NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE

(Accredited by NAAC, Approved by AICTE New Delhi, Affiliated to APJKTU)

Pampady, Thiruvilwamala(PO), Thrissur(DT), Kerala 680 588

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE MATERIALS

EE 372 BIOMEDICAL INSTRUMENTATION

VISION OF THE INSTITUTION

To mould our youngsters into Millennium Leaders not only in Technological and Scientific Fields but also to nurture and strengthen the innate goodness and human nature in them, to equip them to face the future challenges in technological break troughs and information explosions and deliver the bounties of frontier knowledge for the benefit of humankind in general and the down-trodden and underprivileged in particular as envisaged by our great Prime Minister Pandit Jawaharlal Nehru

MISSION OF THE INSTITUTION

To build a strong Centre of Excellence in Learning and Research in Engineering and Frontier Technology, to facilitate students to learn and imbibe discipline, culture and spirituality, besides encouraging them to assimilate the latest technological knowhow and to render a helping hand to the under privileged, thereby acquiring happiness and imparting the same to others without any reservation whatsoever and to facilitate the College to emerge into a magnificent and mighty launching pad to turn out technological giants, dedicated research scientists and intellectual leaders of the society who could prepare the country for a quantum jump in all fields of Science and Technology

ABOUT DEPARTMENT

- Course offered: B.Tech Electrical and Electronics Engineering
- Approved by AICTE New Delhi and Accredited by NAAC
- Affiliated to the University of Dr. A P J Abdul Kalam Technological University.
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DEPARTMENT VISION

To excel in technical education and research in the field of Electrical & Electronics Engineering by imparting innovative engineering theories, concepts and practices to improve the production and utilization of power and energy for the betterment of the Nation.

DEPARTMENT MISSION

- To offer quality education in Electrical and Electronics Engineering and prepare the students for professional career and higher studies.
- To create research collaboration with industries for gaining knowledge about real-time problems.
- To prepare students with sound technical knowledge.
- To make students socially responsible.

Course code	Course Name	L-T-P - Credits	Year of Introduction
EE372	**Biomedical Instrumentation**	**3-0-0-3**	**2016**

Prerequisite: Nil

Course Objectives

- To give a brief introduction to human physiology and various instrumentations system for measurement and analysis of physiological parameters.

Syllabus:

Development of biomedical instrumentation, Sources of bioelectric potentials, Bio potential electrodes, Electro-conduction system of the heart, Measurement of blood pressure, Measurement of heart sounds, Cardiac pacemakers, defibrillators, Electro encephalogram, Muscle response, Respiratory parameters, Therapeutic Equipments, Imaging Techniques, Instruments for clinical laboratory, Electrical safety, tele- medicine

Expected outcome.

Text Book:

1. J. G. Webster, Medical Instrumentation, Application and Design, John Wiley and Sons
2. L. Cromwell, F. J. Weibell and L. A. Pfeiffer, Biomedical Instrumentation Measurements, Pearson education, Delhi, 1990.

References:

1. R. S. Khandpur, Handbook of Biomedical Instrumentation, Tata Mc Graw Hill
2. J. J. Carr and J. M. Brown, Introduction to Biomedical Equipment Technology, Pearson Education

Course Plan

Module	Contents	Hours	Sem. Exam Marks
I	Development of biomedical instrumentation, biometrics, man instrument system components block diagram, physiological systems of the body (brief discussion on Heart and cardio vascular system, Anatomy of nervous system, Physiology of respiratory systems) problems encountered in biomedical measurements. Sources of bioelectric potentials – resting and action potentials - propagation of action potentials – bio electric potentials example (ECG, EEG, EMG, ERG, EOG,EGG etc.)	7	15%
II	Bio potential electrodes – theory – microelectrodes – skin surface electrodes – needle electrodes – biochemical transducers – transducers for biomedical applications. Electro-conduction system of the heart. Electro cardiography – electrodes and leads – Einthoven triangle, ECG read out devices, ECG machine – block diagram.	7	15%
FIRST INTERNAL EXAMINATION			
III	Measurement of blood pressure – direct and indirect measurement – oscillometric measurement –ultrasonic method, measurement of blood flow and cardiac output, plethysmography –photo electric and impedance plethysmographs Measurement of heart sounds –phonocardiography.	7	15%

IV	Cardiac pacemakers – internal and external pacemakers, defibrillators. Electro encephalogram –neuronal communication – EEG measurement. Muscle response– Electromyogram (EMG) – Nerve Conduction velocity measurements- Electromyogram Measurements. Respiratory parameters – Spiro meter, pneumograph	7	15%
SECOND INTERNAL EXAMINATION			
V	Ventilators, heart lung machine, hemodialysis, lithotripsy, infant incubators X-rays- principles of generation, uses of X-rays- diagnostic still picture, fluoroscopy, angiography, endoscopy, diathermy. Basic principle of computed tomography, magnetic resonance imaging system and nuclear medicine system – radiation therapy. Ultrasonic imaging system - introduction and basic principle.	8	20%
VI	Instruments for clinical laboratory – test on blood cells – chemical tests - Electrical safety– physiological effects of electric current – shock hazards from electrical equipment – method of accident prevention, introduction to tele- medicine.	6	20%
END SEMESTER EXAM			

QUESTION PAPER PATTERN:

Maximum Marks: 100 Exam Duration: 3Hourrs.

Part A: 8 compulsory questions.

One question from each module of Modules I - IV; and two each from Module V & VI.

Student has to answer all questions. (8 x5)=40

Part B: 3 questions uniformly covering Modules I & II. Student has to answer any 2 from the 3 questions: (2 x 10) =20. Each question can have maximum of 4 sub questions (a,b,c,d), if needed.

Part C: 3 questions uniformly covering Modules III & IV. Student has to answer any 2 from the 3 questions: (2 x 10) =20. Each question can have maximum of 4 sub questions (a,b,c,d), if needed.

Part D: 3 questions uniformly covering Modules V & VI. Student has to answer any 2 from the 3 questions: (2 x 10) =20. Each question can have maximum of 4 sub questions (a,b,c,d), if needed.

Syllabus

Introduction to bio-medical instrumentation system, overview of anatomy and physiological systems of the body. Sources of bio-electric potential: Resting and action potential, propagation of action potentials. Bioelectric potentials examples (ECG, EEG, EMG, ERG, EOG, EGG, etc introduction only.) Electrode theory: Nernst relation. Bio potential electrodes: Microelectrodes, skin surface electrodes, needle electrodes. Instrumentation for clinical laboratory: Bio potential amplifiers-instrumentation amplifiers, carrier amplifiers, isolation amplifiers, chopper amplifiers.

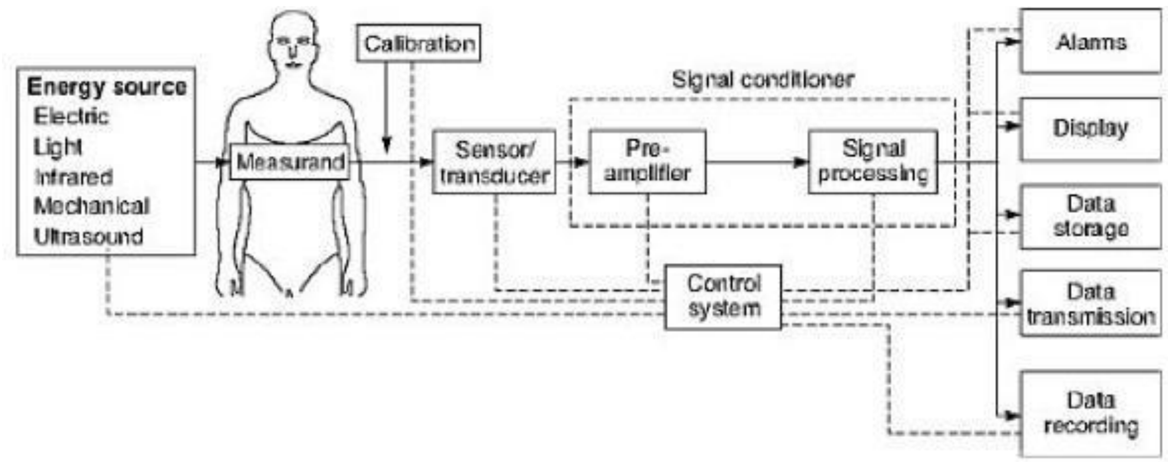
Biomedical Engineering

Biomedical Engineering is the application of engineering principles and design concepts to medicine and biology

The biomedical engineering provides electrical, electronic, electro-optical, and computer engineering support to clinical and biomedical applications.

Biomedical Engineering improves the field of healthcare diagnosis, monitoring and therapy.

Introduction to Biomedical Instrumentation System



Major Components of Medical Instrumentation System

1. Energy Source 2. Measurand 3. Sensor / Transducer 4. Signal Conditioning 5. Output Display

Auxiliary Components

A calibration signal

1. **Energy Source**

   Used to energize the whole instrumentation system

   Examples: Different sources used are electric, light, infrared, mechanical and ultrasound

2. **Measurand**

   The physical quantity, property, or condition that the system measures is called measurand.

   Examples:

   Internal (Blood Pressure)

   On the Body Surface (Electrocardiogram)

   Emanate from the body (Infrared Radiation)

Derived from Tissue Sample (such as Blood or a Biopsy)

3. **Sensor / Transducer**
   The transducer is defined as a device that converts one form of energy to another.
   A sensor converts a physical measurand to an electric output.
4. **Signal Conditioning**
   Simple signal conditioners may only amplify and filter the signal or merely match the impedance of the sensor to the display.
   Often sensor outputs are converted to digital form and then processed by specialized digital circuits or a microcomputer.
   For example, signal filtering may reduce undesirable sensor signals.
   It may also average repetitive signals to reduce noise, or it may convert information from the time domain to the frequency domain.
5. **Output Display**
   The results of the measurement process must be displayed in a form that the human operator can perceive.
   The best form for the display may be:

a. Numerical
b. Graphical,
c. Dispalcement,
d. CRT
e. Visual / Hearing

The processed signal after conditioning passed through

1. Alarm System: Indicate when measurand goes beyond a preset limit.
2. Data Storage: To maintain the data for future reference
3. Data Transmission: Used to transmit the information obtained from one location to another.

Auxiliary Components

1. **Calibration signal:** with the help of this, measurand should be applied to the sensor input or as early in the signal-processing chain as possible.
2. **Contro**l and **Feedback Signal:** Required to bring out the measurand, to adjust the sensor and signal conditioner, and to direct the flow of output for display, storage or transmission. The control and feedback may be automatic or manual.

Measurement in biomedical instrumentation can be divided in to two

1. VIVO
   - Measurement is made on or within the human body
   - E.g. Device inserted in to the blood stream to measure PH of blood
2. VITRO
   - Measurement is performed outside of the body.
     E.g. Measurement of blood PH from blood samples

Overview of Anatomy and Physiological Systems of the Body

Anatomy –The study of the s*tructure* and *shape* of the body and body parts & their *relationships* to one another. The term anatomy comes from the Greek words meaning to cut (tomy) apart (ana) .
Gross anatomy(macroscopic anatomy) – the study of large, easily observable structures (by naked eye), such as the heart or bone.
Microscopic anatomy (cytology, histology) – the study of very small structures, where a magnifying lens or microscope is needed.

Physiology – the study of how the body and its parts *work or function*

Physiology can be classified in to

1. Cell Physiology: Study of cells
2. Patho Physiology: Pathological Functions
3. Circulatory Physiology: Study of blood circulation
4. Respiratory Physiology: Study of breathing organs

Major Subsystems of the body

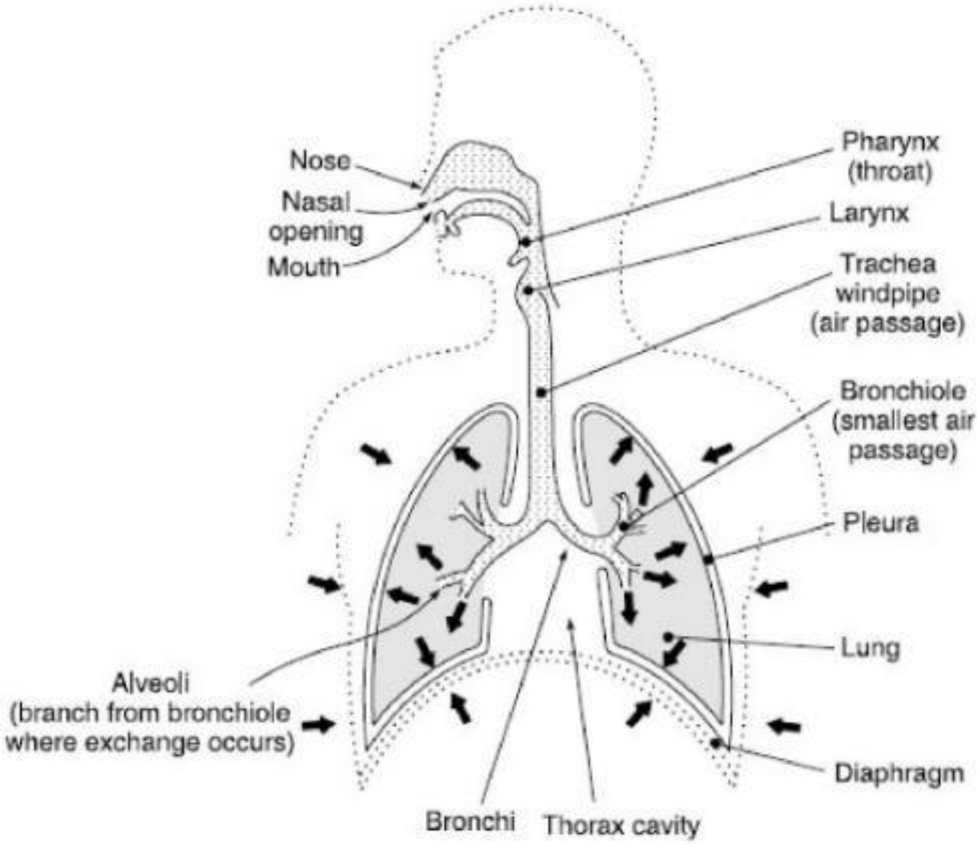
1. **The Cardiovascular System**

- Complex closed hydraulic system performs service of transportation of oxygen, CO2, numerous chemical compounds and the blood cells to maintain optimum environment for cellular function.
- The heart is the power source which provides energy to move the blood through the body and remove waste products.

2. **The Respiratory System**
   The respiratory system supplies the blood with oxygen and removes carbon dioxide waste that cells produce.

- Nasal Cavity: Passes air through nose
- Mouth: Passes air through
- Pharynx: The throat. Cone shaped passageway leading to trachea.
- Trachea: Windpipe. Main tube connecting nose/mouth to lungs.
- Epiglottis: Flap that covers the entrance to the trachea.
- Lungs: Main organ of the respiratory system.
- Bronchi: Two tubes inside of lungs that air passes through to the bronchioles.
- Bronchioles: Small branching out tubes divided into alveoli.
- Alveoli: Tiny air sacs that do the oxidation and the exhale of carbon dioxide.

- Capillaries: Blood vessels that are imbedded in the walls of the alveoli. While in the capillaries the blood discharges carbon dioxide into the alveoli and takes up oxygen from the air in the alveoli.
- Cilia: Hair like structures that remove dust and dirt from the air.



Respiratory System Structure

Working

- Air that flows from the mouth or nasal cavity travels through the pharynx and moves down to the trachea.
- Then the air moves to the bronchi tubes as they enter the lungs.
- The primary organs of the respiratory system are the lungs, which function to take in oxygen and expel carbon dioxide as we breathe.
- The gas exchange process is performed by the lungs and respiratory system. Air, a mix of oxygen and other gases, is inhaled.
- In the throat, the trachea, or windpipe, filters the air. The trachea branches into two bronchi, tubes that lead to the lungs.
- Once in the lungs, oxygen is moved into the bloodstream. Blood carries the oxygen through the body to where it is needed.
- Red blood cells collect carbon dioxide from the body's cells and transports it back to the lungs.

- An exchange of oxygen and carbon dioxide takes place in the alveoli, small structures within the lungs. The carbon dioxide, a waste gas, is exhaled and the cycle begins again with the next breath.

- The diaphragm is a dome-shaped muscle below the lungs that controls breathing. The diaphragm flattens out and pulls forward, drawing air into the lungs for inhalation. During exhalation the diaphragm expands to force air out of the lungs.

- Adults normally take 12 to 20 breaths per minute. Strenuous exercise drives the breath rate up to an average of 45 breaths per minute.

3. Nervous System

- The nervous system includes the brain, spinal cord, and a complex network of neurons. This system is responsible for sending, receiving, and interpreting information from all parts of the body.
- The nervous system monitors and coordinates internal organ function and responds to changes in the external environment.
- This system can be divided into two parts: the central nervous system and the peripheral nervous system.

The **central nervous system (CNS)**

- It is the processing center for the nervous system. It receives information from and sends information to the **peripheral nervous system**. The two main organs of the CNS are the brain and spinal cord. The brain processes and interprets sensory information sent from the spinal cord. Both the brain and spinal cord are protected by a three-layered covering of connective tissue called the **meninges**.

The **Peripheral nervous system (PNS)**

- The primary role of the PNS is to connect the CNS to the organs, limbs and skin.
- The nerves that make up the peripheral nervous system are actually the axons or bundles of axons from neuron cells.
- The peripheral nervous system is divided into two parts:

1. The somatic nervous system

- The **somatic system** is the part of the peripheral nervous system **responsible for carrying sensory and motor information to and from the central nervous system**.
- This system contains **two major types of neurons**:
- **Sensory neurons** (or afferent neurons) that carry **information from the nerves to the central nervous system**.

Motor neurons (or efferent neurons) that carry information from the **brain and spinal cord to muscle fibers throughout the body.**

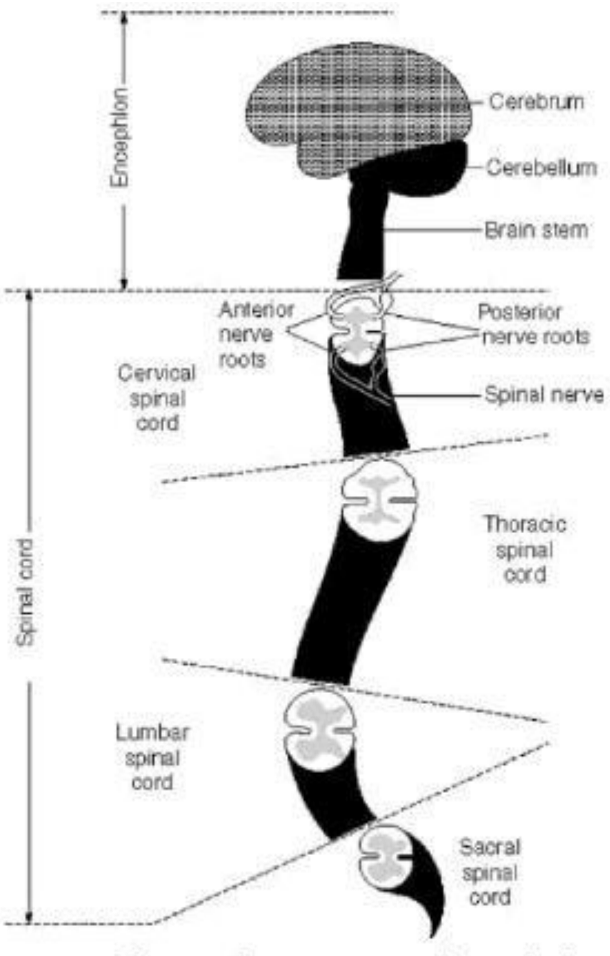
2. Autonomic Nervous systems

- The autonomic system is the part of the peripheral nervous system responsible for regulating involuntary (reflex/Un intentional)body functions, such as blood flow, heartbeat, digestion and breathing.
- This system is further divided into two branches:

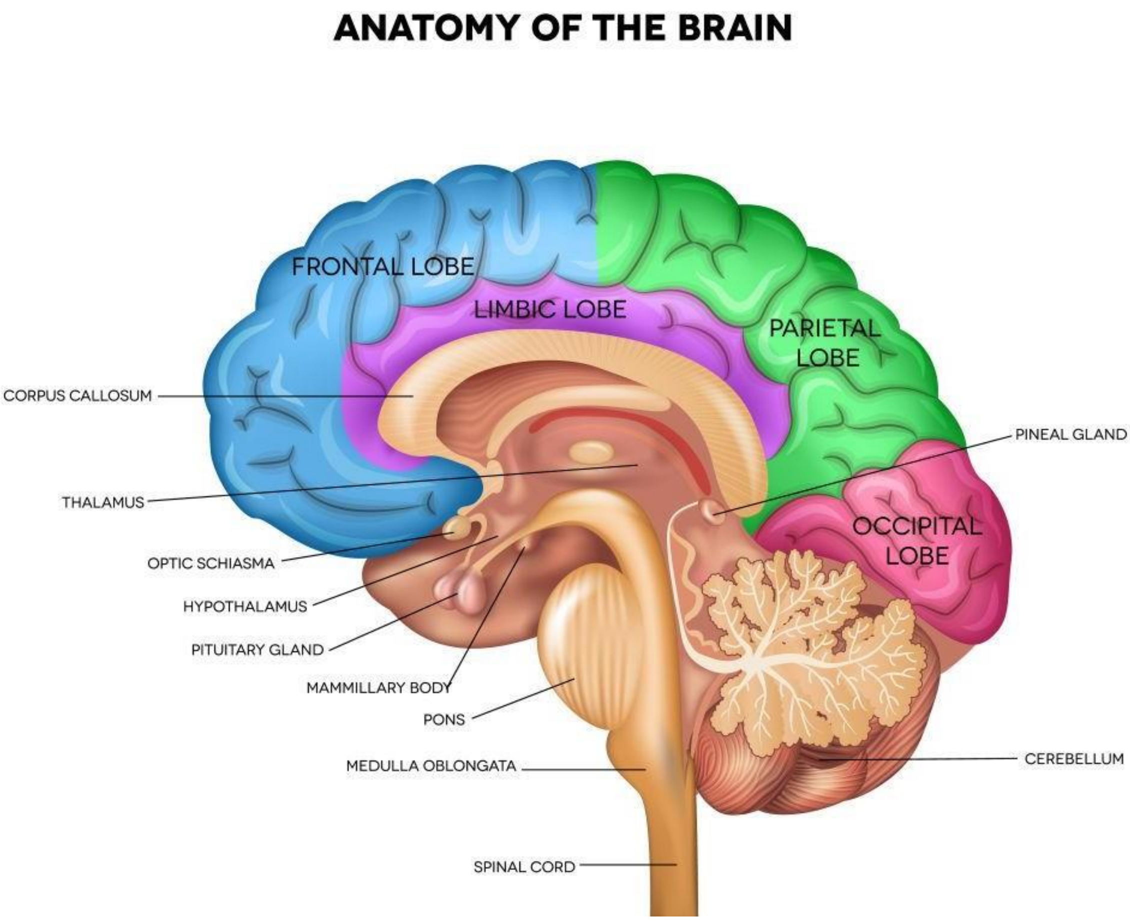
The sympathetic system regulates the flight-or-fight responses.

The "fight or flight response" is our body's primitive, automatic, inborn response that prepares the body to "fight" or "flee" from perceived attack, harm or threat to our survival.

Parasympathetic system helps maintain normal body functions and conserves physical resources



The central nervous system. Human brain and the spinal cord



- The brain is the control center of the body. Covering the brain is a protective layer of connective tissue known as the meninges.
- There are three main brain divisions: the forebrain, the brainstem, and the hindbrain.
- The forebrain is responsible for a variety of functions including receiving and processing sensory information, thinking, perceiving, producing and understanding language, and controlling motor function.
- The forebrain contains structures, such as the thalamus and hypothalamus. It also contains the largest part of the brain, the cerebrum.
- Most of the actual information processing in the brain takes place in the cerebral cortex. The cerebral cortex is the thin layer of gray matter that covers the brain.
- It is divided into four cortex lobes: frontal lobes, parietal lobes, occipital lobes, and temporal lobes. These lobes are responsible for various functions in the body that include everything from sensory perception to decision-making and problem solving.
- Below the cortex is the brain's white matter, which is composed of nerve cell axons that extend from the neuron cell bodies of gray matter. White matter nerve fiber tracts connect the cerebrum with different areas of the brain and spinal cord.
- The midbrain and the hindbrain together make up the brainstem. The midbrain is the portion of the brainstem that connects the hindbrain and the forebrain. This region of the brain is involved in auditory and visual responses as well as motor function.
- The hindbrain extends from the spinal cord and contains structures such as the pons and cerebellum. These regions assist in maintaining balance and equilibrium,

movement coordination, and the conduction of sensory information. The hindbrain also contains the medulla oblongata which is responsible for controlling such autonomic functions as breathing, heart rate, and digestion.

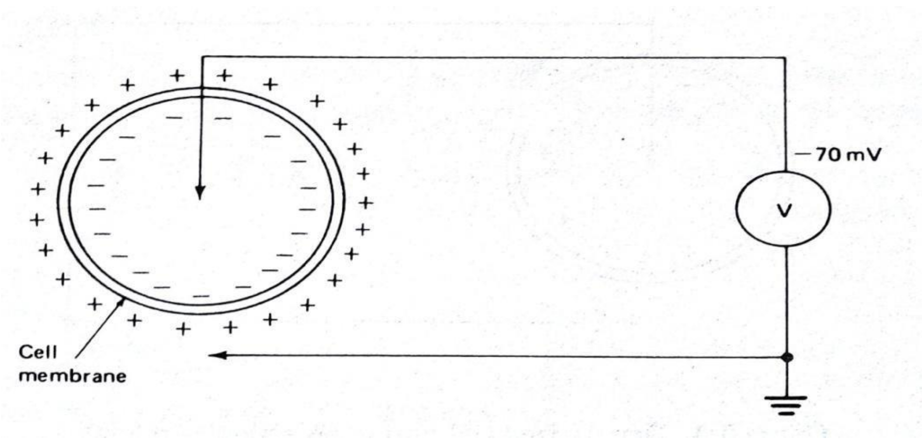
Sources of Bioelectric Potential

- The systems in the human body generate their on monitoring signals when they carry out their functions.
- These signals provide useful information about their function.
- These signals are bioelectric potentials associated with nerve conduction, brain activity, heartbeat, muscle activity and so on.
- Bioelectric potentials are actually ionic voltages produced as a result of electro chemical activity of certain cell.
  Transducers are used to convert these ionic potentials in to electrical signals

Resting and Action potentials

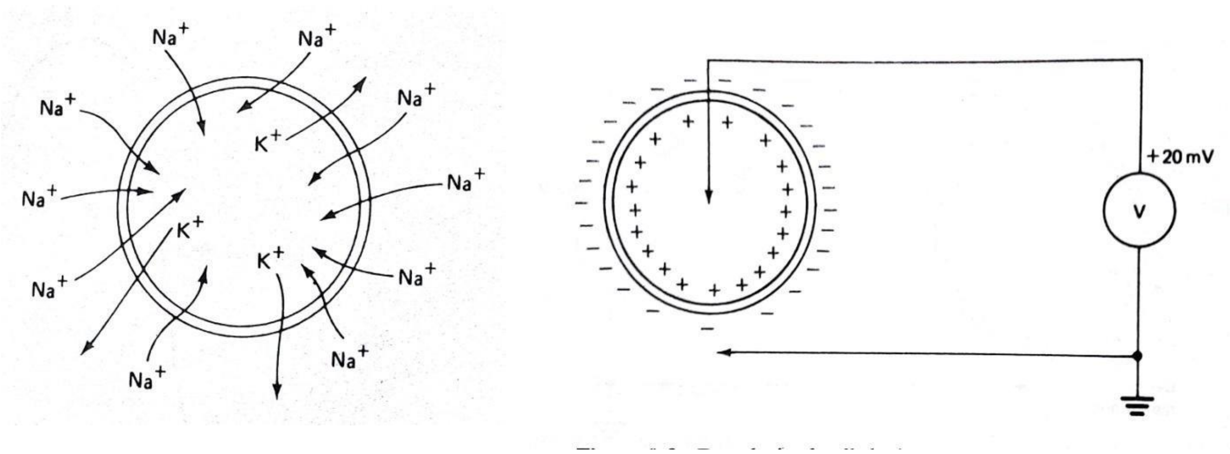
Resting Potential [Polarization]

- Certain types of cells within the body, such as nerve and muscle cells are encased in a semi permeable membrane. This membrane permits some substances to pass through while others are kept out. Surrounding the cells of the body are the body fluids. These fluids are conductive solutions containing charged atoms known as ions.
- The principle ions are sodium (Na^+) Potassium (K^+) and chloride (Cl^-). The membrane of excitable cells permits entry of Potassium (K^+) and chloride(C^-) ions but blocks the entry of sodium (Na^+) ions. So inside the cell is more negative than outside cell. This membrane potential is called Resting potentials. This potential is measured from inside the cell with respect to body fluids. So resting potential of a cell is negative.
- This resting potential ranging from **-60mv to -100 mv.**
- Cell in the **resting state is called polarized cell.**

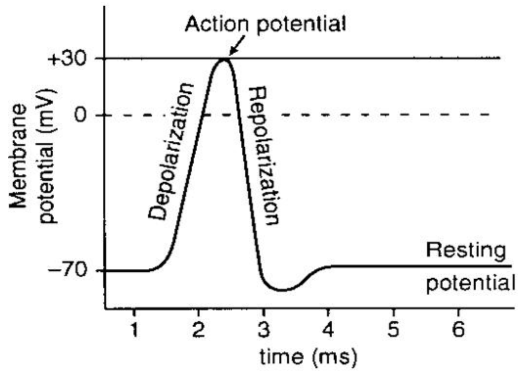


Action Potential [Depolarization]

- When a section of a cell membrane is excited by the flow of ionic current or by some form of externally applied energy,, the membrane allows some Na+ and try to reach some balance of potential inside and outside. Same time the some K+ goes outside but not rapidly like sodium.
- As a result, the cell has slightly Positive potential on the inside Due to the imbalance of the Potassium ions. This potential is known as "action potential" and is approximately +20 mV.
- A cell that has been excited and that displays an action potential is said to be depolarized and process from resting to action potential is called depolarization.
-

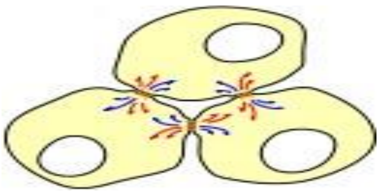


Characteristics of Resting and Action Potential



Propagation of action potentials

- When a cell is exited and generates an action potentials ionic currents to flow. This process excite neighboring cells or adjacent area of the same cell
- The rate at which an action potential moves down a fiber or is propagate from cell to cell is called the propagation rate.
- In nerve fiber the propagation rate is also called the nerve conduction rate, or conduction velocity. Velocity range in nerves is from 20 to 140 meters per second. In heart muscle, the rate is slower, average 0.2 to 0.4 m/sec.

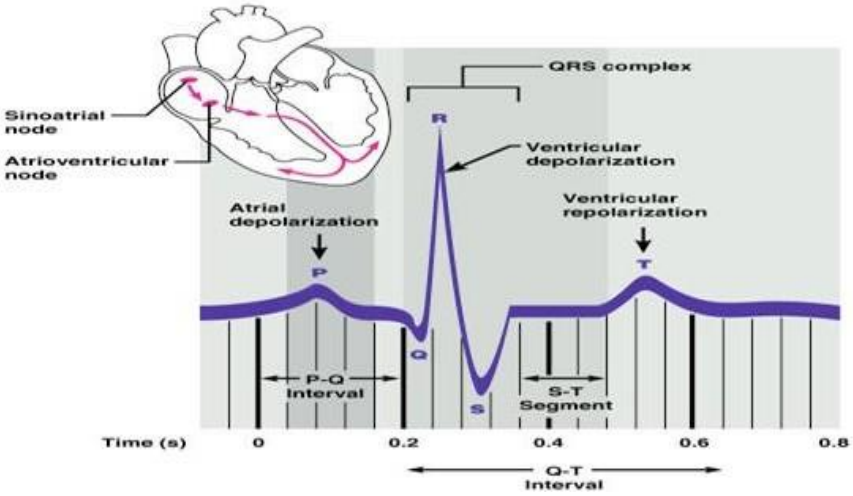


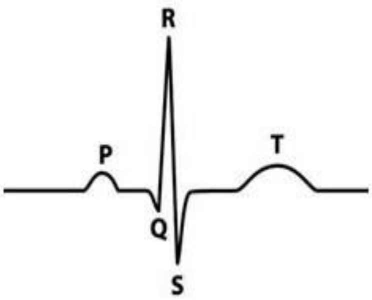
The Bioelectric Potentials

- The Electrocardiogram(ECG)
- The Electroencephalogram(EEG)
- The Electromyogram(EMG)
- The Electroretinogram(ERG)
- The Electro-oculogram(EOG)
- The Electrogastrogram(EGG)

1. **The Electrocardiogram(ECG)**

- The bio-potentials generated by the muscles of the heart result in the electrocardiogram (ECG). German word EKG. The Electrical activity of the heart is recorded by electrocardiogram (ECG).





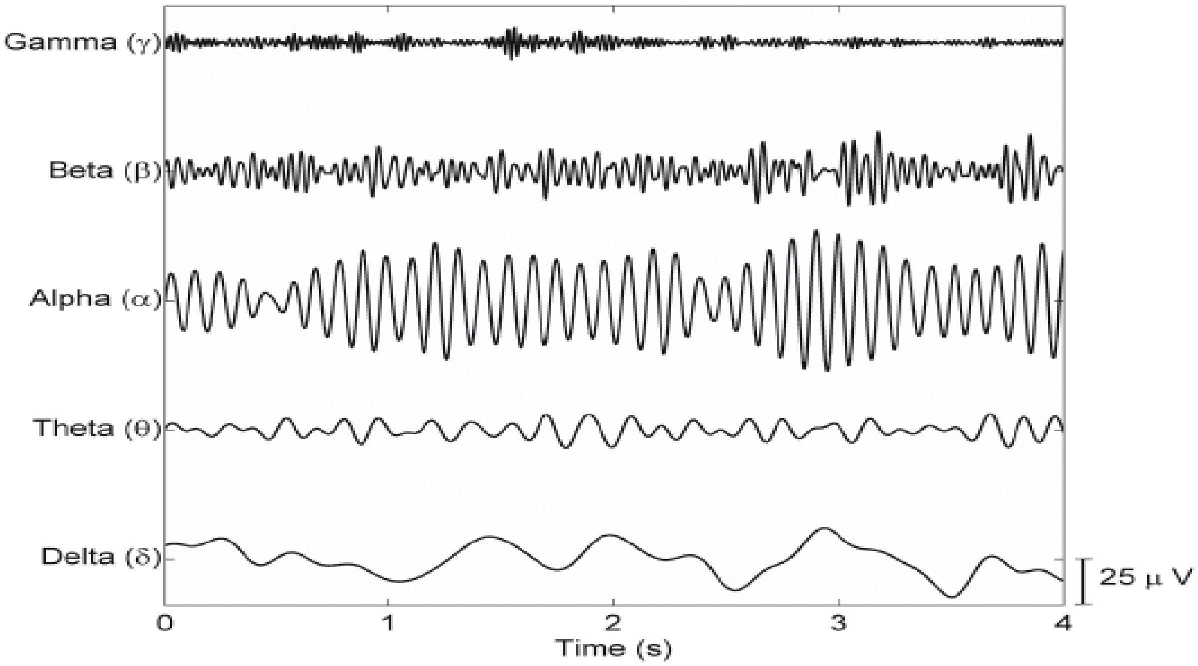
General Waveform

- P wave corresponds to Atrial depolarization of SA node
- Atrial repolarization record is masked by the larger QRS complex
- QRS complex corresponds to ventricular depolarization
- T wave corresponds to ventricular repolarization

2. <u>The Electroencephalogram(EEG)</u>

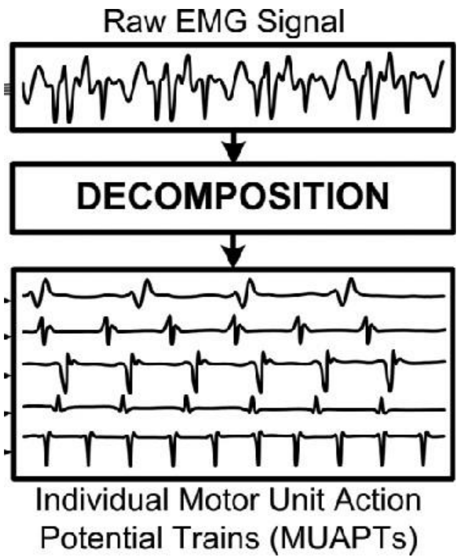
The recorded representation of bioelectric potential by the neuronal activity of the brain is called the electroencephalogram.

The waveform varies greatly with the location of the measuring electrodes on the surface of the scalp.



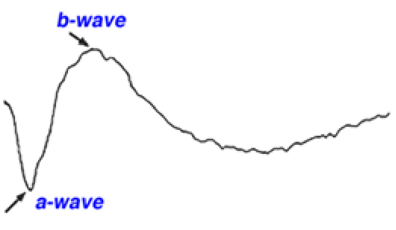
Frequency Range	Signal Type	Activity
Below 3.5 Hz	Delta	Deep sleep
From 3.5 Hz to about 8 Hz	Theta	Fall aslpeep
From about 8 Hz to about 13 Hz	Alpha	Drowsy person
Above 13 Hz	Beta	Paradoxial sleep, Rapid eye movement(REM)

3. **Electromyogram** **[EMG]**: The bioelectric potentials associated with muscle activity constitute the electromyogram. Can be measure on the surface of the body or by penetrating the skin using needle electrodes.



4. **Eelctoretinogram** **[ERG]:** A record of the complex pattern of the bioelectric potentials obtained from the retina of the eye. This is usually a response to a visual stimulas.

- The two components that are most often measured are the a- and b-waves. The a-wave is the first large negative component, followed by the b-wave which is corneal positive and usually larger in amplitude.



The basic waveform of the ERG

- When light falls on photo receptors outer portion of photoreceptor becomes positive and inner part becomes negative
- ‘a’ wave - Reflects the potential of photoreceptors in outer retina
- ‘b’ wave - Reflects the function of the inner layers of the retina.

5. **Electro-oculogram** [EOG]: A measure of the variation in the corneal-retinal potential as affected by the position and movement of eye.

- The clinical electro-oculogram (EOG) makes an indirect measurement of the minimum amplitude of the standing potential in the dark and then again at its peak after the light rise.

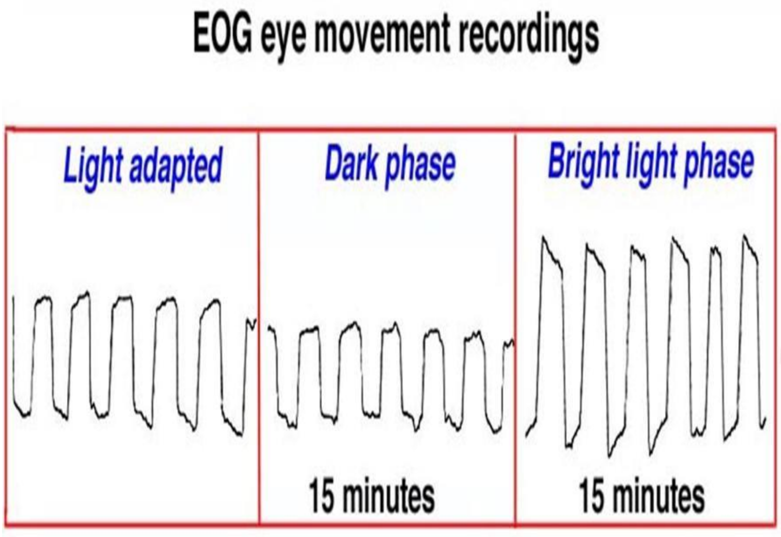
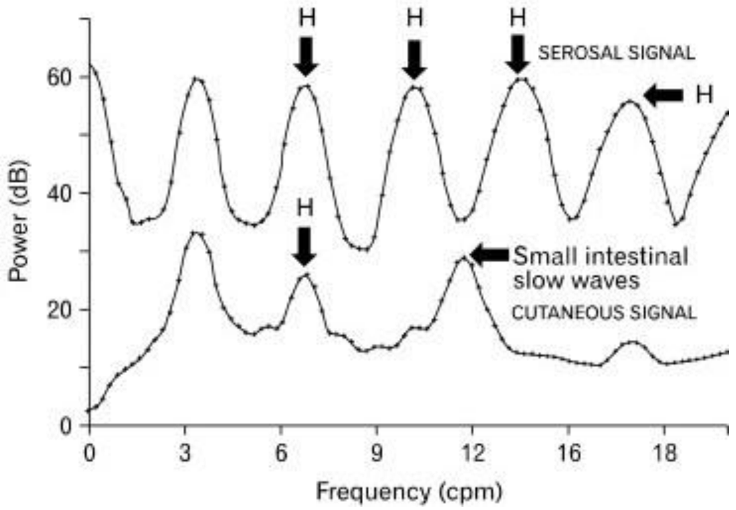


Fig. 47. Light adapted pre-EOG, dark adaptation phase and light-rise phase.

6. **Electrogastrogram** [EGG]: Electrogastrography is a non-invasive technique for recording gastric myoelectrical activity using cutaneous electrodes placed on the abdominal skin over the stomach. The surface recording obtained using electrography is called the electrogastrogram.



Electrode Theory

- To measure bioelectric potentials, a transducer is required. Electrical signals produced by various body activities are used in monitoring / diagnosis.
- In order to measure and record potentials and, hence, currents in the body, it is necessary to provide some interface between the body and the electronic measuring apparatus. Bio-potential electrodes carry out this interface function.
- A transducer consists of two electrodes, which measure ionic potential difference between two points.
- The designation of the Bio potential waveform ends with "Gram". The name of the instrument bio potential normally ends with "Graph". Propagation of action potential through different body tissues produces final waveform recorded by electrodes
- Electrical activity is explained by differences in ion concentrations within the body (sodium, Na+; chloride, Cl–; potassium, K+). A potential difference (voltage) occurs between 2 points with different ionic concentrations
- Propagation of action potential through different body tissues produces final waveform recorded by electrodes
- Electrical activity is explained by differences in ion concentrations within the body (sodium, Na+; chloride, Cl–; potassium, K+). A potential difference (voltage) occurs between 2 points with different ionic concentrations

Nernst Relation

- It can be shown that an electric potential *E* will exist between the solutions on either side of the membrane, based upon the relative activity of the permeable ions in each of these solutions. This relationship is known as the Nernst equation.

