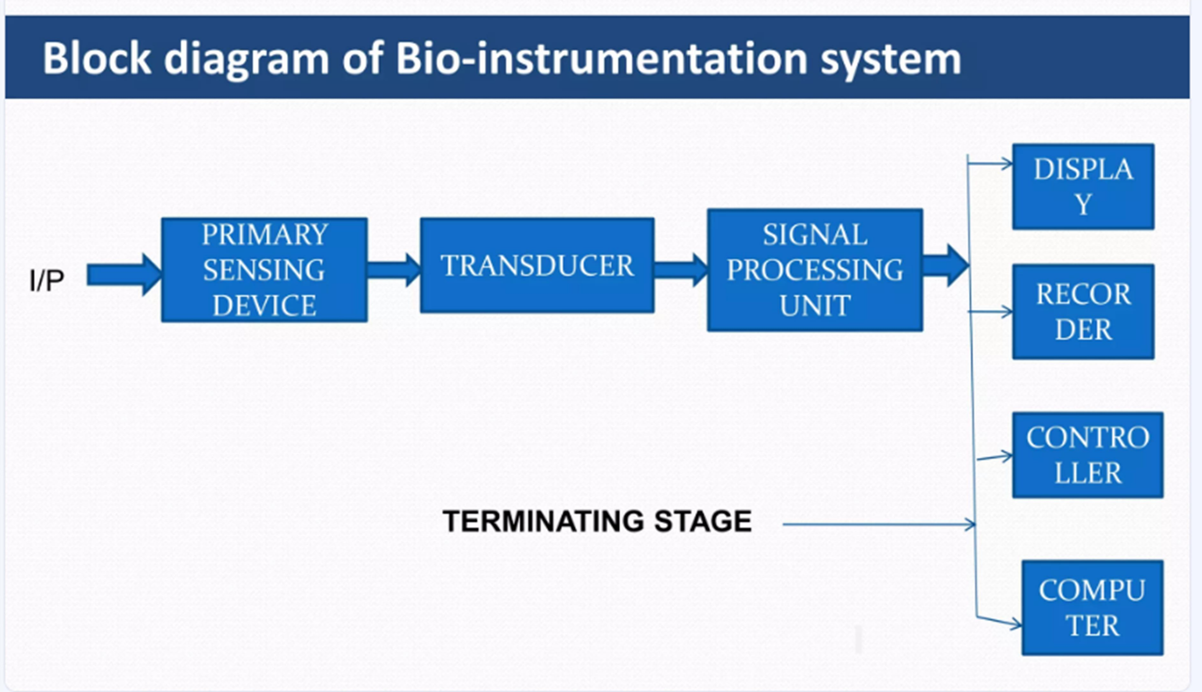
Unit-1 Introduction to Biomedical Instruments

Generalized Block Diagram of a Medical Instrumentation System

A biomedical instrumentation system is essentially a tool that measures or manipulates physiological signals in the human body. The general block diagram provides a simplified overview of its key components:



1. **Sensor:** This is the interface between the human body and the instrument. It converts the physiological signal (e.g., temperature, blood pressure) into an electrical signal.
2. **Signal Conditioner:** This block processes the raw signal from the sensor to make it suitable for further analysis. It may involve amplification, filtering, or other signal processing techniques.
3. **Transducer:** This component converts the processed electrical signal from the signal conditioner into a different form, often a digital signal, for display or further processing.
4. **Display/Recorder:** This is the output device that presents the processed information to the user. It could be a simple meter, a complex graphical display, or a data storage device.
5. **Processor/Controller:** This optional component provides additional processing or control capabilities. It may perform calculations, make decisions, or control other devices within the system.

Types of Instruments

Biomedical instruments can be broadly categorized into three main types:

1. **Therapeutic Instruments:** These instruments are used to treat or manage medical conditions. They actively intervene in the body's physiological processes.

Examples:

- **Pacemakers:** Regulate heart rhythm.
- **Defibrillators:** Deliver electric shocks to restore normal heart rhythm.
- **Implantable drug pumps:** Deliver medications directly to the target site.
- **Surgical lasers:** Precisely cut and coagulate tissue.

1. **Clinical Laboratory Instruments:** These instruments are used to analyze biological samples (blood, urine, tissue) to diagnose diseases or monitor health status.

Examples:

- **Blood analyzers:** Measure various blood components like glucose, cholesterol, and electrolytes.
- **Urine analyzers:** Detect the presence of abnormal substances in urine.
- **Microscope:** Examine cells and tissues for abnormalities.
- **DNA sequencers:** Analyze genetic material for diagnostic purposes.

1. **Diagnostic Instruments:** These instruments are used to monitor physiological signals or produce images to assist in diagnosis.

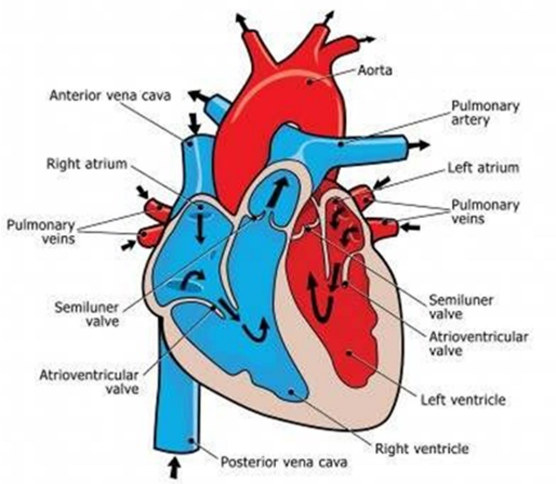
Examples:

- **Electrocardiogram (ECG):** Records electrical activity of the heart.
- **Electroencephalogram (EEG):** Records brainwave activity.
- **X-ray machines:** Produce images of internal structures.
- **Ultrasound machines:** Use sound waves to create images of internal organs.
- **Magnetic resonance imaging (MRI) machines:** Use magnetic fields to create detailed images of the body.

Physiological Systems of the Human Body

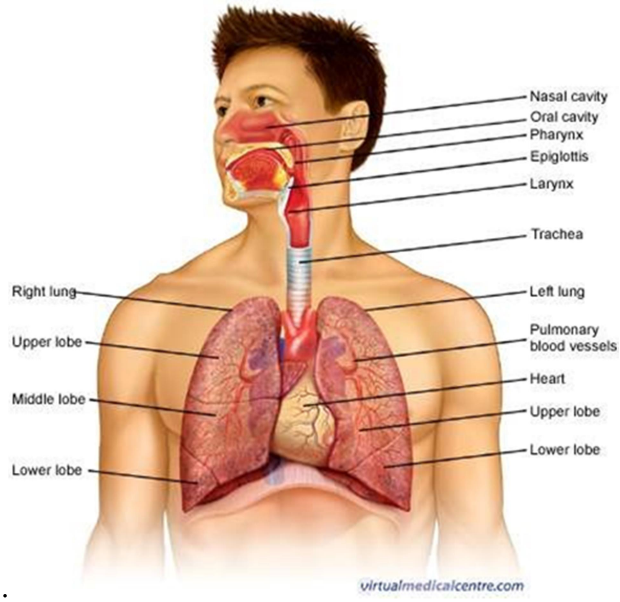
Biomedical instruments are often designed to interact with specific physiological systems:

