
    - -Display
    - -Data storage
    - -Data transmission
    - -Data recording
  - Control System

- Clinical instrumentation
- Research instrumentation

Measurements obtained from such Instrumentation-

  - In-vivo measurement
  - In-vitro measurement

General Consideration
Design of Medical Instrumentation System:

- General consideration:
  - Signal consideration: Types of sensors, sensitivity, range, input impedance, frequency response, accuracy, linearity, reliability, differential or absolute input
- Environmental Consideration:
  - S/N ratio, Stability, atmospheric temperature, pressure, humidity, vibration, radiation, etc
- Medical Consideration:
  - Invasive or Non-invasive technique, patient discomfort, radiation and heat dissipation, electrical safety, material toxicity, etc.
- Economic Consideration
  - Initial cost, cost and availability of consumables and compatibility with exiting equipments

Common Medical Measurands:

- The following table shows few of the measurement parameters generally used in medical instrumentation system along with its operational range and methods employed in attaining the same.

TABLE I: Measurement Parameters with range

Measurement Type	Range	Frequency Hz	Method
Blood Flow	1 to 300 mL/s	0 to 20	EM or US
Blood Pressure	0 to 400 mm Hg	0 to 50	Cuff or Strain Gage
Cardiac Output	4 to 25 L/min	0 to 20	Fick, dye dilution
ECG	0.5 to 4 mV	0.05 to 150	Skin Electrodes
EEG	5 to 300 µV	0.5 to 150	Scalp Electrodes
EMG	0.1 to 5 mV	0 to 10000	Needle Electrodes
Electroretinography	0 to 900 µV	0 to 50	Contact Lens Electrodes
pH	3 to 13 pH units	0 to 1	pH Electrodes
pCO_2	40 to 100 mm Hg	0 to 2	pCO_2 Electrodes
pO_2	30 to 100 mm Hg	0 to 2	PO_2 Electrodes
Pneumotachography	0 to 600 L/min	0 to 40	Pneumatochometer
Respiratory Rate	2 to 50 breaths/min	0.1 to 10	Impedance
Body Temperature	32 °C to 40 °C	0 to 0.1	Thermistor

Components of Biomedical Instrumentation System

Any medical instrument consists of the following functional basic parts

1. Measurand:

- The measurand is the physical quantity, and the instrumentation systems measure it.
- Human body acts as the source for measurand, and it generates bio-signals. Example: body surface or blood pressure in the heart

2. Sensor / Transducer:

- The transducer converts one form of energy to another form usually electrical energy. For example, the piezoelectric signal which converts mechanical vibrations into the electrical signal.
- The transducer produces a usable output depending on the measurand.
- The sensor is used to sense the signal from the source. It is used to interface the signal with the human.

3. Signal Conditioner:

- Signal conditioning circuits are used to convert the output from the transducer into an electrical value. The instrument system sends this quantity to the display or recording system.
- Generally, signal conditioning process includes amplification, filtering, analogue to digital and Digital to analogue conversions.
- Signal conditioning improves the sensitivity of instruments.

4. Display:

- It is used to provide a visual representation of the measured parameter or quantity. Example: Chart recorder, Cathode Ray oscilloscope (CRO). Sometimes alarms are used to hear the audio signals.
- Example: Signals generated in Doppler Ultrasound Scanner used for Fetal Monitoring.

5. Data Storage and Data Transmission: Data storage is used to store the data and can be used for future reference.

Types

- Clinical - It is devoted to the diagnosis, care and treatment of patients.
- Research - It is used primarily in the search for new knowledge pertaining to the various systems that compose the human organism.

Types of Measurements

- Vivo - It is made on or within the living organism itself. For Example - A device inserted into the blood stream to measure the pH of the blood directly.
- Vitro - It is performed outside the body, even though it relates to the functions of the body. For Example - pH of a sample of blood.

Bioamplifier:

- It is an electrophysiological device, a variation of the instrumentation amplifier, used to gather and increase the signal integrity of physiologic electrical activity for output to various sources.