- The relationship between the ionic concentration (activity) and the electrode potential is given by the Nernst equation:

- When no electric current flows between an electrode and the solution of its ions or across an ionpermeable membrane, the potential observed should be the half-cell potential or the Nernst potential, respectively. If, however, there is a current, these potentials can be altered.

$$E = -\frac{RT}{nF}\ln\left(C1F1 / C2F2\right)$$

where

R – universal gas constant [8.31 J/(mol K)]

T – absolute temperature in K

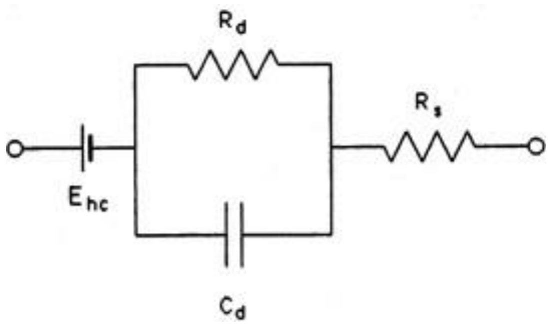
n – valence of the electrode material

F – Faraday constant [96,500 C/(mol/valence)

C1,C2- Concentration of ion on either side of membrane

f1,f2- Respective activity coefficientsof ions on either side

Equivalent circuit for bio-potential electrode

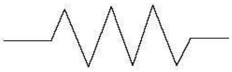


- Where R_d and C_d are components that represent the impedance associated with the electrode-electrolyte interface and polarization at this interface.
- *Rs* is the series resistance associated with electrode materials.
- The battery E_{hc} represents the half-cell potential

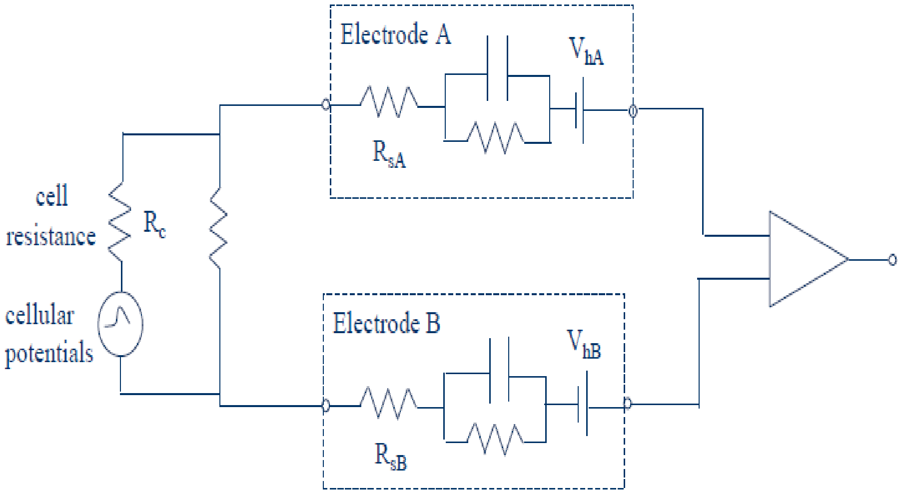
Polarizable and Non-Polarizable Electrodes

1. **Polarizable Electrodes**
   No charge crosses the electrode-electrolyte interface when a current is applied. (e.g Platinum electrode)

2. **Non-Polarizable Electrode**
   Current passes freely across the electrode-electrolyte interface. (e.g. Ag/AgCl Electrode)



Equivalent circuit for bio-potential with two electrode



Bio Potential Electrodes

- Bio-potential electrodes transduce ionic conduction to electronic conduction so that bio-potential signals can be obtained

  They generally consist of metal contacts packaged so that they can be easily attached to the skin or other body tissues

Classification of Electrodes

1. **Micro Electrodes---** Bio electric potential near or within a single cell

   Metal Type—Tip must be tungsten or stainless steel

   Micro pipette---It is a glass micropipet with size of 1 micron, It is filled with electrolyte

2. **Skin surface electrode** —Measure ECG,EEG,EMG

3. **Needle electrode** ---Penetrate the skin to record EEG

1. Micro Electrodes: To measure potential across the cell membrane.

Smaller in size with respect to the cell dimension
Avoids causing serious injury
Doesn't change the cell's behavior
Tip diameter ranging from approximately 0.05 to 10μm

Formed from

Solid-metal needles

Or a Metal contained within or on the surface of a glass needle.

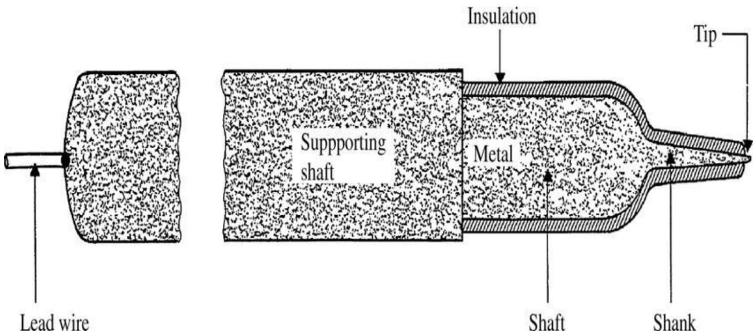
A glass micropipette having a lumen filled with an electrolytic solution.

a. Two types
   Metal
   Micropipette

1. Metal Electrodes

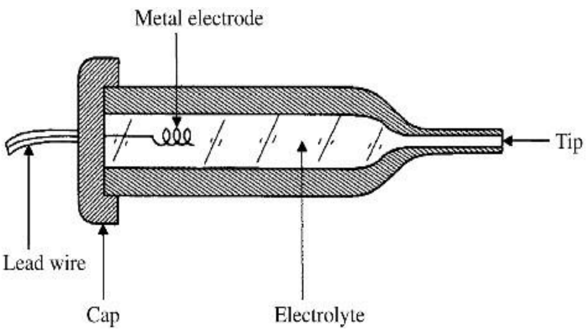
   Fine needle of strong metal

- Stainless Steel
- Platinum-iridium alloy
- Tungsten
- Compound tungsten carbide



- Insulated with an appropriate insulator up to its tip.
- Usually produced by electrolytic etching, using an electrochemical cell in which the metal needle is the anode.
- The electric current etches the needle as it is slowly withdrawn from the electrolytic solution.
- The etched metal needle is then supported in a larger metallic shaft that is then insulated.

2. Micropipette Electrodes



- Prepared from glass capillaries
- Glass Micropipette with the tip drawn out to the desired size (usually about 1µm) in diameter.
- The central region of a piece of capillary tubing is heated to the softening point
- It is then rapidly stretched to produce the constriction
- Is then broken apart at the constriction to produce a pipette structure.
- Filled with an electrolyte solution frequently 3M KCL
- A Cap containing a metal electrode is then sealed to the pipette.

2. <u>Surface electrodes</u>

- These are placed in contact with the skin of the subject

a. Immersion electrodes

Early stages immersion electrodes were used.
A bucket of saline water is used

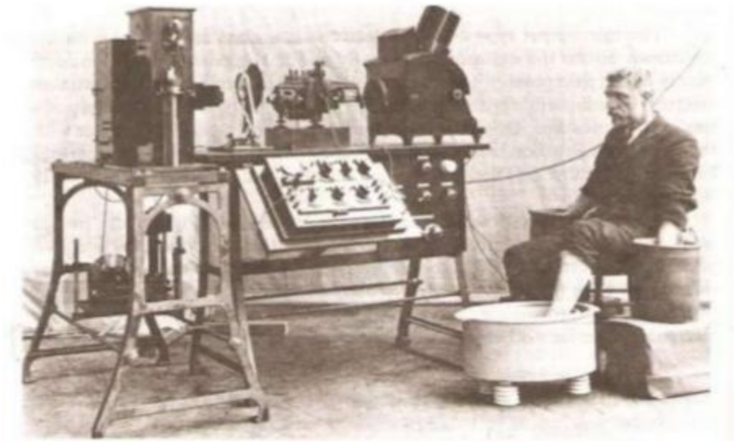
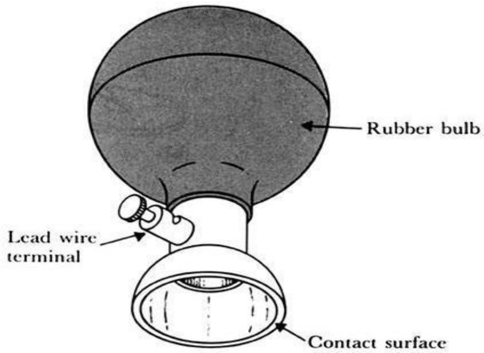


Figure 1 ECG measurement using immersion electrodes. Original Cambridge electrocardiograph (1912) built for Sir Thomas Lewis.

An improvement of immersion electrode is the plate electrode.
Another old type electrode is suction type

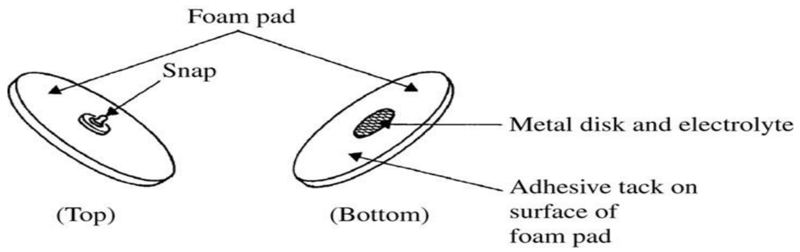
b. Suction type



- Modification of metal-plate electrode that require no straps or adhesives for holding it in place
- Frequently used in precordial (chest) leads
- Can be placed at a particular location
- Consists of a hollow metallic cylindrical electrode that makes contact with the skin at its base.
- A Lead wire is attached to the metal cylinder
- A rubber suction bulb fits over its other base.
- Electrolyte gel is placed over the contacting surface.
- The bulb is squeezed and placed on the chest wall and then the bulb is released and applies suction against the skin, holding the electrode assembly in place.
- Suction & pressure of the contact surface against the skin creates irritation
- Small contacting area with a large overall size

c. Metal-Plate Electrodes

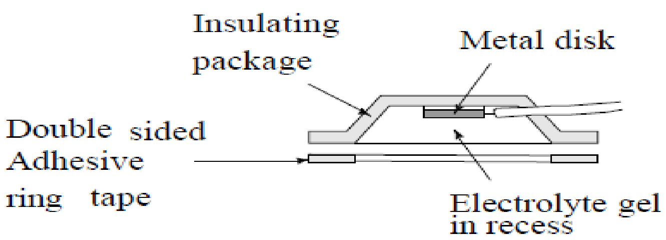
- Historically, one of the most frequently used forms of bio-potential sensing electrodes is the metal-plate electrode.
- In its simplest form, it consists of a metallic conductor in contact with the skin.
- An electrolyte soaked pad or gel is used to establish and maintain the contact.



d. Floating electrodes

Conductive paste reduces effect of electrode slippage and resulting motion artifact.

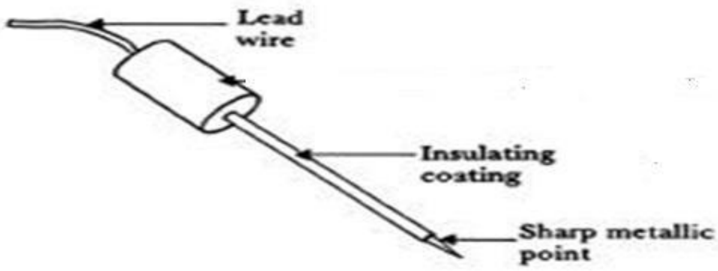
- In practice the electrode is filled with electrolyte gel and then attached to the skin surface by means of a double-sided adhesive tape ring.
- The electrode element can be a disk made of a metal such as silver coated with AgCl.



3. **<u>Needle electrodes</u>**

- Unipolar electrode---Single wire inside a needle
- Bipolar electrode---Two wires inside a needle
- Mostly used for contacting with internal body tissues
- (a) Insulated needle electrode.
- (b) Coaxial needle electrode.
- (c) Bipolar coaxial electrode.
- (d) Fine -wire electrode connected to hypodermic needle, before being inserted .
- (e) Coiled fine -wire electrode in place
- ***Coaxial needle electrode***

- A shielded percutaneous electrode consists of a small-gage hypodermic needle that has been modified by running an insulated fine wire down the center of its lumen and filling the remainder of the lumen with an insulating material such as resin.
- When the resin has set, the tip of the needle is filed to its original bevel, exposing an oblique cross section of the central wire, which serves as the active electrode.
- The needle itself is connected to ground through a shield of a coaxial cable, thereby extending the coaxial structure to its very lip.
- ***Bipolar coaxial needle electrode***
- Two wires are placed within the lumen of the needle
- Connected differentially to be sensitive only to the electrical activity in the immediate vicinity of the needle.



<u>Bio potential Amplifiers</u>

- These are very important part of modern medical instrumentation. We need to amplify bio-potentials which are generated in the body at low levels with high source impedance.
- Bio-potentials amplifiers are required to increase signal strength while maintaining fidelity
- To take a weak bio-potential and increase its amplitude so that it can be processed, recorded or displayed
- To amplify voltage, power and current.
- In some cases a biopotential amplifier is used to isolate the load from the source current gain only

Characteristics

1. high input impedance
2. low output impedance
3. The biopotential amplifier must be sensitive to important frequency components of the biosignal.
4. Biopotential amplifiers have a gain of **1000** or greater.
5. most biopotential amplifiers are differential
6. High common mode rejection ratio.

Commonly used Bio-potential Amplifier is Differential amplifier. But it has some limitations.

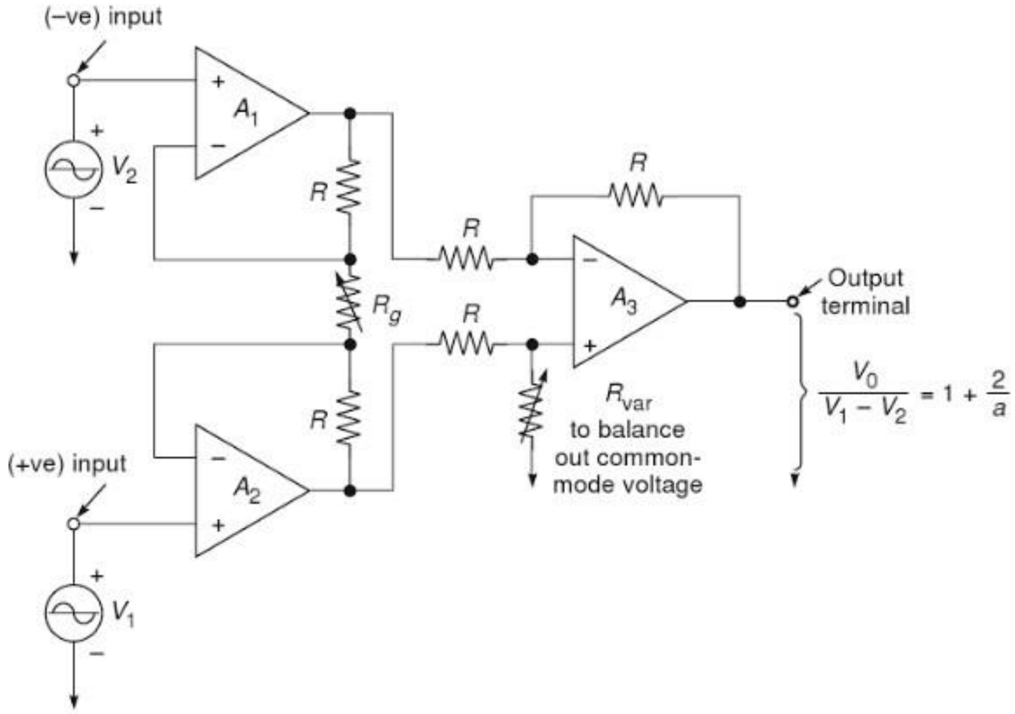
- The amplifier has a limited input impedance and therefore, draws some current from the signal source and loads them to some extent.
- The CMRR of the amplifier may not exceed 60 dB in most of the cases, which is usually inadequate in modern biomedical instrumentation systems.

These limitations overcome with the availability of improved version of differential amplifier called Instrumentation Amplifier

1. **Instrumentation Amplifier**

Advantages

- Extreme high i/p impedence
- Very high CMRR
- Low power consumption
- Available in single IC
- High slew rate
- Low bias & offset currents



Schematic diagram of an instrumentation amplifier

- Structure consists of 3 op-amps and seven resistors
- Two buffer amplifiers A1 and A2 connected to a differential amplifier A3.
- In the above circuit op-amp A3 with four equal resistors R form a differential amplifier with gain 1.
- Rvar = Variable resistance, used to balance out any common mode voltage.
- Rg = used to set the gain using the formula

$$\frac{V_0}{V_1 - V_2} = 1 + \frac{2}{a}$$

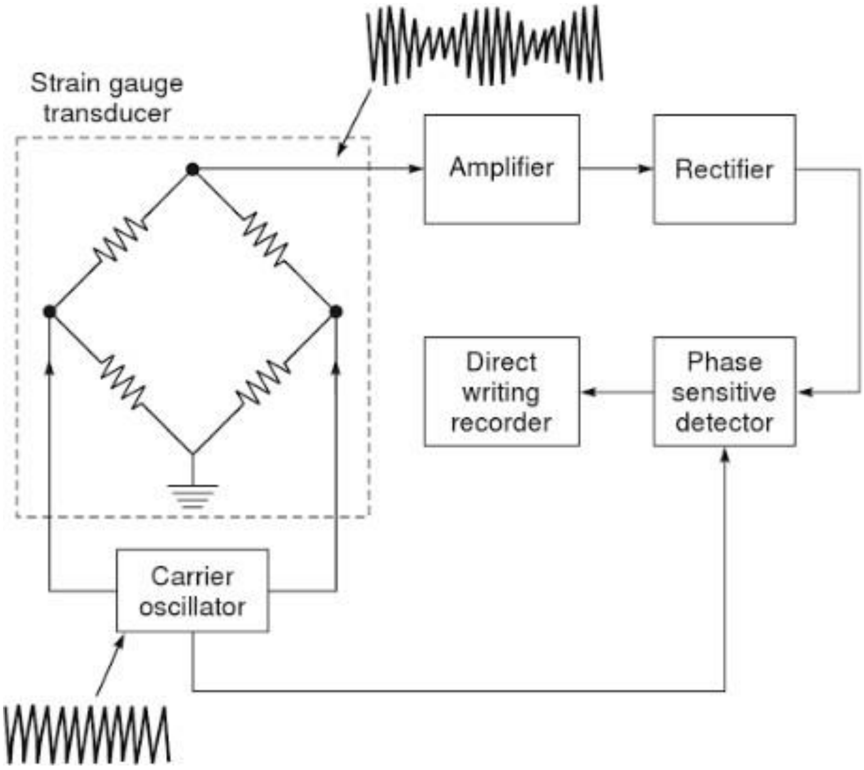
Where $a = R_g / R$

V_1 is applied to the +ve input terminal and V_2 to the –ve input terminal. V_0 is proportional to the difference between the two input voltages.

The important characteristics of the instrumentation amplifier are:

- Voltage gain from differential input $(V_1 - V_2)$ to single ended output, is set by one resistor.
- The input resistance of both inputs is very high and does not change as the gain is varied.
- V_0 does not depend on common-mode voltage, but only on their difference.

2. Carrier Amplifier



Structure consists of

1. Carrier Oscillator: used to energize the transducer with an alternating carrier voltage.

2. Strain gauge transducer:

- The information signal from the body electrodes reaches the transducer where it is amplitude modulated using carrier signal from the carrier oscillator.
- The transducer changes the amplitude of carrier signal with respect to the physiological variable being measured.
- The output of transducer is amplitude modulated signal.

3. Amplifier

- Amplifier used is Multistage Capacitance coupled Amplifier
- The modulated signal from the transducer is given to this amplifier.

- The first stage produces amplification of AM signal.
- Second stage responds to signal frequency components of carrier signal only.
- Further amplified in the third stage.

4. Rectifier

- Output from the amplifier is converted into unidirectional signal using a rectifier.

5. Phase sensitive Detector

- The signal is demodulated and extracts the amplified information signal.

6. Direct Writing Recorder

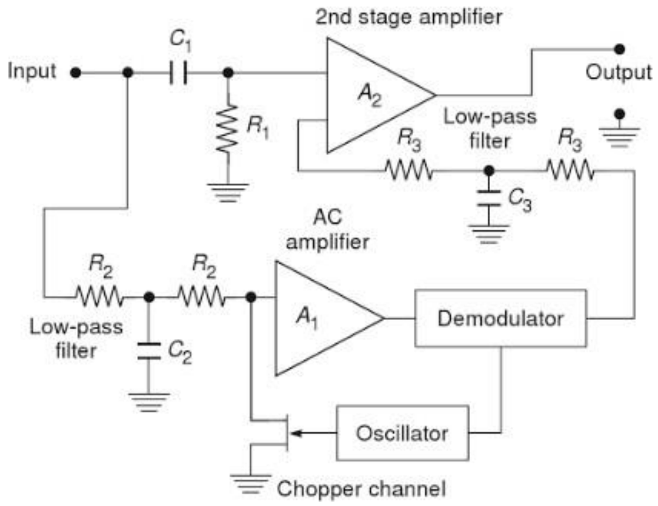
- The voltage produced by the detector stage is then fed to the driver stage of the recording system.

Features of carrier amplifier

- Used to obtain zero frequency response of dc amplifier.
- Inherent stability of capacitance coupled amplifier.

3. **<u>Chopper Amplifier</u>**

- Used to avoid the drift problem occurs in the direct coupled amplifier.
- This circuit uses a chopping device which converts slowly varying dc to an alternating form with amplitude proportional to the input direct current and phase depends on the polarity of original signal.
- The ac voltage is then amplified by an ac amplifier whose output is then rectified back to get an amplified direct current.
- Figure given below shows single ended chopper stabilizer amplifier.
- Aim of this circuit is to avoid the dc offset voltage present in the output signal.
- For that purpose first convert the dc signal into ac using a chopper.



1. Low Pass Filter

- The low frequency components derived from the input signal by passing it through low pass filter R2C2 and R2

2. Chopper

- The output of LPF is then chopped using a transistor switch w.r.t a carrier signal from the oscillator.

3. Demodulator

- The original signal recovered in demodulator which is again applied to second stage of amplification.

4. Low Pass Filter

- Before given to the amplifier low frequency components again derived using LPF

5. Second Stage of Amplification (A2)

- At the input of A2 an HPF C1R1 is used to derive the high frequency signals.
- This is to reduce the dc offset and drift of second amplifier A2.

Advantage of Chopper Amplifier

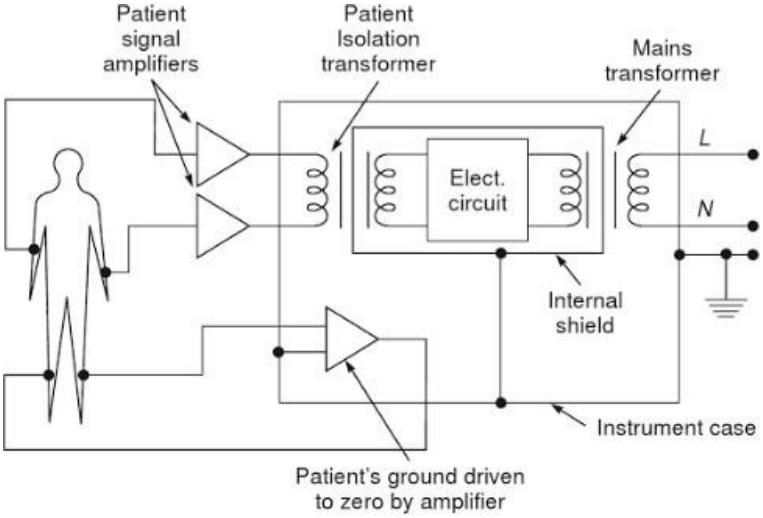
- Insensitivity to component changes due to ageing, temperature change, power supply variation, or other environmental factors.
- Small offset voltage
- Used to amplify small dc signals of few microvolts.

4. **Isolation Amplifier**

Isolation amplifiers are commonly used for providing protection against leakage currents. They break the ohmic continuity of electric signals between the input and output of the amplifier. The isolation includes different supply voltage sources and different grounds on each side of the isolation barrier. Three methods are used in the design of isolation amplifiers: (i) transformer isolation (ii) optical isolation (iii) capacitive isolation.

1. Transformer Isolation

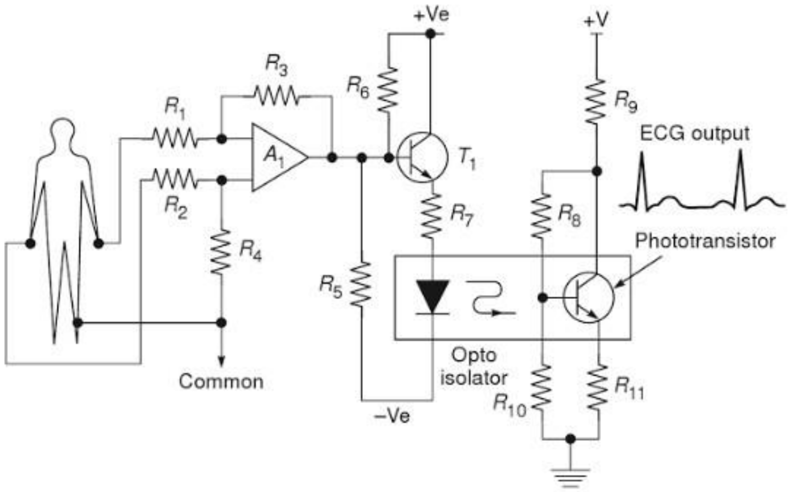
The transformer approach is shown in Fig. . It uses either a frequency-modulated or a pulse-width-modulated carrier signal with small signal bandwidths up to 30 kHz to carry the signal. It uses an internal dc–to-dc converter comprising of a 20 kHz oscillator, transformer, rectifier and filter to supply isolated power.



2. Optical Isolation

Isolation could also be achieved by optical means in which the patient is electrically connected with neither the hospital line nor the ground line. A separate battery operated circuit supplies power to the patient circuit and the signal of interest is converted into light by a light source (LED).

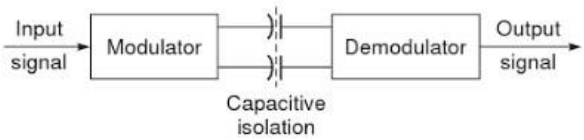
This light falls on a phototransistor on the output side, which converts the light signal again into an electrical signal (Fig. 4.9), having its original frequency, amplitude and linearity. No modulator/ demodulator is needed because the signal is transmitted optically all the way.



Optically isolated isolation amplifier

3. Capacitive Isolation

The capacitive method (Fig. 4.10) uses digital encoding of the input voltage and frequency modulation to send the signal across a differential capacitive barrier. Separate power supply is needed on both sides of the barrier. Signals with bandwidths up to 70 kHz can be conveniently handled in this arrangement.



➤ **Fig. 4.10** ***Capacitively coupled isolation amplifier***

The relative merits of the three types of isolation techniques are:

- All three types are in common use, though the transformer isolation amplifier is more popular.
- Opto-coupled amplifier uses a minimum number of components and is cost effective, followed by the transformer coupled amplifier. The capacitor coupled amplifier is the most expensive.
- Opto-isolated amplifiers offer the lowest isolation voltage (800 V continuous) between input and output; transformer coupled 1200 V and capacitance coupled 2200 V.
- Isolation resistance levels are of the order of 10^{10}, 10^{12} and 10^{12} ohms for transformer coupled, opto-coupled and capacitance coupled amplifiers respectively.
  - Gain stability and linearity are best for capacitance coupled versions—0.005%, and on par for the transformer and opto-coupled amplifier—0.02%.

Electrical isolation is the most commonly used technique to ensure patient protection against electrical hazards. Instruments such as electrocardiographs, pressure monitors, pressure transducers, pacemakers and others have been designed to electrically separate the portion of the circuit to which the patient is connected from the portion of the circuit connected to the ac power line and ground.

Module II

MODULE 2

BIOPOTENTIAL ELECTRODES

- To measure and record potentials and currents in the body, it is necessary to provide some interface between the body and the electronic measuring apparatus.
- The interface function is carried out by biopotential electrodes.
- The electrode must serves as a transducer to change an ionic current into an electronic current.
- When electrodes in their simplest form made of pieces of metal, are placed on or inside the body, they come in contact with body fluids which may be considered as electrolytes.
- Due to this contact between a metal and an electrolyte solution, an electrochemical reaction produces a difference of potential between the metal and solution.
- The chemical reactions that occur between metals and electrolytes influence the performance of biopotential electrodes.
- When electrode is placed on the skin surface, there is some electrical resistance at the electrode-skin interface.
- Since the skin's natural resistance is high compared to the resistance of the body fluids, the selected skin site is to be well prepared by cleaning with alcohol or acetone and by applying a commercially available conductive gel.
- This ensures a low value of electrode-skin interface resistance.
- When an electrode makes contact with the skin via an electrolyte paste, the equivalent circuit is shown below in figure 1.

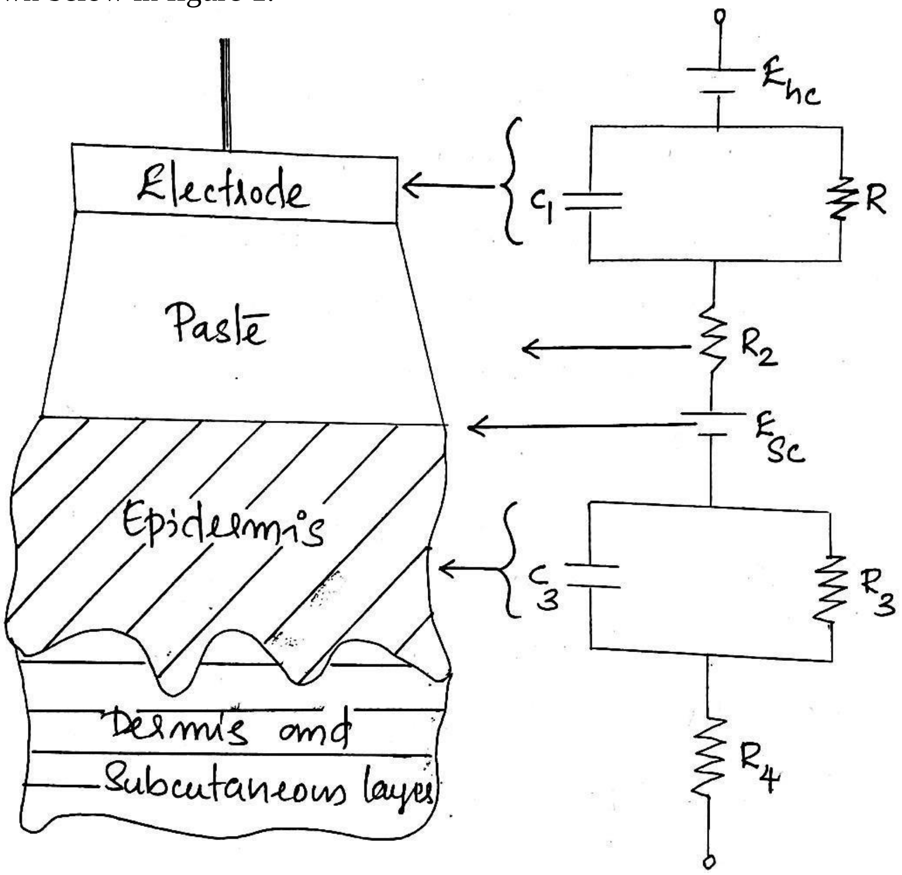


Figure 1: Total electrical equivalent circuit between the electrode and the skin

- R_2 becomes the effective resistance of the paste (gel) between the electrode and the skin.
- The epidermis of the skin may be considered as a semipermeable membrane and the potential difference across it is represented by E_{SC}.
- The epidermic layer has also an electrical impedance, which is represented by the parallel circuit C_3 and R_3.
- The dermis and subcutaneous layer under it behaves in general as pure resistance R_4.

ELECTRODE TYPES

- A wide variety of electrodes can be used to measure bioelectric events, but nearly all can be classified as belonging to one of these three basic types:

1. **Skin surface Electrodes:** They are used to measure ECG, EEG and EMG potentials on the surface of the skin.
2. **Needle Electrodes:** They are used to penetrate the skin to record EEG potentials from a local region of the brain, or EMG potentials from a specific group of muscles.
3. **Micro Electrodes:** They are used to measure bioelectric potentials near a single cell.

1. SKIN SURFACE ELECTRODES

- Many different types of electrodes for recording various potentials on the body surface have been developed over many years.
- Here we let us discuss three types of electrodes with examples of their application.
  - **A.** Metal-plate electrodes
  - **B.** Suction electrodes
  - **C.** Floating electrodes

A. METAL PLATE ELECTRODES

- Most frequently used form of biopotential sensing electrode is the metal-plate electrode.
- In its simplest form, it consists of metallic conductor in contact with the skin.
- An electrolyte soaked pad or gel is used to establish and maintain good contact.
- Three different types of metal plate electrodes are available:

a) Metal-plate electrode is used for application of limbs

- It consists of a flat metal plate that has been bent into a cylinder segment.
- A terminal is placed on its outside surface near one end; this terminal is used to attach the lead wire to the electrocardiograph.
- A post, placed on this same side near the center is used to connect a rubber trap to the electrode and hold it in place on an arm or leg.
- The electrode is traditionally made of German silver (a nickel-silver alloy).
- Before it is attached to the body, its concave surface is covered with electrolyte gel.

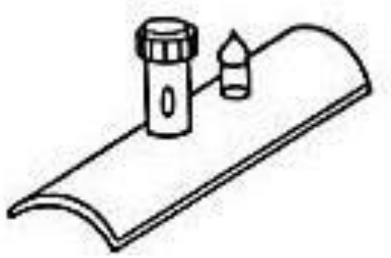


Figure 2: Metal-plate electrode is used for application of limbs

b) Metal-disk electrode is used applied with surgical tape

- Second common variety of meta-plate electrode is the metal disk as shown in figure 3, which has a lead wire soldered or welded to the back surface.
- They can be made of several different materials.
- At times the connection between lead wire and electrode is protected by a layer of insulating material such as epoxy or polyvinylchloride.

Figure 3: Metal-disk electrode is applied with surgical tape

c) <u>Disposable foam-pad electrodes</u>

- They can be used as a chest electrode for recording ECG or in cardiac monitoring for long term recordings.
- It consists of a relatively large disk of plastic foam material with a silver plated disk on one side attached to a silver plates snap similar to that used on clothing in the center of other side.
- A lead wire is connected on to the electrode and used.
- The silver plated disk serves as the electrode and may be coated with AgCl layer.
- A layer of electrolyte gel covers the disk.
- The electrode side of the foam is covered with an adhesive material that is compatible with the skin.
- A protective cover or strip of paper or cotton or cloth placed over the electrode side.
- The technician has only to clean the area of skin on which the electrode is to be placed, and open the electrode packet, and remove the disposable paper or cloth or cotton that used as foam.
- Such procedure is quickly accomplished and no special technique need to be learned.
- We have to only consider using the correct amount of gel to the adhesive material to hold the electrode in place for use.

B. <u>SUCTION ELECTRODES</u>

- A modification of the metal plate electrode that requires no straps or adhesives for holding it in place is the suction electrode which is shown in figure 4.

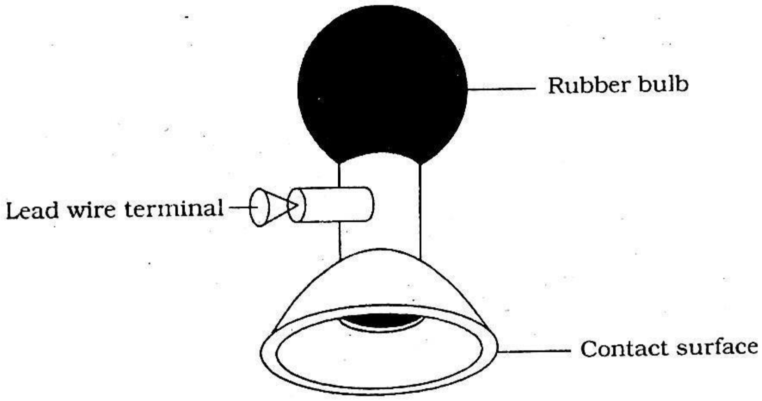


Figure 4: A metallic suction electrode

- Such electrodes are frequently used electrocardiography as the precordial (chest) leads, because they can be placed at particular locations and used that makes contact with the skin at its base.
- An appropriate terminal for the lead wire is to be attached to the metal cylinder, and a rubber suction bulb fits over its other base.
- The electrolyte gel is placed over the contacting surface of the electrode, the bulb is squeezed, and the electrode is then placed on the chest wall.
- The bulb is released and applies suction against the skin holding the electrode assembly in place.
- Such electrode can be used only for short periods of time; the suction and the pressure of the contact surface against the skin can cause irritation.
- Although the electrode itself is quiet large.
- It is observed that the actual contacting area is relatively small.
- This electrode thus tends to have higher source impedance than the relatively large surface area metal plate electrodes used for ECG limb electrodes.

C. FLOATING ELECTRODES

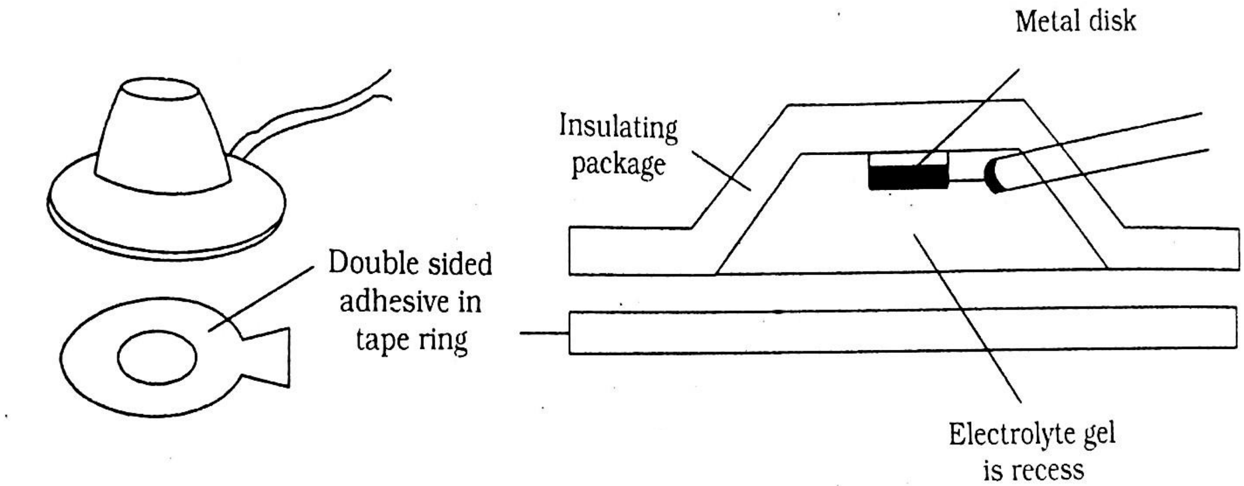


Figure 5: Reversed floating electrode with top hat structure and its cross-sectional view

- Another type of skin surface electrode is floating electrode or liquid junction electrode shown in figure 5.
- The principle feature is that the actual metal disk is recessed in a cavity so that it does not make direct contact with the skin.
- The electrical contact is established through the electrolyte paste filled in the cavity.
- The electrode element is made of silver and is often coated with silver chloride (AgCl).

2. NEEDLE ELECTRODES

- For measuring bio-potentials from within the body, the transcutaneous types of electrodes are used (Figure 6).
- In which the electrode or the lead wire penetrates the skin, or they may be implanted internally and connected to an implanted electronic circuit.
- To evaluate individual motor units within a muscle, a needle electrode must be placed into the muscle itself.
- Basic needle electrode consists of a solid needle usually made of stainless steel with a sharp point.
- The shank of the needle is insulated with a coating such as an insulating varnish; only the tip is left exposed.
- A lead wire is attached to the other end of the needle, and the joint is encapsulated in a plastic hump to protect it.
- This electrode, frequently used in electromyography.

3. MICROELECTRODES

- While studying the electrophysiology of excitable cells, it is often important to measure potential differences across the cell membrane.
- To be able to do this, we must have an electrode within the cell.
- Such electrodes must be small with respect to the cell dimensions to avoid causing serious cellular injury and thereby changing the cell's behaviour.
- In addition to being small, the electrode used for measuring intracellular potential must also be strong so that it can penetrate the cell membrane and remain mechanically stable.
- The electrodes that meet these requirements are known as microelectrodes.
- They have tip diameter ranging from approximately 0.05 to 10 µm.
- Microelectrodes can be formed from solid-metal needles, from metal contained within or on the surface of a glass needle, or from a glass micropipette having a lumen filled with an electrolyte solution.