- **Cardiovascular System:** Regulates blood flow and oxygen delivery throughout the

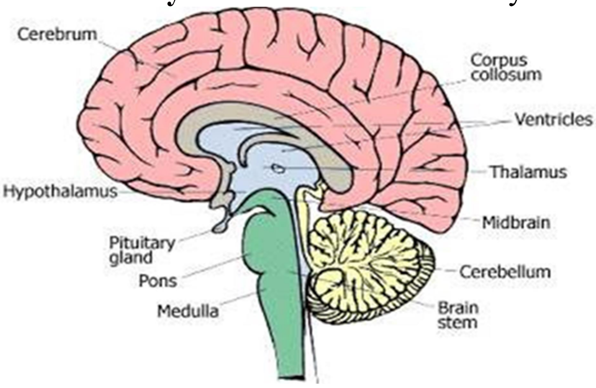


body.

- **Respiratory System:** Responsible for gas exchange (oxygen intake and carbon



dioxide removal).
- **Nervous System:** Controls bodily functions through electrical signals.



- **Biochemical System:** Regulates the body's chemical processes, such as metabolism and hormone production.

Understanding these physiological systems is crucial for designing effective biomedical instruments that can accurately measure and manipulate their functions.

Unit II: Signal Conditioning

This unit likely focuses on techniques and circuits used to modify or enhance electrical signals before they are processed or used in other systems. Signal conditioning is crucial in various applications, such as instrumentation, control systems, and communication.

2.1. Introduction to Operational Amplifier

2.1.1 Characteristics of an Ideal Operational Amplifier and its Block Diagram

- Ideal Operational Amplifier (Op-Amp): An ideal op-amp is a theoretical device with the following characteristics:

- Infinite Input Impedance: It draws no current from the input terminals, making its input resistance infinitely high.
- Zero Output Impedance: It can supply any amount of current to the load without its output voltage being affected.
- Infinite Gain: It can amplify signals to extremely high levels.
- Infinite Bandwidth: It can amplify signals of any frequency without any loss in gain.
- Zero Input Offset Voltage: The output voltage is zero when no input signal is applied.

- Block Diagram: An op-amp is typically represented by a triangular symbol with two input terminals (inverting and non-inverting) and one output terminal. The power supply connections are usually omitted in the simplified block diagram.

2.1.2 IC-741 and its Pin Configuration

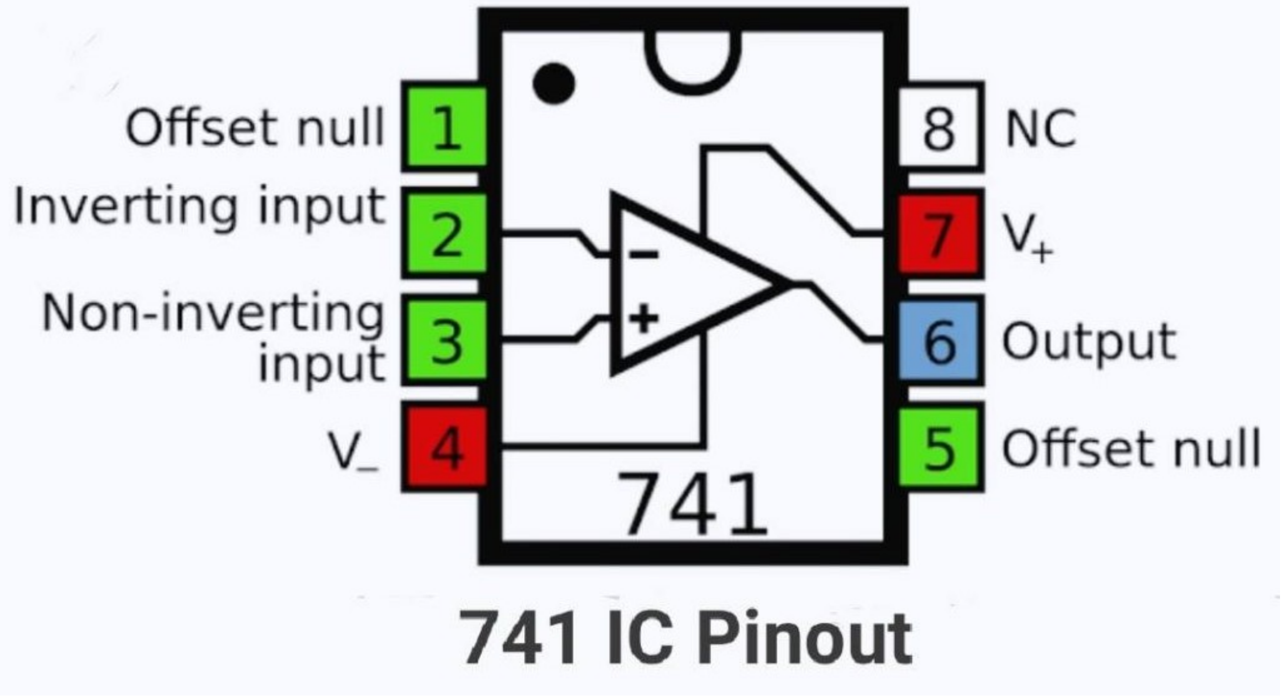
IC LM741 OP AMP

Advantages/Special Features of IC 741 OP AMP:

1. General Purpose: The 741 is a general-purpose op-amp suitable for a wide range of applications in analog electronic circuits.
2. Single Operational Amplifier: The IC 741 contains a single operational amplifier in an 8-pin dual in-line package (DIP).
3. Low Input Offset Voltage: The 741 typically has a low input offset voltage, meaning that the output voltage is close to zero when the input voltages are equal. It has offset voltage null capability.
4. High Input Impedance: The input impedance of the 741 is high, which means it draws very little current from the input source.
5. High Gain: The 741 has a Large differential voltage gain, typically around 100,000 or more.
6. Wide Frequency Response: It has a wide frequency response, typically from a few hertz to several megahertz. Frequency compensation is not required.
7. Low Input Bias Current: The 741 has low input bias current, which reduces errors in applications where input currents are significant.
8. Short Circuit Protection: It usually incorporates short-circuit protection, safeguarding the device from damage in case of output short circuits.

9. Operating Voltage: The typical operating voltage for the 741 is between ±5V and ±18V.
10. Temperature Range: It can operate over a wide temperature range, typically from -55°C to 125°C, making it suitable for various environments.
11. Low Cost: One of the advantages of the 741 is its low cost, making it accessible for a wide range of applications.