- It may be an independent unit, or integrated into the electrodes.

Why is Bio Amplifier Required?

- Generally, biological/bioelectric signals have low amplitude and low frequency. Therefore, to increase the amplitude level of biosignals amplifiers are designed.
- The outputs from these amplifiers are used for further analysis and they appear as ECG, EMG, or any bioelectric waveforms.
- Such amplifiers are defined as Bio Amplifiers or Biomedical Amplifiers.
- Gain refers to the relationship between the **input signal and the output signal** of any electronic system.
- Higher levels of gain amplify the signal, resulting in greater levels of brightness and contrast. Lower levels of gain will darken the image, and soften the contrast.

What is the voltage gain value of a bioelectric amplifier?

- Since the output of a bioelectric signal is in millivolts or microvolt range, the voltage gain value of the amplifier should be higher than 100dB.

- Throughout the entire bandwidth range, a constant gain should be maintained.

- A bio-amplifier should have a small output impedance.

Types of Bio Amplifiers

- Differential Amplifier
- Operational Amplifier
- Instrumentation Amplifier
- Chopper Amplifier
- Isolation Amplifier

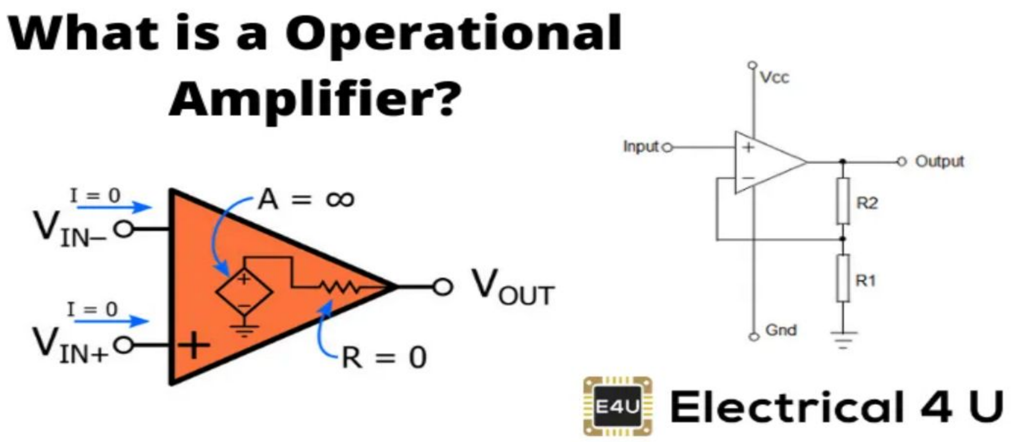
Basic Requirements for Biological Amplifiers

- The biological amplifier should have a high input impedance value. The range of value lies between 2 MΩ and 10 MΩ depending on the applications.
- When electrodes pick up biopotentials from the human body, the input circuit should be protected.
- Every bio-amplifier should consist of isolation and protection circuits, to prevent the patients from electrical shocks.
- Since the output of a bioelectric signal is in millivolts or microvolt range, the voltage gain value of the amplifier should be higher than 100dB.
- Throughout the entire bandwidth range, a constant gain should be maintained.
- A bio-amplifier should have a small output impedance.
- A good bio-amplifier should be free from drift and noise.
- Common Mode Rejection Ratio (CMRR) value of amplifier should be greater than 80dB to reduce the interference from common mode signal.
- The gain of the bio-amplifier should be calibrated for each measurement.

Operational amplifier:

- It is an electronic device that consists of large numbers of transistors, resistors, and capacitors.

- Op-amp is basically a multistage amplifier in which a number of amplifier stages are interconnected to each other in a very complicated manner.



An **operational amplifier** or **op amp** is a DC coupled voltage amplifier with a very high voltage gain.

- So, it is packed in a small package and is available in the Integrated Circuit (IC) form.