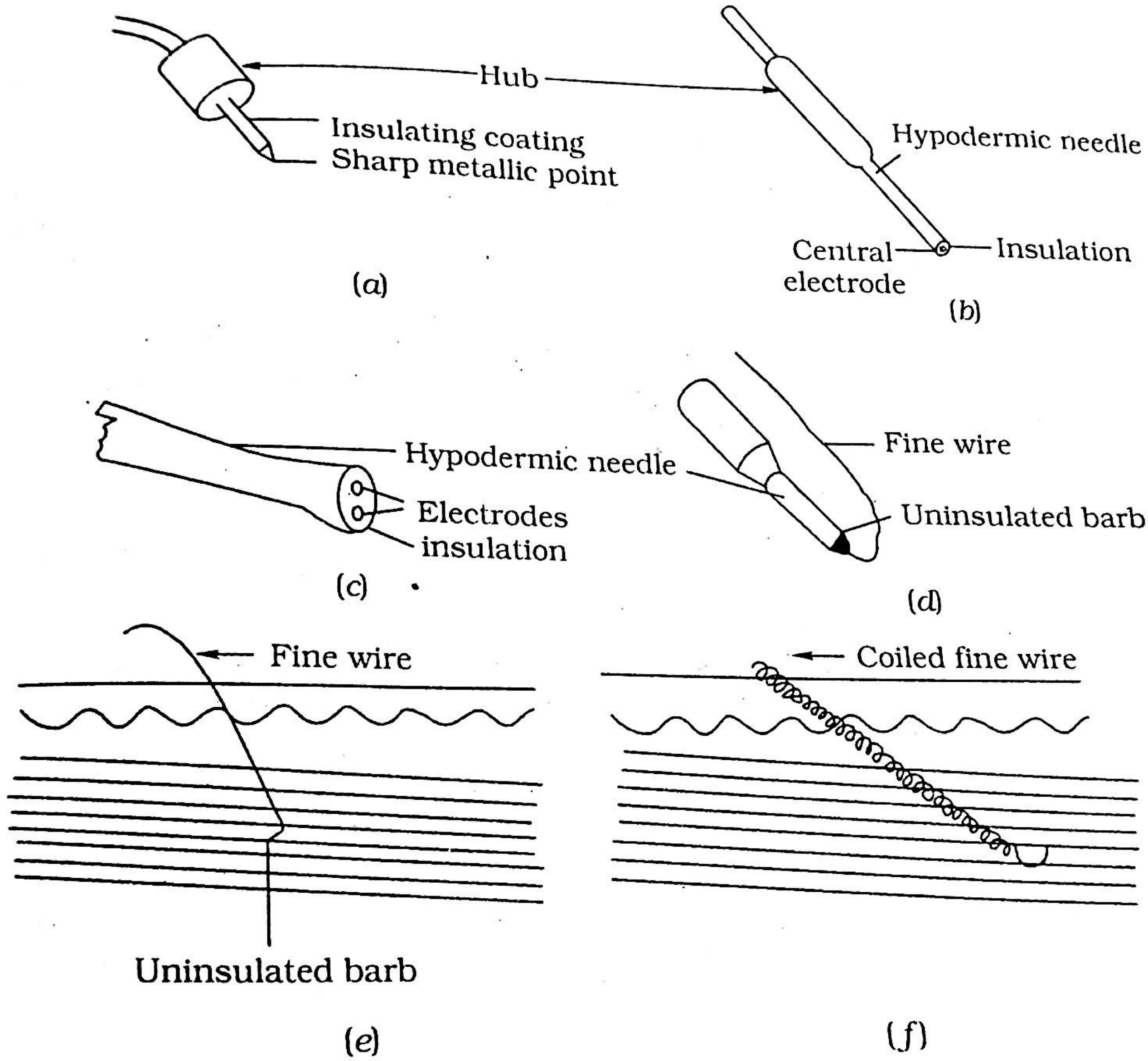


Figure 6: Needle and wire electrodes for percutaneous measurement of bio-potentials: (a) Insulated needle electrode. (b) Coaxial needle electrode. (c) Bipolar coaxial electrode. (e) Cross-sectional view of skin and muscle showing fine-wire electrode in place. (f) Cross-sectional view of skin and muscle showing coiled fine-wire electrode in place.

a) <u>METAL MICROELECTRODES</u>

- The metal microelectrodes is essentially a fine needle of a strong metal is insulated with an appropriate insulator up to its tip, as shown in figure 7.

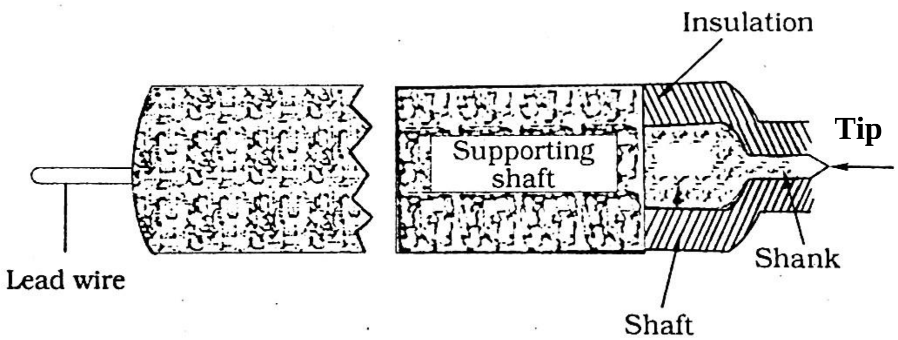


Figure 7: Metal microelectrode

- The metal needle is prepared in such a way as to produce a very fine tip.
- This is usually done by electrolytic etching process.
- Suitable strong metals for these microelectrodes are stainless steel, platinum iridium alloy, and tungsten.
- In the compound tungsten carbide, is also used because of its great strength.
- The etched metal needle is then supported on a larger metallic shaft that can be insulated.
- Such shaft serves as a sturdy mechanical support for the microelectrode and as a means of connecting it to its lead wire.
- The microelectrode and supporting shaft are usually insulated by a film of some polymeric material or varnish whereas the extreme tip of the electrode remains uninsulated.

b) <u>SUPPORTED METAL MICROELECTRODES</u>

- The properties of two different materials are used to advantage in supported metal microelectrodes.
- A strong insulating material that can be drawn to a fine point makes up the basic support and a metal with good electrical conductivity constitutes the contacting portion of the electrode.
- Figure 8 shows examples of supported metal microelectrodes.

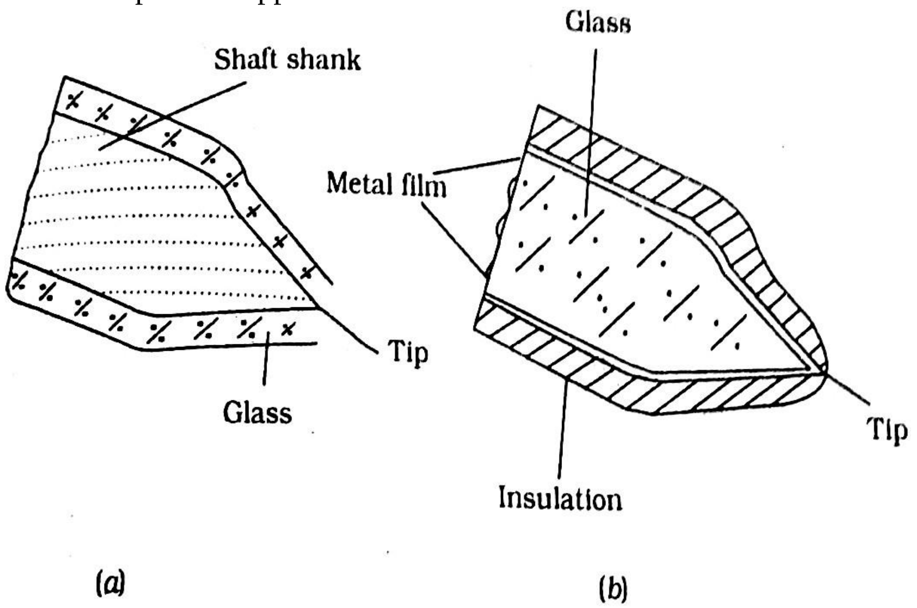


Figure 8: Structure of two supported metal microelectrode, (a) Metal filled glass micropipette. (b) Glass micropipette coated with metal film.

- The classic example of this form is a glass tube drawn to a micropipette structure with its lumen filled with an appropriate metal.
- Often this type of microelectrodes as shown are prepared by first filling a glass tube with a metal that has a melting point near the softening point of glass.
- The tube can be heated to the softening point and pulled to form a narrow construction.
- In this type of structure, the glass not only provides the mechanical support but also serves as the insulation.
- The active tip is the only metallic area exposed in cross-section where the pipette was broken away.
- The metals such as silver alloy and platinum alloys are used.
- New supported metal electrode structures have been developed using techniques employed in the semiconductor microelectronics industry.
- Figure 8 (b) shows the cross-section of the tip of a deposited metal-film microelectrode.
- A solid glass rod or glass tube is drawn to form the micropipette.

- A metal film is deposited uniformly on this surface of the glass rod.
- A polymeric insulation is then coated over this, leaving just the tip with the metal film exposed.

1. MICROPIPETTE ELECTRODES

- Glass micropipette microelectrodes are fabricated from glass capillaries as shown in figure 9.
- The central region of a piece of capillary tubing, as shown in figure 9 (a), is heated with a burner to the softening point.
- Then it is rapidly stretched to produce the construction as shown in figure 9 (b).
- Special devices known as microelectrodes pullers, that heat and stretch the glass capillary is an uniform reproducible way to fabricate micropipettes are commercially available.
- The two halves of the stretched capillary structure are broken apart at the constriction to produce a pipette structure that has a tip diameter of the order of 1 µm, such pipette fabricated into the electrode form is shown in figure 9 (c).

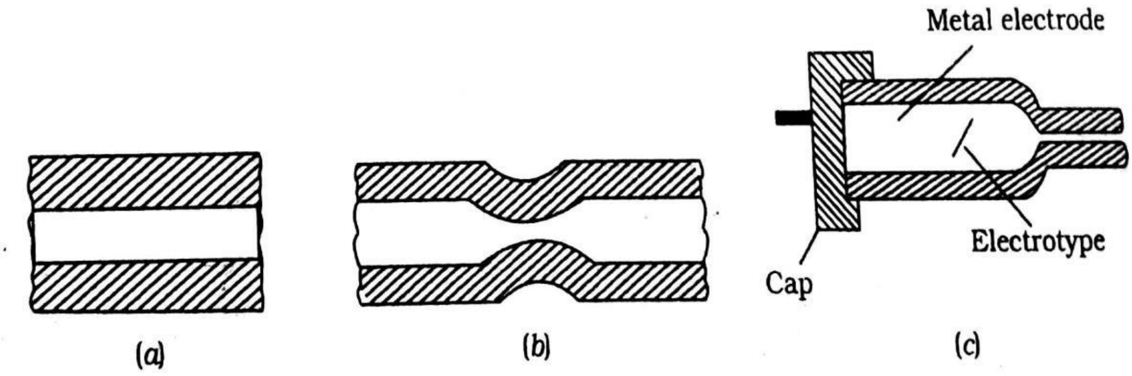


Figure 9: A glass micropipette filled with an electrolyte solution. (a) Section of fine-bore glass capillary. (b) Capillary narrowed through heating and stretching. (c) Final structure of glass pipette microelectrodes.

- It is filled with an electrolyte solution that is frequently potassium chloride (KCl).
- A cap containing a metal electrode is then scaled to the pipette as shown.
- The metal electrode contacts the electrolyte within the pipette.

BIOCHEMICAL TRANSDUCERS

- A transducer may be considered as a sensor, which is also capable of converting one form of the sensed energy or signal into another form, preferably electrical signal.
- It can act as an impedance matching device between the biological system and signal processor.
- In biomedical system, it transforms the physiological information like temperature, pressure or biopotential into a form that can be read by the signal processor.

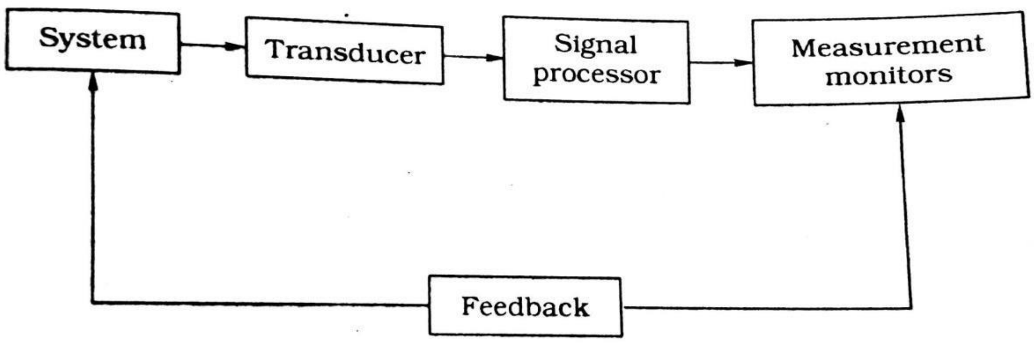


Figure 10: Biochemical transducer system

- Medical instrumentation deals with measurement of physiological variables. A variable is any quantity whose value changes with time.
- Variable associated with physiological process of human body is known as physiological variable.
- The variables are like blood pressure, body temperature, etc.
- Transducers are the devices, which convert one form of energy into another.
- Biochemical transducers will convert all physiological variables into electrical signals.
- A transducer will have nonelectrical variable as its input and electrical signals as its output. The relationship between output and input should be linear.
- There are two different principles involved in the process of converting electrical variables into electrical signals:
  1. Energy conversion (active transducers)
  2. Modulation of carrier signals (passive transducers)

TRANSDUCERS FOR BIOMEDICAL APPLICATIONS

- The different types of **active transducers** are:
  1. Magnetic induction type
  2. Piezoelectric type
  3. Photovoltaic type
  4. Thermoelectric type

1. Magnetic induction type:

- When an electrical conductor moves relative to a magnetic field such that the magnetic field linking the conductor changes, a voltage is induced in conductor. This induced emf referred to as a dynamically induced emf, is given by,

$$e = B \cdot l \cdot v$$

- where *e = induced emf*
  l = length of conductor
  B = magnetic flux density
  v = velocity of conductor

- It is also true that when a current carrying conductor is placed on a magnetic field the conductor experiences a force. i.e.,

$$F = B \times l \times I$$

- These types of transducers are used in electromagnetic flow meters, heart sensor microphones and biomedical recorders.

2. Piezoelectric type transducer:

- When certain crystals are subjected to compression or tension, charge separation occurs in the components and an electrical voltage is developed.
- This is called piezoelectric effect. If we apply a dynamic pressure along mechanical axis of the crystal an a.c. voltage is developed along the electrical axis.
- This effect is also reversible, that is if electrical signal is applied along the electrical axis, a mechanical force is developed along the mechanical axis.
- High frequency ultrasonic waves are produced by this effect.
- Quartz, Barium titanate ($BaTiO_3$), Potassium dihydrogen phosphate (KH_2PO_4) are some piezoelectric materials.
- These types of transducers are used in pulse sensors.

3. Photovoltaic type transducer:

- Ejection of electron from a metal or semiconductor surface when it is illuminated by light or radiation of suitable wavelength is called photoelectric effect.
- There are three types of photoelectric effects. They are photoemissive, photoconductive and photovoltaic.
- The third one, photovoltaic transducer generates electrical voltage in proportion to the incident light energy. Hence it is an active transducer.
- Silicon photoelectric cells are used as pulse sensors and they are also used to determine sodium and potassium ion concentration in human body.

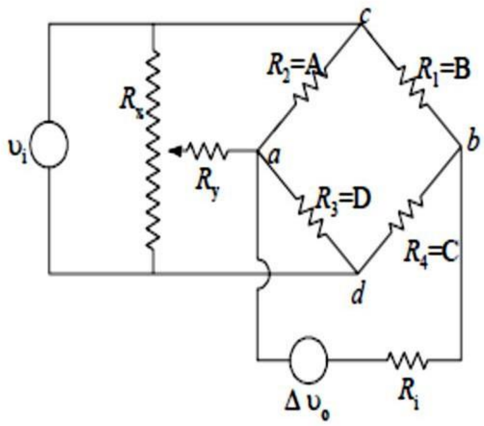
4. Thermoelectric transducer:

- When two junctions of a thermocouple are maintained at two different temperatures, an emf proportional to the temperature difference between the junctions is produced. This effect is called Seeback effect.
- Thermoelectric transducers are based on this principle.
- These types of transducers are used to measure physiological temperature. This is used in doctor's cold box to store and carry plasma and antibodies, etc.

- The different types of **passive transducers** are:
  1. Resistive transducer
  2. Thermistor type transducer
  3. Capacitive transducer
  4. Inductive transducer

1. Resistive transducer:

- The resistance of the resistor changes in proportion to the quantity being measured.
- Strain gauge, photo resistors, photo transistors etc,. fall in this category.



$$\Delta V_0 = 0 \Leftrightarrow \frac{R_1}{R_2} = \frac{R_4}{R_3}$$

Let all R initially be equal to $R_0 \ll R_i$. If R_1 and R_3 increase and R_2 and R_4 decrease by ΔR, then

$$\Delta v_0 = \frac{\Delta R}{R_0} v_i$$

Figure 11: Wheatstone bridge circuit

- Strain gauges are used for intra vascular pressure measurements.

2. Thermistor type transducer:

- This is used as a thermal sensor. In which the resistance of material changes due to change in temperature.
- The specific resistance of a material changes due to the change in mobility of charge carriers.
- The mobility of charge carriers increases with temperature then resistance decreases. They are under the category of negative temperature coefficient thermistors.
- When the temperature increases then the resistance also increases then they are known as positive temperature coefficient thermistors.
- Thermistors used for biomedical instrumentation are all small in size.

3. <u>Capacitive transducer:</u>

- The capacitance of a capacitor depends upon the spacing between the two conducting surfaces, area of the conducting surfaces and the dielectric medium between the surfaces.

$$\text{Capacitance, } \boldsymbol{C} = \frac{s\boldsymbol{A}}{\boldsymbol{d}}$$

- When anyone of above parameter is changed, the capacitance will vary.

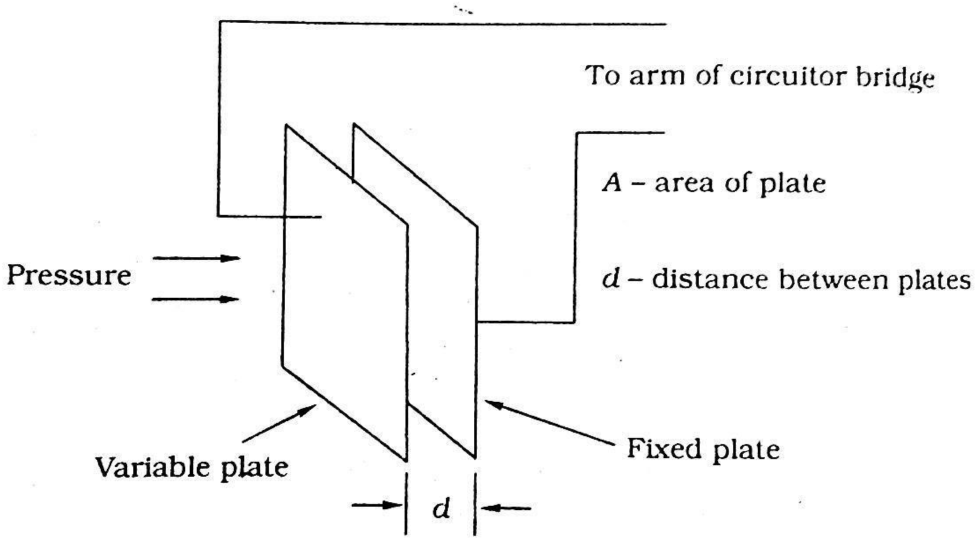


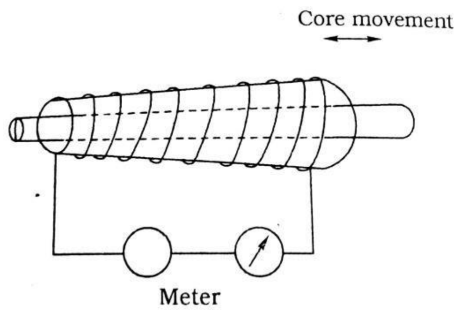
Figure 12: Capacitive transducer

- The capacitor will be connected as a part of a circuit or branch of a bridge, as per the arrangement of the system to measure pressure.
- In the measuring arrangement of pressure, one plate is normally fixed and other is variable.
- The pressure is applied to the variable plate.
- Relationship of capacitance, *C* with respect to separation *d* which is inverse, says that capacitance increases as plate separation decreases.
- Therefore, it is suitable to design a capacitance transducer, with small plate separation and large area.

4. <u>Inductive transducer:</u>

- It is based on the principle of change in reluctance, permeability, number of turns of coil and orientation of the coil which may produce a change in inductance.

$$\text{Inductance, } \boldsymbol{L} = \frac{\boldsymbol{N^2 \mu A}}{\boldsymbol{l}}$$



- There may be one coil, or more coils transducer giving single output, or differential output.
- Linear variable differential transformer, LVDT is an example of inductive transducer, used to measure pressure.

MODULE 2

ELECTRO-CONDUCTION SYSTEM OF THE HEART

- Impulse for cardiac contraction starts at Sino atrial node (SA node). It present at opening of superior venacava into right atrium.
- SA node is called as pacemaker of heart.
- Impulse then passes through the atrial muscle to the AV node (Atrio ventricular node).
- From AV node splits nervous muscle tissue into left side and right side.
- Both left side and right side nervous muscle tissue is collectively called 'Bundle of His'.
- Bundle of his is again divided into branches called Purkinje fibers causing ventricles to contract.
- Cardiologist look at heart rate for diagnosis
- Normal value of heart rate lie in 60-100 beats per minute.
- Slower than this rate is called Brady cardia.
- Higher than the normal rate is Tachy cardia
- The heart rate cycles are evenly spaced if not evenly spaced than condition is called arrhythmia.

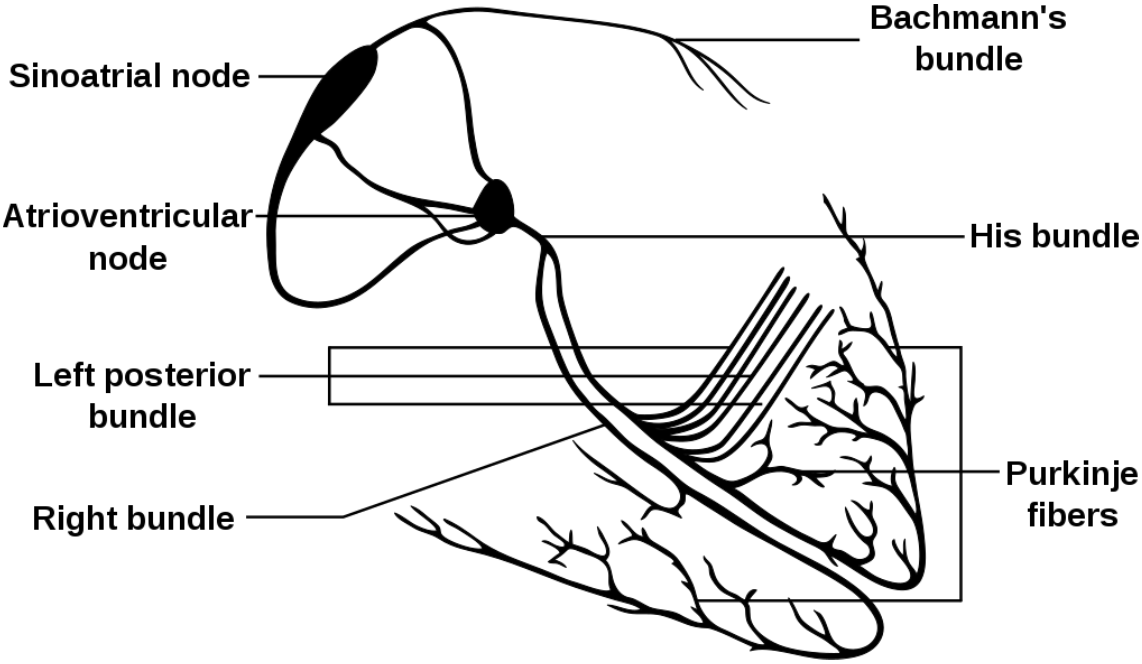
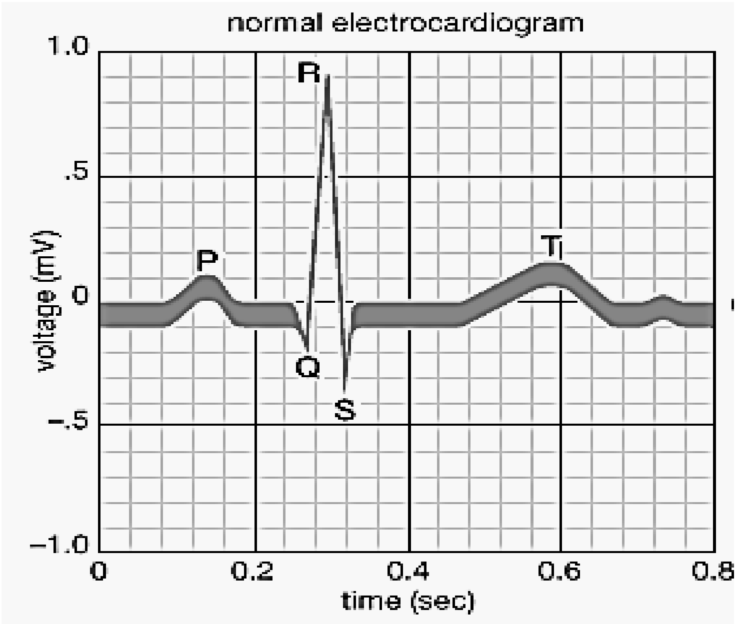


Figure 13: Electro-conduction system of heart

ELECTROCARDIOGRAPHY

- Electrocardiography, method of graphic tracing (electrocardiogram; ECG or EKG) of the electric current generated by the heart muscle during a heartbeat.
- The tracing is recorded with an electrocardiograph and it provides information on the condition and performance of the heart.
- Dutch physiologist Willem Einthoven developed the first electrocardiogram in 1903, and for many years the tracing was called an EKG after the German Elektrokardiogramm.
- During the late 1960s, computerized electrocardiography came into use in many of the larger hospitals.
- Electrocardiograms are made by applying electrodes to various parts of the body.
- Electrodes that record the electrical activity of the heart are placed at 10 different locations: one on each of the four limbs and six at different locations on the anterior surface of the chest.
- After the electrodes are in place, a millivolt from a source outside the body is introduced so that the instrument can be calibrated.
- Standardizing electrocardiograms makes it possible to compare them as taken from person to person and from time to time from the same person.



- The normal electrocardiogram shows typical upward and downward deflections that reflect the alternate contraction of the atria (the two upper chambers) and of the ventricles (the two lower chambers) of the heart.
- The first upward deflection, P, is due to atrial contraction and is known as the atrial complex.
- The other deflections—Q, R, S, and T—are all due to the action of the ventricles and are known as the ventricular complexes.
- Any deviation from the norm in a particular electrocardiogram is indicative of a possible heart disorder.

ELECTRODES AND LEADS

- To record an ECG normally five electrodes are affixed to the body of the patient.
- These electrodes are connected to ECG machine by the same number of electrical wires.
- These wires or electrodes to which they are connected are called as **leads**.
- The placement and colour code, used to identify each electrode is as shown in figure 14.
- Experimentally, it is found that advantageous to record the electrocardiogram from electrodes placed vertically as well as horizontally on the body.

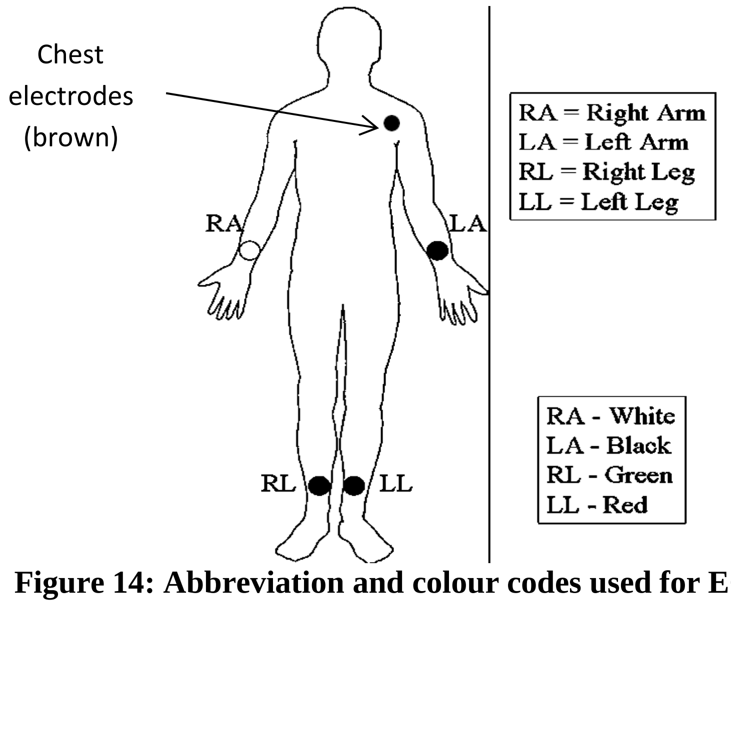


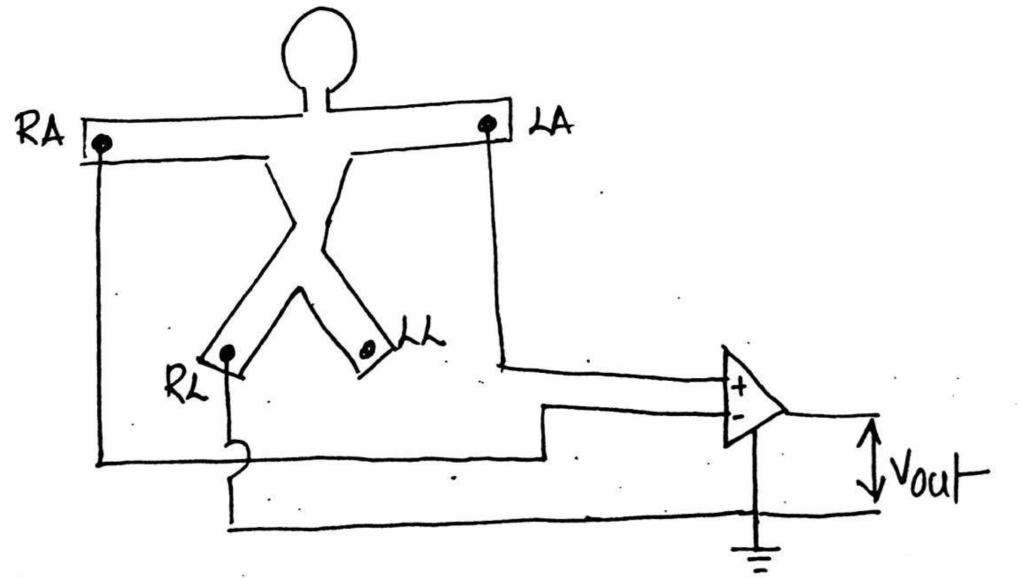
Figure 14: Abbreviation and colour codes used for ECG electrode

- Early electrocardiograph machine employed three electrodes, of which only two are used at one time.
- With the introduction of electronic amplifier, additional connection to the body is used as ground reference.
- The right leg was used for this purpose. Chest or precordial electrodes were introduced later.

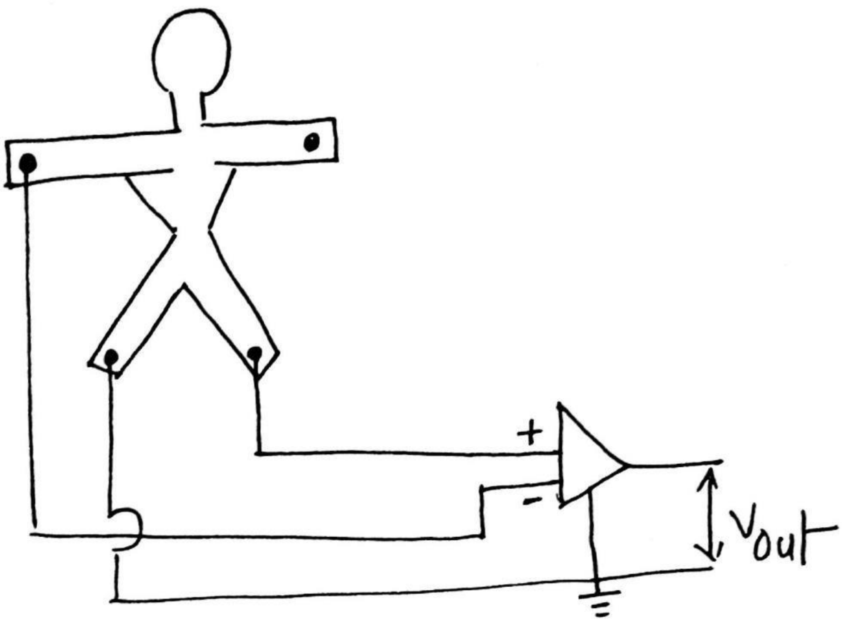
STANDARD BIPOLAR LEADS

- The bipolar lead is formed by a connection of two active electrodes. One electrode is positive (+) and the second one is negative (-).
- One of the most important methods is that discovered by Einthoven, who selected the bipolar standard leads (I, II and III) to record the ECG in the frontal plane.
- Electrodes are applied to the left arm, right arm and left leg and the bipolar leads represent a potential difference (P.D.) between two selected sites.

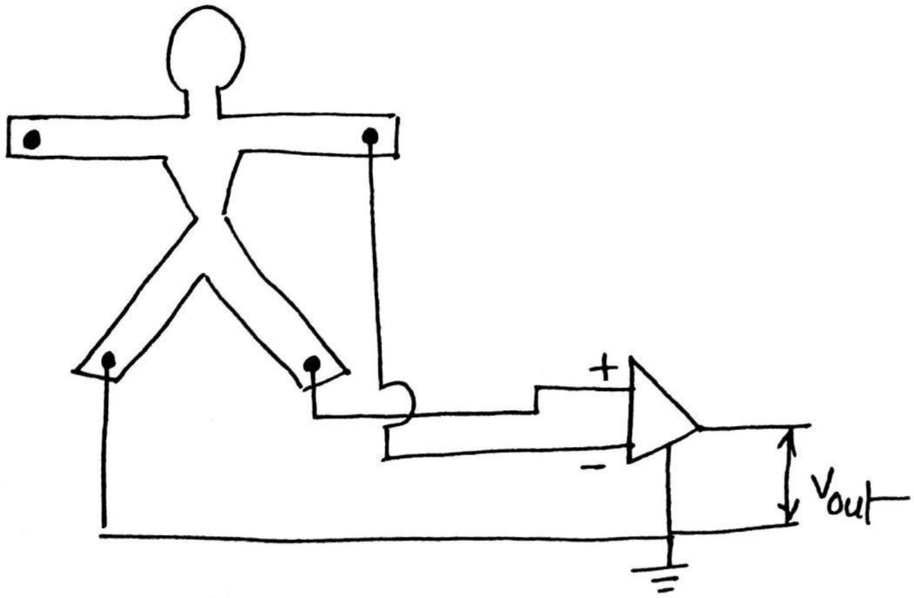
1. LEAD – I : Potential difference between left arm and right arm (LA – RA)



2. LEAD – II : Potential difference between left leg and right arm (LL – RA)



3. LEAD – III : Potential difference between left leg and left arm (LL – LA)



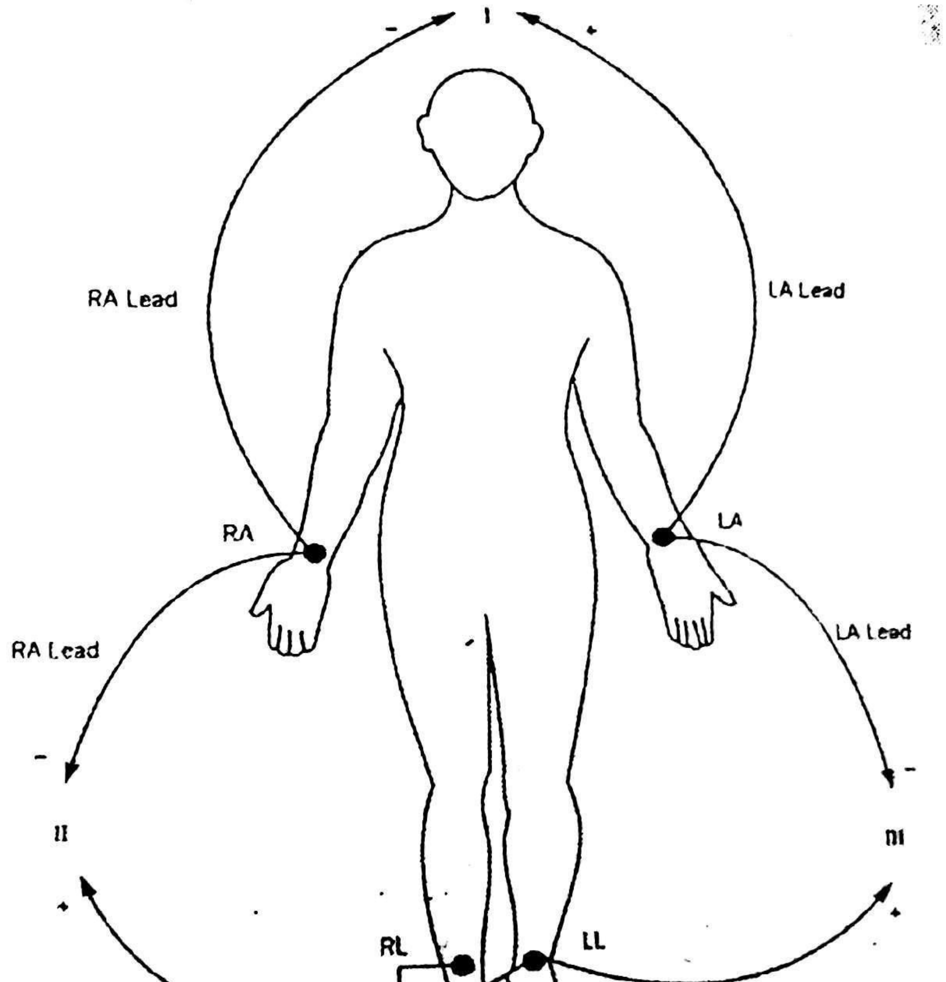


Figure 15: Bipolar leads I, II and III

- An electrode is also placed on the right leg and is earthed through the electrocardiograph machine for the electrical protection of the patient and to eliminate electrical interference in the recordings.

UNIPOLAR LEADS

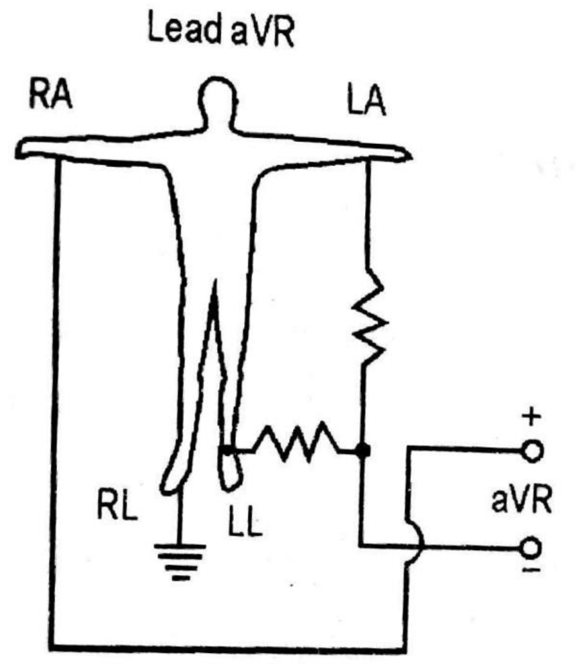
- The standard leads record the difference in electrical potential between two points on the body produced by the heart action.
- Quiet often, this voltage will show smaller changes than either of the potentials and, so, better sensitivity can be obtained if the potential of a single electrode is recorded.
- Moreover, if the electrode is placed on the chest close to the heart, we can detect much greater potentials than normally available at the limbs.
- If the single electrode potential (unipolar) is to be measured, it is necessary to have a reference electrode at a fixed potential. In practice, the reference electrode is obtained by a combination of several electrodes tied together at one point.
- Two types of unipolar leads are employed:
  1. Augmented unipolar limb leads
  2. Unipolar chest leads or precordial leads

1. AUGMENTED UNIPOLAR LIMB LEADS:

- Leads aVR, aVL and aVF are augmented limb leads. They are derived from the same three electrodes as LEAD I, LEAD II and LEAD III.

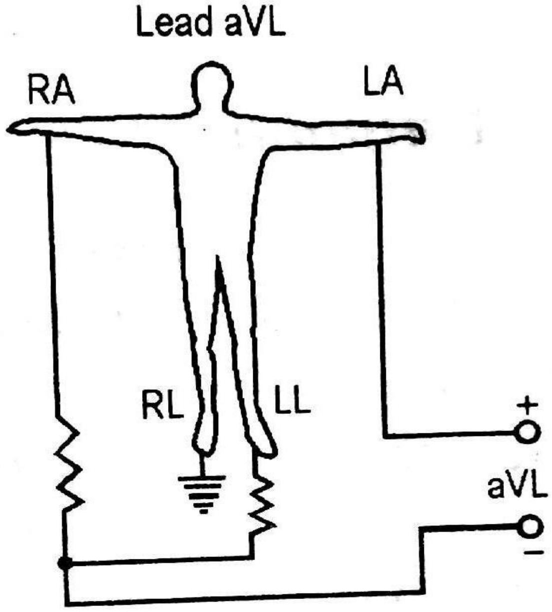
LEAD AUGMENTED VECTOR RIGHT (aVR)

- It has a positive electrode on right arm.
- The negative electrode is a combination of left arm electrode and left leg electrode which augments signal strength of positive electrode on right arm.



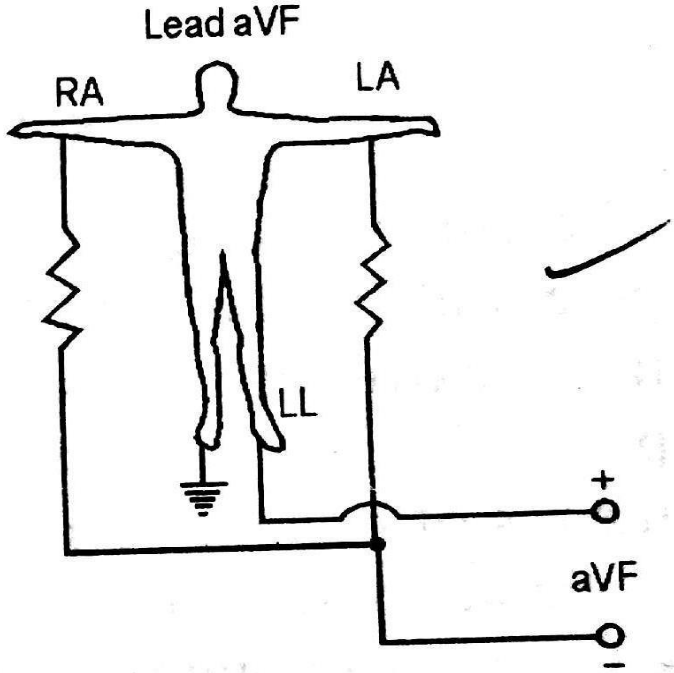
LEAD AUGMENTED VECTOR LEFT (aVL)

- It has a positive electrode on left arm.
- The negative electrode is a combination of right arm electrode and left leg electrode which augments the signal strength of positive electrode on left arm.



LEAD AUGMENTED VECTOR FOOT (aVF)

- It has positive electrode on left leg.
- The negative electrode is a combination of right arm electrode and left arm electrode which augments the signal of positive electrode on left leg.