OP AMP IC 741 Pin Diagram/Pinout:



OP AMP IC 741 Pin Diagram

The operational amplifier (op-amp) IC 741 is a widely used integrated circuit in electronics. It has eight pins, each serving a specific purpose:

1. Offset Null (NC): This pin is usually not connected (NC). It was used in older versions of the 741 op-amp for offset nulling, but modern versions typically don't utilize it.
2. Inverting Input (-): This pin is denoted with a negative (-) sign and is used as the inverting input terminal of the op-amp.
3. Non-Inverting Input (+): This pin is denoted with a positive (+) sign and is used as the non-inverting input terminal of the op-amp.
4. V- (Negative Power Supply): This pin is connected to the negative power supply terminal.
5. Offset Null (NC): Similar to pin 1, this pin is usually not connected (NC) in modern applications.
6. Output: This pin is the output terminal of the op-amp.
7. V+ (Positive Power Supply): This pin is connected to the positive power supply terminal.
8. NC: This pin is typically not connected and left unused.

This is standard OP AMP IC 741 Pin Diagram but do check the datasheet of the specific manufacturer for any variations or additional features. OP AMP IC 741 is available in many other packages.

Important characteristics of IC 741 op-amp:

Sr, No	Characteristics	Value for IC 741	Ideal value
1	Input resistance Ri	2M ohm	infinity
2	Output resistance Ro	75 ohm	0
3	Voltage gain Av	2*10^5	infinity
4	Bandwidth B.W.	1MHz	infinity
5	CMRR	90dB	infinity
6	Slew rate S	0.5V/uS	infinity
7	Input offset voltage Vios	2mV	0
8	PSRR	150uV/V	0
9	Input bias current Ib	50nA	0
10	Input offset current	6nA	0

Working of IC 741 Op-Amp:

IC 741 is widely used operational amplifiers (Op-Amps) in various electronic circuits due to its versatility and reliability. Here’s a brief overview of its working:

Internal Circuitry: The IC 741 contains multiple transistors, resistors, and other components integrated into a single chip. Its internal circuitry consists of several stages, including differential amplifier stage, gain stage, output stage, and compensation network.

1. Differential Amplifier Stage: The input stage of the 741 consists of a differential amplifier. This stage amplifies the voltage difference between its two input terminals (inverting and non-inverting). The gain of this stage is typically very high, providing high input impedance and low output impedance.
2. Gain Stage: The amplified voltage from the input stage is then further amplified by the gain stage. The 741 has a high open-loop voltage gain, typically around 100,000. This gain can be adjusted using external feedback components like resistors.
3. Output Stage: The output stage of the 741 is designed to provide a high output current capability while maintaining a low output impedance. It also ensures compatibility with various loads.
4. Compensation Network: The 741 incorporates internal compensation to stabilize its operation and prevent oscillations. This compensation network typically consists of capacitors and resistors.
5. Power Supply: The IC 741 requires dual power supplies (positive and negative) for its operation. These power supplies typically range from ±5V to ±15V.

IC 741 Op Amp Transistor Level Circuit

Internal Circuit of IC 741 Operational Amplifier:

The internal circuitry of the IC 741 operational amplifier. Let me summarize the key points based on your description:

1. Input Stage with Transistors Q1 and Q2: These transistors serve as the input stage of the op-amp, with Q1 connected to the inverting terminal and Q2 connected to the non-inverting terminal. This configuration helps to isolate the input signals and prevent feedback.
2. Current Mirrors (Q8/Q9 and Q12/Q13): These circuits regulate the current flow within the op-amp, ensuring stable operation and minimizing the impact of input voltage fluctuations on internal circuitry.
3. Voltage Level Shifter (Q16): This circuit reduces the voltage level from the amplifier circuit at the input section before passing it to the next stage. This helps prevent signal distortion.
4. Class A Amplifier Stage (Q15, Q19, Q22) and Output Stage (Q14, Q17, Q20): These stages are responsible for amplifying the input signal and driving the output with sufficient power. The class A amplifier stage ensures linear amplification with minimal distortion.
5. Offset Null Configuration (Q5, Q6, Q7): These transistors are part of a configuration that allows for offset null adjustment, balancing both the inverting and non-inverting inputs to minimize any irregularities at the input phase of the differential circuit.

Overall, these components and circuits work together to ensure the proper operation of the IC 741 op-amp, providing high gain and stable amplification for various applications.

2.1.3 Definitions of Differential Voltage Gain, CMRR, Slew Rate, and Input Offset Current

- **Differential Voltage Gain:** The ratio of the change in output voltage to the change in the difference between the input voltages. It's a measure of the op-amp's ability to amplify the difference between the two input signals.
- **Common-Mode Rejection Ratio (CMRR):** The ratio of the differential gain to the common-mode gain. It's a measure of the op-amp's ability to reject signals that are common to both input terminals. A high CMRR is desirable in many applications.
- **Slew Rate:** The maximum rate of change of the output voltage. It's a measure of how quickly the op-amp's output can respond to a sudden input change.
- **Input Offset Current:** The small current that flows into the input terminals of the op-amp even when no input signal is applied.

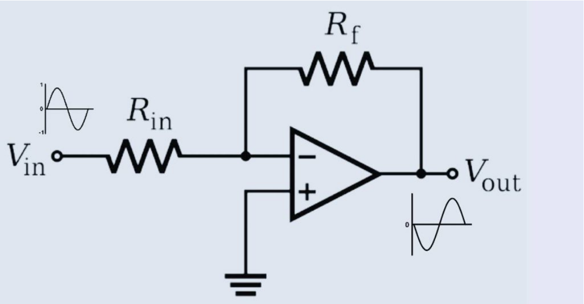
2.1.4 Operational Amplifier as an Inverting Mode & Non-Inverting Mode, Adder, Subtractor, Differentiator, and Integrator

Mode of operation:

The 741 can operate in both inverting and non-inverting configurations. Inverting configuration means the output is inverted concerning the input signal, while non-inverting configuration maintains the same phase.

Inverting Mode:

Inverting Configuration of IC 741:



By connecting the input signal to the inverting terminal (-) and providing feedback from the output to the inverting input, the op-amp can be configured to produce an inverted and amplified output signal relative to the input.

Gain (Av) = -(Rf/Rin)

741 IC is used in various modes.

- As a buffer Amplifiers
- Summing Amplifier
- Difference Amplifier
- Schmitt trigger
- Integrator
- Comparator

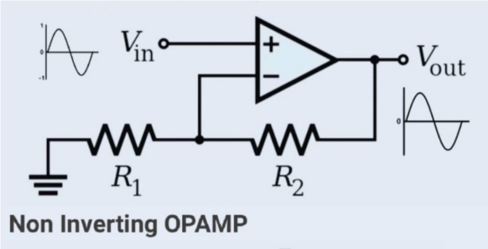
IC 741 Op-Amp Applications:

The IC 741 finds applications in various circuits such as amplifiers, filters, oscillators, voltage followers, comparators, and many more.

Log and Antilog Amplifier:

The IC 741 op-amp can be used to create log and antilog amplifiers. These circuits are essential for mathematical operations and signal processing.

- The input signal is applied to the inverting input terminal through a resistor. The output voltage is 180 degrees out of phase with the input signal.