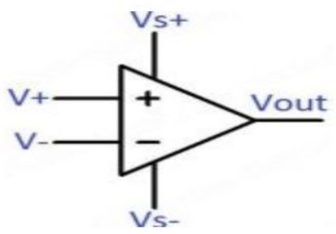
- Used to perform various operations like amplification, subtraction, differentiation, addition, integration etc.

- An example is the very popular IC 741.

What makes opamp different from other amplifiers ?

- Opamp is a differential amplifier having very high gain.
- It has basically 2 inputs, non-inverting input (Vp or V+) and inverting input (Vn or V-).
- It will amplify only the difference between these two inputs ie (Vp – Vn) or (V+ – V-).
- Important features of opamp compared to normal amplifiers are given below.
  - Very high gain
  - Very high input impedance
  - Very low output impedance
  - High CMRR
  - High bandwidth
  - Able to amplify both AC and DC
  - Low noise

Opamp Symbol



Op-Amp Block Diagram

Vs+	:	Positive Power Supply
Vs-	:	Negative Power Supply
V+	:	Non-inverting input
V-	:	Inverting Input
Vout	:	Output

- **They are used in variety of applications** such as inverting amplifier and non inverting amplifiers, unity gain buffer, summing amplifier, differentiator, integrator, adder, instrumentation amplifier, Wien bridge oscillator, Filters etc.

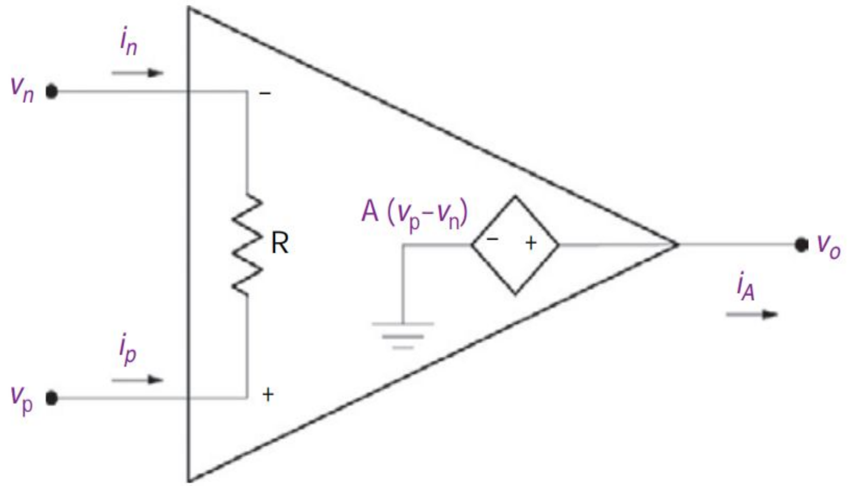
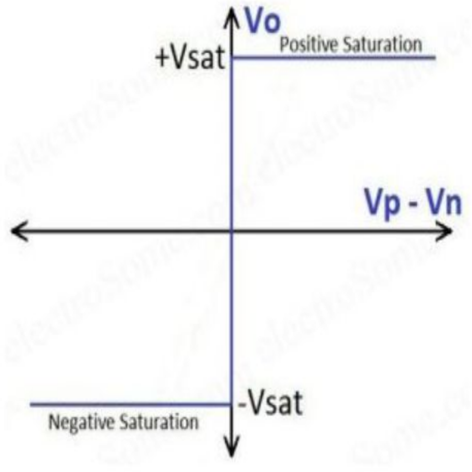


FIGURE 9.30 An internal model of the op amp. The internal resistance between the input terminals, R, is very large, exceeding 1 MΩ. The gain of the amplifier, A, is also large, exceeding 10^4. Power supply terminals are omitted for simplicity.