- The three unipolar leads bear a direct vector relationship to the three bipolar standard limb leads.

aVR = -(I + II)/2

aVL = (I - III)/2

aVF = (II + III)/2

UNIPOLAR CHEST LEADS

- The unipolar chest leads are also called precordial leads.
- Changes in the potentials in the specific regions of the heart are not necessarily recorded in the extremely leads (lead I, II and III).
- They may also be recorded with precordial leads.
- The electrodes near the heart (chest electrode) or exploring electrode is placed at the 6 standard points on the chest and are designated V1 through V6.
- The unipolar chest lead measurements are also known as “transverse plane measurements” or the “V lead measurements”.
- The ECG potentials are measured with colour coded leads according to the convention:

  White – Right Arm
  Black – Left Arm
  Green – Right Leg
  Red – Left Leg
  Brown – Chest

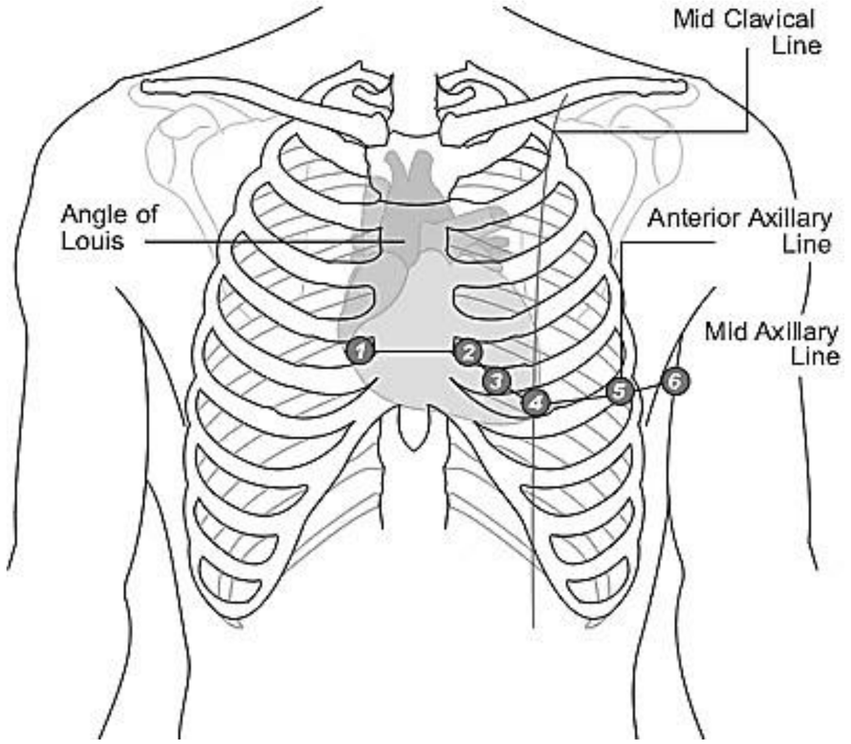


Fig 16: Location of the active electrodes in the chest leads

- V_1 – the fourth right intercostal space near the sternum
- V_2 – the fourth left intercostal space near the sternum
- V_3 – the midway between V_2 and V_4
- V_4 – the fifth left intercostal space in the mid-clavicular line
- V_5 – the fifth left intercostal space in the anterior axillary line
- V_6 – the fifth left intercostal space in the mid-axillary line.

- An electro cardiologist utilizes all the 12 lead selections: three standard bipolar leads (I, II and III), three augmented unipolar leads (aVR, aVL and aVF) and six chest leads (V1 to V6).

EINTHOVEN TRIANGLE

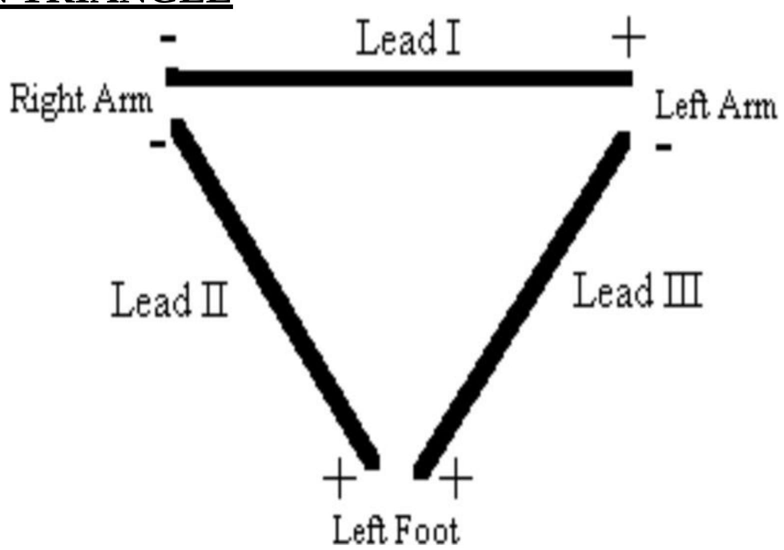


Fig 17: Einthoven's triangle

- The bipolar limb leads in a standing person with abducted arms form approximately an equilateral triangle with the heart in its center.
- This triangle called the Einthoven´s triangle is used (among others) for a determination of the electric heart axis.
- The triangle's sides represent the individual bipolar limb leads and the signs determine the polarity of the electrodes (figure 17).
- The relationship between the standard leads called Einthoven's triangle and is used when determining electrical axis of the heart.
- The instantaneous voltage measured from any one of three limb lead position is approximately equal to algebraic sum of other two.
- So it is an imaginary equilateral triangle with heart at its center.

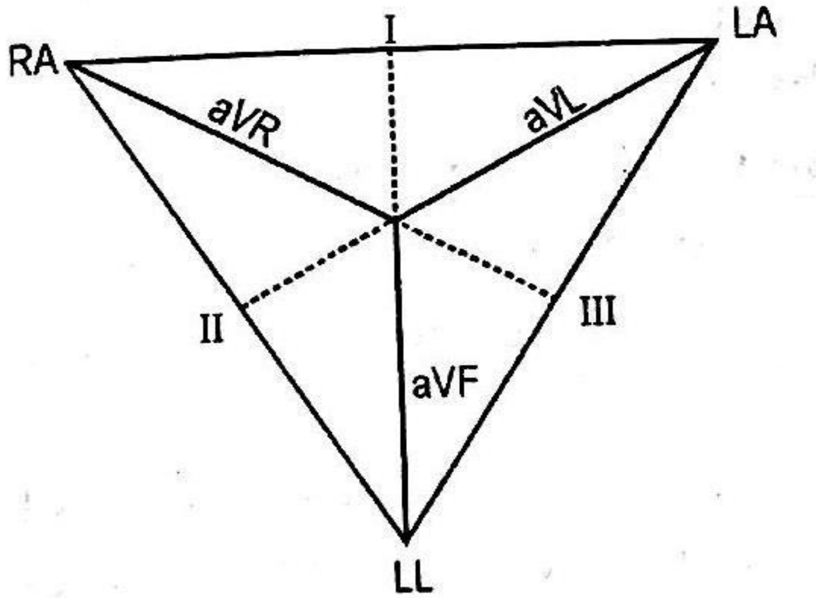
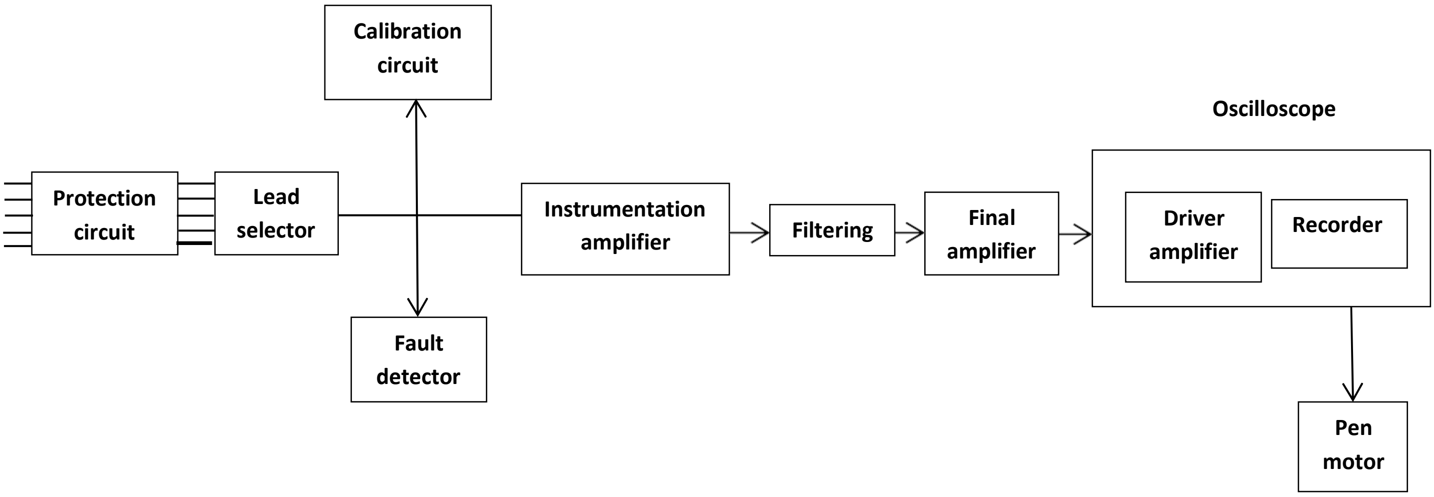


Fig 18: Relationship between bipolar and unipolar limb leads with Einthoven triangle

MODULE 2

ECG MACHINE – BLOCK DIAGRAM



- **Protection circuit:** protect system from high level voltages
- **Lead selector:** it act as switch connect the patient lead to either inverting terminal (-) or the non-inverting terminal of amplifier (+).
- **Calibration circuit:** consisting of resistive network connected to a voltage source that gives output 1 mV for standardize. Use to check amplifying factor of system before using ECG system.
- **Fault detector:** it can detect manually or automatically depending on operating modes. System failures can be detected quickly by human visual or auditory sensors
- **Instrumentation amplifier:** a transducer converts ionic potential and current into electric potential. The output of the transducer is amplified by an instrumentation amplifier. It is a type of differential amplifier with its main features such as high gain, accuracy, high CMRR, high gain stability etc.
  - **Filters:** Low pass filter – used to filter out signals at frequency higher than the cut of frequency
  - High pass filter – passes high frequency and attenuates low frequency and used in application requiring the rejection of low frequency signal.
  - Notch filter- it is required to eliminate the interference. Interference comes from power line when frequency of patient and equipment come closer.
- **Oscilloscope:** basically graph displaying device. Draws a graph of an electrical signal.
- **Pen motor:** pen is actually an electrically heated stylus. Temperature of stylus can be adjusted and used for optimal recording trace.
- Types of ECG Recorder:
  - Single Channel Recorder
  - Three Channel Recorder
  - Vector Electro cardiographs
  - Electrocardiograph system for stress testing
- ECG Applications:
  - Vector cardiograph
  - Phono cardiograph

END OF MODULE 2

Module III

MODULE 3

MEASUREMENT OF BLOOD PRESSURE

- Determining an individual's blood pressure is a standard clinical measurement, it can be taken in a physician's office or in the hospital during a specialized surgical procedure.
- With the blood pressure values, physician can determine the functional integrity of the cardio-vascular system.
- A number of direct or indirect techniques are being used to measure blood pressure in the human.
- Fluctuations in pressure recorded over the frequency range of hearing are called "sound"(20-20KHz
- The source of heart sounds are the vibrations setup by the accelerations and decelerations of blood.
- The function of blood circulation is to transport oxygen and other nutrients to the tissues of the body and to carry metabolic waste products away from the cells.
- An electric impulse is generated by specialized cells located in the Sino-Atrial node (SA node) of the right atrium.
- This electric impulse quickly spreads over both the atria.
- At the junction of the atria and ventricles, the electric impulse is conducted after a short delay at the Atrial-Ventricular node (AV node).
- Conduction quickly spreads over the interior of both ventricles by means of specialized conduction system, the His bundle and the Purkinje system.
- Conduction then propagates throughout both ventricles.
- This impulse causes mechanical contraction of both ventricles. This mechanical contraction and relaxation generates pressures.

- The method of measurement of blood pressure can be divided into two groups.
  1. Direct method
  2. Indirect method

DIRECT METHOD

- In which we insert a tube or catheter directly into the blood vessel.
- That catheter is connected to a blood pressure transducer, which generates corresponding electrical signal.

INDIRECT METHOD

- In which an external pressure is applied to the artery using an instrument called sphygmomanometer.
- In this class we have 2 techniques:
  1. Palpatory method ⟶ Touch
  2. Auscultatory method ⟶ Stethoscope

DIRECT METHOD

- This method is classified into two,
  1. Extra vascular pressure sensor
  2. Intra vascular pressure sensor

1. EXTRA VASCULAR PRESSURE SENSOR

- Basically in which, we couple the vascular pressure to an external sensor via a liquid-filled catheter.
- Catheter connected to a pressure sensor through 3-way stopcock.
- System is filled with Saline-heparin solution (anti-coagulant agent), must be flushed every minutes (To prevent blood from clotting).

- The catheter inserted to the human body by surgical cut down or percutaneous insertion.

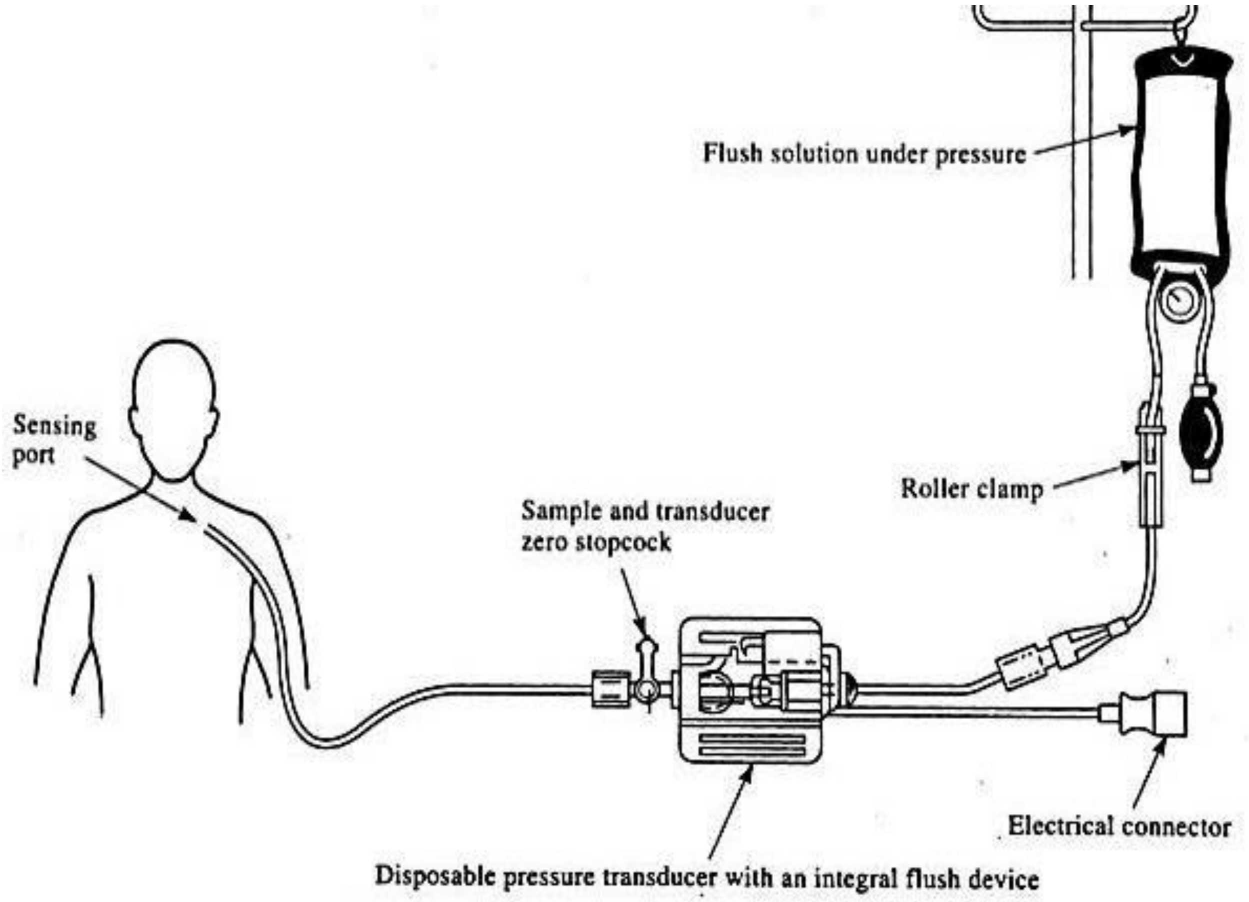
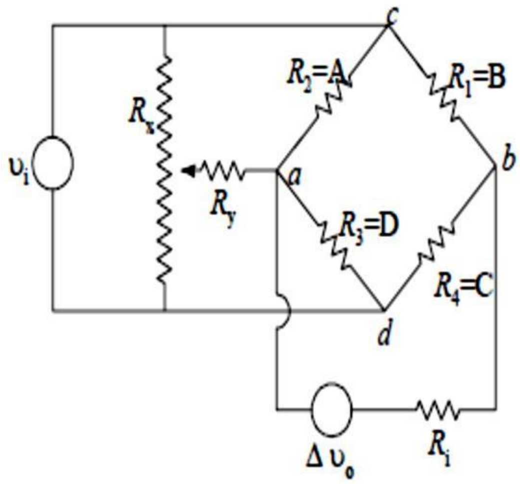


Figure 1: Extra vascular pressure sensor system

- Blood pressure information transmitted via catheter fluid to the sensor diaphragm.
- A thin flexible metal diaphragm is stretched across the opening of the transducer top.
- Diaphragm is connected to an inductive bridge or Wheatstone bridge strain gauge.
- The strain gauge will move an amount which is proportional to the applied pressure.



$$\Delta V_0 = 0 \Leftrightarrow \frac{R_1}{R_2} = \frac{R_4}{R_3}$$

Let all R initially be equal to $R_0 \ll R_i$. If R_1 and R_3 increase and R_2 and R_4 decrease by ΔR, then

$$\Delta v_0 = \frac{\Delta R}{R_0} v_i$$

2. INTRA VASCULAR PRESSURE SENSOR

- We have some disadvantages with the previous system,
  1. The frequency response of the system limited by the hydraulic properties
  2. The tubing system shows low pass filter effect.
- Intra vascular system eliminates the time delay introduced by the tubing system.
- It allows high fidelity measurement of the high frequency components of the blood pressure signal.
- Typical sensors used;
  - Strain gauge bonded onto a flexible diaphragm at the catheter tip
  - Fiber optic systems where the displacement of the diaphragm is made optically

STRAIN GAUGE BONDED ONTO A FLEXIBLE DIAPHRAGM AT CATHETER TIP

- Using this system we can eliminate the delay problems by making the measure "at the site".
- In which the pressure is detected at the tip of the catheter without the use of liquid coupling system.
- Problems of temperature, electric drift and non-destructive sterilization are solved more satisfactorily.
- So the physician can obtain high frequency response without time delay.
- A disadvantage of the catheter tip pressure sensor is that it is more expensive than others.
- And it may break after only a few uses. So it increases its "cost per use".
- In order to reduce this disadvantage we are using "Fiber-optic intravascular pressure sensor".

FIBER OPTIC SYSTEMS WHERE THE DISPLACEMENT OF THE DIAPHRAGM IS MADE OPTICALLY

- Fiber bundle is connected to a light-emitting diode (LED) source and to a photodetector.
- The pressure sensor tip consists of a thin metal membrane mounted at the common end of the mixed fiber bundle.
- External pressure causes membrane deflection, varying the coupling between the LED source and the photodetector.
- It measures displacement of diaphragm optically by varying reflection of light.
- The size of the device is comparable to strain gauge and a lower cost.

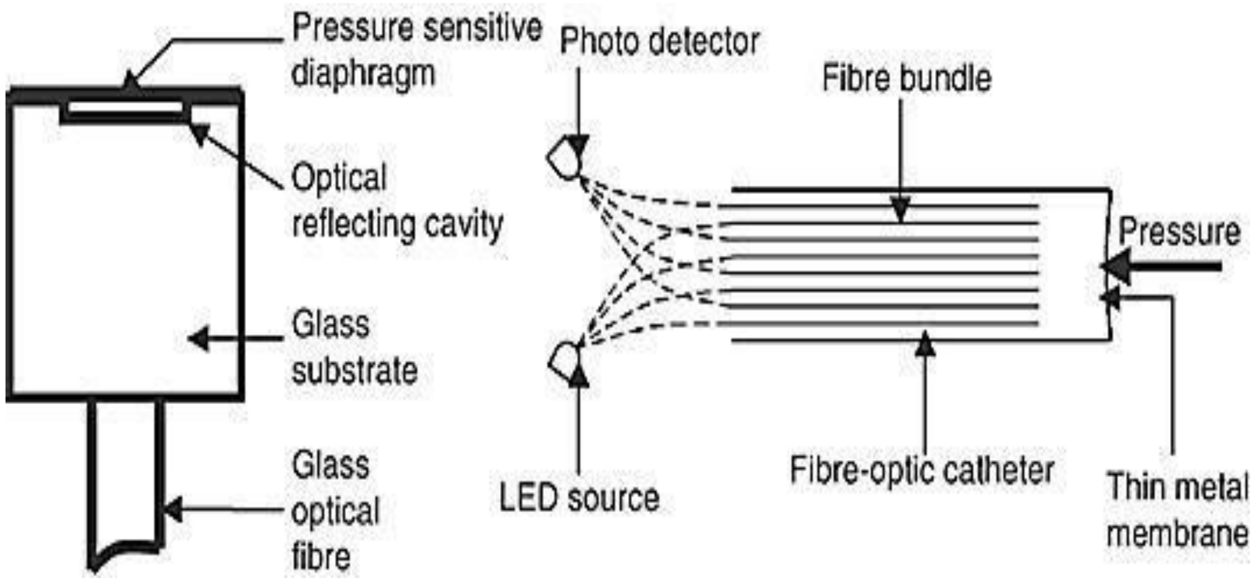
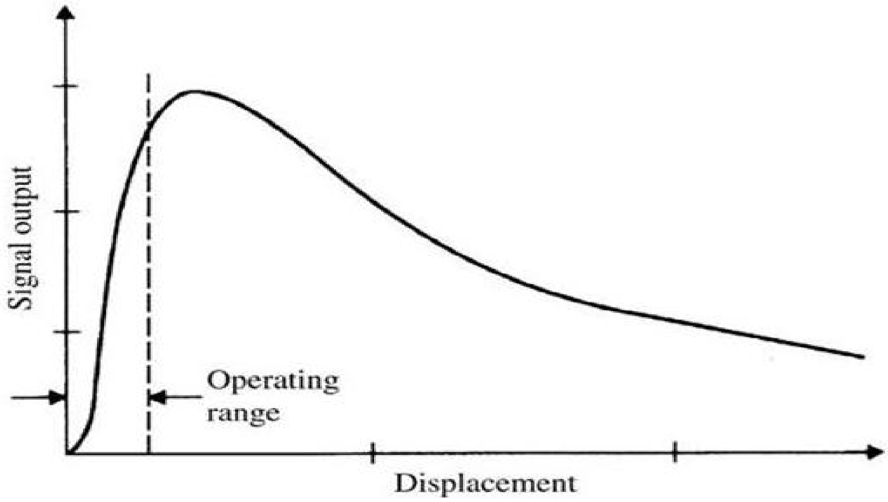


Figure 2: Fiber-optic intravascular pressure sensor

- Characteristic curve for the fiber optic pressure sensor



INDIRECT BLOOD PRESSURE MEASUREMENT

- Indirect measurement of blood pressure is an attempt to measure intra-arterial pressures noninvasively.
- Mainly we have two techniques,
  1. Palpatory method
  2. Auscultatory method

1. PALPATORY METHOD

- Seat the subject comfortably with his right arm resting on the laboratory table.
- Legs should not cross; this may raise systolic blood pressure (ventricular closure) by 2-8 mm Hg.
- Wrap "pressure cuff" around base arm above elbow.
- "Inflatable bag" should be inside that can exert pressure on brachial artery.
- Outside inflatable bag wrap 'cloth strap flat'. For external support, when it is blown up.
- Loose enough to avoid all possibility of interfering with the venous return from the forearm.
- Close the valve on the bulb by turning it clockwise.
- With one hand, palpate (feel) the radial pulse in the wrist.

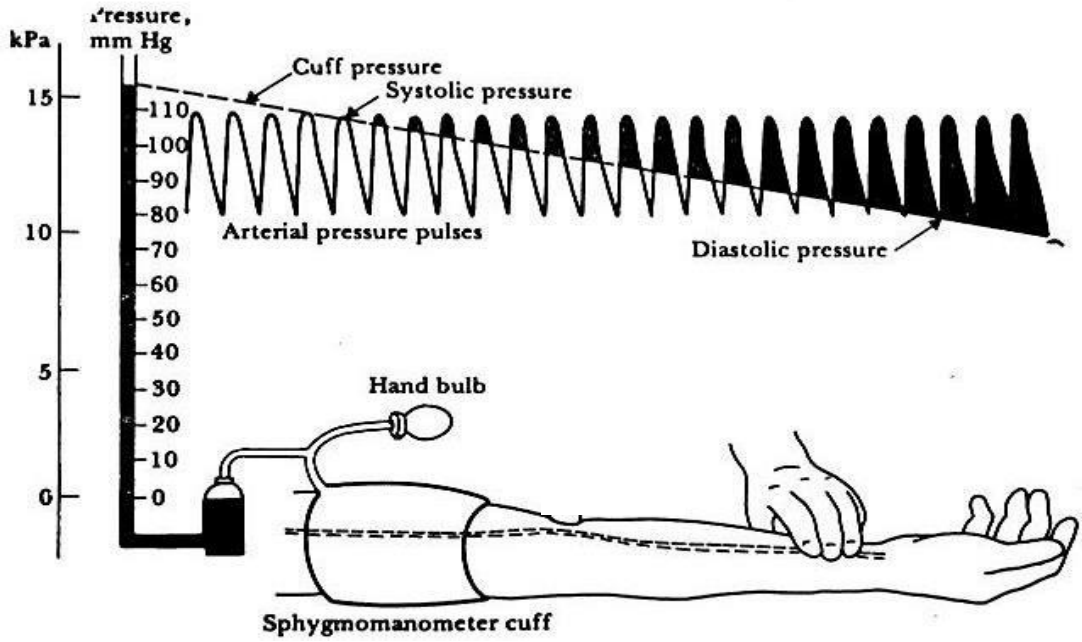


Figure: 3 Palpatory method

- Slowly inflate the cuff by pumping the bulb with the other hand, and note the pressure reading when the radial pulse is first lost.
- Then increase the pressure 30 mm Hg above this point.
- Slowly reduce the pressure in the cuff (2-3 mm Hg/heart beat) by turning the valve counter clockwise slightly to let air out of the bag.
- Note the pressure when the radial pulse first reappears, this is the **systolic blood pressure**.
- Let all the air out of the cuff.
- Do not leave the cuff inflated for over 2 minutes as it is uncomfortable and will cause a sustained increase in blood pressure.
- The systolic pressure recorded by the Palpatory method is usually around 5 mmHg lower than that obtained using the Auscultatory method.
- A major disadvantage of this method is that it can't readily be used to measure diastolic pressure.

2. AUSCULTATORY METHOD

- Wrap "pressure cuff" around base arm above elbow.
- With one hand, place the stethoscope on the hand, above brachial artery and listen the heat beat sounds.
- Brachial artery is the major blood vessel present in the upper arm.
- Inflate the cuff 20 to 30 mmHg above the estimated systolic pressure.
- Release the pressure slowly, no greater than 3 mmHg per second.
- The level at which you consistently hear heart beats is the **systolic pressure**.
- The sounds are heard through stethoscope is called Korotkoff sounds.
- The sounds decrease in pitch during the next 10-15 mmHg drop in pressure.
- The sounds suddenly become muffled and distant. The pressure at this point is termed as **diastolic pressure**.
- The muffled sound continues for another 5mmHg pressure drop, after which all sound disappears. This point is called the **end-diastolic pressure**.
- Systolic/diastolic pressure range is 120/80 mmHg (16 kPa/10.7 kPa).

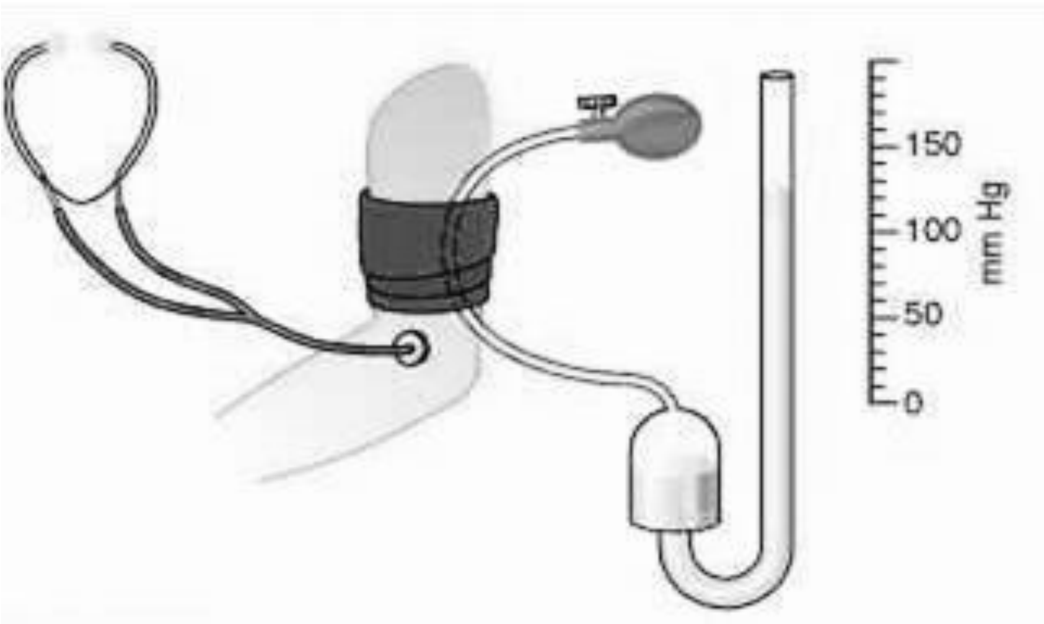
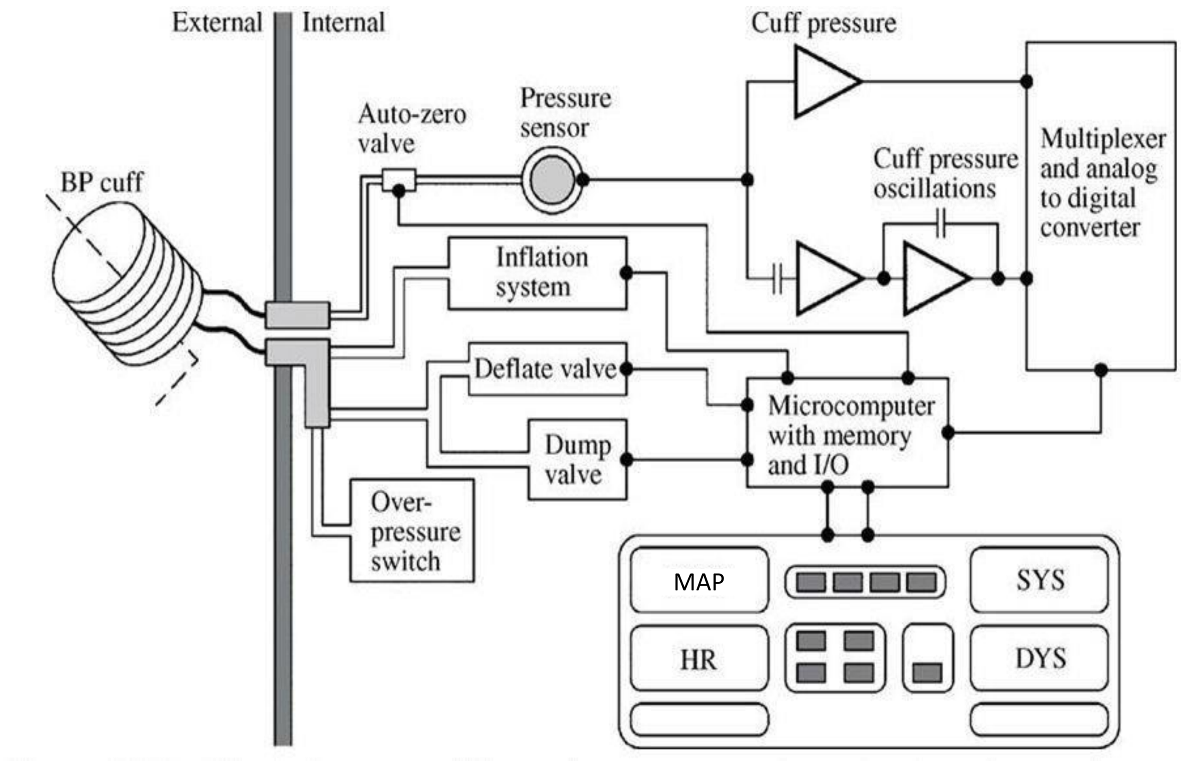


Figure 4: Auscultatory method

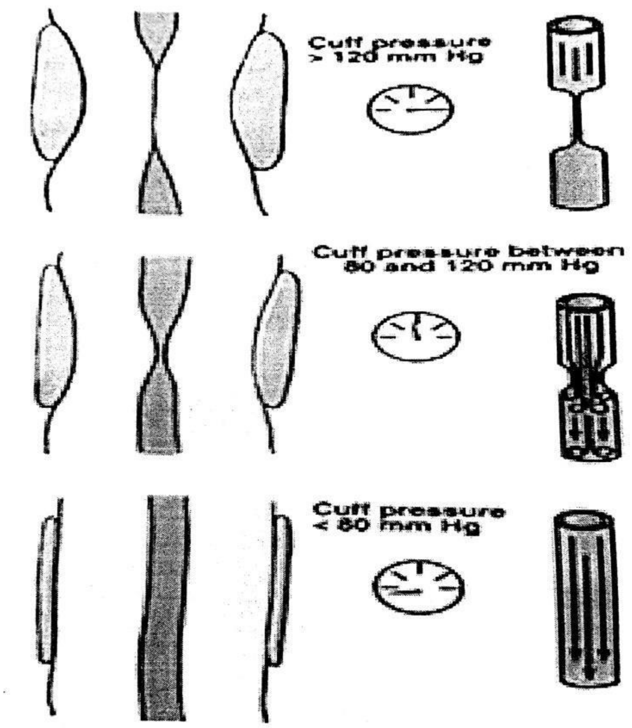
MODULE 3

OSCILLOMETRIC MEASUREMENT



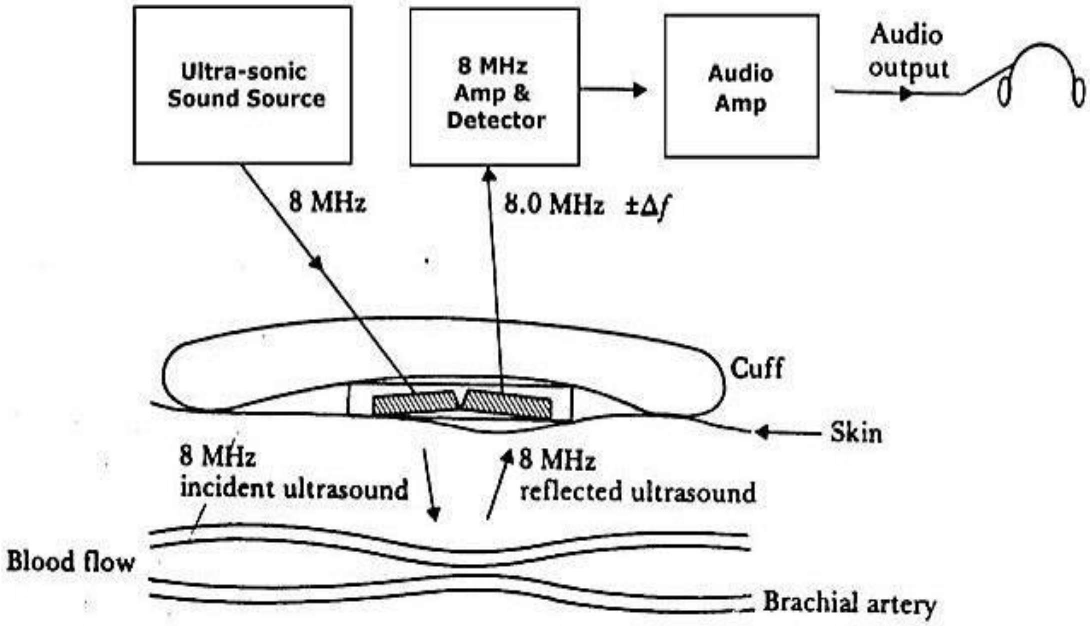
- Where

  I/O – Input/output
  MAP – Mean Arterial Pressure
  HR – Heart Rate
  SYS – Systolic Pressure
  DYS – Diastolic Pressure
- With an oscillatory device, a cuff is inflated over the upper arm.

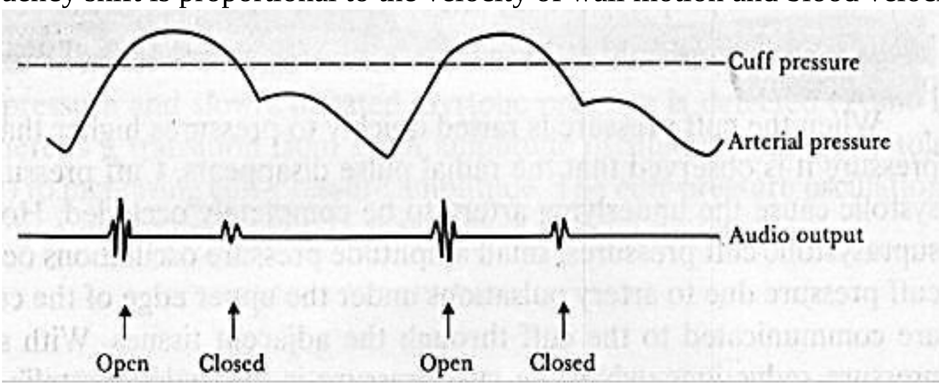


- Cuff should be inflated to reach a pressure about 20mm Hg above systolic pressure.
- When the cuff is fully inflated to this pressure, no blood flow occurs through the artery.
- As the cuff is deflated below the systolic pressure, the reducing pressure exerted on the artery allows blood to flow through it and sets up a detectable vibration in the arterial wall.
- When the cuff pressure falls below the patient's diastolic pressure, blood flows smoothly through the artery in the usual pulses, without any vibration being setup in the wall.
- Vibrations occur at any point where the cuff pressure is sufficiently high that the blood has to push the arterial wall open in order to flow through the artery.
- The vibrations are transferred from the arterial wall, through the air inside the cuff, into a transducer in the monitor that converts the measurements into electrical signals.
- These digital devices deflate at about 4mm Hg per second.

ULTRASONIC METHOD



- Ultra-sonic determination of blood pressure employs a transcutaneous Doppler sensor that detects the motion of blood vessel walls in various states of occlusion.
- Placement of compression cuff over two small transmitting and receiving ultra-sonic crystals.
- Cuff pressure is increased above diastolic but below systolic the vessel opens and closes with each heartbeat.
- The Doppler ultra-sonic transmitted signal is focused on the vessel wall and the blood.
- The reflected signal with frequency shift is detected by the receiving crystal and decoded.
- The difference in frequency, in the range of 40 to 500 Hz between transmitted and received signals.
- That frequency shift is proportional to the velocity of wall motion and blood velocity.



MODULE 3

MEASUREMENT OF BLOOD FLOW AND CARDIAC OUTPUT

- Blood flow meters are used to monitor the blood flow in various blood vessels and to measure cardiac output.
- Types
  1. Electromagnetic blood flow meters
  2. Ultrasonic blood flow meters

1. ELECTROMAGNETIC BLOOD FLOW METER

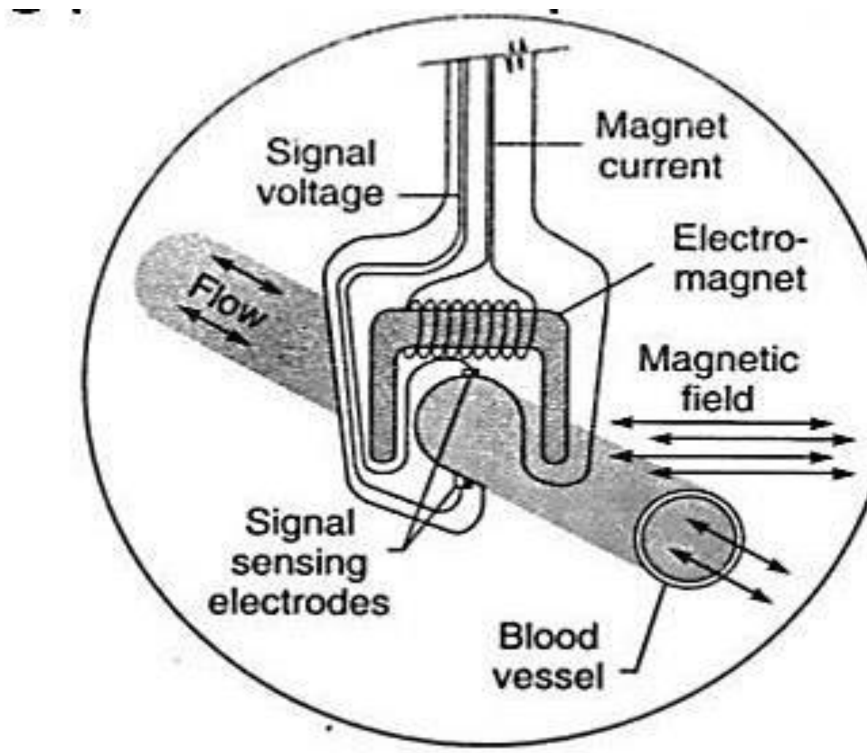


Figure 5: Electromagnetic flow meter

- An electromagnetic flow meter is a volumetric flow meter which does not have any moving parts.
- The flowing liquid (blood) through this meter should be conductive.
- The operation of electromagnetic flow meters or 'magmeters' are based upon Faraday's law.
- It states that;

  The voltage induced across a conductor as it moves at right angles through the magnetic field is proportional to the velocity of those conductors.
- Voltage induced on the conductor is perpendicular to both magnetic field and velocity of the conductor and it is proportional to the velocity.
- Faraday's formula;

  $$e \propto u \times B \times L$$

  e = voltage generated in the conductor

  u = velocity of conducting medium

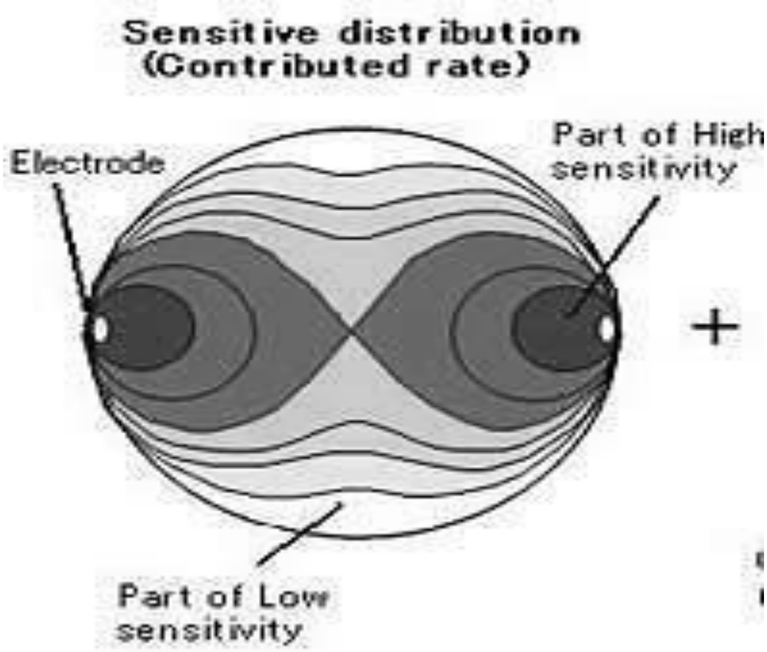
  B = magnetic field strength

  L = length between the electrodes/electrode spacing
- Instead of copper wires, the flow meter depends on the movement of blood, which has a conductance similar to that of saline.