Non-Inverting Mode: The input signal is applied to the non-inverting input terminal. The output voltage is in phase with the input signal. Non-Inverting Configuration of IC 741: 

Here, the input signal is connected to the non-inverting terminal (+) and feedback is applied from the output to the inverting input. This configuration produces a non-inverted and amplified output signal relative to the input.

Gain (Av) = 1 + (R2/R1)

Applications:-

Adder: A circuit that sums multiple input signals.

Subtractor: A circuit that subtracts one input signal from another.

Amplifier:

As a general-purpose amplifier, the 741 op-amp can amplify weak signals. It's commonly used in audio amplification, instrumentation, and other applications where signal gain is necessary.

Voltage Comparator:

The 741 op-amp can compare two input voltages and provide a high or low output based on their relative magnitudes. This functionality is useful in threshold detection and switching applications.

Active Filter:

By configuring external components like capacitors and resistors, the 741 op-amp can function as an active filter. It's commonly used in low-pass, high-pass, band-pass, and band-reject filter designs.

Waveform Generator:

The 741 op-amp can generate various waveforms, such as square waves, triangular waves, and sine waves. It's useful in signal generation and testing.

Multiplier:

When combined with external components, the 741 op-amp can perform multiplication operations. It's used in analog computing and modulation circuits.

Voltage Controlled Oscillator (VCO):

By using the op-amp in conjunction with other components like resistors, capacitors, and a voltage source, a VCO can be constructed. VCOs find applications in frequency modulation (FM) synthesis and phase-locked loops (PLLs).

Voltage Follower (Buffer):

In this configuration, the output follows the input voltage without any amplification. This setup is useful for impedance matching and isolation between two parts of a circuit.

Integrator:

When a capacitor is placed in the feedback loop of the op-amp, it integrates the input signal. This configuration finds applications in signal processing and waveform generation.

Differentiator:

Placing a capacitor in series with the input signal, this configuration produces an output voltage proportional to the rate of change of the input voltage. It's useful in applications like differentiation of signals.

Limitations/Disadvantages of 741 OP AMP:

Although the IC 741 is a versatile Op-Amp, it has some limitations such as limited bandwidth, slew rate, and input common-mode range compared to modern Op-Amps. It also suffers from offset voltage and bias current, which can affect precision applications.

1. Limited Bandwidth: The 741 op-amp has a relatively low bandwidth compared to modern op-amps. This limitation can affect its performance in high-frequency applications.
2. High Input Bias Current: The input bias current of the 741 can be relatively high, which can cause errors in precision applications or when driving high impedance loads.
3. Limited Slew Rate: The slew rate of the 741 is relatively low compared to newer op-amps, which can limit its ability to accurately reproduce fast-changing signals.
4. Low Input Impedance: The input impedance of the 741 op-amp is relatively low, which can cause loading effects in some circuits and affect performance.
5. Single Power Supply Operation: The 741 op-amp typically requires dual power supplies (+V and -V) for optimal performance. Single-supply operation can be achieved, but it requires additional circuitry for biasing and level shifting.

In summary, the IC 741 is a fundamental building block in analog electronic circuits, offering high gain, versatility, and reliability for a wide range of applications. However, its usage is somewhat limited in high-frequency and precision applications compared to newer Op-Amps with advanced features and specifications.

IC 741 is a very old IC it is existing from late 1960s. Though it is a good ic, it has many drawbacks. These drawbacks have been compensated by new comparator ICs like LM358 etc.

2.1.5 OP-Amp as an Instrumentation Amplifier

- **Instrumentation Amplifier:** A high-precision differential amplifier used to amplify small signals in the presence of large common-mode voltages. It typically has very high input impedance and CMRR.

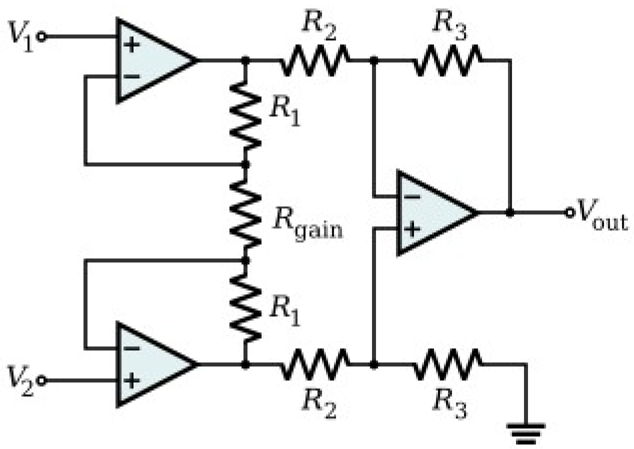


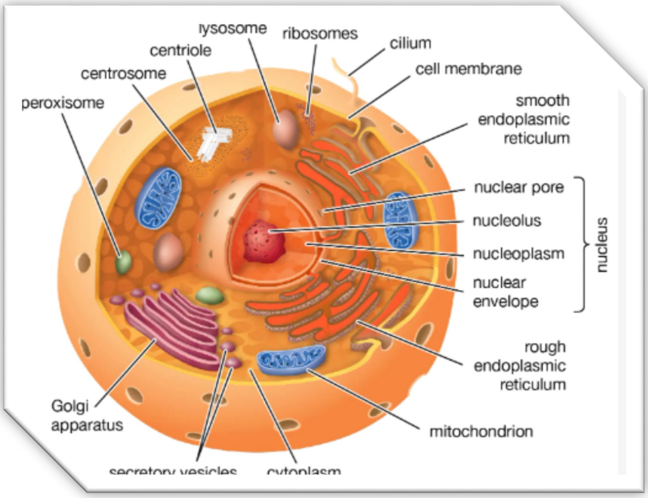
Fig: instrumentation amplifier

Unit III: Bio-medical Signals and Electrodes

3.1 Elementary Idea of Cell Structure

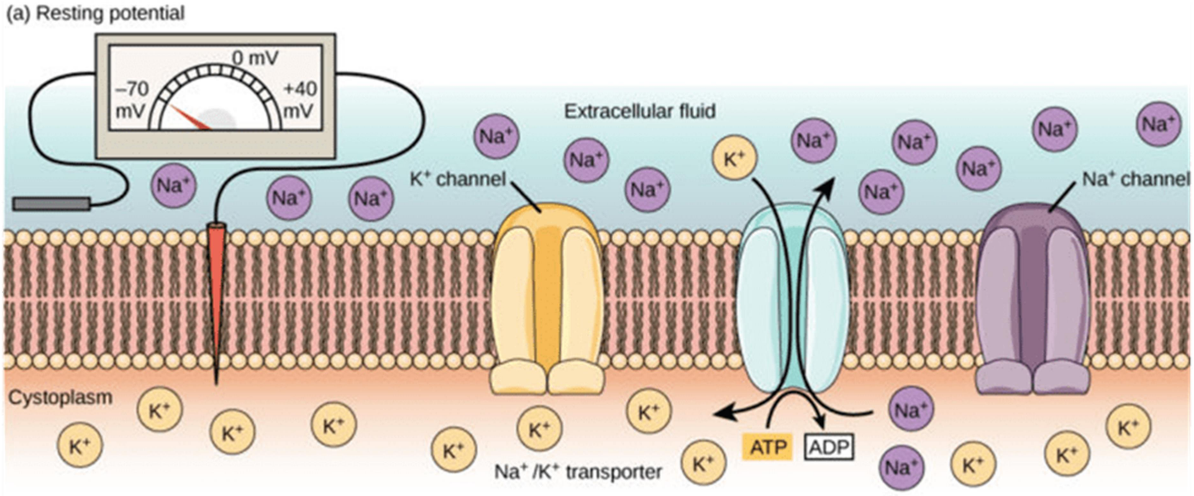
The basic building blocks of life, cells, are incredibly complex structures. They consist of various components, including:

- **Cell Membrane:** A semi-permeable barrier that encloses the cell, regulating the passage of substances in and out.
- **Nucleus:** The control center of the cell, containing genetic material (DNA).
- **Cytoplasm:** A jelly-like substance that fills the cell, where most cellular activities occur.
- **Organelles:** Specialized structures within the cell that perform specific functions, such as mitochondria (powerhouses of the cell), ribosomes (protein synthesis), and endoplasmic reticulum (protein and lipid synthesis).



3.2 Bio-electric Potentials

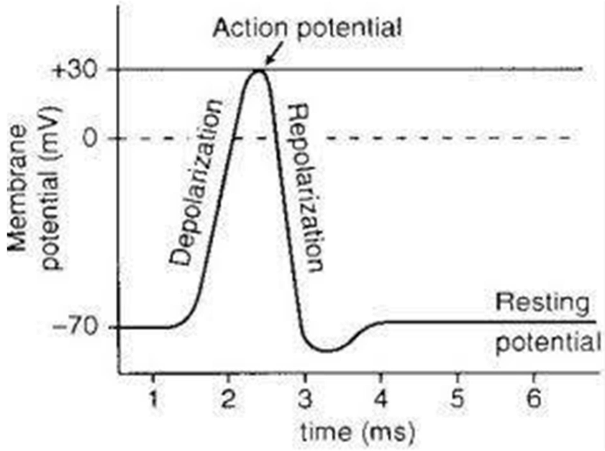
Cells maintain an electrical potential difference across their membranes, known as the **resting membrane potential**. This potential arises from the unequal distribution of ions (charged particles) inside and outside the cell. The inside of the cell is typically negatively charged compared to the outside.



At the resting potential, all voltage-gated Na^+ channels and most voltage-gated K^+ channels are closed. The Na^+/K^+ transporter pumps K^+ ions into the cell and Na^+ ions out.

3.3 Resting and Action Potentials

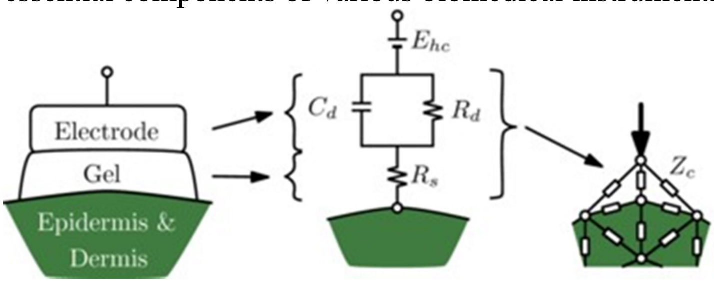
- **Resting Potential:** The stable, negative electrical charge of a neuron when it is not active.
- **Action Potential:** A brief, rapid reversal of the membrane potential, generating a nerve impulse. It involves a sequence of events: depolarization, repolarization, and



hyperpolarization.

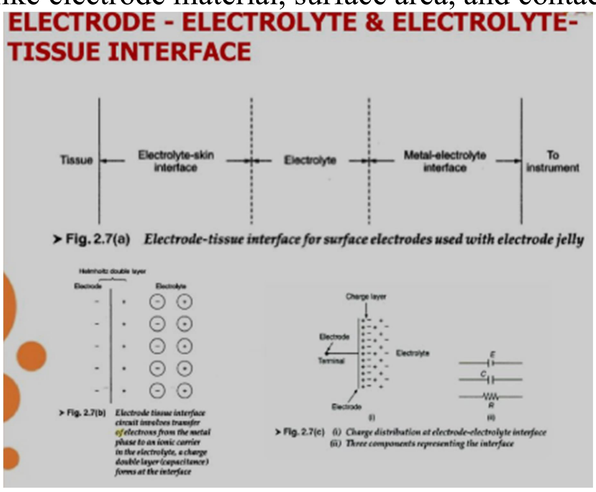
3.4 Bio-electrodes

Bio-electrodes are devices used to make electrical contact with biological tissues. They are essential components of various biomedical instruments.



3.5 Electrode-Tissue Interface

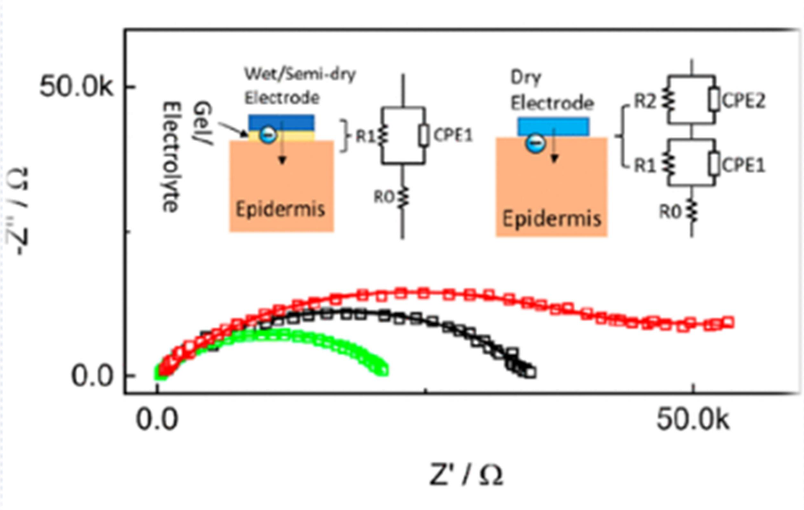
The interface between an electrode and biological tissue is crucial for accurate signal acquisition. Factors like electrode material, surface area, and contact impedance influence the



quality of the signal.

3.6 Contact Impedance

Contact impedance refers to the electrical resistance at the electrode-tissue interface. It can affect signal quality and can be minimized through proper electrode preparation and

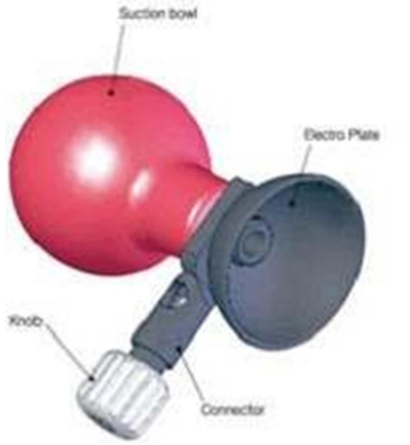


placement.