Ideal Op-amp Transfer Characteristics

- Infinite open loop voltage gain
- Infinite input impedance
- Zero output impedance
- Infinite bandwidth
- Zero input offset voltage
- Zero common mode gain
- Infinite CMRR (Common Mode Rejection Ratio)
- Zero DC output offset
- Zero noise contribution
- Infinite power supply rejection ratio
- Positive and negative voltage swings to supply rail
- Output swings instantly to the correct value

Characteristics of an Ideal Opamp

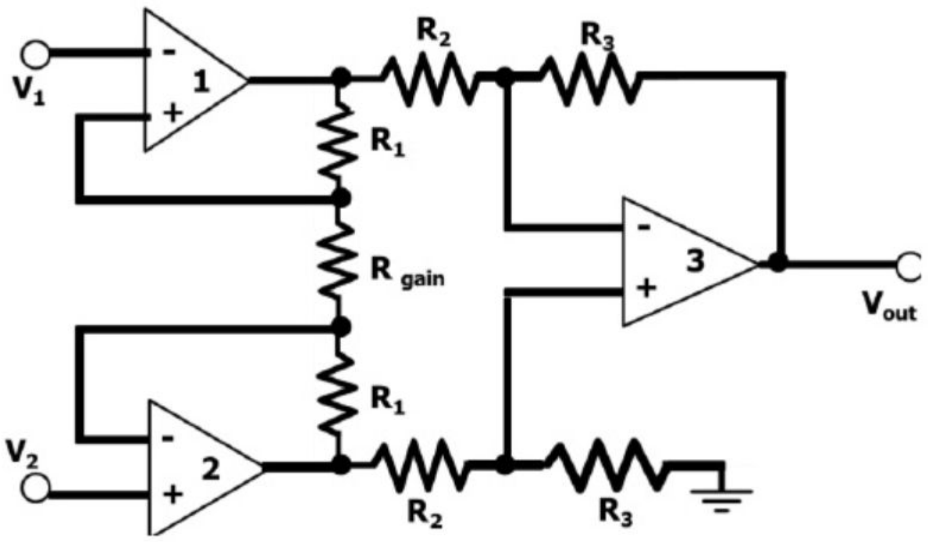


Ideal Op-amp Transfer Characteristics

Instrumentation amplifier

- It is an IC mainly used for amplifying a signal.
- This amplifier comes under the family of the differential amplifier
- Its function of this amplifier is to diminish surplus noise that is chosen by the circuit.
- The capacity to refuse noise is familiar to every IC pins which are known as the CMRR (common-mode rejection ratio).
- It is an essential component in the designing of the circuit due to its characteristics like high CMRR, open-loop gain is high, low drift as well as low DC offset, etc.
- An instrumentation amplifier is used to amplify very low-level signals, rejecting noise and interference signals.
- Examples can be heartbeats, blood pressure, temperature, earthquakes and so on.

- Instrumentation Amplifier using Op Amp
- The instrumentation amplifier using op-amp circuit is shown below.



Instrumentation Amplifier using Op Amp

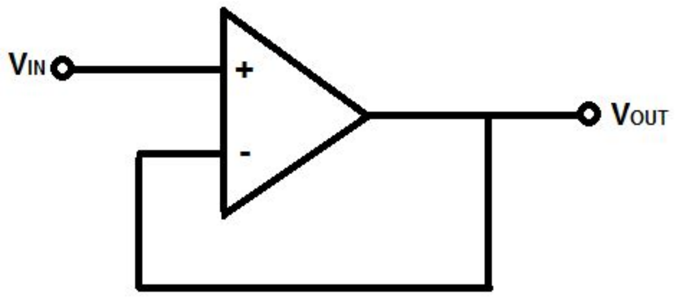
- The op-amps 1 & 2 are non-inverting amplifiers and op-amp 3 is a difference amplifier.
- These three op-amps together, form an instrumentation amplifier.

- Instrumentation amplifier's final output Vout is the amplified difference of the input signals applied to the input terminals of op-amp 3.

- Let the outputs of op-amp 1 and op-amp 2 be Vo1 and Vo2 respectively.