- The formula for the induced emf is given by,

$$e = \int_0^L u \times B \, dL$$

- For uniform magnetic field, B and a uniform velocity profile u, then the induced emf:
  e = B L u
- Where these 3 components are orthogonal
- The electrode used in it is very small.
- So the velocities near them contribute more to the signal than do velocities farther away.



- Solid lines show the weighting function that represents relative velocity contributions to the total induced voltage for electrodes at the top and bottom of the circular cross section.

2. <u>ULTRASONIC BLOOD FLOW METERS</u>

- Just like electromagnetic flow meter, it can measure instantaneous flow of blood.
- Ultrasound is generated above the human hearing range (above 20KHz).
- At the heart of each ultrasonic flow meter transducer is piezo-electric crystal.
- They are glass disks about the size of a coin.
- These crystals are polarized or expand when electrical energy is applied to the surface electrodes.
- As it expands, the transducer emits an ultrasonic beam.
- There are two types of ultrasonic flowmeters in use;
  - Transit Time Ultrasound flow meters
  - Doppler Ultrasound flow meters

<u>TRANSIT TIME ULTRASONIC FLOW METERS</u>

- This is today's state of the art technology and most widely used type.
- This type of ultrasonic flow meter makes use of the difference in the time for a sonic pulse to travel a fixed distance.
- First against the flow and then in the direction of flow.
- Transit flowmeters are sensitive to air bubbles in the fluid. (Disturbances in the path)
- Transit time transducer typically operates in the 1-2 MHz frequencies.

- In which higher frequency designs are normally used in smaller pipes and lower frequencies for large pipes.
- So operators must select transducer pair or frequencies according to the application.
- Transit time flow meters must have a pair of transducers, each containing a piezo-electric crystal.

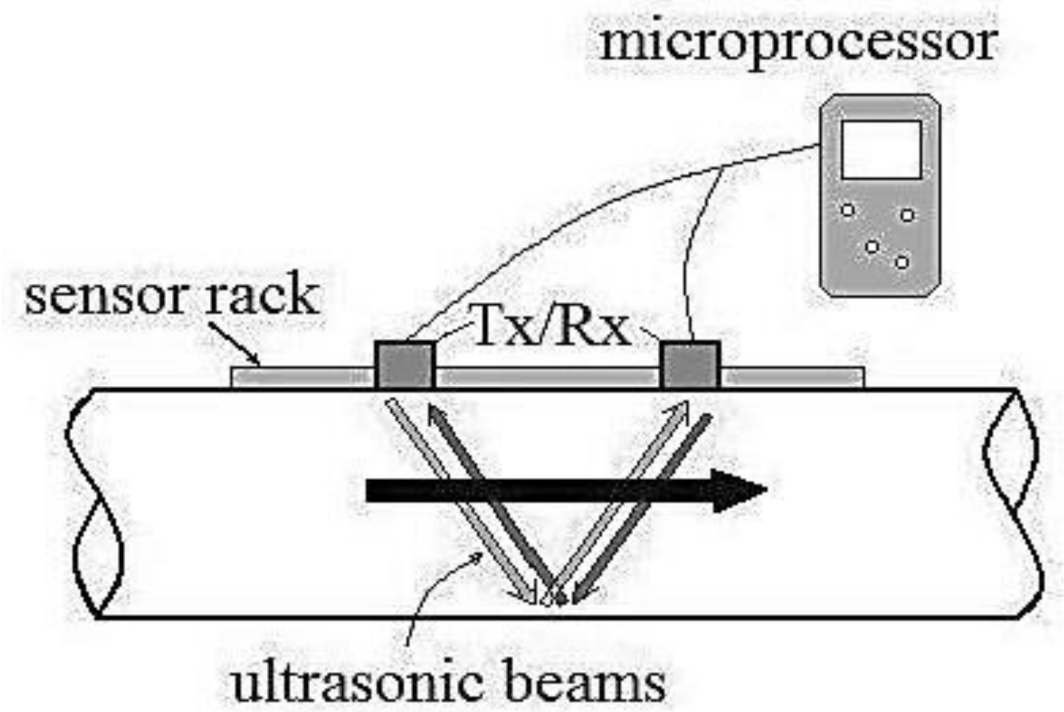


Figure 6: Transit time ultrasonic flowmeter

- One transducer transmits sound while the other acts as a receiver.
- As the name suggests, transit time flowmeters measure the time it takes for an ultrasonic signal transmitted from one sensor, to cross a pipe and be received by a second sensor.
- Upstream and downstream time measurements are compared.
- With no flow, the transmit time would be equal in both the upstream and downstream directions.
- With flow, sound will travel faster in the direction of flow and slower against the flow.
- Through fluid and bubbles, the high frequency sound will be attenuated and too week to transverse.
- Transit time in the downstream,

$$t_1 = \frac{distance}{conduction\ velocity} = \frac{D}{C + u\ cos\theta}$$

- Transit time in the upstream,

$$t_2 = \frac{distance}{conduction\ velocity} = \frac{D}{C - u\ cos\theta}$$

- Total transit time $= \frac{2CD}{C^2 - u^2\ cos^2\theta}$

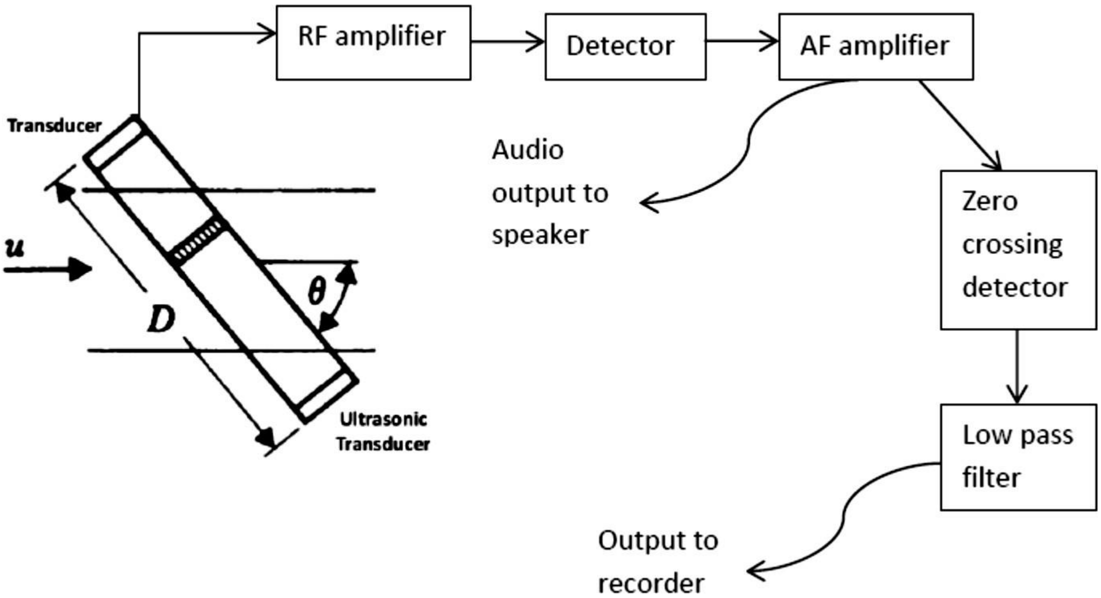


Figure 7: Transit time flow measuring system

DOPPLER ULTRASONIC FLOW METERS

- This type of flow meter is more popular and less expensive, but is not considered as accurate as the transit time flow meter.
- It makes use of Doppler frequency shift.
- Doppler frequency shift is the change in frequency or wavelength of a wave for an observer who is moving relative to the wave source.

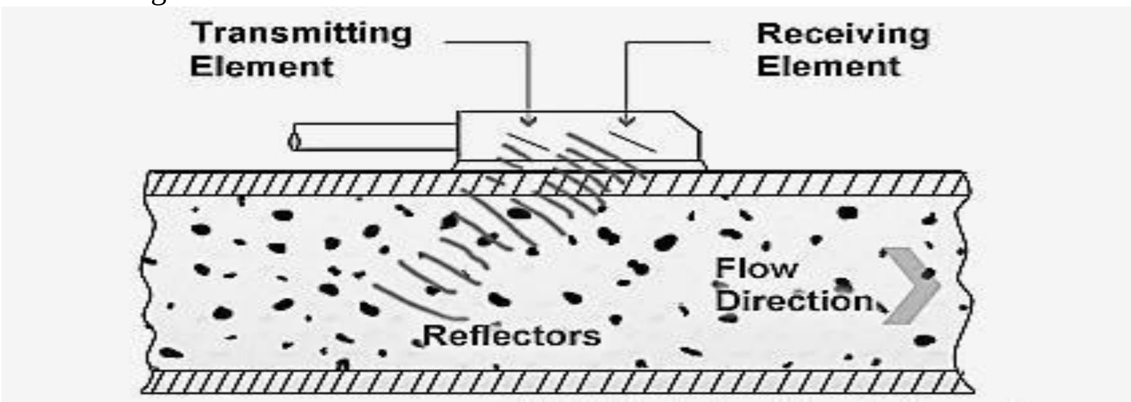


Figure 8: Doppler ultrasonic flowmeter

- It uses a single head sensor design.
- The single head transducer includes both transmit and receive piezo-electric crystals in the same housing.
- The functional change in frequency the fractional changes in velocity.

$$\frac{f_d}{f_0} = \frac{u}{c}$$

f_d = Doppler frequency shift
f_0 = Source frequency
u = Target velocity
c = Velocity of sound

$$\frac{f_d}{f_0} = \frac{2u}{c+u} = \frac{2u}{c}$$

$$f_d = \frac{2f_0 u\cos\theta}{c}$$

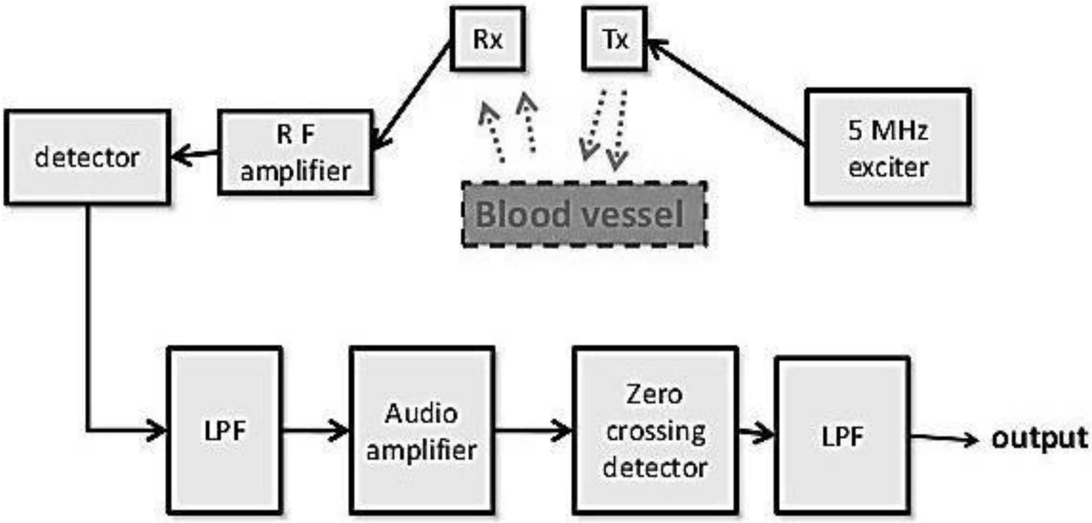


Figure 9: Doppler ultrasonic flow measuring system

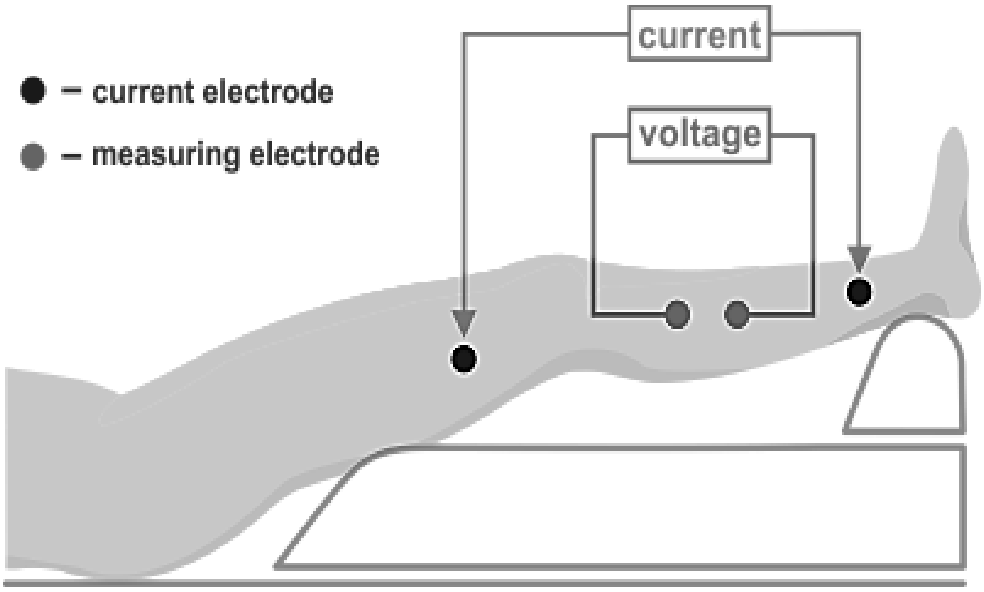
PLETHYSMOGRAPHY

- A plethysmograph is an instrument for measuring changes in volume within an organ or whole body.
- Usually resulting from fluctuations in the amount of blood or air it contains.
- Plethysmography measures changes in volume in different areas of your body.
- It measures these changes with blood pressure cuffs or other sensors.
- These are attached to a machine called a plethysmograph.
- Plethysmography is especially effective in detecting changes caused by blood flow.
- It can help your doctor determine if you have a blood clot in your arm or leg.
- It can also help your doctor calculate the volume of air your lungs can hold.
- Your doctor may order a limb plethysmography if you show signs of blood clots in your legs.
- Symptoms of blood clots include redness, warmth, swelling, and tenderness.
- But it’s less invasive and less expensive. These factors make it more appealing to many individuals.

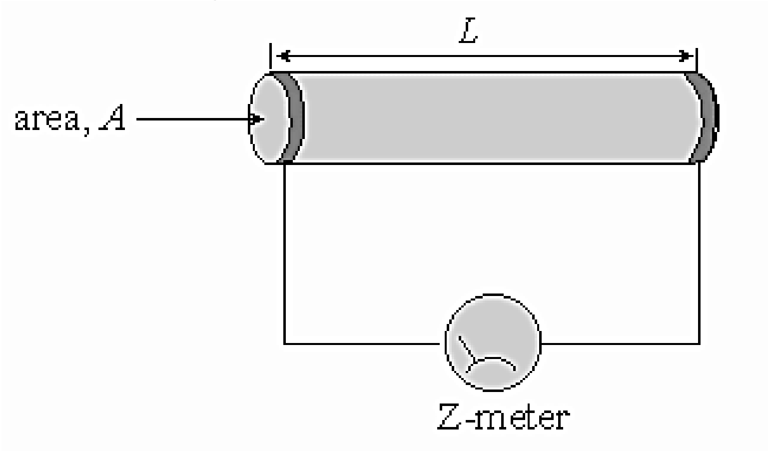
IMPEDANCE PLETHYSMOGRAPH

- The IPG is based on the measurement of the electrical impedance (resistance) of a selected body segment.
- In comparison to other tissue, such as, muscle or bone, blood has a much lower impedance.
- Therefore, blood volume variations correspond with measurable changes of the electrical impedance whereby an increase of the blood volume results in a lower impedance.
- For the measurement of the electrical impedance usually 4 electrodes are applied to the body surface.
- The 2 outer electrodes (usually called current electrodes) are used to pass a very low and constant alternating current (1.5 mA, 86 kHz) through the body segment which is imperceptible to the patient and does not cause any physiological reaction.

- The 2 inner electrodes (usually called measuring electrodes) are placed between the 2 current electrodes and measure the voltage which is caused when the current flows through the body segment.
- This voltage corresponds with the impedance of the body segment which changes depending on venous and arterial blood volume variations.



- The positioning of the measuring electrodes defines the segment which is analysed.
- Limb is modelled as a uniform cylinder:



- If limb volume increases by ΔV, cross sectional area increases by ΔA, L stays the same.
- Impedance equation for blood is,

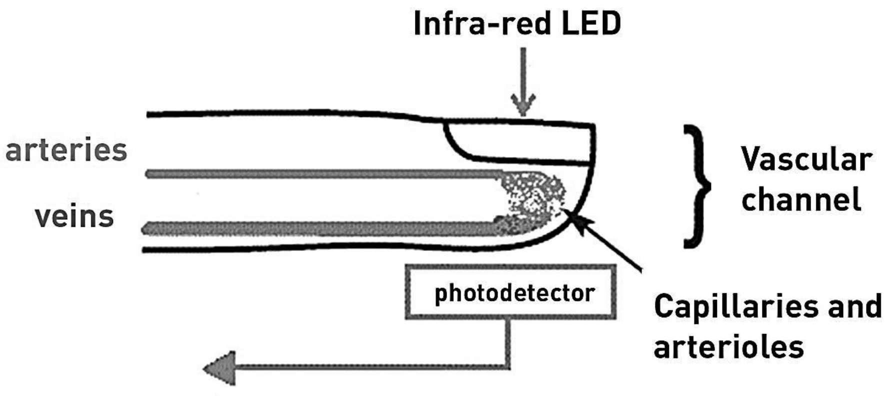
$$Z_b = \frac{\rho_b L}{\Delta A}$$

$$\Delta V = \Delta A L \qquad \Rightarrow \Delta A = \frac{\Delta V}{L}$$

$$Z_b = \frac{\rho_b L}{\Delta A} = \frac{\rho_b L^2}{\Delta V}$$

PHOTO ELECTRIC PLETHYSMOGRAPH

- Photo electric plethysmography or simply photo plethysmography (PPG) is a simple optical technique used to detect volumetric changes in blood in peripheral circulation.
- It is a low cost and non-invasive method that makes measurements at the surface of the skin.
- The technique provides valuable information related to our cardiovascular system.
- Recent advances in technology has revived interest in this technique, which is widely used in clinical physiological measurement and monitoring.
- PPG makes uses of low-intensity infrared (IR) light. When light travels through biological tissues it is absorbed by bones, skin pigments and both venous and arterial blood.
- Since light is more strongly absorbed by blood than the surrounding tissues, the changes in blood flow can be detected by PPG sensors as changes in the intensity of light.
- The voltage signal from PPG is proportional to the quantity of blood flowing through the blood vessels.
- Even small changes in blood volume can be detected using this method, though it cannot be used to quantify the amount of blood.
- PPG shows the blood flow changes as a waveform with the help of a bar or a graph.
- The waveform has an alternating current (AC) component and a direct current (DC) component.
- The AC component corresponds to variations in blood volume in synchronization with the heartbeat.
- The DC component arises from the optical signals reflected or transmitted by the tissues and is determined by the tissue structure as well as venous and arterial blood volumes.
- The DC component shows minor changes with respiration. The basic frequency of the AC component varies with the heart rate.



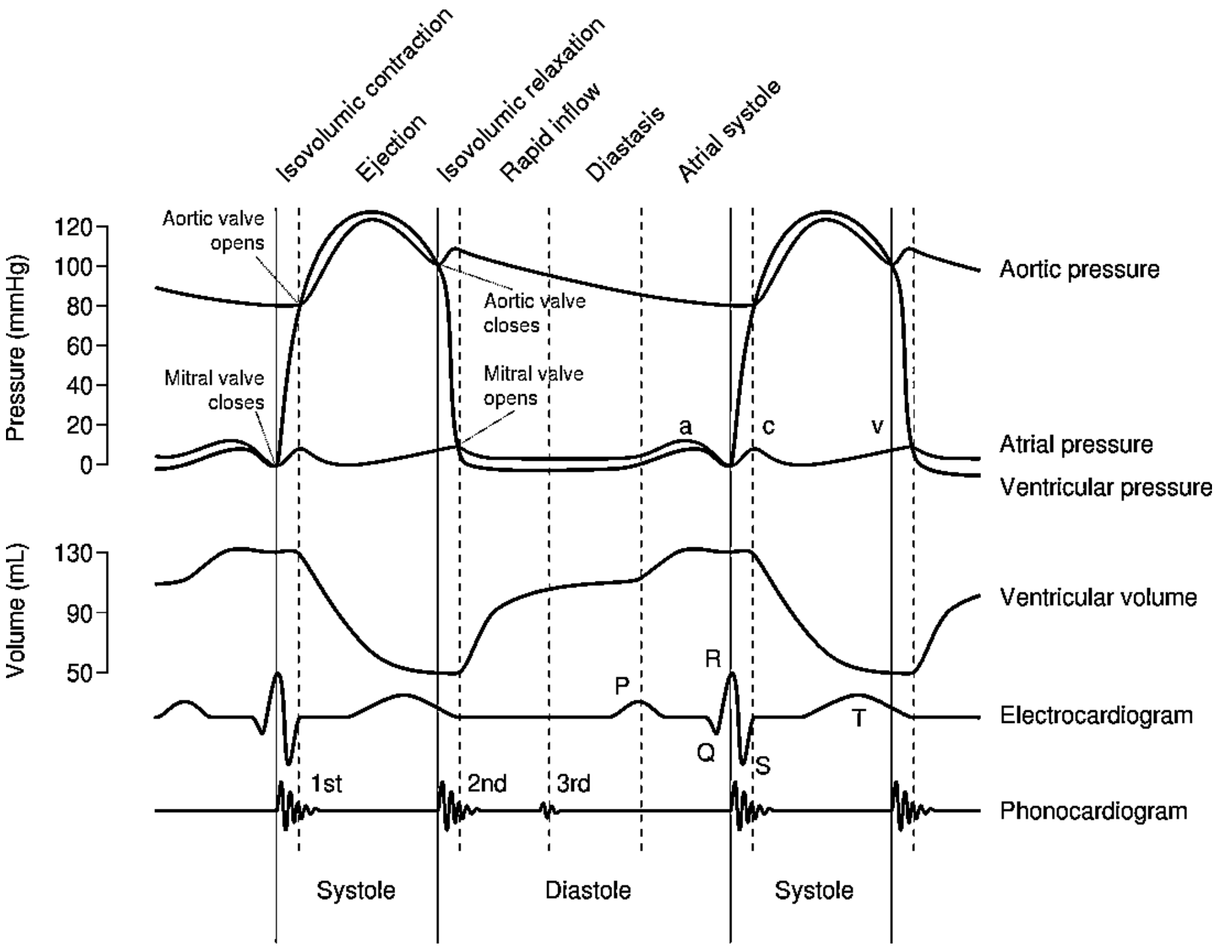
MEASUREMENT OF HEART SOUNDS

- The mechanical activities of the heart during each cardiac cycle cause the production of some sounds, which are called heart sounds.
- Factors involved in the production of heart sounds are:
  1. The movement of blood through the chambers of the heart.
  2. The movement of cardiac muscles.
  3. The movement of valves of the heart.
- **First heart sound:**
- It is produced during isometric contraction and earlier part of ejection period.
- It resembles spoken word “LUBB”.
- It is long, soft, low pitched sound. Duration of this sound is 0.10 to 0.17 seconds.
- It is mainly occurs due to the sudden closure of atrioventricular valves.
- It coincides with peak of ‘R wave’ of ECG.
- **Second heart sound:**
- It produces during the onset of diastole.

- It resembles the spoken word “DUBB”.
- It is short, sharp, high pitched sound. Duration of this sound is 0.10 to 0.14 seconds.
- It mainly produces during sudden closure of semilunar valves.
- It coincides with the ‘T wave’ of ECG.
- **Third heart sound:**
- It is produced during rapid filling period of the cardiac cycle.
- It is short and low pitched sound. Duration of this sound is 0.07 to 0.10 seconds.
- It is produced due to the vibrations which set up in ventricular wall, due to rushing of blood into ventricles during rapid filling phase.
- It appears between ‘T and P waves’ of ECG.
- **Fourth heart sound:**
- It is produced during atrial systole and considered as physiologic heart sound.
- It is short and lo pitched sound. Duration of the sound is 0.02 to 0.04 seconds.
- It occurs due to the vibrations which set up in atrial muscles during atrial systole.
- It coincides with interval between end of ‘P wave and onset of Q wave’ in ECG.
- Heart sounds generally alters during cardiac diseases involving the valves of the heart. That’s why heart sounds are having important diagnostic value.
- There are three methods to study heart sounds:
  1. By using stethoscope
  2. By using microphone
  3. By using phonocardiogram
- Murmurs are extra heart sounds that are produced as a result of turbulent blood flow which is sufficient to produce audible noise.
- Innocent murmurs are present in normal hearts without any heart disease.
- Pathologic Murmurs are as a result of various problems, such as narrowing or leaking of valves, or the presence of abnormal passages through which blood flows in or near the heart.

PHONOCARDIOGRAPHY

- It is a plot of high fidelity recording of sounds and murmurs made by the heart with the help of the machine called the **Phonocardiograph.**
- Phonocardiography is the recording of the all the sounds made by the heart during a cardiac cycle.
- The sounds result from vibrations created by closure of the heart valves.
- Two closure sounds:
  1) Atrio ventricular valves (Tricuspid & Bicuspid valves) close at the beginning of systole.
  2) Semilunar valves (Aortic valve & Pulmonary valve) close at the end of systole.
- Phonocardiography allows detection of sub-audible sounds and murmurs and makes a permanent record of these events.
- In contrast the stethoscope cannot always detect all such sounds or murmurs, and it provides no record of their occurrence.
- It is also an effective method for tracking the progress of person’s diseases.
- In the clinical evaluation of a patient, a number of other heart-related variables may be recorded simultaneously with the phonocardiogram.
- These include the ECG, carotid arterial pulse, jugular venous pulse and apex cardiogram.
- The indirect carotid, jugular and apex-cardiogram pulses are recorded by using a microphone system with a frequency response from 0.1 to 100 Hz.
- The cardiologist evaluates the results of a phonocardiograph on the basis of changes in wave-shape and in a number of timing parameters.


Isovolumic contraction
Ejection
Isovolumic relaxation
Rapid inflow
Diastasis
Atrial systole
Pressure (mmHg)
120
100
80
60
40
20
0
Aortic valve opens
Aortic valve closes
Mitral valve closes
Mitral valve opens
a
c
v
Aortic pressure
Atrial pressure
Ventricular pressure
Volume (mL)
130
90
50
Ventricular volume
R
P
Q
S
T
Electrocardiogram
1st
2nd
3rd
Phonocardiogram
Systole
Diastole
Systole

END OF MODULE 3

Module IV

MODULE 4

CARDIAC PACEMAKERS

- Cardiac pacemaker is an electric stimulator that produces periodic electric pulses that are conducted to electrodes located on the surface of the heart, within heart muscles or within the cavity of the heart or the lining of the heart.
- It is used for the treatment of;
    1. Cardiac rhythm disorders
    2. Abnormalities in SA node, AV node and Purkinje system

TYPES OF PACEMAKERS

- Classification of pacemakers into different types is based on the mode of application
    - External Pacemaker
    - Internal Pacemaker

EXTERNAL PACEMAKER: They are used when heart block presents itself as an emergency and expected to be present for a short time.
INTERNAL PACEMAKER: They are used in cases requiring long term pacing because of permanent damage that prevents normal cardiac operations.

MODES OF OPERATION

- Two modes of operation are possible with both internal and external pacemakers and they are,
    - **Asynchronous:** the fixed rate impulses occur along with natural pacing impulses.
    - **Synchronous:** they are programmed either in demand or synchronized mode.

ASYNCHRONOUS PACEMAKER

- An asynchronous pacemaker is a free running oscillator type.
- The electrical pulses are produced at uniform rate thereby giving a fixed heart rate.

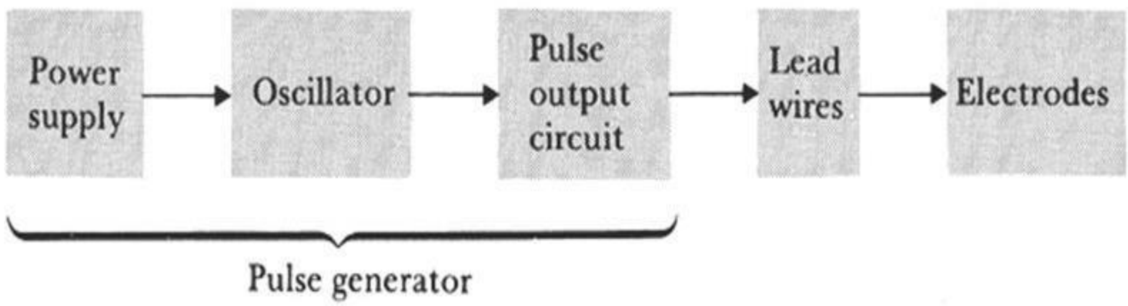


Figure 1: Asynchronous pacemaker – block diagram

POWER SUPPLY:

- It is required to supply energy to the pacemaker
- Primary or secondary batteries are used as power source
- For long life lithium batteries are used
- Sometimes external power sources can be used for implantable pacemakers.

OSCILLATOR:

- The asynchronous pacemakers provide stimulus pulses at a constant rate
- It is either a free running blocking oscillator or a multi-vibrator

PULSE OUTPUT CIRCUIT:

- It consists of a timing circuit to determine when a stimulus should be applied to the heart.

- It produces pulses at a fixed rate between 70 to 90 beats per minute.

LEAD WIRES:

- In most of the cases the generator is positioned at location away from the heart.
- There should be appropriate connection to carry the electric stimuli to the heart and to apply them in the appropriate place.
- So simply lead wires are the connecting electrical wires between the electrodes and the operating device.
- These lead wires being good electrical conductors must also be mechanically strong to with stand of movements and must have a high grade of insulation.
- Thus lead wires are interward helical coils of spring wire alloy moulded in silicon rubber cylinder.

ELECTRODES:

- Electrodes must with stand flexing due to the pumping action of the heart and must remain in place.
- The material chosen is of great importance as it should not have any electrolytic relations with heart tissue and must not cause irritation to the myocardium.
- Materials commonly used are platinum and silver-silver chloride, carbon and titanium.

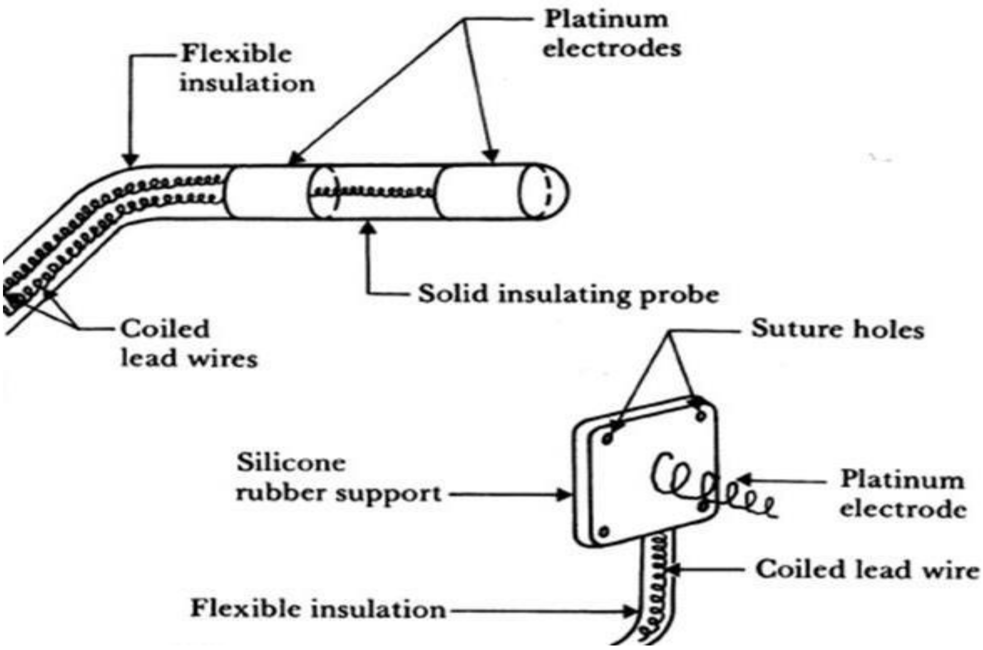


Figure 2: Pacemaker electrodes

<u>SYNCHRONOUS PACEMAKER</u>

- We have two forms of synchronous pacemakers:
    1. Demand Pacemaker
    2. Atrial Synchronous pacemaker
- Most of the patients require pacing intermittently; this is because the patients can establish normal cardiac rhythm between periods of block.
- In this case it is not necessary to stimulate the ventricles continuously as it may cause ventricular fibrillation.
- The pacemaker should not compete with normal pacing of the heart.
- It is also known as **Demand pacemaker**.

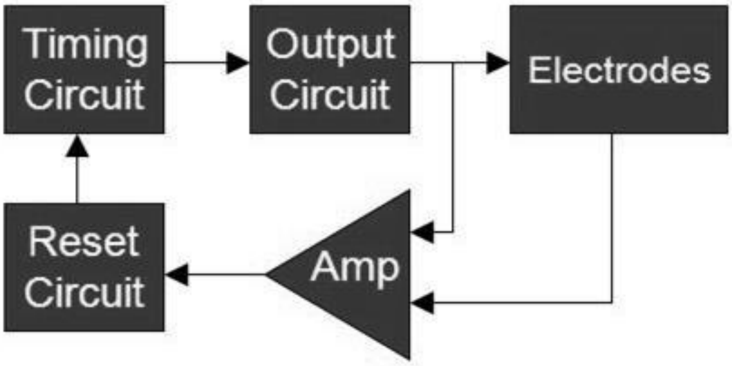


Figure 3: Demand Pacemaker

- It consists of a timing circuit, an output circuit and electrodes along with a feedback path.
- Timing circuit has a fixed rate of 60/80 beats per minute.
- Timing circuit reset itself after each stimulus waits for appropriate time and then generates the next pulse.
- The feedback circuit detects the QRS complex of ECG signal from electrodes and amplifies it.
- The signal is used to reset the timing circuit. It waits for the assigned interval before producing next stimulus.
- If heart beats again, before the stimulus is produced the timing circuit is reset and process repeats itself.

ATRIAL SYNCHRONOUS PACEMAKER

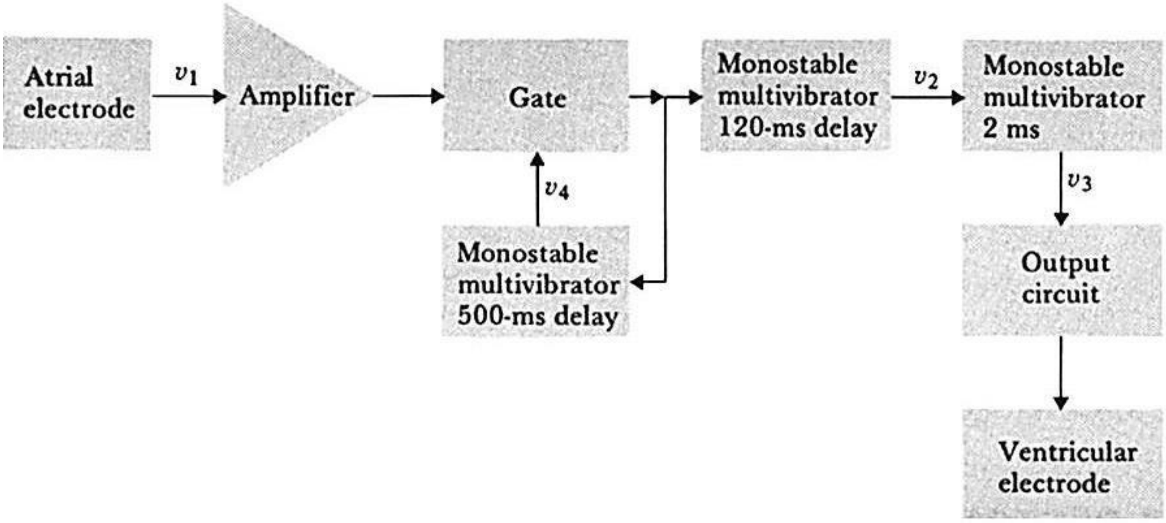


Figure 4: Atrial synchronous pacemaker

- The heart's physiological pacemaker located at SA node, initiate the cardiac cycle by stimulating the atria to contract and then providing stimulus to AV node, which after appropriate delay stimulates ventricles.
- If SA node is able to stimulate the atria, the electric signal corresponding to atrial contraction can be detected by an electrode implanted in atrium and used to trigger the pacemaker in same way that it triggers AV node.
- Voltage is a pulse that corresponds to each beat.
- The atrial signal is then amplified and passed through a gate to a monostable multivibrator giving a pulse V_2 of 120ms duration, the approximate delay of AV node.

- Another monostable multivibrator giving pulse duration of 500ms is also triggered by atrial pulse and it produce V_4 which causes the gate block any signal from atrial electrodes for a period of 500ms following contraction.
- This eliminates any artifact caused by ventricular contraction from stimulating additional ventricular contraction.
- V_2 is used to trigger a monostable multivibrator of 2ms duration.
- Pulse V_2 acts as a delay allowing V_3 to be produced which follows atrial contraction.
- Then V_3 controls an output circuit that applies stimulus to the appropriate ventricular electrodes.

DEFIBRILLATORS

- **CARDIAC FIBRILLATION** is a condition where the individual myocardial cells contact asynchronously and an irregular cardiac rhythm is produced which cause the cardiac output to near zero.
- The fibrillation of atrial muscle is called atrial fibrillation and that of the ventricles is called ventricular fibrillation.
- It must be corrected as soon as possible to avoid irreversible brain damage to the patient and death.
- Electric shock to the heart can be used to re-establish a normal cardiac rhythm.
- Electric machines that produce the energy to carry out this function are known as defibrillators.
- Defibrillator consists of an electric supply unit and two metal electrodes called "Paddles" that are pressed very firmly to the patient's chest using insulating plastic handles. So the person using them does not get a shock too.
- The important thing is that current should flow through the heart so where the paddles are applied is crucial.
- For getting good electrical contact solid or liquid conducting gel is used.
- There are four basic type:
    1. AC Defibrillator
    2. Capacitive Discharge DC Defibrillator
    3. Capacitive Discharge Delay Line Defibrillator
- Defibrillation by electric shock is carried out either by passing current through electrodes placed directly on heart or by using large area electrodes placed against the anterior thorax.

AC DEFIBRILLATOR

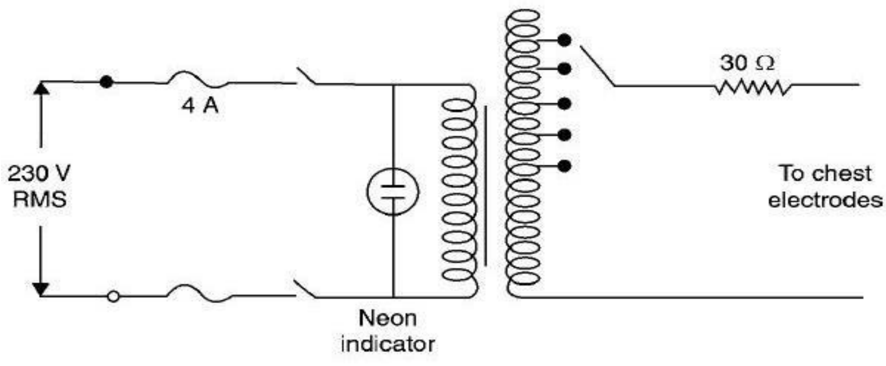


Figure 5: AC Defibrillator

- By construction it consists of a step up transformer with various tapping on the secondary side.
- An electronic timer circuit is connected to the primary of the transformer
- This timer device is a simple capacitor and resistor or mono-stable multivibrator.

- Applying brief 0.25 -1 second burst of 60 Hz AC act as intensity of around 6A.
- It acts as counter shock for resynchronization and repeats until defibrillation occurs.
- It is constructed in such a way that appropriate voltages for internal and external defibrillation are available.
- External defibrillation voltage range: 250 – 750V
- Internal defibrillation voltage range: 60 – 250V
- Large currents are required in external defibrillation to produce uniform and simultaneous contraction of the heart muscle fibers.