3.7 Types of Electrodes

There are various types of electrodes, including:

- **Surface Electrodes:** Placed on the skin to record signals from underlying tissues.



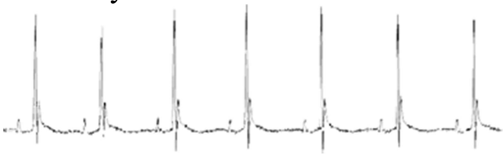
- **Needle Electrodes:** Inserted into tissues to record more localized signals.

- **Depth Electrodes:** Implanted into deeper tissues for long-term recordings.

Unit IV: Medical Instruments

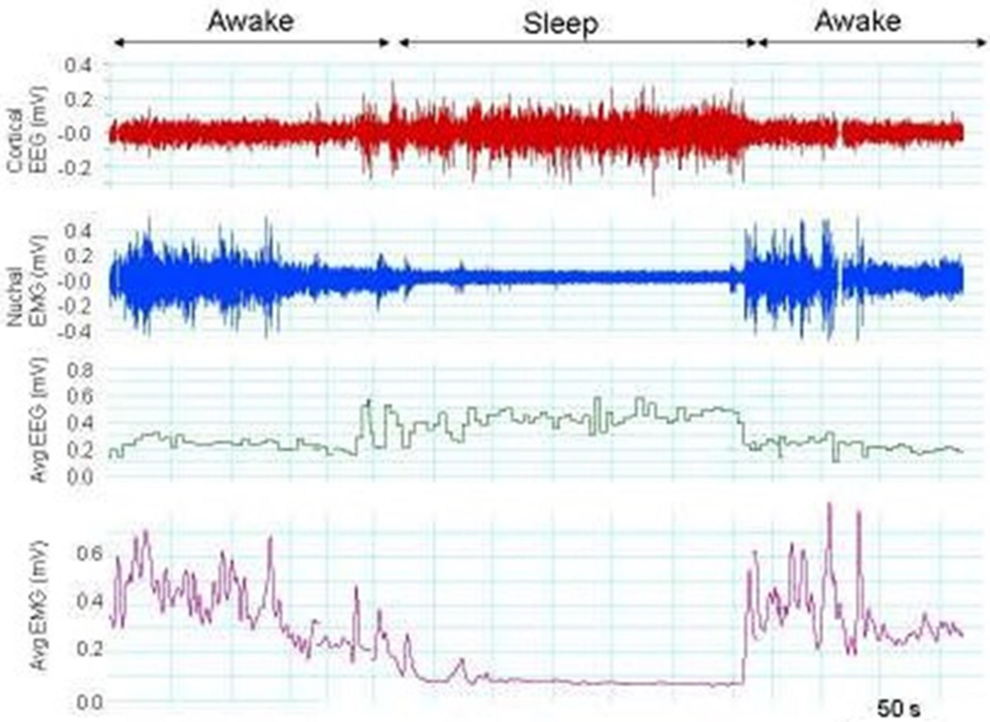
Here's a brief overview of some common medical instruments:

4.1 Electrocardiograph (ECG)

- **Purpose:** Records electrical activity of the heart.
- **Working Principle:** Uses surface electrodes placed on the chest to detect electrical signals generated by the heart.
- **Diagram:** 

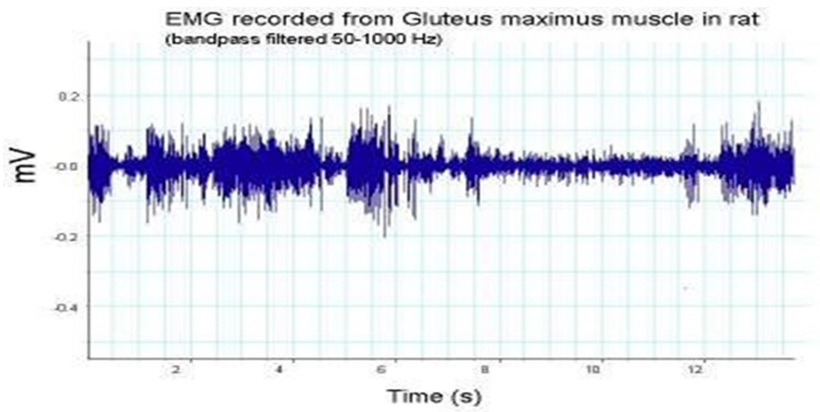
4.2 Electroencephalograph (EEG)

- **Purpose:** Records electrical activity of the brain.
- **Working Principle:** Uses surface electrodes placed on the scalp to detect brainwaves.
- **Diagram:**



4.3 Electromyograph (EMG)

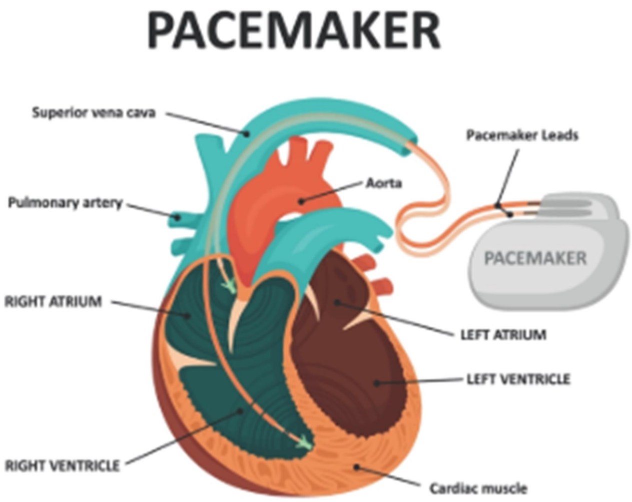
- **Purpose:** Records electrical activity of muscles.
- **Working Principle:** Uses surface or needle electrodes to detect electrical signals generated by muscle contractions.



- **Diagram:**

4.4 Pacemakers

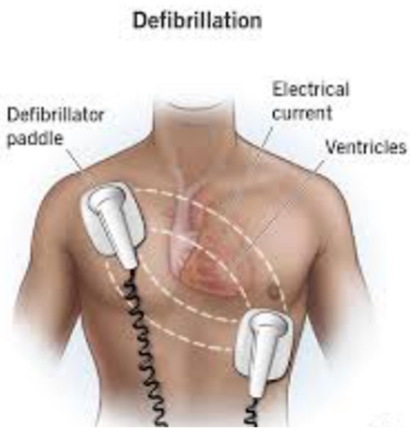
- **Purpose:** Used to regulate heart rhythm in patients with bradycardia (slow heart rate).
- **Working Principle:** Delivers electrical pulses to stimulate the heart.



- **Diagram:**

4.5 Defibrillators

- **Purpose:** Used to treat life-threatening cardiac arrhythmias (irregular heart rhythms).
- **Working Principle:** Delivers a high-energy shock to the heart to restore normal rhythm.