- **Then, Vout = (R3/R2)(Vo1-Vo2)**

Isolation Amplifier



Working and Its Applications

- An isolation amplifier or a unity gain amplifier provides isolation from one fraction of the circuit to another fraction.

- So, the power cannot be drawn, used and wasted within the circuit.
- The main function of this amplifier is to increase the signal.

- It is a form of differential amplifier that allow measurement of small signals in the presence of a high common mode voltage by providing electrical isolation and an electrical safety barrier.

- It protect data acquisition components from common mode voltages, which are potential differences between instrument ground and signal ground.

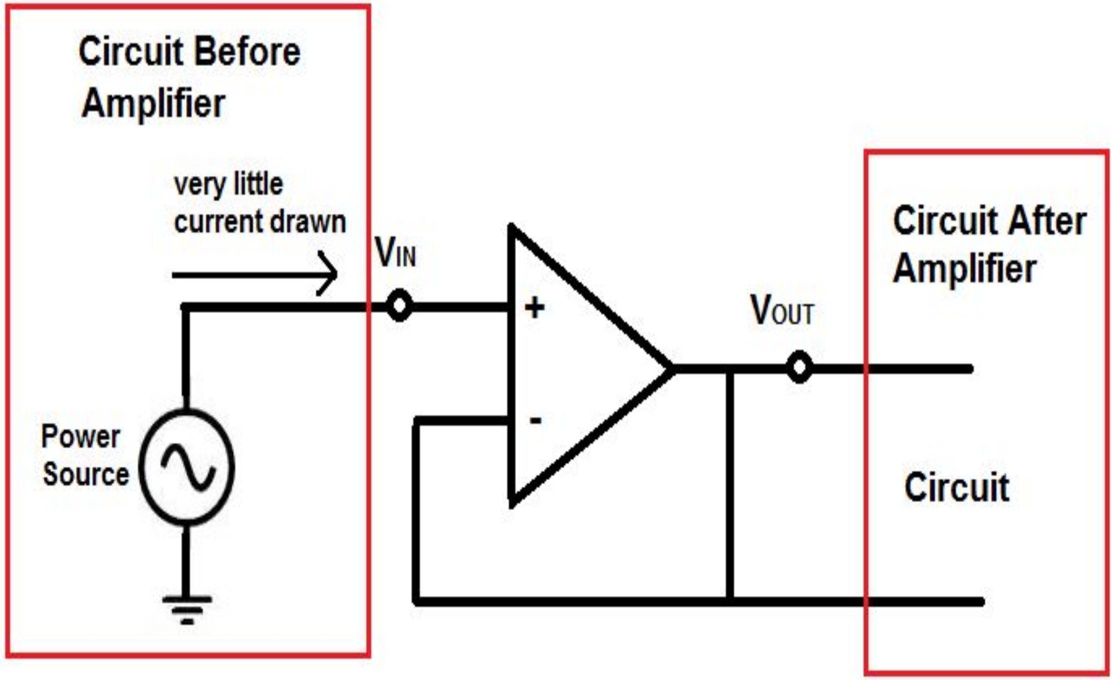
- The same input signal of the op-amp is passed out exactly from the op-amp as an output signal.

- Used to give an electrical safety battier as well as isolation.

- It protect the patients from the outflow of current.

How Isolation Achieves?

- An op amp has very high input impedance, that causes isolation.
- When a circuit has a very high input impedance, very little current is drawn from the circuit. Ohm's law, current, I=V/R.
- Thus, the greater the resistance, the less current is drawn from a power source.



- It draws very little current; thus, practically no current is drawn and transferred from the first part of the circuit to the second.
- The high-impedance load of the op-amp ensures this.

- Thus, the op-amp serves as an isolation device from one part of a circuit to the next or of different circuits.

- So, the low-level signals can be amplified.

- This isolation must have less leakage as well as a high amount of dielectric breakdown voltage.

Isolation Amplifier: Design Methods

- Three kinds of design methods are used in isolation amplifiers which include the following.

- Transformer Isolation
- Optical Isolation
- Capacitive Isolation