CAPACITIVE DISCHARGE DC DEFIBRILLATOR

- The 230 V AC mains supply is connected to variable auto transformer
- The output of this is fed to step up transformer to produce a high voltage
- A half wave rectifier rectifies this high AC voltage to obtain high DC voltage which charges the capacitor C. The voltage to which the Cis charged is determined by the auto-transformer in primary circuit.
- A series resistance R_s limits the charging current to protect the circuit components and an AC voltmeter across the primary is calibrated indicate energy stored in the capacitor.
- With electrodes firmly placed at appropriate position on chest, the clinician discharges the capacitor by changing the switch S from position 1 to 2.
- The capacitor is discharged through electrodes and patient is represented by a resistive load and inductor L.

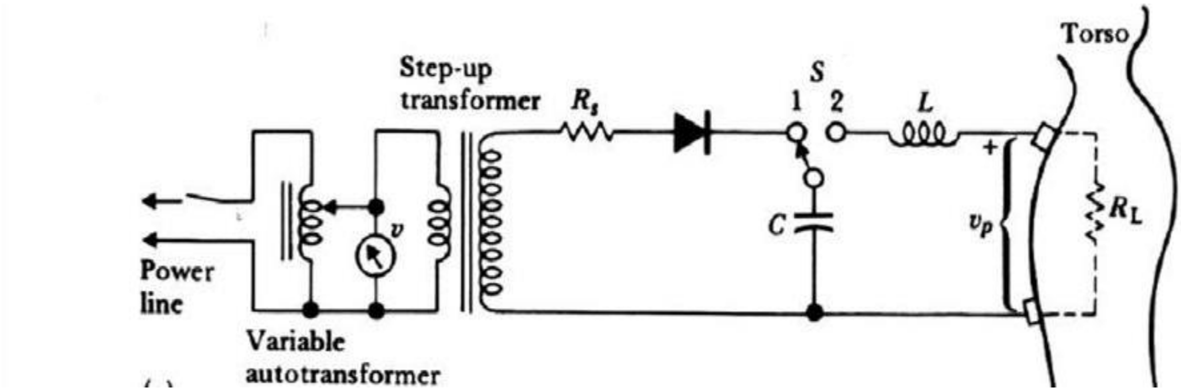


Figure 6: Capacitive Discharge DC Defibrillator

- Inductor L is used to shape the wave in order to eliminate a sharp, undesirable current spike that would otherwise occur at beginning of discharge.
- The energy delivered is represented by typical waveform,

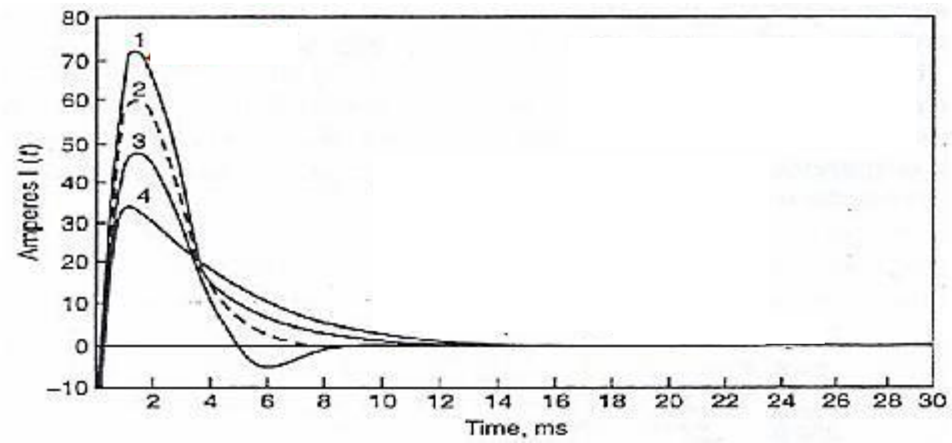


Figure 7: Defibrillator Discharge waveform

- Area under the curve is proportional to energy delivered.
- Once the discharge is completed, the switch automatically returns to position 1 and process can be repeated if necessary.
- Energy stored in capacitor is given by,

  $W = \frac{1}{2} CV^2$

  C= Capacitance

  V= Voltage to which capacitor is discharged

CAPACITIVE DISCHARGE DELAY LINE DEFIBRILLATOR

- Even with dc defibrillation, there is a danger of damage to the myocardium and the chest walls because, peak voltages as high as 6000V may be used.
- To reduce this risk, some defibrillators produce dual-peak waveforms of longer duration at a much lower voltage.
- In this circuit, parallel combination of capacitors C_1 and C_2 stores the same energy as the single capacitor in capacitor discharge type defibrillator.
- But its discharge characteristic is more rectangular in shape at a much lower voltage as shown in second waveform.
- With this type of defibrillation, effective defibrillation can be achieved in adults with lower levels of delivered energy between 50 and 200 watts.

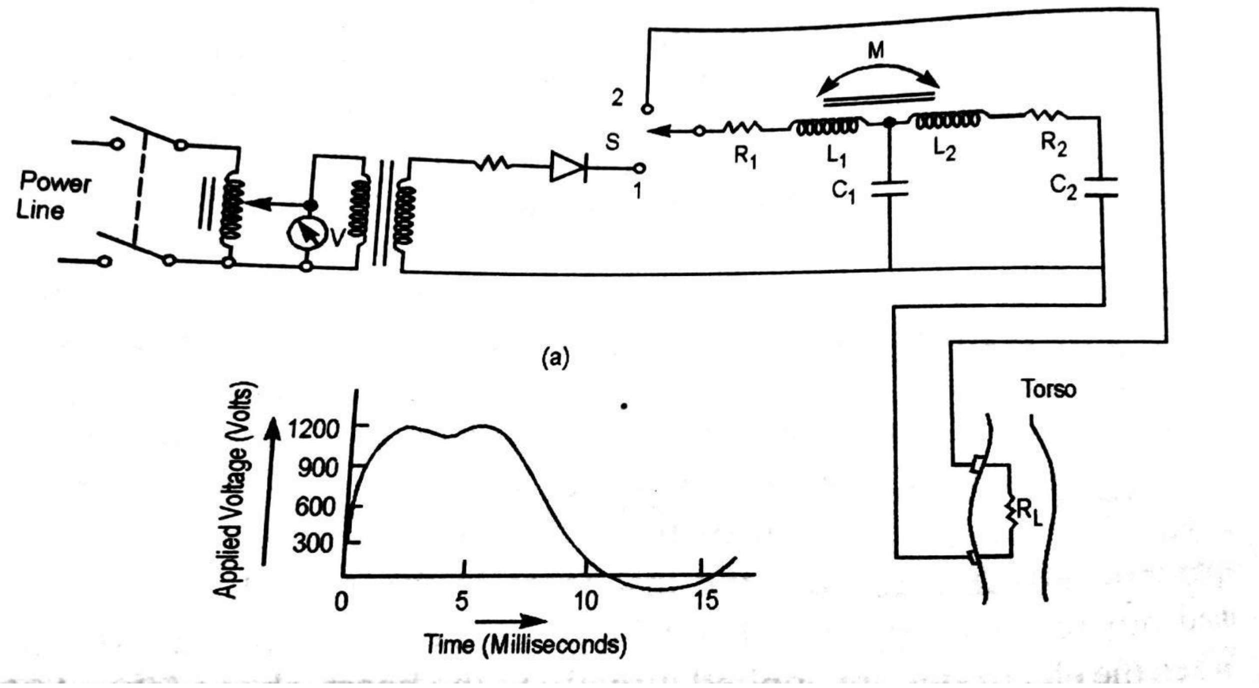


Figure 8: Capacitive discharge delay line defibrillator

ELECTRO ENCEPHALOGRAM

- Electroencephalography (encephalon = brain), or EEG, is the physiological method of choice to record all of the electrical activity generated by the brain from electrodes placed on the scalp surface.
- The EEG has a very complex pattern, which is much more difficult to recognize than the ECG.
- The waveform varies greatly with the location of the measuring electrodes on the surface of the scalp.

MODULE 4

NEURONAL COMMUNICATION

Functions of the Nervous System:

1. Gathers information from both inside and outside the body - Sensory Function
2. Transmits information to the processing areas of the brain and spine
3. Processes the information in the brain and spine – Integration Function
4. Sends information to the muscles, glands, and organs so they can respond appropriately – Motor Function

- It controls and coordinates all essential functions of the body including all other body systems allowing the body to maintain homeostasis or its delicate balance.
- The Nervous System is divided into Two Main Divisions: **Central Nervous System (CNS)** and the **Peripheral Nervous System (PNS)**

Divisions of the Nervous system:

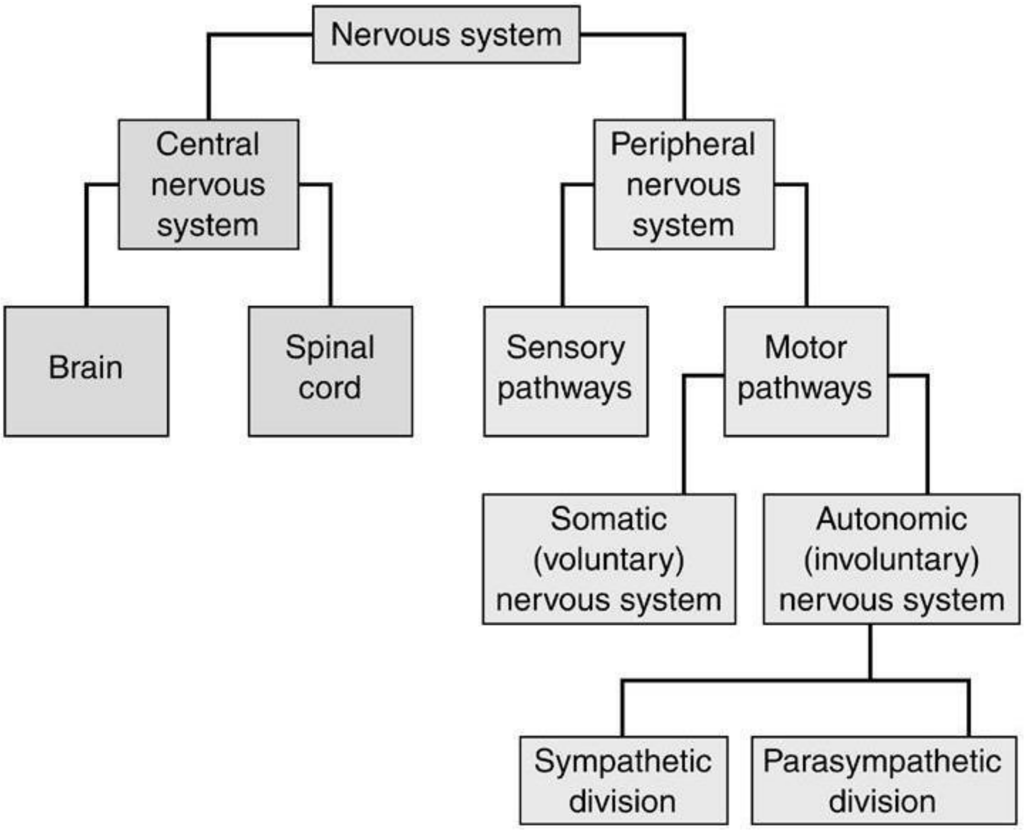


Figure 9: Divisions of nervous system

Basic Cells of the Nervous System:

Neuron

- Basic functional cell of nervous system
- Transmits impulses (up to 250 mph)

Parts of a Neuron

- **Dendrite** – receive stimulus and carries it impulses toward the cell body
- **Cell Body with nucleus** – nucleus and most of cytoplasm
- **Axon** – fiber which carries impulses away from cell body
- **Schwann Cells**- cells which produce myelin or fat layer in the Peripheral Nervous System

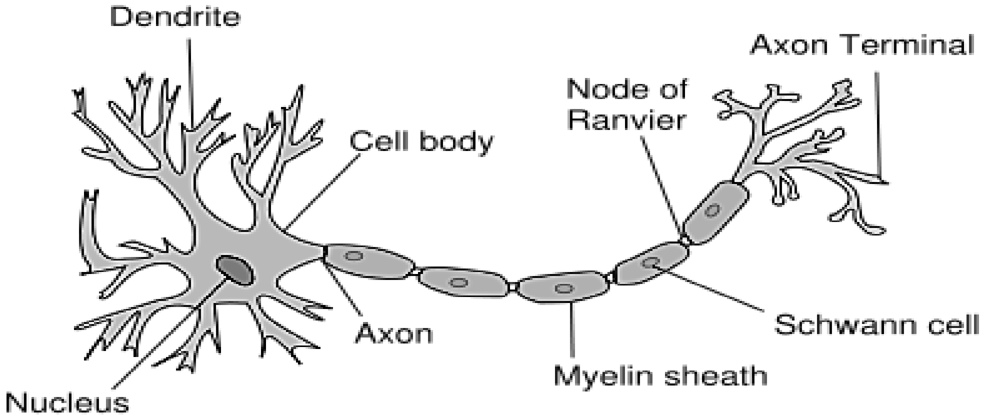


Figure 10: Structure of a neuron

- **Myelin sheath** – dense lipid layer which insulates the axon – makes the axon look gray
- **Node of Ranvier** – gaps or nodes in the myelin sheath
- Impulses travel from dendrite to cell body to axon

Three types of Neurons:
- **Sensory neurons** – bring messages to CNS
- **Motor neurons** - carry messages from CNS
- **Interneurons** – between sensory & motor neurons in the CNS

BRAIN WAVES
- At the root of all our thoughts, emotions and behaviours is the communication between neurons within our brains.
- Brainwaves are produced by synchronised electrical pulses from masses of neurons communicating with each other.
- Brainwaves are detected using sensors placed on the scalp. They are divided into bandwidths to describe their functions.
- It is a handy analogy to think of brainwaves as musical notes - the low frequency waves are like a deeply penetrating drum beat, while the higher frequency brainwaves are more like a subtle high pitched flute.
- Our brainwaves change according to what we're doing and feeling.
- When slower brainwaves are dominant we can feel tired, slow or dreamy.
- The higher frequencies are dominant when we feel wired, or hyper-alert.
- Brainwave speed is measured in Hertz (cycles per second) and they are divided into bands delineating slow, moderate, and fast waves.
- When our brainwaves are out of balance, there will be corresponding problems in our emotional or neuro-physical health.

INFRA-LOW (<0.5 HZ)
- Infra-Low brainwaves are thought to be the basic cortical rhythms that underlie our higher brain functions.
- Very little is known about infra-low brainwaves.
- Their slow nature makes them difficult to detect and accurately measure, so few studies have been done.

DELTA WAVES (0.5 TO 3 HZ)
- Delta Waves, the slowest but loudest brainwaves.
- Delta brainwaves are slow, loud brainwaves (low frequency and deeply penetrating, like a drum beat).

- They are generated in deepest meditation and dreamless sleep.

THETA WAVES (3 TO 8 HZ)

- Theta brain waves occur in sleep and are also dominant in deep meditation.
- Theta is our gateway to learning, memory, and intuition.
- In theta we are in a dream, imagery, intuition and information beyond our normal conscious awareness.
- It's where we hold our 'stuff', our fears, troubled history, and nightmares.

ALPHA WAVES (8 TO 12 HZ)

- Alpha brainwaves are dominant during quietly flowing thoughts, and in some meditative states.
- Alpha is 'the power of now', being here, in the present.
- Alpha is the resting state for the brain.
- Alpha waves aid overall mental coordination, calmness, alertness, mind/body integration and learning.

BETA WAVES (12 TO 38 HZ)

- Beta brainwaves dominate our normal waking state of consciousness when attention is directed towards cognitive tasks and the outside world.
- Beta is a 'fast' activity, present when we are alert, attentive, engaged in problem solving, judgment, decision making, or focused mental activity.
- Beta brainwaves are further divided into three bands;
- **Lo-Beta (Beta1, 12-15Hz)**
- **Beta (Beta2, 15-22Hz)**
- **Hi-Beta (Beta3, 22-38Hz)**

GAMMA WAVES (38 TO 42 HZ)

- Gamma brainwaves are the fastest of brain waves (high frequency, like a flute), and relate to simultaneous processing of information from different brain areas.
- Gamma brainwaves pass information rapidly and quietly.

EEG MEASUREMENT

TYPES OF ELECTRODES IN EEG

- Several types of electrodes may be used to record EEG.
- These include:
    1. Peel electrodes
    2. Stick electrodes
    3. Silver plated cup electrodes
    4. Needle electrodes
- EEG electrodes are smaller in size than ECG electrodes.
- They may be applied separately to the scalp or may be mounted in special bands, which can be placed on the patient's head.
- In either case, electrode jelly or paste is used to improve the electrical contact.
- If the electrodes are intended to be used under the skin of the scalp, needle electrodes are used.
- EEG electrodes give high skin contact impedance as compared to ECG electrodes.
- Good electrode impedance should be generally below 5 kilohms.
- Impedance between a pair of electrodes must also be balanced or the difference between them should be less than 2 kilohms.

- EEG preamplifiers are generally designed to have a very high value of input impedance to take care of high electrode impedance.
- EEG may be recorded by picking up the voltage difference between an active electrode on the scalp with respect to a reference electrode on the ear lobe or any other part of the body.
- This type of recording is called **'monopolar'** recording.
- However, **'bipolar'** recording is more popular wherein the voltage difference between two scalp electrodes is recorded.
- Such recordings are done with multi-channel electroencephalographs.
- EEG signals picked up by the surface electrodes are usually small as compared with the ECG signals.
- They may be several hundred microvolts, but 50 microvolts peak-to-peak is the most typical.
- The brainwaves, unlike the electrical activity of the heart, do not represent the same pattern over and over again.
- Therefore, brain recordings are made over a much longer interval of time in order to be able to detect any kind of abnormalities.

<u>PLACEMENT OF ELECTRODES IN EEG</u>

- The 10/20 system or international 10/20 system is an internationally recognized method to describe the location of the scalp electrodes.
- The system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex.
- The numbers '10' and '20' refer to the fact that the distance between adjacent electrodes are either 10% or 20% of the total front-back or right-left distance of the skull.
- Each site has a letter to identify the lobe and a number to identify the hemisphere location.

ELECTRODE	LOBE
F	Frontal
T	Temporal
C	Central
P	Parietal
O	Occipital

- No central lobe exists; the 'C' letter is used for identification purposes only.
- The 'z' (zero) refers to an electrode placed on the mid line.
- Even numbers (2, 4, 6, 8) refer to electrode positions on the right hemisphere.
- Odd numbers (3, 5, 7, 9) refer to electrode positions on the left hemisphere.

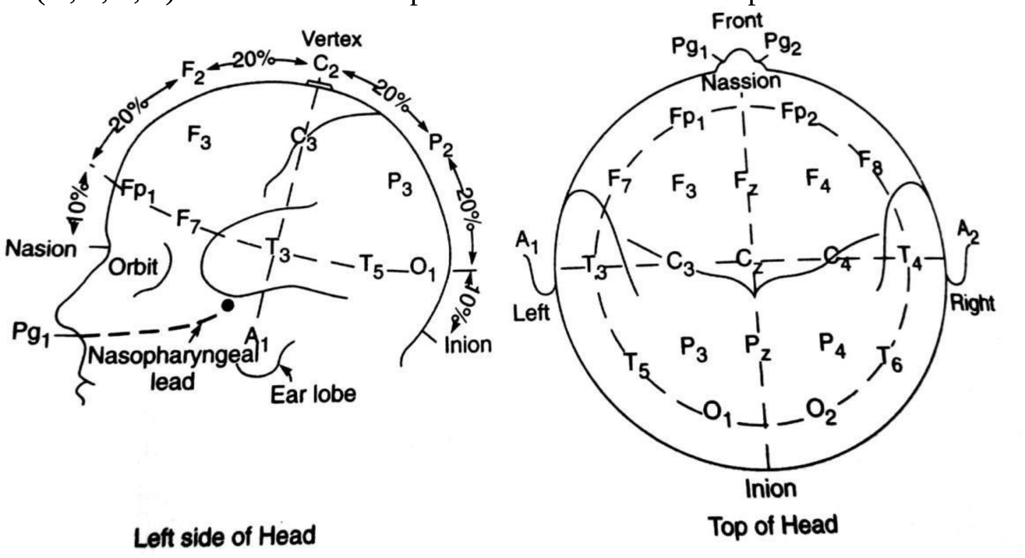


Figure 11: System of placement of electrodes

EEG RECORDING

- The basic block diagram of an EEG machine with both analog and digital components is shown in figure given below.

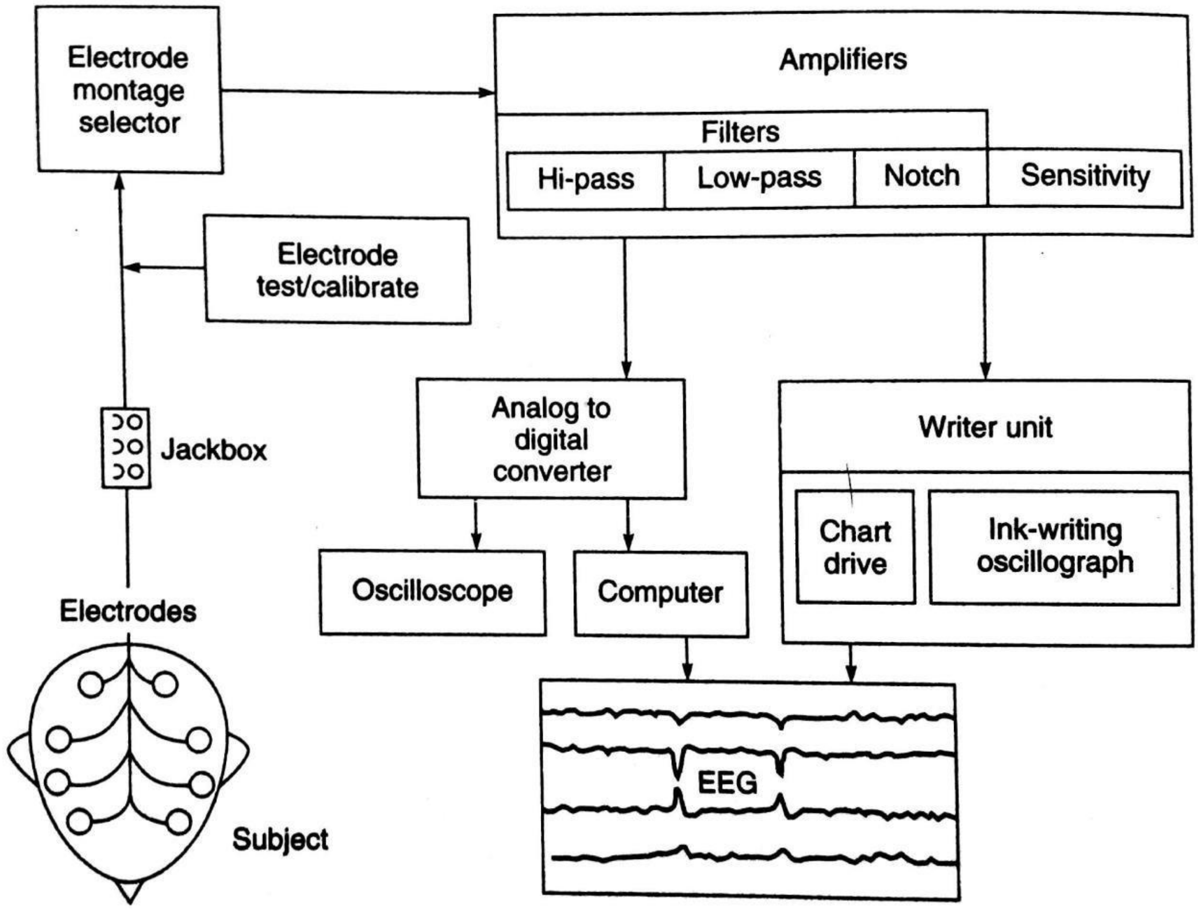


Figure 12: Schematic diagram of an EEG machine

MONTAGES

- A pattern of electrodes on the head and the channels they are connected to is called a montage.
- Montages are always symmetrical.
- The reference electrode is generally placed on a non-active site such as the forehead or earlobe.
- EEG electrodes are arranged on the scalp according to a standard known as the 10/20 system, adopted by the American EEG Society.

ELECTRODE MONTAGE SELECTOR

- EEG signals are transmitted from the electrodes to the head box, which is labelled according to the 10-20 system, and then to the montage selector.
- The montage selector on analog EEG machine is a large panel containing switches that allow the user to select which electrode pair will have signals subtracted from each other to create an array of channels of output called montage.
- Each channel is created in the form of the input from one electrode minus the input from a second electrode.
- The advantage of recording EEG in several montages is that each montage displays different spatial characteristics of the same data.

PREAMPLIFIER

- Every channel has an individual, multistage, ac coupled, very sensitive amplifier with differential input and adjustable gain in a wide range.
- Its frequency response can be selected by single-stage passive filters.
- The preamplifier used in electroencephalographs must have high gain and low noise characteristics because the EEG potentials are small in amplitude.
- In addition, the amplifier must have very high common-mode rejection to minimize stray interference signals from power lines and other electrical equipment.

SENSITIVITY CONTROL

- The overall sensitivity of an EEG machine is the gain of the amplifier multiplied by the sensitivity of the writer.
- Thus, if the writer sensitivity is 1 cm/V, the amplifier must have an overall gain of 20,000 for a 50 µV signal.
- The various stages are capacitor coupled.
- An EEG machine has two types of gain controls.
- One is continuously variable and it is used to equalize the sensitivities of all channels.
- The other control operates in steps and is meant to increase or reduce the sensitivity of a channel by known amounts.

FILTERS

- Low pass filters and high pass filters are used to eliminate or remove the additional unwanted bio-electrical signals from the muscles nearer to the EEG electrodes.
- Some EEG machines have a notch filter sharply tuned at 50 Hz so as to eliminate mains frequency interference.

WRITING PART

- The writing part of an EEG machine is usually of the ink type direct writing recorder.
- The best types of pen motors used in EEG machines have a frequency response of about 90 Hz.

CHANNELS

- An electroencephalogram is recoded simultaneously from an array of many electrodes.
- The record can be made from bipolar or monopolar leads.
- The electrodes are connected to separate amplifiers and writing systems.
- Commercial EEG machines have up to 32 channels, although 8 or 16 channels are more common.

MUSCLE RESPONSE-ELECTROMYOGRAM

- Electromyography is the science of recording and interpreting the electrical activity of muscle's action potentials.
- The recoding of the peripheral nerve's action potentials is called electroneurography.
- The electrical activity of the underlying muscle can be measured by placing surface electrodes on the skin.
- To record the action potentials of individual motor neurons in a muscle, the needle electrode is inserted into the muscle.
- Thus EMG indicates the amount of activity of a given muscle or a group of muscles.
- The action potentials occur both positive and negative polarities at a given pair of electrodes; so they may add or cancel each other.
- Thus EMG appears, very much like a random noise wave form.
- The contraction of a muscle produces action potentials.
- In a relaxed muscle, there is no action potential

ELECTROMYOGRAM MEASUREMENTS

- EMG is usually recorded by using surface electrodes or more often by using needle electrodes, which are inserted directly into the muscle.
- The surface electrode may be disposable, adhesive types.
- A ground electrode is necessary for providing a common reference for measurement.
- These electrodes pick up the potentials produced by the contracting muscle fibers.
- The signal can then be amplified and displayed on the screen of a cathode ray tube.
- It is also applied to an audio amplifier connected to a loudspeaker.
- A trained EMG interpreter can diagnose various muscular disorders by listening to the sounds produced when the muscle potentials are fed to the loudspeaker.

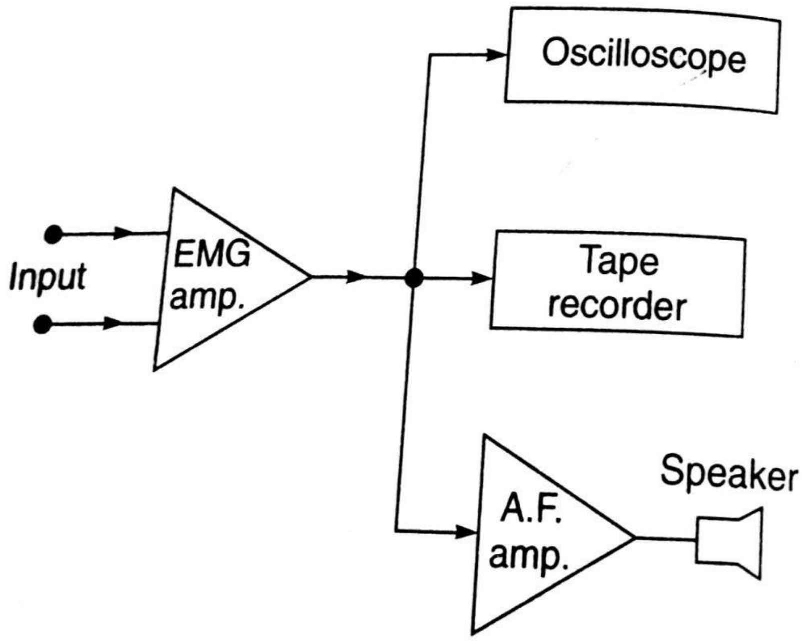
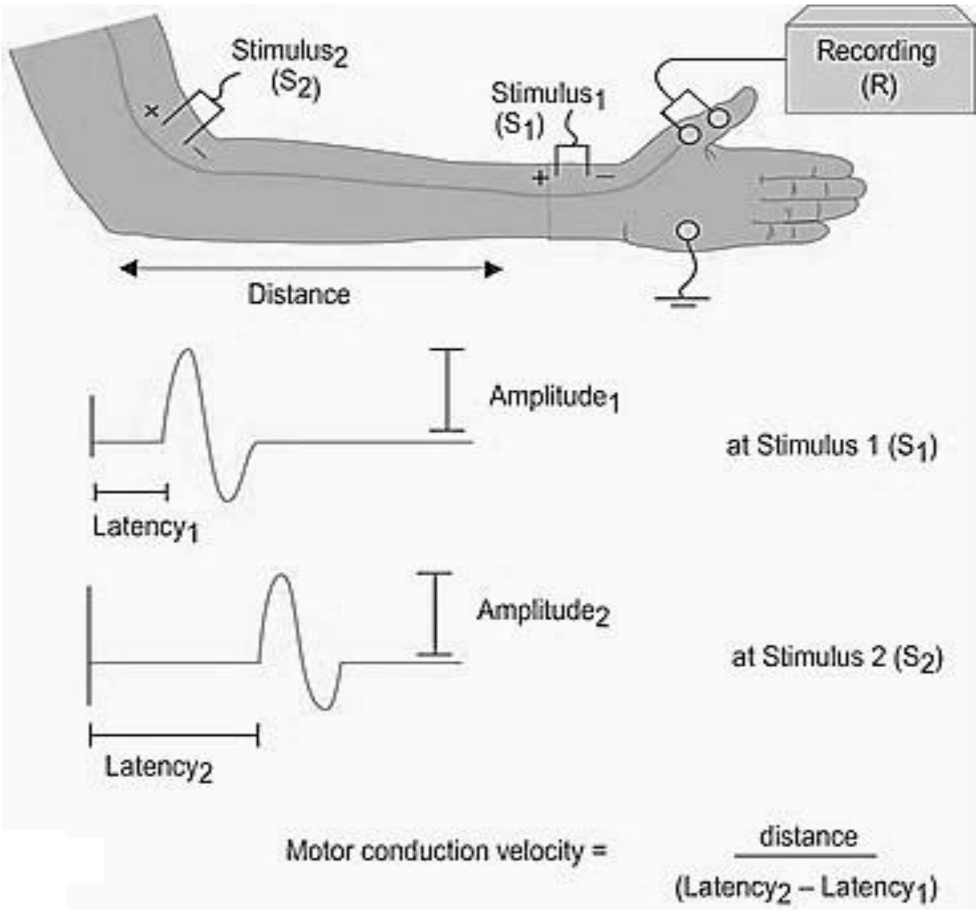


Figure 13: Block diagram of a typical setup for EMG recording

- The block diagram shows a typical setup for EMG recordings.
- The oscilloscope displays EMG waveforms.
- The tape recorder is included in the system to facilitate playback and study of the EMG sound waveforms at a later convenient time.
- The waveform can also be photographed from the CRT screen by using a synchronized camera.
- The amplitude of the EMG signals depends upon various factors, such as type and placement of electrodes used and the degree of muscular exertions.

NERVE CONDUCTION VELOCITY MEASUREMENTS

- The measurement of conduction velocity in motor nerves is used to indicate the location and type of the nerve damages.
- Here the nerve function is examined directly at the various segments of the nerve by means of stimulating it with a brief electric shock having pulse duration of 0.2 to 0.5 milliseconds and measuring the latencies, we can calculate the conduction velocity in that nerve.
- Latency is defined as the elapsed time between the stimulating impulse and the muscle's action potential.



RESPIRATORY PARAMETERS

- **Tidal Volume (TV):** The volume of gas inspired or expired during normal quiet breathing, is known as tidal volume.
- **Minute Volume (MV):** The volume of gas exchanged per minute during quiet breathing.it is equal to the tidal volume multiplied by the breathing rate.
- **Alveolar Ventilation (AV):** The volume of fresh air entering the alveoli with each breath.
  AV = (Breathing rate) x (Tidal volume – Dead space)
- **Inspiratory Reserve Volume (IRV):** The volume of gas, which can be inspired from a normal end-tidal volume.
  IRV = VC – (TV + FRC)
- **Expiratory Reserve Volume (ERV):** The volume of gas remaining after a normal expiration less the volume remaining after a forced expiration.
  ERV = FRC – RV
- **Residual Volume:** The volume of gas remaining in the lungs after a forced expiration.
- **Functional Residual Capacity (FRC):** The volume of gas remaining in the lungs after normal expiration.
- **Total Lung Capacity (TLC):** the volume of gas in the lungs at the point of maximal inspiration.
  TLC = VC + RV
- **Vital Capacity (VC):** The greatest volume of gas that can be inspired by voluntary effort after maximum expiration, irrespective of time.
- **Inspiratory Capacity (IC):** The maximum volume that can be inspired from the resting end expiratory position.
- **Dead Space:** Dead space is the functional volume of the lung that does not participate in gas exchange.

- **Compliance (C):** Change in lung volume resulting from unit change in trans-pulmonary pressure (P_L).
- **Chest-Wall Compliance (C_{cw}):** Change in volume across the chest wall resulting from unit change in trans-chest wall pressure.
- **Elastance (E):** Reciprocal of compliance. Units are cmH_2O/litre.
- **Forced Vital Capacity (FVC):** This is the total amount of air that can be forcibly expired as quickly as possible after taking the deepest possible breath.

SPIROMETER

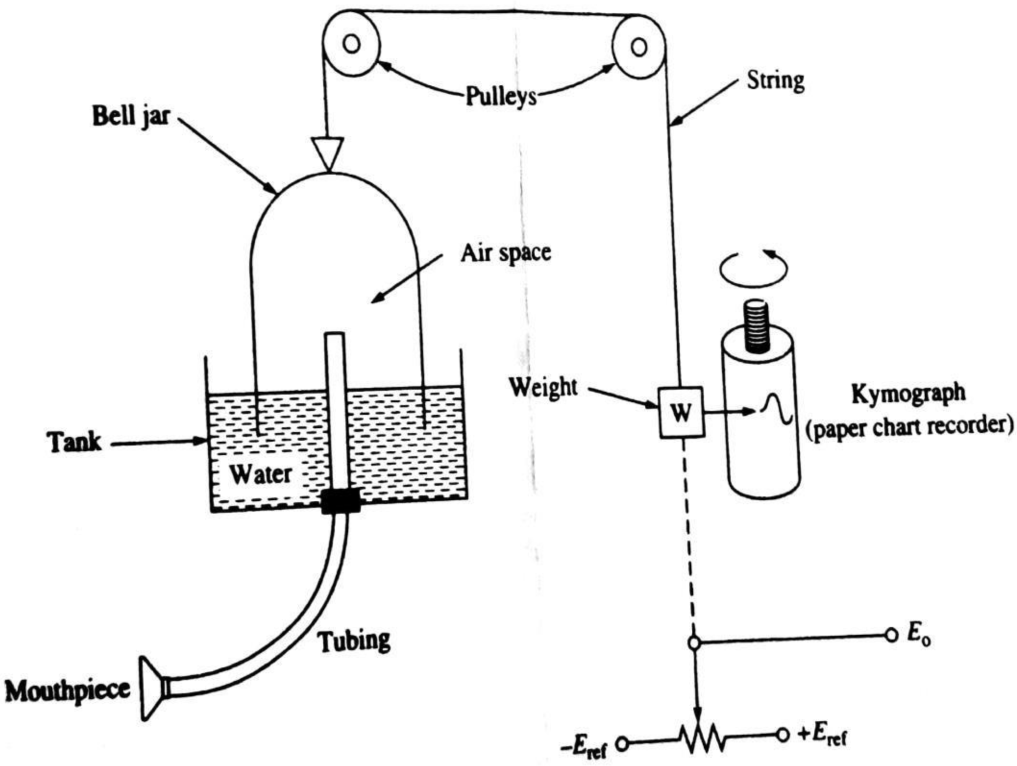


Figure 14: Spirometer

- This instrument uses a bell jar, suspended from above, in a tank of water.
- An air hose leads from mouthpiece to the space inside of the bell above the water level.
- A weight is suspended from the string that holds the bell in such a way that it places a tension force on the string that exactly balances the weight of the bell at atmospheric pressure.
- When no one is breathing into the mouthpiece, therefore, the bell will be at rest with a fixed volume above the water level.
- But when the subject exhales, the pressure inside the bell increases above atmospheric pressure, causing the bell to rise.
- Similarly, when the patient inhales, the pressure inside the bell decreases.
- The bell will rise when the pressure increases and drop when the pressure decreases.
- The change in bell pressure changes the volume inside the bell, which also causes the position of the counterweight to change.
- We may record the volume changes on a piece of graph paper by attaching a pen to the counterweight or tension string.
- The chart recorder is a rotatory drum model called a kymograpgh.
- It rotates slowly at speed between 30 and 2000 mm/min.

PNEUMOGRAPH

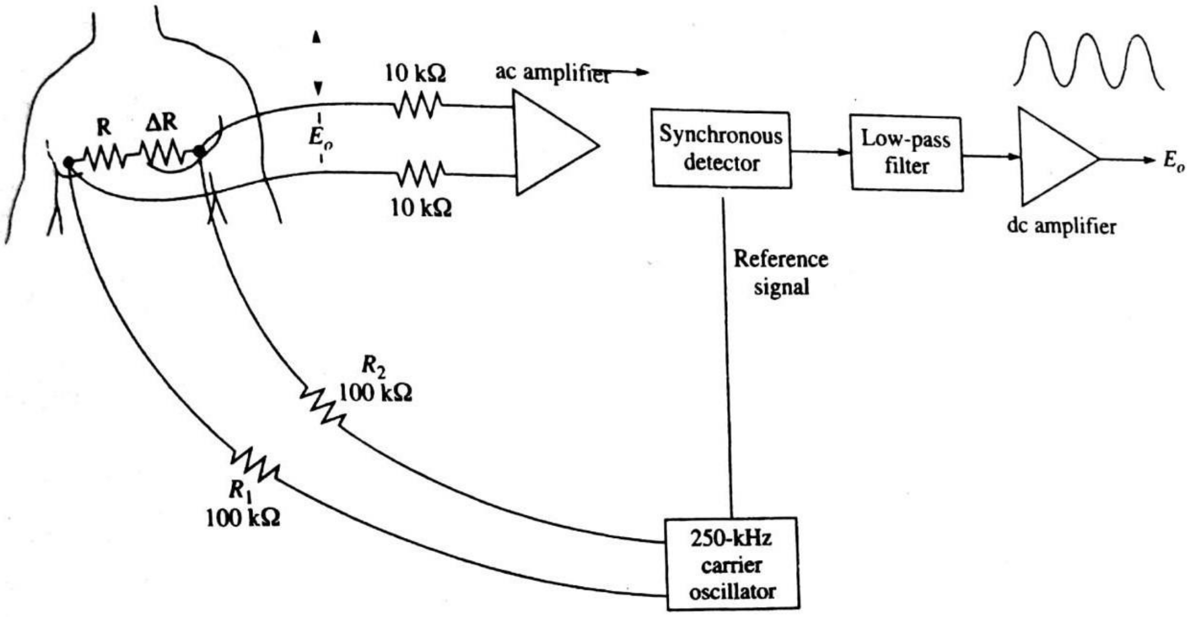


Figure 15: Impedance pneumograph-Block diagram

- An impedance pneumograph is based on the fact that the ac impedance across the chest of a subject changes as respiration occurs.
- Figure 15 shows the block diagram for an impedance pneumograph.
- A low voltage, 50 to 500 KHz ac signal is applied to the chest of the patient through surface electrodes of the same type as used in ECG monitoring.
- In fact, many of these monitors are also ECG monitors, using a common set of electrodes and a single pair of lead wires.
- High value fixed resistors connected in series with each electrode create a constant ac current source.
- The signal voltage applied to the differential ac amplifier is the voltage drop across the resistance, representing the patient's thoracic impedance. (figure 16)

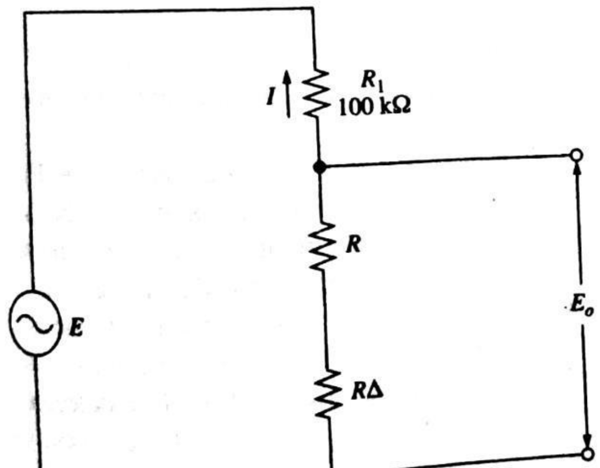


Figure 16: Equivalent circuit-Pneumograph

$$E_0 = I(R \pm \Delta R)$$

- Where,

  E_0 is the output potential in volts (V)
  I is the current through the chest in amperes (A)
  R is the chest impedance, without respiration, in ohms (Ω)
  ΔR is the change of chest impedance caused by respiration, in ohms (Ω)
- The current passed through the patient's chest is very small and is nearly constant without respiration because the source voltage E is constant and the term ΔR is very small with respect to the sum $R_1 + R_2 + R$.
- The signal E_0 is amplified and then applied to a synchronous amplitude modulation (AM) detector; the respiration waveform is contained within amplitude variations in E_0 caused ΔR.
- A low pass filter following the detector removes residual carrier signal, and a dc amplifier scales the output waveform to the level required by the display device.