- **Diagram:**

4.6 Pulse Oximeter (SpO2)

- **Purpose:** Measures the oxygen saturation of blood.
- **Working Principle:** Uses light-emitting diodes (LEDs) and photodetectors to measure the absorption of light by oxygenated and deoxygenated hemoglobin.
- **Diagram:** 

4.7 Blood Pressure Measurement

- **Purpose:** Measures blood pressure, which is the force of blood against the walls of blood vessels.
- **Working Principle:** Uses a sphygmomanometer (blood pressure cuff) and a

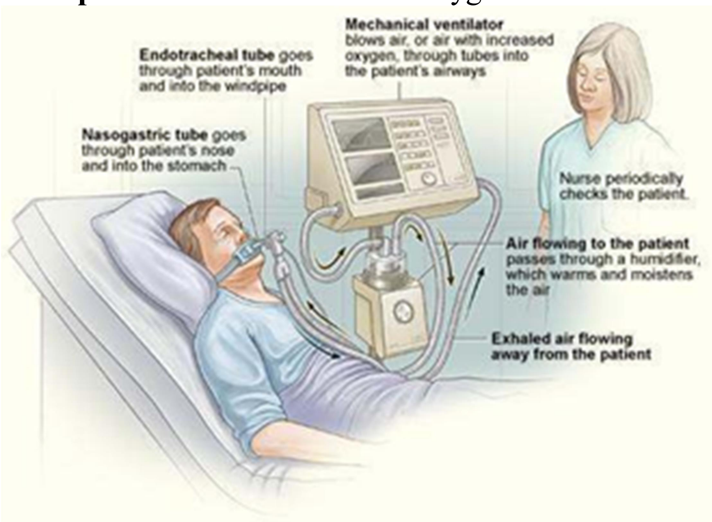
stethoscope to measure systolic and diastolic blood pressure.
- **Diagram:**

4.8 Glucometer

- **Purpose:** Measures blood glucose levels.
- **Working Principle:** Uses a small blood sample to measure the amount of glucose present.

- **Diagram:** 

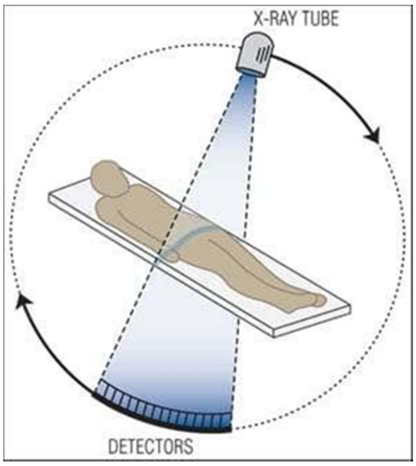
4.9 Ventilators

- **Purpose:** Used to assist or control breathing in patients with respiratory problems.
- **Working Principle:** Delivers a mixture of oxygen and air to the lungs.
- **Diagram:** 

Unit-5 Medical Imaging system

5.1 X-Ray

- **Introduction:** X-ray imaging is one of the oldest and most common medical imaging techniques. It utilizes electromagnetic radiation (X-rays) to create images of the inside of the body.
- **Block Diagram:**
  - **X-ray Source:** Produces X-rays.
  - **Patient:** The body part to be imaged is placed between the source and detector.
  - **Detector:** Captures the X-rays that pass through the patient.
  - **Image Processor:** Converts the detector signal into a visual image.

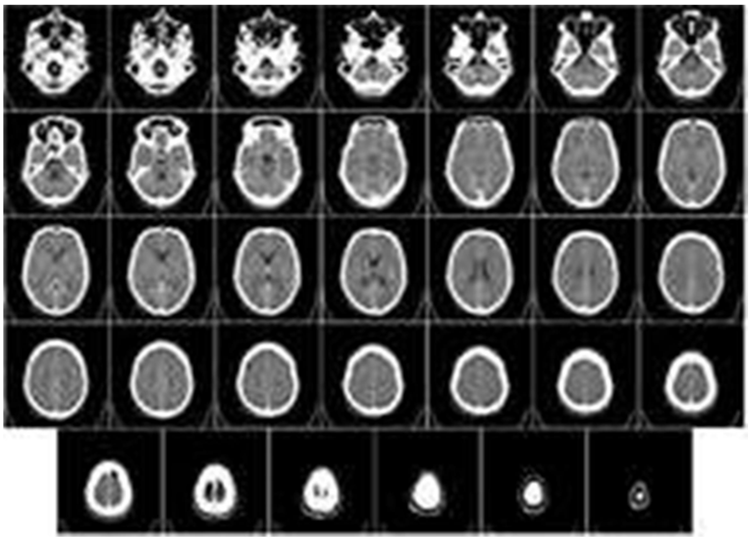


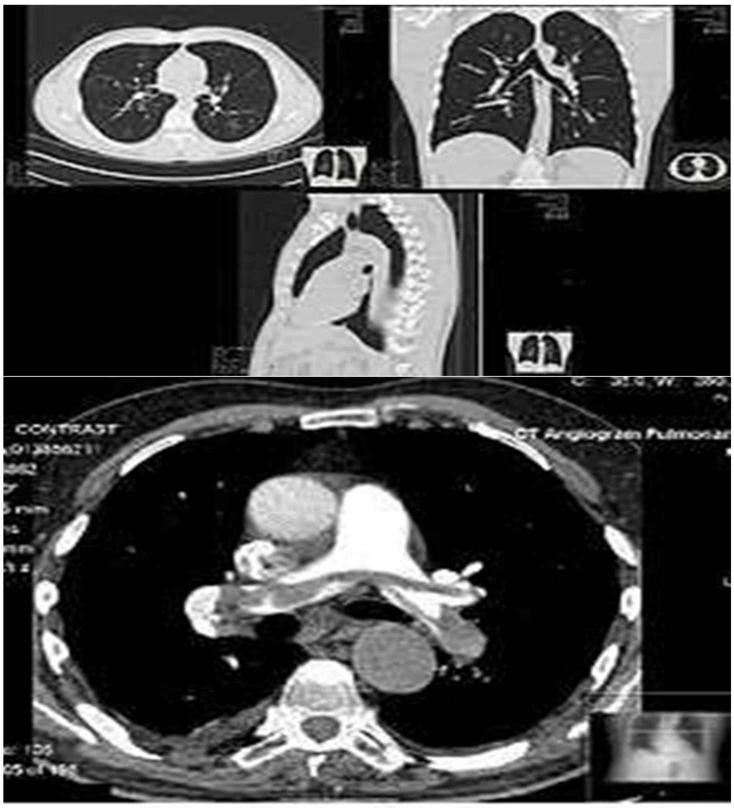
- **Working Principle:** X-rays are directed towards the patient. Different tissues absorb X-rays to varying degrees. Dense tissues like bone absorb more X-rays and appear white on the image, while less dense tissues like muscle and fat absorb less and appear darker.