END OF MODULE 4

Module V

VENTILATORS

- Mechanism of respiration: it is the process of supplying oxygen to tissues and removing carbon dioxide from the tissues.
- These gases are carried in blood, oxygen from lungs to the tissues and carbon dioxide from the tissues to the lung.
- Respiration process:
  - Inspiration – breathing in (air to lungs)
  - Expiration – breathing out (air out from lungs)
- Inspiration results from contraction of the diaphragm whereas expiration results from their relaxation.
- For reduced or respiratory failure, mechanical ventilators or artificial respirators are used in hospitals.

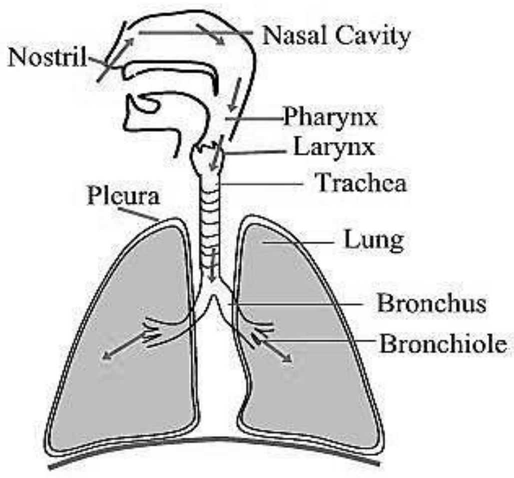


Figure 1: Respiratory system

- A mechanical ventilator is a machine that makes it easier for patients to breath, until they are able to breathe completely on their own.
- It gives breath in various modes in order to maintain the level of oxygen in the blood.
- These devices provide artificial ventilation, supply enough oxygen and eliminate right amount of CO_2.
- It maintains desired arterial partial pressure of O_2 and CO_2.
- An intensive care patient often requires assistance with breathing.
- When artificial ventilation needs to be maintained for a long time, a ventilator is used to provide oxygen enriched medicated air to a patient at a controlled temperature.
- Ventilators can operate in different modes:
  1. Controlled mode – in this mode the breathing is controlled by an automatically timing system which is usually provided for patients who cannot breath on their own.
     - Pressure control (PC)
     - Volume control (VC)

2. Assisted mode/Supported mode – in this mode patients own spontaneous attempt to breath in, causes ventilator to cycle on during inspiration
   - Continuous positive airway pressure (CPAP)
   - Pressure support
3. Assist Control mode/ Combined mode – in this mode, patient controls his own breathing as long as he can, but if he should fail to do so, control mode is able to take over from him.

- A tube (endocardial tube) is inserted in the patient's nose, mouth or through a trachy tube into the lungs, (this process is called ―intubation‖) and is hooked up to the ventilator.

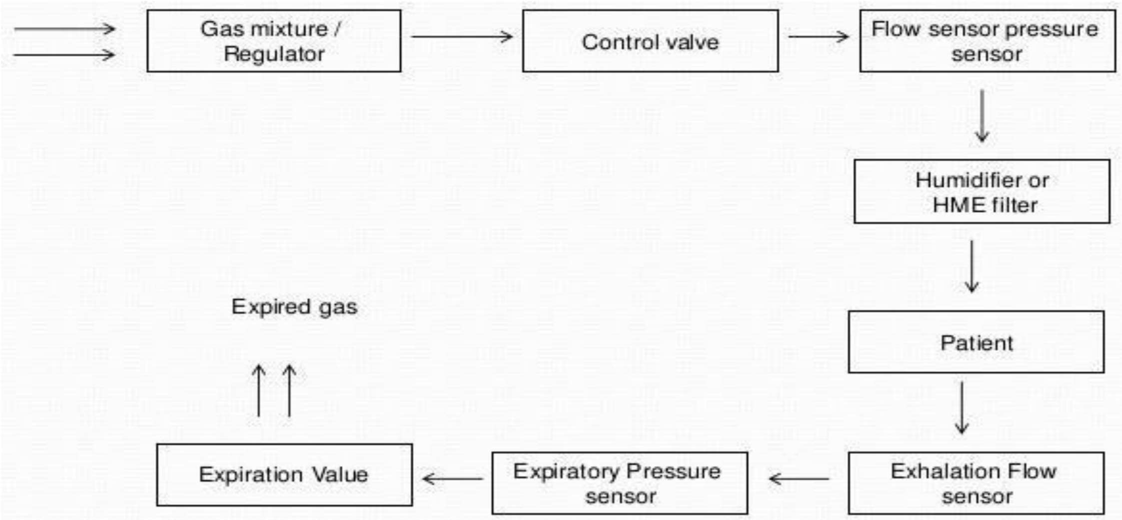


Figure 2: block diagram of Ventilator

- A tube (endocardial tube) is inserted in the patient's nose, mouth or through a trachy tube into the lungs, (this is called intubation) and is hooked up to the ventilator.
- Trachy tube provides an alternative airway for breathing.
- The ventilator pumps air and oxygen into the patient's wind pipe through the tube.
- A ventilator can be used to either assist a patient with breathing or it can be completely take over the breathing.
- In ventilator system, humidifier is used to prevent inspissation.
- Inspissation ⟶ the act of thickening or condensing as by evaporation or absorption of fluid.
- The HME (Heat and Moisture Exchange) is used to help to prevent complications due to drying of the respiratory mucosa.
- The ventilator can provide a pressure which helps hold the patient's lungs open to prevent the sacs from collapsing.
- The goal of mechanical ventilation is to reproduce the body's normal breathing mechanism.

Parameters used in ventilator

1. <u>Inspiration</u>
   - It is an active movement
   - The diaphragm moves downwards
   - The outside air goes into lungs
2. <u>Expiration</u>
   - It is a passive movement
   - Return of the diaphragm to normal
   - Air (more CO_2 goes out from lung
3. <u>Tidal volume/lung volume</u>
   The volume of air/O_2 for one breath. Unit is ml

4. Breath rate
   Number of breaths for one minute. Unit is BPM (Breath per Minute)
5. Minute volume
   Number of breaths in one minute multiplied by tidal volume
   ie., Breath rate X Tidal volume. Unit is ml/minute
6. Airway pressure
   The pressure in the airway or in the tube.
7. Inspiration peak flow
   The maximum flow of air/O_2 during inspiration
8. I:E ratio
   The ratio between inspiration and expiration
9. Percentage of Oxygen
   The oxygen concentration in the air during inspiration
10. Compliance
   Measurement of the elasticity of the lungs and chest wall
11. Positive End Expiratory Pressure (PEEP)
   The pressure maintained in the airway or lung even after the expiration

MICROPROCESSOR BASED VENTILATOR

- Figure 3 shows the microprocessor based automatic feedback control of a mechanical ventilator.
- It consists of a microprocessor with RAM, EPROM, A/D converter and a CRT controller.
- The input signals to the microprocessor are obtained from a CO_2 analyser, a lung machine, gas analyser, oxygen consumption monitor and a servo ventilator.
- The proper controlling signals are delivered to the servo ventilator so as to get correct ventilation adjustment in response to a patient‘s metabolism.

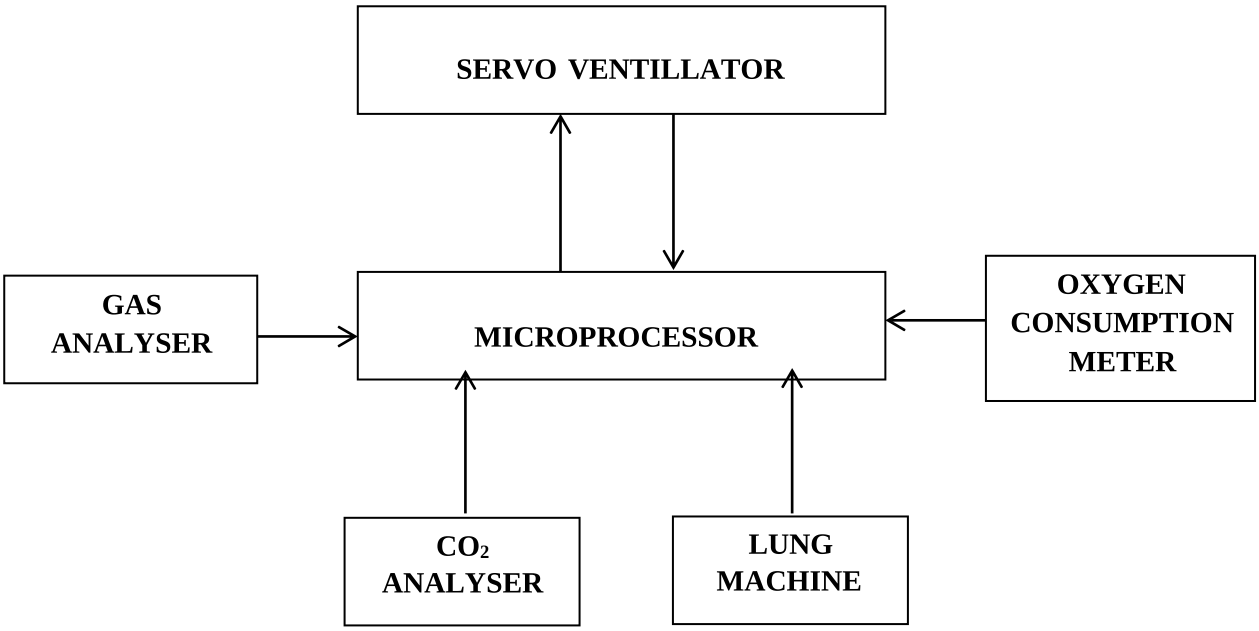


Figure 3: Microprocessor based ventilator

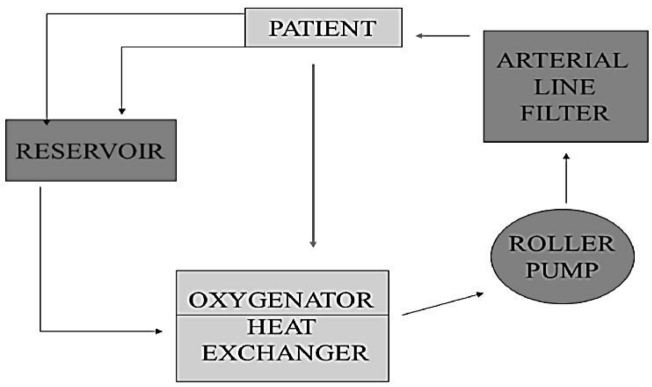
HEART-LUNG MACHINE

- During open heart surgery, the heart cannot maintain the circulation.
- It is then necessary to provide extra corporeal (outside the body) circulation with a special machine called heart lung machine.

- Heart-Lung Machine is a blood pumping machine that takes over the functions of the heart and lungs during surgery (i.e. open-heart surgery).
- It is most commonly used to perform a cardiopulmonary bypass (CPB), which is the technique whereby blood is totally or partially diverted from the heart into a machine with the gas exchange capacity and subsequently returned to the arterial circulation at appropriate pressures & flow rates.
- CPB allows for the heart to stop beating as its function is taken over by Heart Lung Machine, which makes it easier to operate on, and surgeons can operate in a blood-free area.

Functions of a Heart Lung Machine

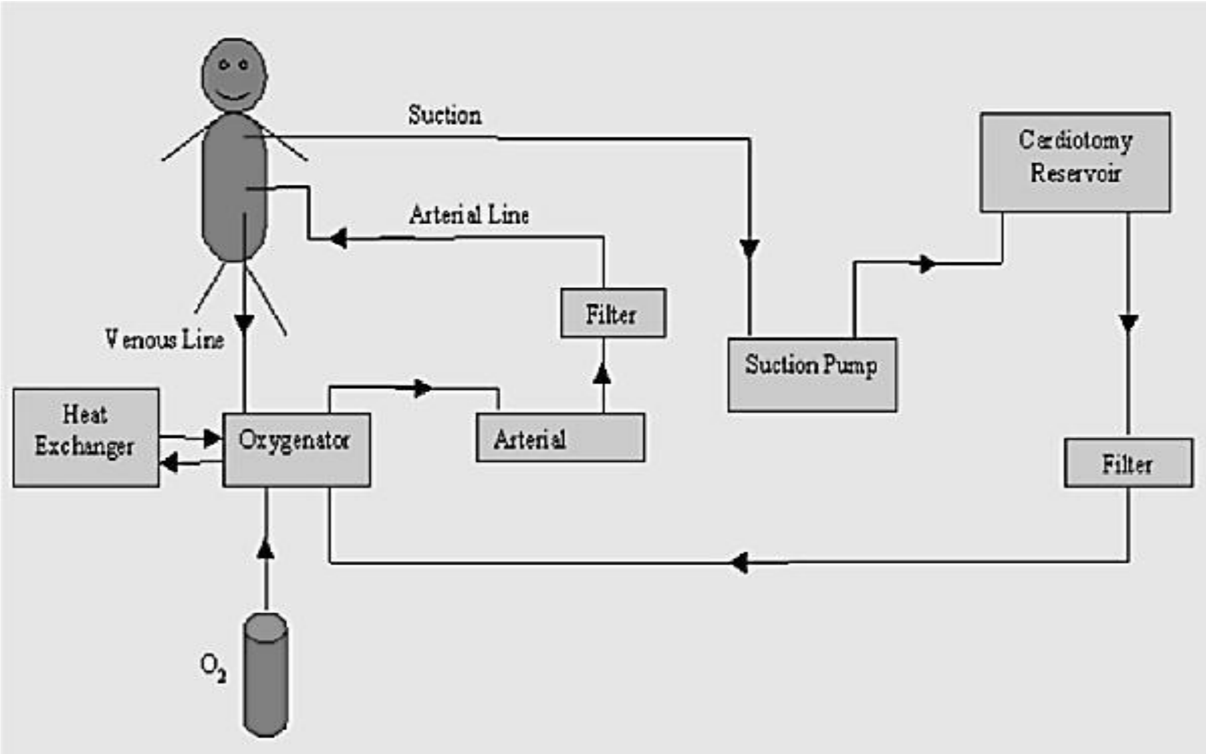
- RESPIRATION: Within which it includes Ventilation and Oxygenation.
- CIRCULATION: Maintaining circulation at appropriate pressures and flow rates.
- TEMPERATURE REGULATION: It involves controlled hypothermia.



The Components of Heart Lung Machine

- PUMPS: The pumps are designed to minimize the damage to blood cells and effective in pumping within physiological range.
- MEMBRANE OXYGENATOR: It imitates the function of lungs. Membrane oxygenator are more common now a days. Here O2 & CO2 Exchange takes place. Gas exchange take place by the process of diffusion across a thin membrane separating blood and gas made of highly permeable silicon rubber or microporous polypropylene, Teflon & polyacrylamide.
- HEAT EXCHANGER: Heat exchangers control body temperature by heating or cooling blood passing through the perfusion circuit.
- Arterial filter/bubble trap: It is used to filter small air bubbles that may have entered, or been generated by the machine.
- Aortic/atrial/vena caval cannulae through which blood is taken and returned to body.

The work flow of Heart Lung Machine



- It Composed of: a chamber that receives all the blood from the body (right atrium of the
- heart), pumps that move the blood through an oxygenator (that mimic function right ventricle), oxygenator removes the carbon dioxide and adds oxygen to the blood (mimic lungs).
- Machine continues by pumping the oxygenated blood back to the body (that mimic function of left atrium and ventricle) using a series of tubes.
- Advantage of using Heart Lung machine: The ability of a surgeon to perform an open-heart surgery in a blood-free zone while the heart is not beating.
- It also allows for medications and anesthetics to be administered directly into the blood, adding them to the blood in the heart-lung reservoir, arriving immediately to the patient.

HEMODIALYSIS

- Main function of the kidney is to form urine out of blood plasma, which basically consists of two process:
    1. The removal of waste products from blood plasma
    2. The regulation of the composition of blood plasma
- Kidney performs these functions through a process involving filtration, reabsorption, excretion.

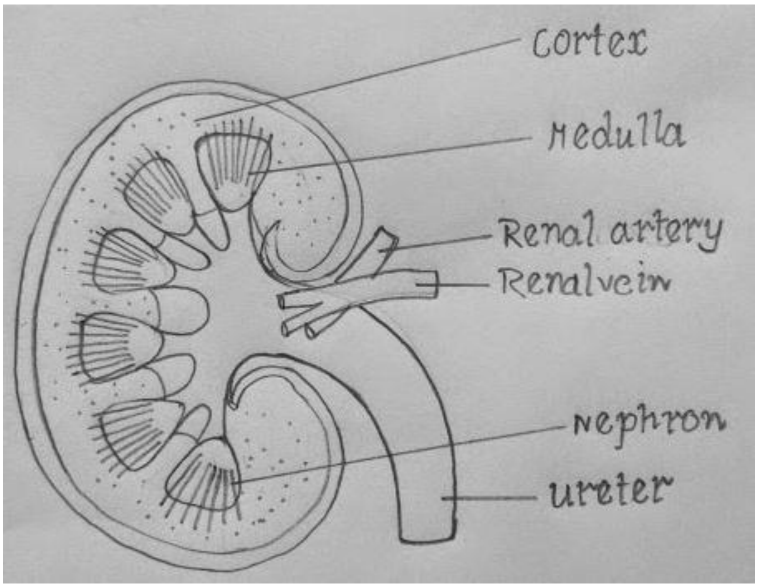


Figure 4: Section of Kidney

- Human body has two kidneys. Each kidney consists of about a million individual units which are all having similar structure and function.
- These tiny units are called nephrons.
- Its main functions include regulating the concentration of sodium salts and water by filtering the kidney's blood, excreting any excess in the urine and reabsorbing the necessary amounts.
- Healthy kidneys clean your blood and remove extra fluid in the form of urine. They also make
- substances that keep your body healthy. Dialysis replaces some of these functions when your kidneys no longer work.
- One of the most important prosthetic (artificial body part) device in modern is the artificial kidney, which is periodically connected to the circulatory systems of uremic patients to remove metabolic waste products from their body.
- In uremic patients,

  Amino acids + proteins ⟶ urea, creatinine
- Excess of these products in blood cause kidney failure.
- Hemodialysis is a therapy that filters waste, removes extra fluid and balances electrolytes (sodium, potassium, bicarbonate, chloride, calcium, magnesium and phosphate).
- In hemodialysis, blood is removed from the body and filtered through a man-made membrane called a dialyzer, or artificial kidney, and then the filtered blood is returned to the body.
- The dialysis machine is like a big computer and a pump. It keeps track of blood flow, blood pressure, how much fluid is removed and other vital information.
- It mixes the dialysate, or dialysis solution, which is the fluid bath that goes into the dialyzer.
- This fluid helps pull toxins from the blood, and then the bath goes down the drain.
- The dialysis machine has a blood pump that keeps the blood flowing by creating a pumping action on the blood tubes that carry the blood from the body to the dialyzer and back to the body.

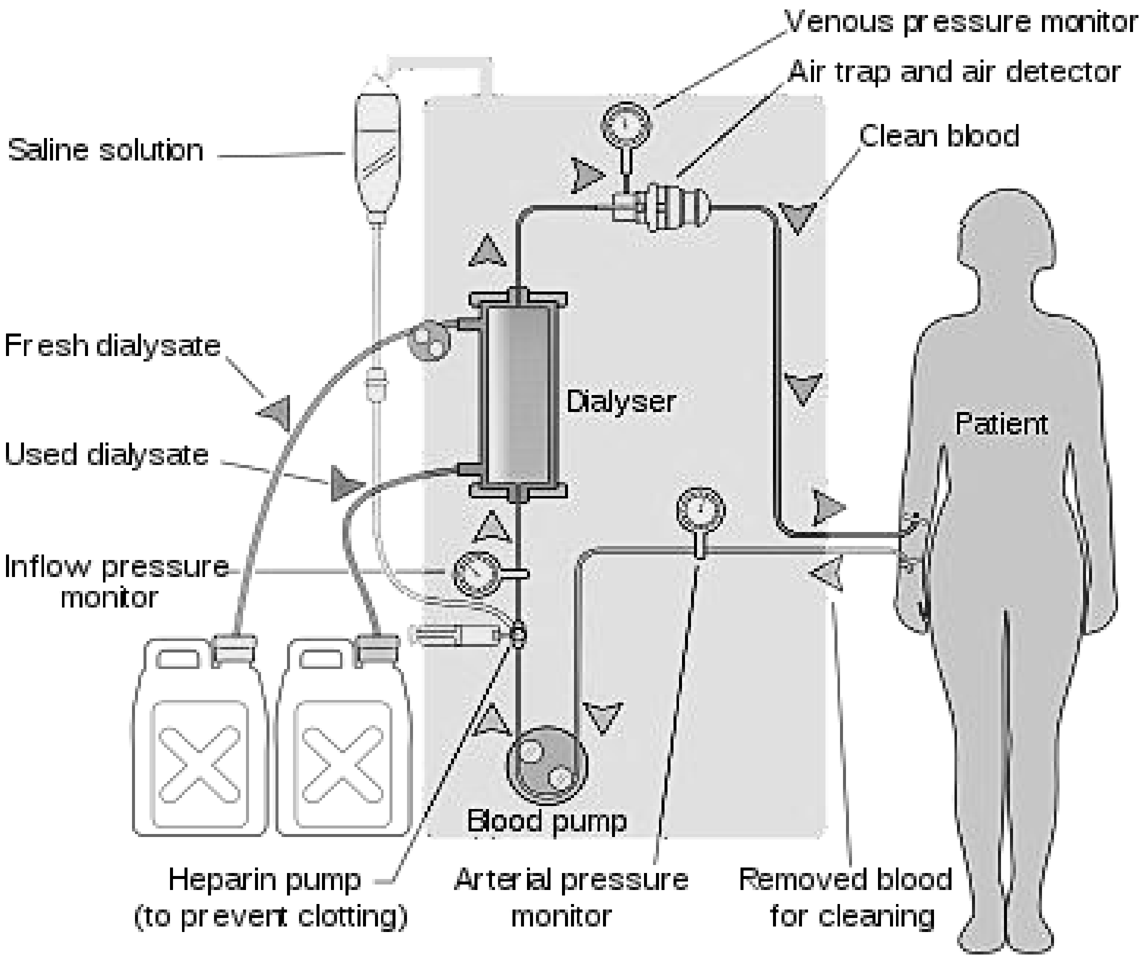


Figure 5: Hemodialysis

How does hemodialysis work?

- The dialyzer is the key to hemodialysis. The dialyzer is called the artificial kidney because it filters the blood — a job the kidneys used to do.
- The dialyzer is a hollow plastic tube about a foot long and three inches in diameter that contains many tiny filters.
- There are two sections in the dialyzer; the section for dialysate and the section for the blood.
- The two sections are divided by a semipermeable membrane so that they don‘t mix together.
- A semipermeable membrane has microscopic holes that allow only some substances to cross the membrane.
- Because it is semipermeable, the membrane allows water and waste to pass through, but does not allow blood cells to pass through.
- Dialysate, also called dialysis fluid, dialysis solution or bath, is a solution of pure water, electrolytes and salts, such as bicarbonate and sodium.
- The purpose of dialysate is to pull toxins from the blood into the dialysate.
- The way this works is through a process called diffusion.
- In the blood of the hemodialysis patient, there is a high concentration of waste, while the dialysate has a low concentration of waste.
- Due to the difference in concentration, the waste will move through the semipermeable membrane to create an equal amount on both sides.
- The dialysis solution is then flushed down the drain along with the waste.

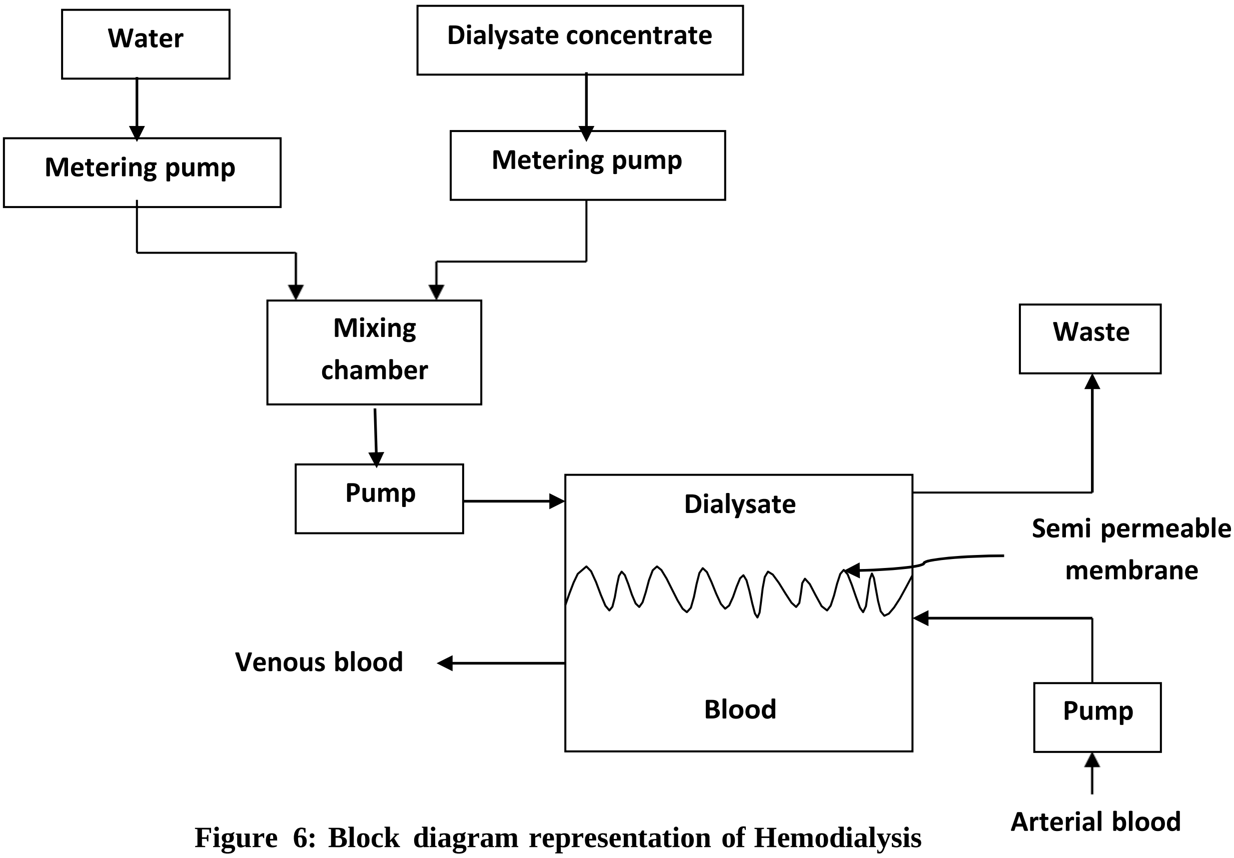


Figure 6: Block diagram representation of Hemodialysis

LITHOTRIPSY

- Kidney stones are small masses of salts and minerals that form inside the kidneys and may travel down the urinary tract.
- Kidney stones range in size from just a speck to as large as a ping pong ball.
- Signs and symptoms of kidney stones include blood in the urine, and pain in the abdomen, groin, or flank.
- An open incision surgical technique known as ―lithotomy‖ can be used to remove stone but that procedure include risk, complications, discomfort and disability of major surgery.
- Lithotripsy is a non-invasive or minimally invasive surgical technique for removing kidney stones without risk and complications.
- The kidney stones are disintegration so that they will be removed from body in the form of small particles without any discomfort.
- There are mainly two methods:
    - Percutaneous Lithotripsy
    - Extracorporeal shock wave lithotripsy

PERCUTANEOUS LITHOTRIPSY

- A probe is guided under x-ray fluoroscopy through a small incision into the location of kidney stone.
- Mechanical shock waves are provided at tip of probe by a controlled electric discharge (spark) or probe contains an ultrasonic transducer that provides ultrasonic waves.
- These waves break up the stone and are withdrawn through probe outside element.

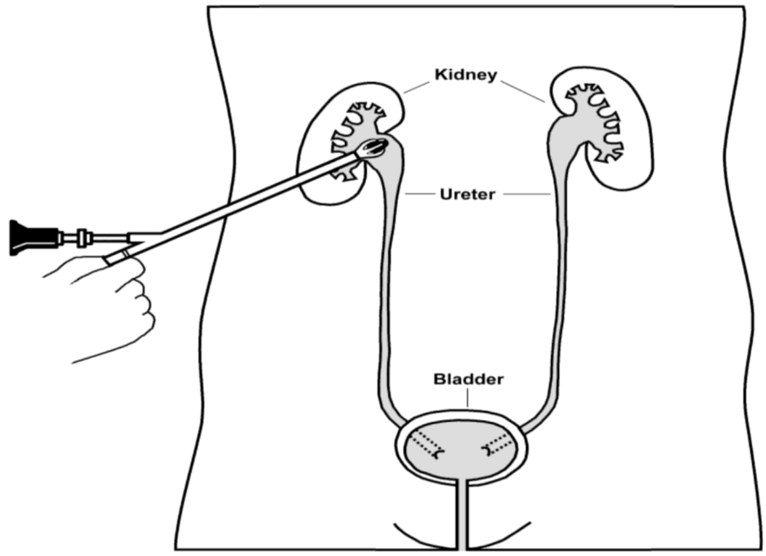
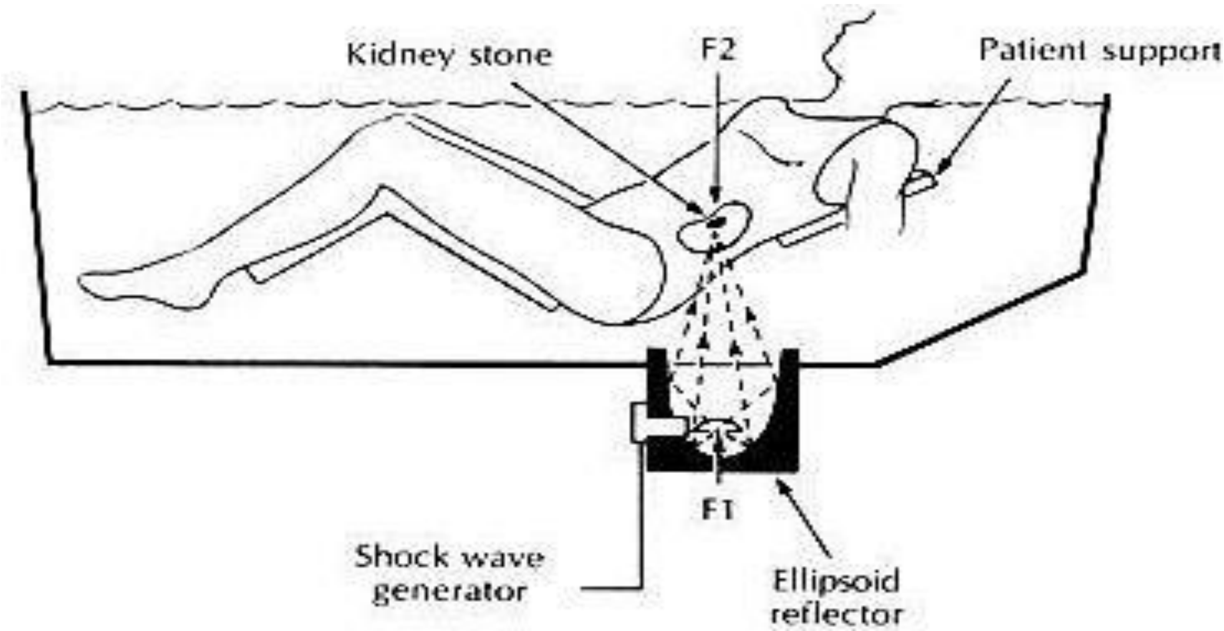


Figure 7: Percutaneous Lithotripsy

EXTRACORPOREAL SHOCK WAVE LITHOTRIPSY

- This is a non-invasive method to breakup kidney stone.
- Multiple shock waves are generated by multiple discharge up to 2000 shock wave may be necessary to reduce the kidney stone through urinary tract.



- Patient lies down in an apparatus bed, with back supported by a water filled coupling device placed at the level of kidney.
- Positioning of the patient is critical and biplane x-ray system used to establish position of stone.
- A high voltage pulse is applied to spark gap and discharge produces a shock wave that is propagated through water.
- Stone will observe on biplane x-ray monitors.
- Multiple shocks generated multiple discharges and reduce kidney stone.
- Up to 2000 shock may be necessary to reduce a kidney stone to 1-2 mm fragments that can pass through urinary tract.
- With this treatment most patients are able to resume full activity within two days.

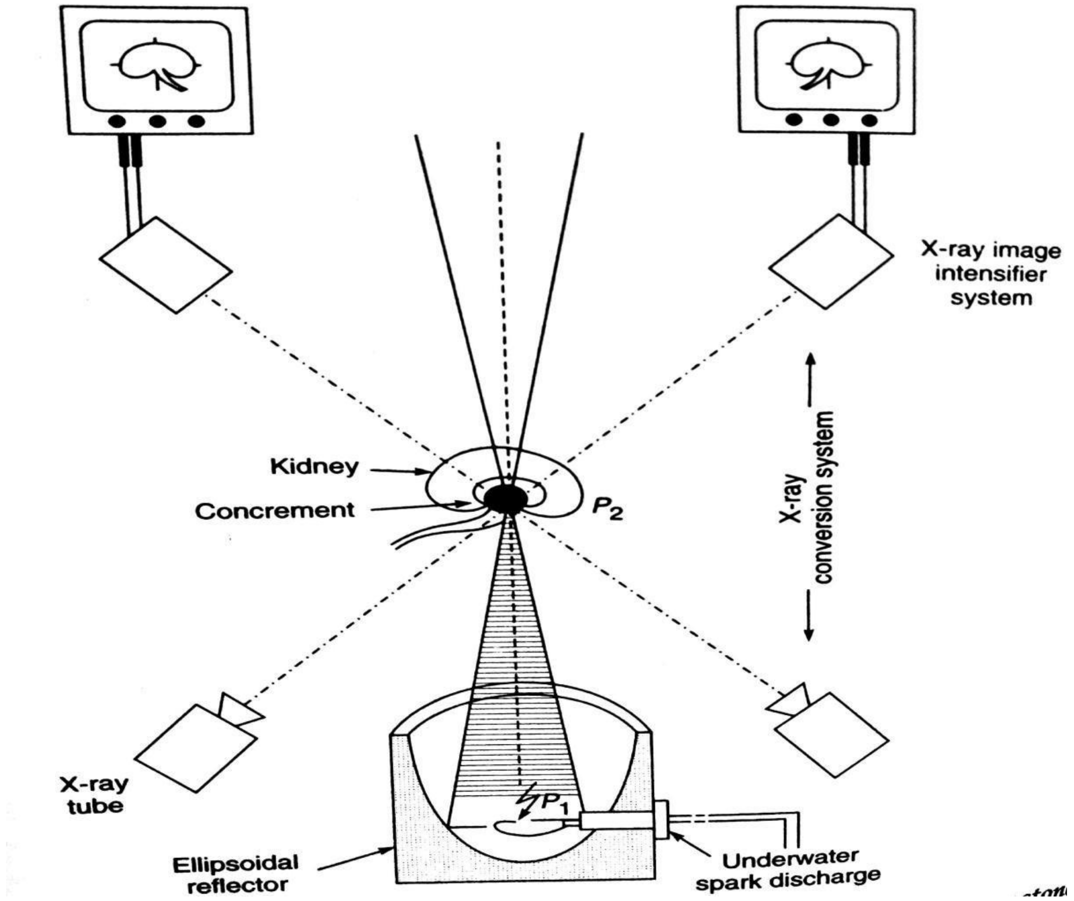
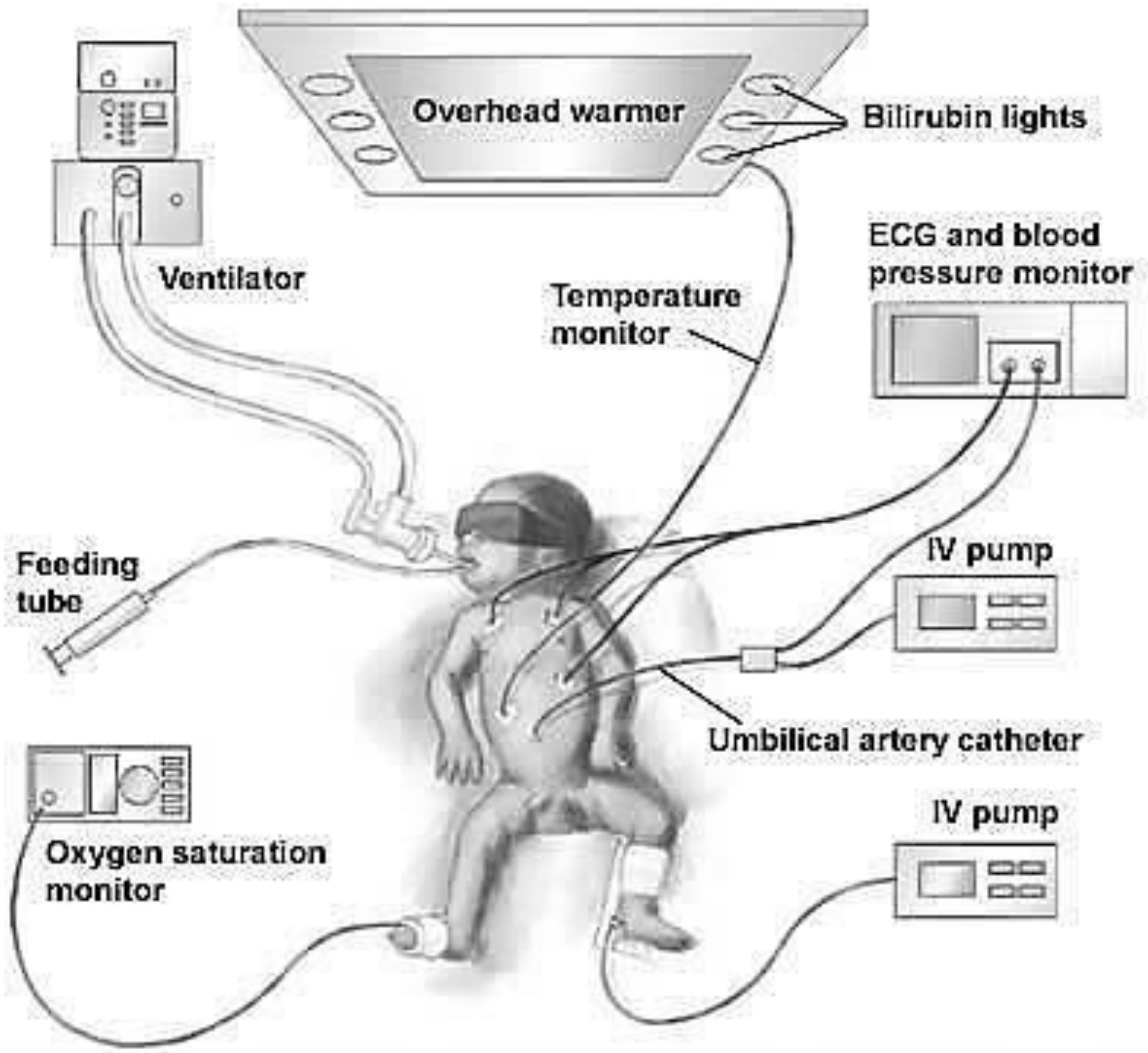


Figure 8: Construction for extracorporally induced destruction of kidney stone with 2 integrated x-ray positioning system

INFANT INCUBATOR

- Infant incubator is a biomedical device which provides warmth, humidity and O_2 all in a controlled environment as required by the new born.
- The temperature is maintained within specific temperature range, O_2 requirements are minimized.
- In premature newborns susceptible to respiratory problems, because lungs may be unable to supply enough O_2 to meet demands.
- Such controlled temperature environments are maintained infant incubators
- The control system uses the thermistor in a bridge circuit with the set point resistance as another arm of the bridge
- The bridge output is amplified giving the voltage V_1 at the output which is proportional to the difference in temperature between thermistor and the set point.
- Some incubators instead of controlling air temperature directly use the skin temperature of infant as a control parameter.
- Thermistor is placed against the skin of infant and controller is set to maintain the infant skin at a given temperature.
- If the infant is cooler than the set point, air entering the chamber of incubator is heated an amount proportional to difference between the set temperature and baby‘s actual temperature.
- Incubators also have a simple alarm system to alert the clinical staff if there is any dangerous overheating of the device.
- If the infant is cooler than the set point, air entering the chamber of incubator is heated an amount proportional to difference between the set temperature and baby‘s actual temperature.



- Incubators also have a simple alarm system to alert the clinical staff if there is any dangerous overheating of the device.
- A buzzer system keeps it simple and reliable and in some cases the circuit also immediately reduces power to the heater to stop the overheating.
- If the temperature of the air entering the infant chamber is lower than the set temperature, power is applied to heater to correct for this difference.
- The infant incubator is normally in the form of a trolley with a small mattress on the top covered by a rigid clear plastic cover.
- Incubator chamber provides a clean environment, and helps to protect the baby from noise, dust, infection, and excess handling.
- Underneath the baby is an air-blown electric heating system and humidification system which circulates heated humid air at a desired temperature and humidity through the incubator chamber.
- Additional oxygen may also be introduced into the chamber.