5.2 CT Scan (Computed Tomography)

- **Introduction:** CT scans use X-rays to create 3D images of the body. It provides more detailed information than a standard X-ray.
- **Block Diagram:**
  - **X-ray Source:** Rotates around the patient.
  - **Detector Array:** Detects X-rays passing through the patient at multiple angles.
  - **Computer:** Reconstructs the 3D image from the detector data.

  Working Principle: The X-ray source and detector rotate around the patient, taking multiple images from different angles. The computer processes these images to create cross-sectional slices of the body, which can be stacked to form a 3D image.



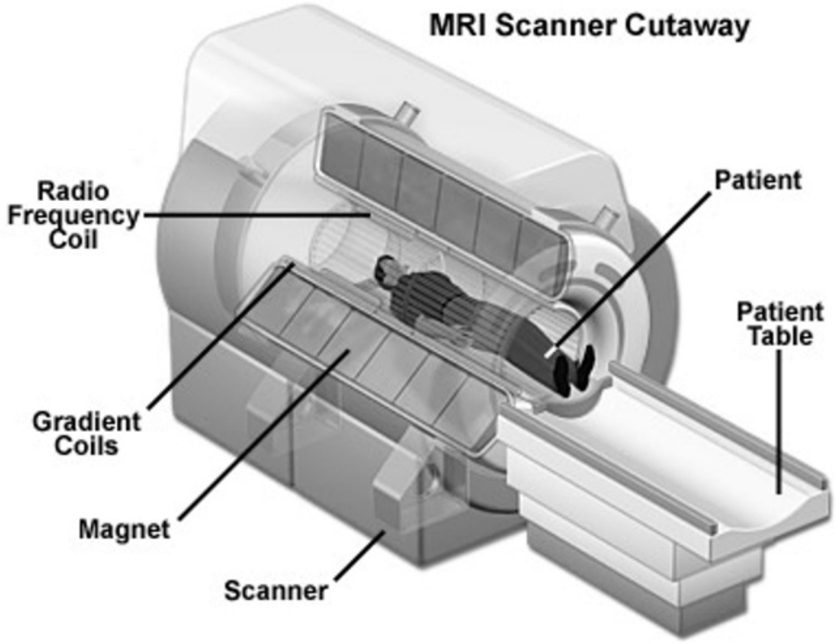


- Fig:- X-Ray

5.3 MRI (Magnetic Resonance Imaging)

- **Introduction:** MRI uses a strong magnetic field and radio waves to create detailed images of the body. It is particularly useful for imaging soft tissues like the brain and muscles.
- **Block Diagram:**
  - **Magnet:** Creates a strong magnetic field.
  - **Radiofrequency Coils:** Transmit and receive radio waves.
  - **Gradient Coils:** Shape the magnetic field to get specific image slices.
  - **Computer:** Processes the signals to create images.
- **Working Principle:** The magnetic field aligns the hydrogen atoms in the body. Radio waves are then used to excite these atoms. When the atoms return to their original state, they emit signals that are detected by the coils.

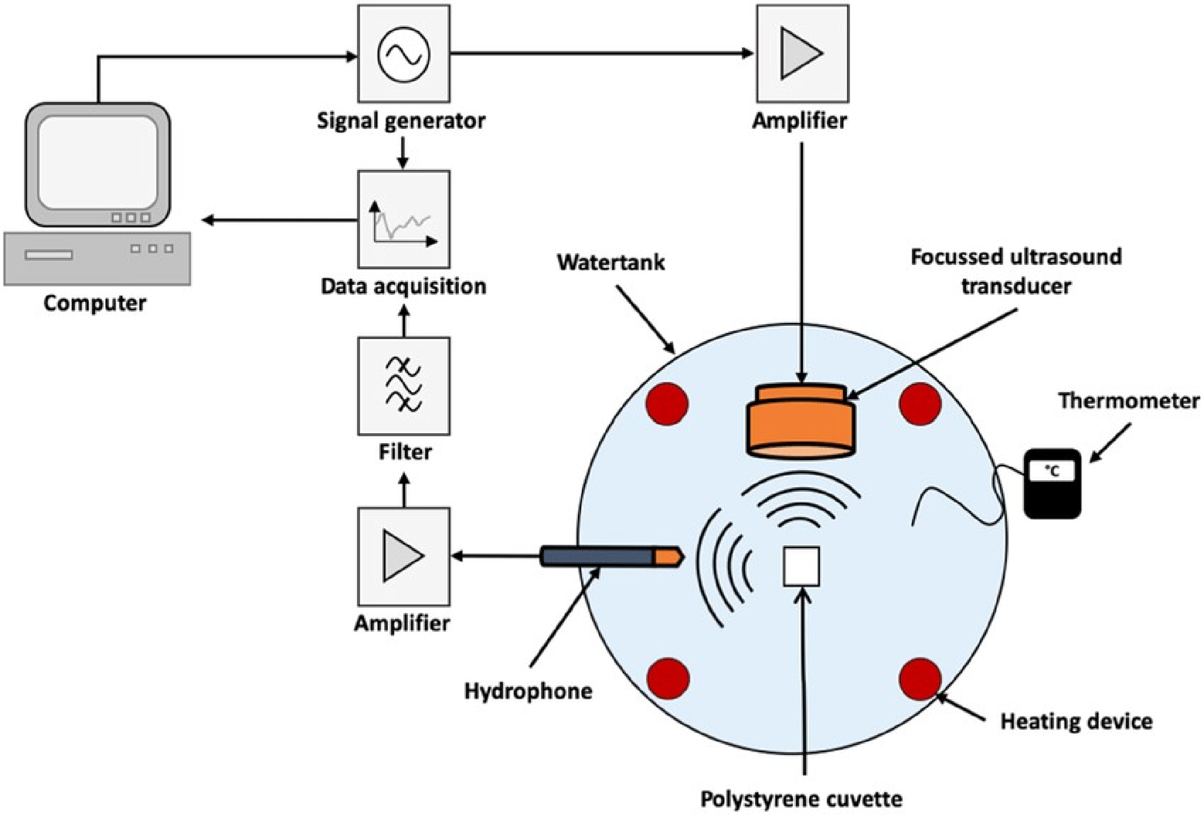
The computer analyzes these signals to create detailed images.



5.4 Ultrasound

- **Introduction:** Ultrasound uses high-frequency sound waves to create images of the body. It is commonly used for imaging fetuses during pregnancy and for diagnosing heart problems.
- **Block Diagram:**
    - **Transducer:** Sends and receives sound waves.
    - **Patient:** The transducer is placed on the body.
    - **Computer:** Processes the reflected sound waves to create images.
- **Working Principle:** The transducer emits sound waves into the body. When these waves encounter different tissues, they are reflected back to the transducer. The computer analyzes the time it takes for the sound waves to

return and the strength of the reflected signals to create images.



In summary, this unit covers four major medical imaging techniques: X-ray, CT scan, MRI, and ultrasound. Each technique uses different principles to create images of the body, providing valuable information for diagnosis and treatment.