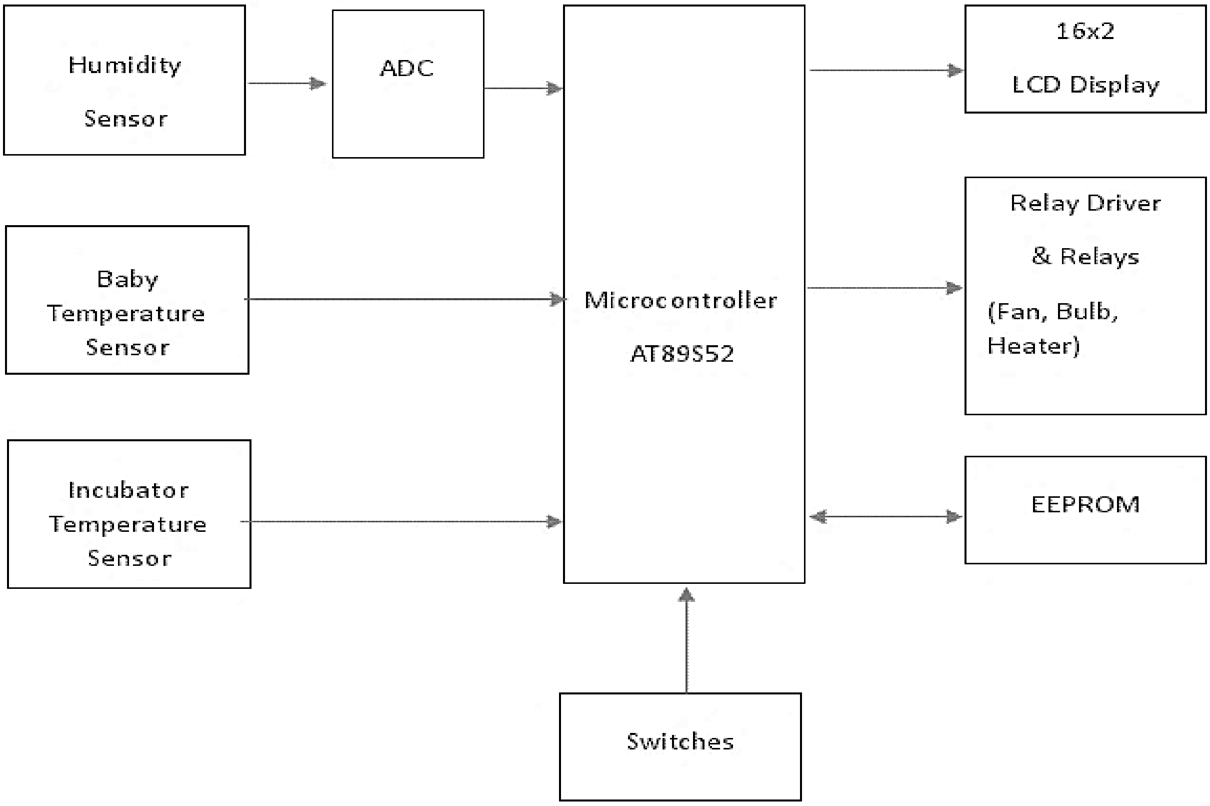


Figure 9: Infant incubator – simple block diagram

X-RAY IMAGING

- X-rays are electromagnetic radiations with a much shorter wavelength than radio waves or visible light.
- It is beyond the range of ultraviolet light that the X-rays begin.
- The shorter the wavelength, the stronger is the penetration power of the X-rays.
- X-rays normally move in a straight line like light.
- These are used for both diagnostic as well as therapeutic purposes. The use for diagnostic purposes is more relevant.
- When they travel through the body of the patient, a portion of them will be either absorbed or scattered, which depends on the density of the medium.
- It is, therefore, greater in metal than in bone, greater in bone than in soft tissues and greater in soft tissues than in air.
- The X-rays, thus absorbed, interact with the atoms of the matter and dislodge electrons.
- This process is called ionization and X-rays are hence referred to as ionizing radiation.
- The ionization due to X-rays has a therapeutic effect as well as possible harmful effects.
- The image of intensity distribution of the X-rays that have passed through the body of a patient help to visualize the internal structures of the body.

PRINCIPLES OF GENERATION

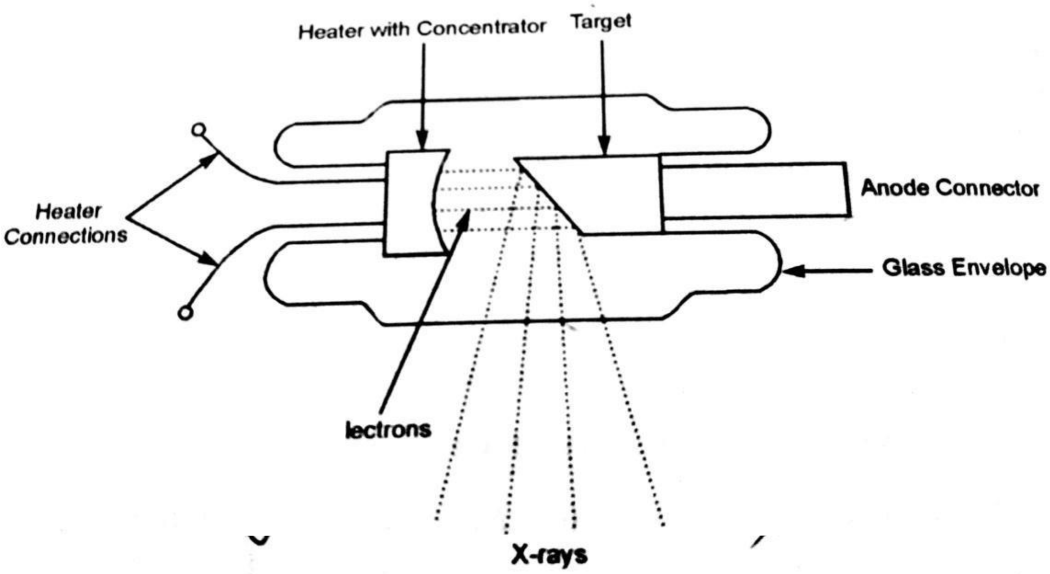


Figure 10: The principle of X-ray generation

- An X-ray generator is a device that produces X-rays.
- Together with an X-ray detector, it is commonly used in a variety of applications including medicine, fluorescence, electronic assembly inspection, and measurement of material thickness in manufacturing operations.
- In medical applications, X-ray generators are used by radiographers to acquire x-ray images of the internal structures (e.g., bones) of living organisms, and also in sterilization.
- An X-ray generator generally contains an X-ray tube to produce the X-rays.
- Possibly, radioisotopes can also be used to generate X-rays.
- An X-ray tube is a simple vacuum tube that contains a cathode, which directs a stream of electrons into a vacuum, and an anode, which collects the electrons and is made of tungsten to evacuate the heat generated by the collision.
- When the electrons collide with the target, about 1% of the resulting energy is emitted as X-rays, with the remaining 99% released as heat.
- An X-ray generator also needs to contain a cooling system to cool the anode; many X-ray generators use water or oil recirculating systems.

PROPERTIES OF X-RAYS

1. Highly penetrating invisible rays
2. Electrically neutral
3. Poly-energetic
4. Liberate heat on passing through the matter
5. Travel ordinarily in straight lines
6. Travel with the speed of light in vacuum
7. Ionize gases indirectly
8. Cannot be focussed by lens
9. Affect photographic film
10. Produce chemical and biological change

USES OF X-RAYS

- The uses of X-rays in the fields of medicine and dentistry have been extremely important.
- Examples might include the observation of the broken bones and torn ligaments of football players.
- The detection of breast cancer in women.

- The discovery of cavities and impacted wisdom teeth.
- Since X-rays can be produced with energies sufficient to ionize the atoms making up human tissue, it can be used to kill the affected cells like cancer cells.
- Demonstrates the difference between bone density and soft tissue.
- Show detailed images of bone structure.

DIAGNOSTIC STILL PICTURE

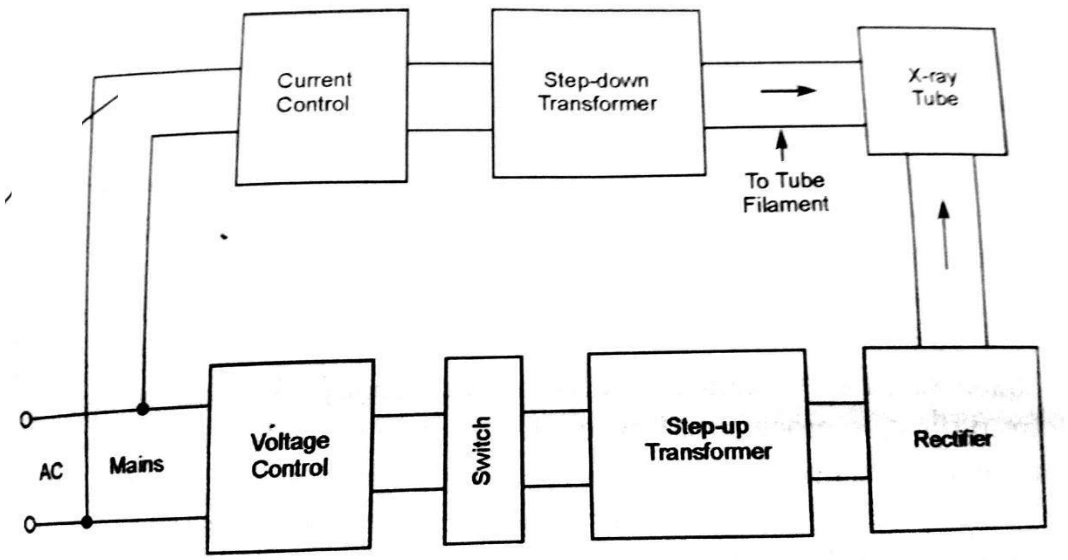


Figure 11: Block diagram of X-ray machine

- The main part of an X-ray machine is the X-ray generator.
- In the X-ray generator, the X-rays are produced in the X-ray tube by bombardment of an anode target with fast moving electrons (figure 1) obtained from a red-hot cathode.
- The characteristics of the X-ray beam depend on the anode-cathode voltage and temperature of the electron emitting cathode.
- The voltages used may vary from 20 KV to several megavolts.
- The currents are less than a few hundred mill amperes.
- The X-ray tube for operation requires a high voltage DC source and a low AC voltage source for filament heating.
- Since control on the high voltage side is not convenient, the controls are incorporated on the low voltage side of the step-up transformer.
- The filament heating current is obtained from a low voltage AC, obtained by stepping down from the mains supply.
- For medical applications, particularly in diagnostic procedures, only short bursts of X-ray are used for photographing images.
- A longer duration of radiation may be required for screening and therapy.
- Therefore, a timing unit and switches operated by the timing unit are provided so that the duration of the X-ray beam can be controlled.
- Figure 2 shows schematically the X-ray generating system.
- Thus, there are three different controls on the control panel of an X-ray machine.
- The tube voltage expressed in KVP (Kilovolts-peak), determine the hardness or penetration power of the X-ray beam.
- The beam current, expressed in milli amperes (mA), determines the intensity of the X-ray beam.
- The third control determines the time (expressed in seconds) that the beam is turned on for X-ray photos.

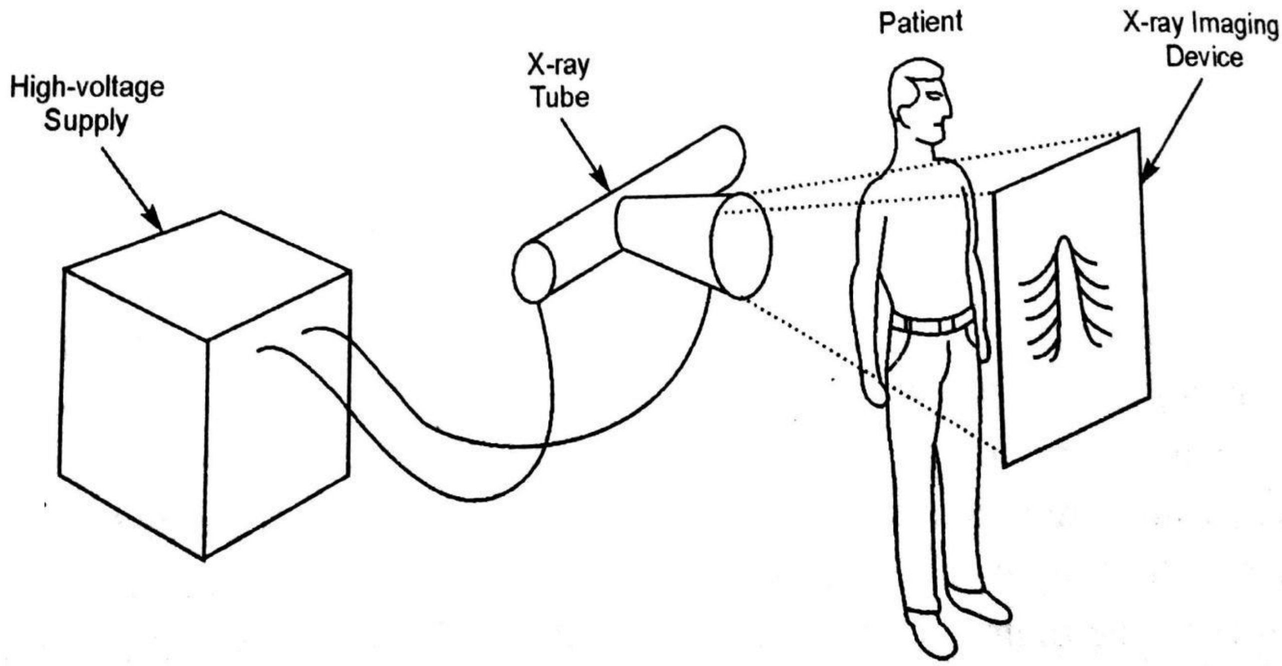


Figure 12: The use of X-rays to visualize the inner structure of the body

- As shown in the figure 3, the region of the body to be imaged is positioned between the X-ray tube and the imaging device.
- The X-ray tube projects the ―shadow‖ of the structures inside the body on the imaging device.
- For the image to be sharp, the part of the body being X-rayed must be as close as possible to the imaging device while the X-ray tube is positioned as far as possible.
- The instantaneous picture obtained is useful for a number of diagnostic purposes, but does not allow a study of the dynamics of the living system.
- For a study of the dynamics of the system, low intensity X-rays must be used.
- The beam, after passing through the part to be examined, strikes a fluorescent screen.
- The fluorescent material emits visible light when the X-ray beam strikes and as a result the image becomes visible to naked eye.
- Two techniques have been developed to eliminate the difficulty of reduced image intensity and contrast.
- The techniques are image intensification and television fluoroscopy.
- Both utilize an image intensification procedure.

FLUOROSCOPY

- The primary function of a fluoroscope is to perform dynamic studies; that is, the fluoroscope is used to visualize the motion of internal structures and fluids.
- The purpose of this technique is to get real time and moving images of the insides of a person by way of the fluoroscope.
- If something is observed that the radiologist would like to preserve for later study, a radiograph can be made with little interruption of fluoroscopic examination. Such radiograph is known as spot film.

COMPONENTS OF FLUOROSCOPE

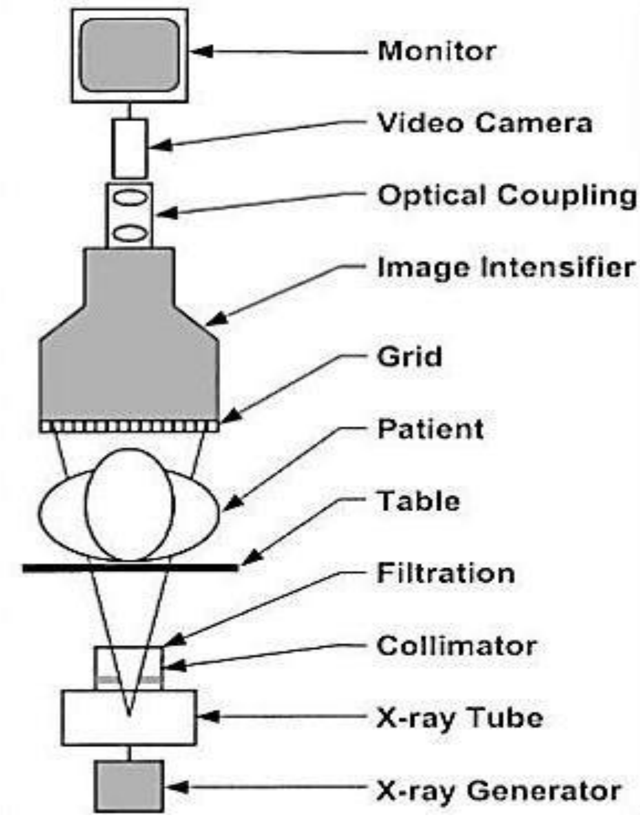
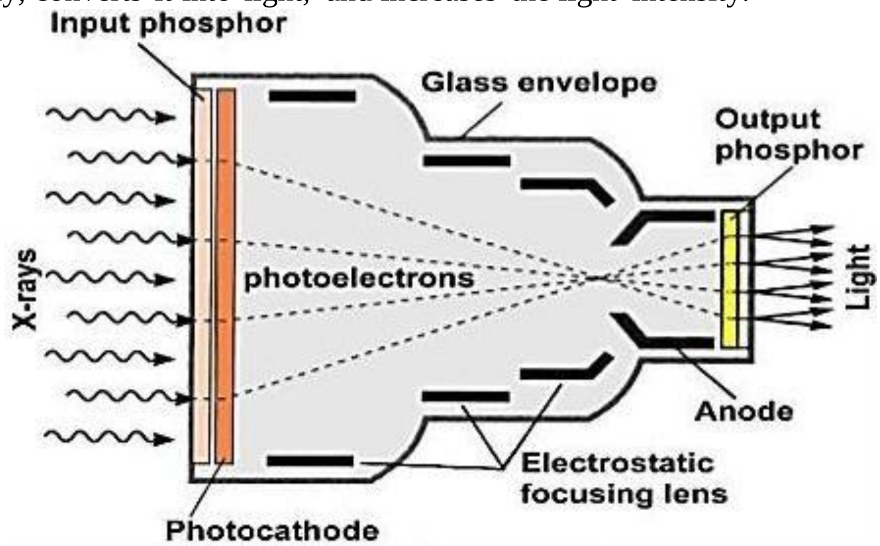


IMAGE INTENSIFIER

- The image intensifier is a complex electronic device that receives the X-Ray beam from the human body, converts it into light, and increases the light intensity.



- **Glass envelope** maintains tube vacuum to allow control of photoelectron flow. It has no functional part in image formation.
- X-Rays that exit from the patient are incident on the image intensifier tube are transmitted through the glass envelope and interact with the **input phosphor**, which is made up of Caesium iodide.
- When X-Rays interacts with the input phosphor, its energy is converted into a burst of visible light photons as occur on the intensifying screen.
- Photocathode is bonded directly to the input phosphor with a thin, transparent, adhesive layer. It is made up of caesium and antimony compounds that respond to the stimulation by light with the emission of electron. This process is known as photoemission.

- **Electrostatic focusing lenses** located along the tube, responsible for focusing the electrons across the tube from input to output phosphor.
- **Anode** is used to accelerate electrons across the tube.
- **Output phosphor** is usually made up of zinc cadmium sulphide crystals, and it converts all the photoelectrons into light.

OPTICAL COUPLING

- Coupling between two circuits by means of light beam or light pipe having transducers at opposite ends.

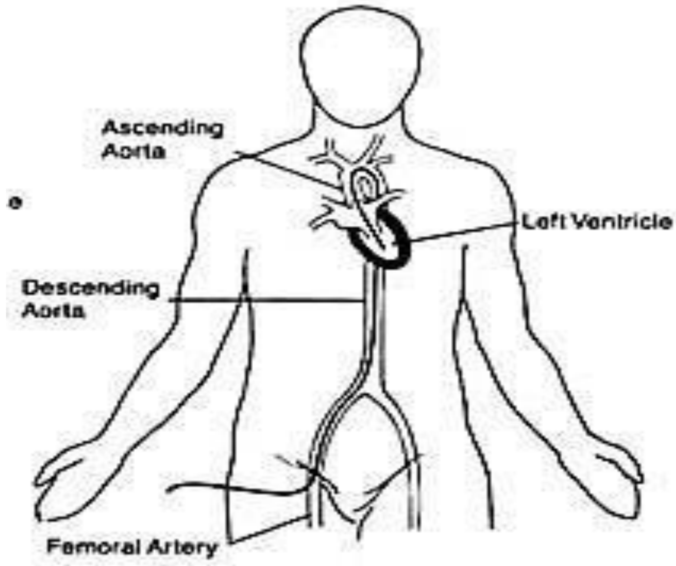
- The video signal from the video camera is amplified and is transmitted by cable to the television monitor, where it is transformed back into a visible image.
- The fluoroscopy machine takes a continuing stream of X-Ray images, approximately 25-30 images per second.
- Because fluoroscopy is an X-Ray machine, it has the same risks as other X-ray machine.

ANGIOGRAPHY

- Angiography is a type of X-ray used to check the blood vessels.
- Blood vessels don't show up clearly on a normal X-ray, so a special dye needs to be injected into your blood first.
- This highlights your blood vessels, allowing your doctor to spot any problems.
- The X-ray images created during angiography are called "angiograms".
- Angiography is carried out in a hospital X-ray or radiology department.
- **or the test:** you'll usually be awake, but may be given a medication called a sedative to help you relax.
- You lie down on a table and a small cut is made over one of your arteries, usually near your groin or wrist – local anaesthetic is used to numb the area where the cut is made.
- A very thin flexible tube (catheter) is inserted into the artery.
- The catheter is carefully guided to the area that's being examined (such as the heart).
- A dye (contrast medium) is injected into the catheter.
- A series of X-rays are taken as the dye flows through your blood vessels.
- The test can take between 30 minutes and two hours. You'll usually be able to go home a few hours afterwards.
- There are several different types of angiogram, depending on which part of the body is being looked at.
- Common types include:
- Coronary angiography – to check the heart and nearby blood vessel
- Cerebral angiography – to check the blood vessels in and around the brain
- Pulmonary angiography – to check the blood vessels supplying the lungs
- Renal angiography – to check the blood vessels supplying the kidneys

PROCEDURE:

- You'll be asked to change into a hospital gown and lie down on a special table.
- A small cut is made in the skin over one of your arteries, usually near your groin (femoral artery) or wrist (radial artery) – local anaesthesia is given to the area so it doesn't hurt.
- A long, thin, flexible tube (catheter) is inserted into the artery and is carefully guided to the area being examined – you may feel some pushing and pulling when this is done, but it shouldn't be painful.
- A special dye (contrast agent) is injected through the catheter – you may feel warm, flushed.
- A series of X-rays are taken as the dye flows through your blood vessels.



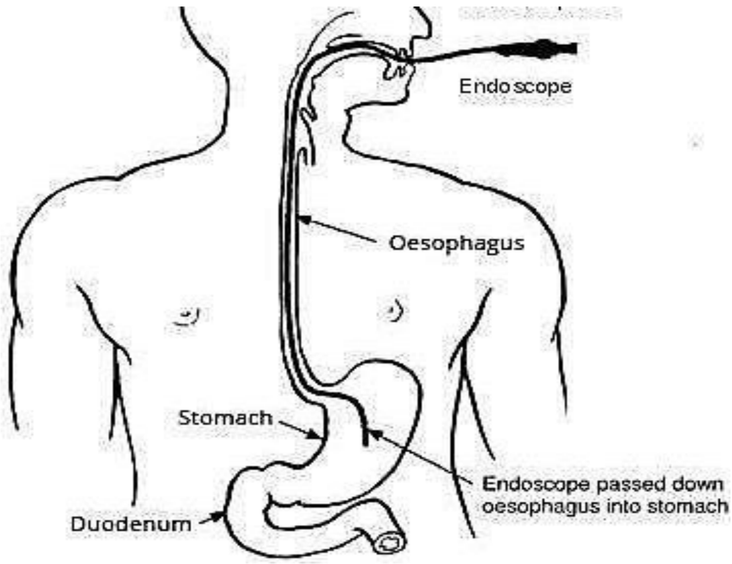
- Once the procedure is finished, the catheter is removed and a plastic cuff is placed on the cut to stop any bleeding. Stitches aren't needed.
- After the test, you'll be taken to a recovery ward where you'll be asked to lie still for a few hours to prevent bleeding from the cut.
- You'll usually be able to go home the same day, although sometimes you may need to stay in hospital overnight.
- It may be possible to tell you the results of the test before you go home, but often the X-rays need to be studied in detail and the results are not available for a few weeks.
- You can usually return to most normal activities the next day, although you may need to avoid heavy lifting and strenuous exercise for a few days.

ENDOSCOPY

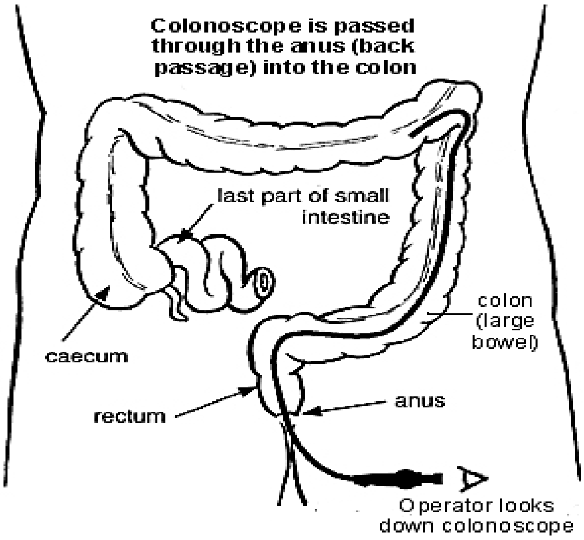
- Endoscopy is the insertion of a long, thin tube directly into the body to observe an internal organ or tissue in detail.
- It can also be used to carry out other tasks including imaging and minor surgery.
- Endoscopes are minimally invasive and can be inserted into the openings of the body such as the mouth or anus.
- Alternatively, they can be inserted into small incisions, for instance, in the knee or abdomen. Surgery completed through a small incision and assisted with special instruments, such as the endoscope, is called keyhole surgery.
- Because modern endoscopy has relatively few risks, delivers detailed images, and is quick to carry out, it has proven incredibly useful in many areas of medicine.
- Today, tens of millions of endoscopies are carried out each year.
- Endoscopies are quick and relatively safe procedures.
- The first endoscope was designed in 1806.
- The main reasons for endoscopy are investigation, confirmation, and treatment.
- Endoscopy can be used to remove tumours or polyps from the digestive tract.

List of the major types of endoscopy

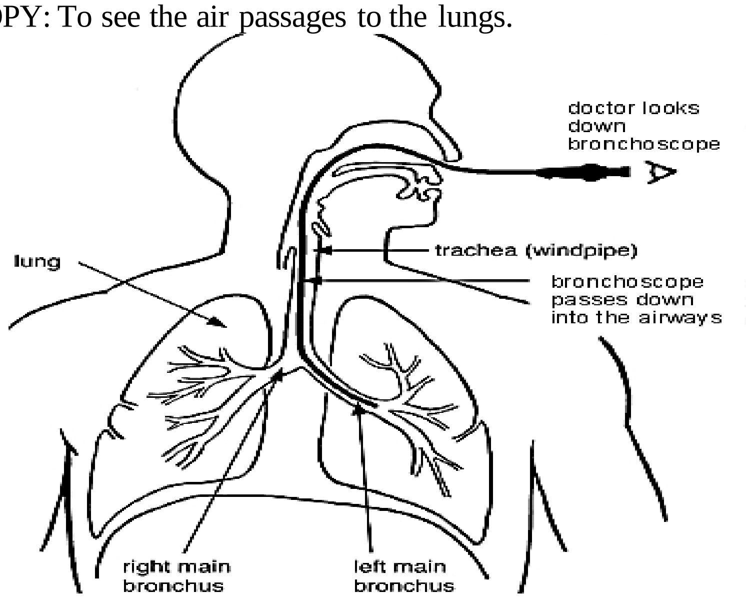
- GASTROSCOPY: To see the stomach and upper small intestine.



- COLONOSCOPY: To see the large intestine.



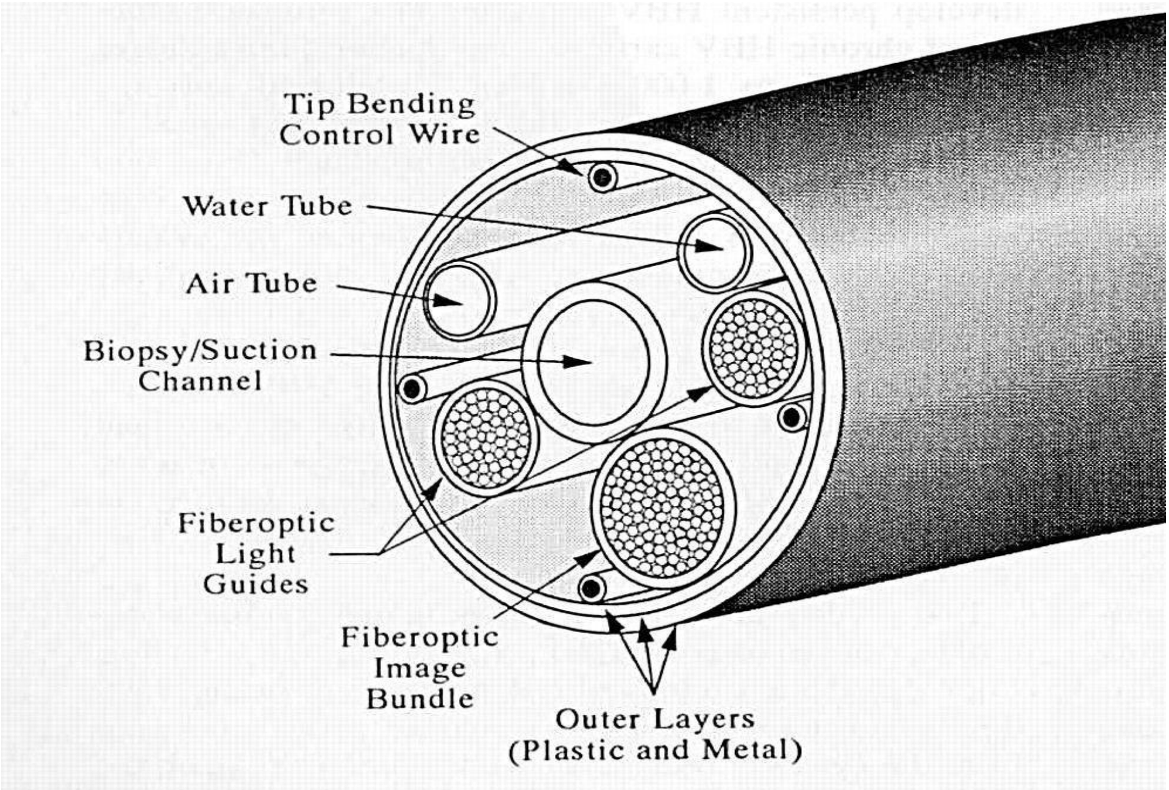
- LAPAROSCOPY: To see the "stomach cavity" and the organs therein.
- CYSTOSCOPY: To see the urinary bladder.
- BRONCHOSCOPY: To see the air passages to the lungs.



- LARYNGOSCOPY: To see the larynx or voice box.
- NASOPHARYNGOSCOPY: To see the nose and related cavities.
- ARTHROSCOPY: To see inside joints such as the knee joint.
- THORACOSCOPY: To see inside the chest cavity.

ENDOSCOPY PRINCIPLE

- Endoscope may have rigid or flexible tube inserted into the body.
- It has ability to looking inside the body using a variety of very small cameras attached to flexible or rigid tube.
- It facilitates direct viewing the interior of an organ is often very helpful in determining the cause of a problem.
- An endoscope is flexible tube equipped with lenses and a light source.
- Illumination is done by the help of a number of optical fibers.
- Video endoscopy performed by attaching in microchip camera at the insertion tube, setup image is viewed on a video monitor.



DISTAL TIP OF INSERTION TUBE

- **Biopsy/or suction channel:** It is used for suction of sample tissue. May be needed to remove or may for diagnostic purposes.
- **Fiber optic light guide:** They act as a light source.
- **Fiber optic image bundle/Objective lens:** Allows visualisation of the inside part of internal organs.
- **Air nozzle:** To blow air.
- **Water nozzle:** To clear the lens.
- **Water jet nozzle:** Water introduced with a syringe through the forward water jet connector comes to this port and gives a more powerful blast of water.

DIATHERMY

- High frequency currents, apart from their usefulness for therapeutic applications, can also be used in operating rooms for surgical purposes involving cutting and coagulation.
- The frequency of currents used in surgical diathermy units is in the range of 1-3 MHz in contrast with much higher frequencies employed in short wave therapeutic diathermy machines.
- This frequency is quite high in comparison with that of the 50Hz mains supply.
- This is necessary to avoid the intense muscle activity and the electrocution (death caused by electric current passing through the body) hazards which occur if lower frequencies are employed.
- For their action, surgical diathermy machines depend on the heating effect of electric current.

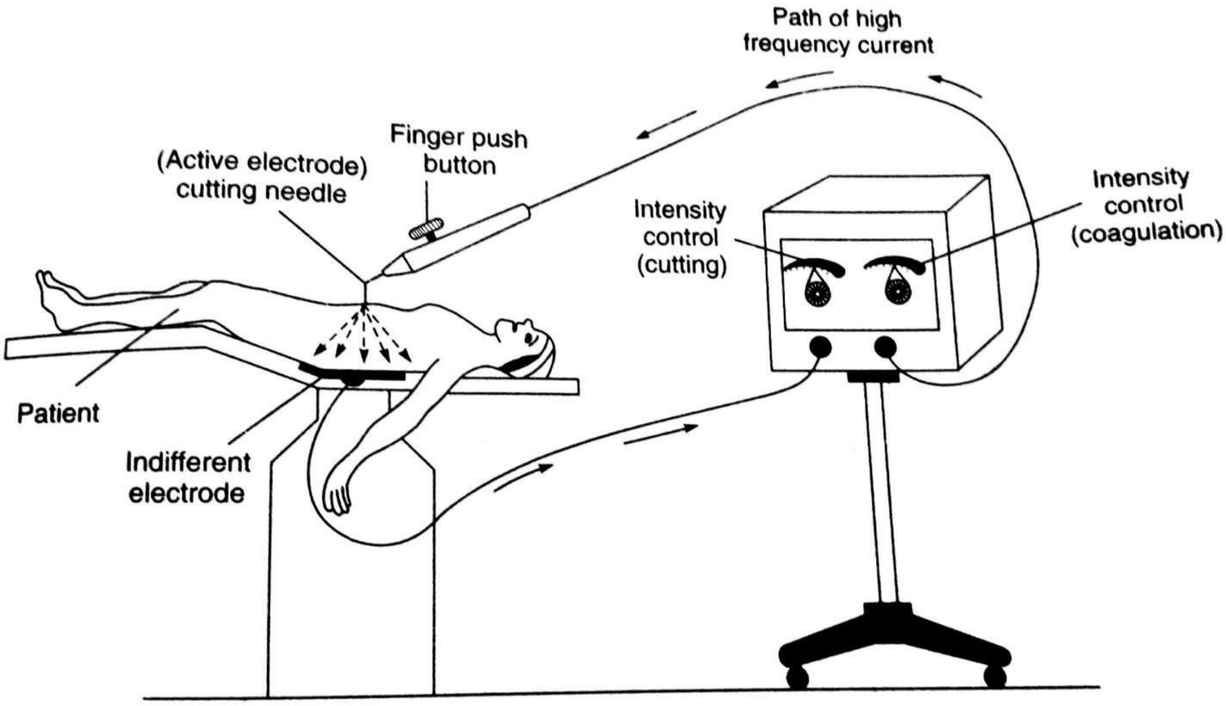


Figure 13: Principle of Surgical diathermy machine

- When high frequency current flows through the sharp edge of a wire loop or band loop or the point of a needle into the tissue , there is high concentration of current at this point.
- The tissue is heated to such an extent that the cells which are immediately under the electrode, are torn apart by the boiling of the cell fluid.
- The indifferent electrode establishes a large area contact with the patient and the RF current is therefore, dispersed so that very little heat is developed at this electrode.
- This type of tissue separation forms the basis of **electro-surgical cutting**.
- There are various electro-surgery techniques using diathermy unit.

I. ELECTROTOMY

- When the electrode is kept above the skin, an electrical arc is sent.
- The developed heat produces a wedge shaped narrow cutting of the tissue on the surface.
- By increasing the current level, deeper level cutting of the tissue takes place.
- Normally continuous RF current is used for cutting

II. COAGULATION

- When the electrode is kept near the skin, high frequency current is sent through the tissue in the form of bursts and heating it locally so that it coagulates from inside.

- The concurrent use of continuous RF current for cutting and a RF wave burst for coagulation is called **Haemostasis.**

III. FULGURATION

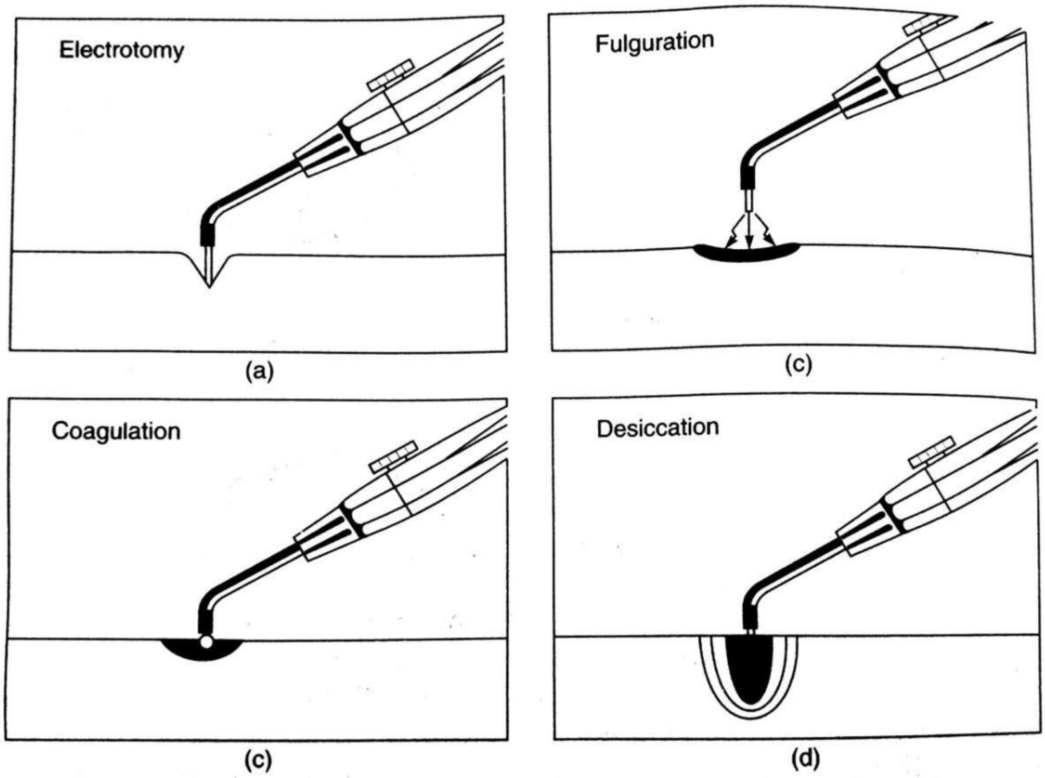
- By passing sparks from a needle or a ball electrode of small diameter to the tissue, the developed heat dries out the superficial tissue without affecting deep-seated tissues.
- This is caled _Fulguration' in which the electrode is held near the tissue without touching it and due to the passage of the electric arc, the destruction of superficial tissue takes place.
- Thus it is related to the localised surface level destruction of the tissues.

IV. DESICCATION

- The needle point electrodes are stuck into the tissue and kept steady while passing electric current.
- This is caled _desiccation' which produces dehydration in the tissues.

V. BLENDING

- When the electrode is kept above the skin, the separated tissues or nerves can be welded or combined together by an electric arc. This is called blending.



- Figure given below shows various types of electro surgery techniques that are commonly employed in practice.

Figure 14: Various types of electro-surgery techniques commonly employed in practice

COMPUTED TOMOGRAPHY

- There are two main limitations of using conventional X-rays to examine internal structures of the body.
- Firstly, the super imposition of the 3-dimensional information onto a single plane makes diagnosis confusing and often difficult.
- Secondly, the photographic film usually used for making radiographs has a limited dynamic range and, therefore, only objects that have large variations in X-ray absorption relative to their surroundings will cause sufficient contrast differences on the film to be distinguished by the eyes.

- Thus, the details of bony structures can be clearly seen, it is difficult to identify the shape and composition of soft tissue organs accurately.
- In such situations, growths and abnormalities within tissue only show a very small contrast difference on the film and consequently, it is extremely difficult to detect them.
- The problem becomes even more serious while carrying out studies of the brain due to its overall shielding of the soft tissue by the dense bone of the skull.
- Various techniques have been applied in an effort to overcome these limitations, but the most powerful technique which has shown dramatic results is computed tomography.
- Tomography is a term derived from the Greek word ‗tomos', meaning ‗to write a slice or section' and is wel understood in radiographic circles.
- Conventional tomography was developed to reduce the super-imposition effect of simple radiographs.
- In this arrangement, the X-ray tube and photographic film are moved in synchronization so that one plane of the patient under examination remains in focus, while all other planes are blurred.
- In computed tomography (CT), the picture is made by viewing the patient via X-ray imaging from numerous angles, by mathematically reconstructing the detailed structures and displaying the reconstructed image on a video monitor.
- Computed tomography enabled radiologists to distinguish, for the first time, between different types of brain tissue, and even between normal and coagulated blood.
- With CT images, radiologists could easily visualize the ventricles of the brain and repositories of the cerebro-spinal fluid.

BASIC PRINCIPLE AND IMAGE RECONSTRUCTION

- Computed tomography (CT) scanning, also known as computerized axial tomography (CAT) scanning, is a diagnostic imaging procedure that uses X-rays to build cross-sectional images ("slices") of the body.
- Cross-sections are reconstructed from measurements of attenuation coefficients of X-ray beams in the volume of the object studied.
- CT is based on the fundamental principle that the density of the tissue passed by the X-ray beam can be measured from the calculation of the attenuation coefficient.
- Using this principle, CT allows the reconstruction of the density of the body, by two-dimensional section perpendicular to the axis of the acquisition system.
- The CT X-ray tube emits N photons (monochromatic) per unit of time.
- For monochromatic X-ray beam, the tissue attenuation characteristics can be described by,

$$I_t = I_o e^{-\mu x}$$

Io = Incident radiation intensity
It = Transmitted intensity
x = Thickness of tissue
μ = Characteristic attenuation coefficient of tissue

- Attenuation values of the X-ray beam are recorded and data used to build a 3D representation of the scanned object/tissue.
- Unlike X-ray radiography, the detectors of the CT scanner do not produce an image. They measure the transmission of a thin beam (1-10mm) of X-rays through a full scan of the body. The image of that section is taken from different angles, and this allows retrieving the information on the depth (in the third dimension).
- In order to obtain tomographic images of the patient from the data in "raw" scan, the computer uses complex mathematical algorithms for image reconstruction.

- The image by the CT scanner is a digital image and consists of a square matrix of elements (pixel), each of which represents a voxel (volume element) of the tissue of the patient.
- In conclusion, a measurement made by a detector CT is proportional to the sum of the attenuation coefficients.
- The typical CT image is composed of 512 rows, each of 512 pixels, i.e., a square matrix of 512 x 512 = 262144 pixels (one for each voxel).

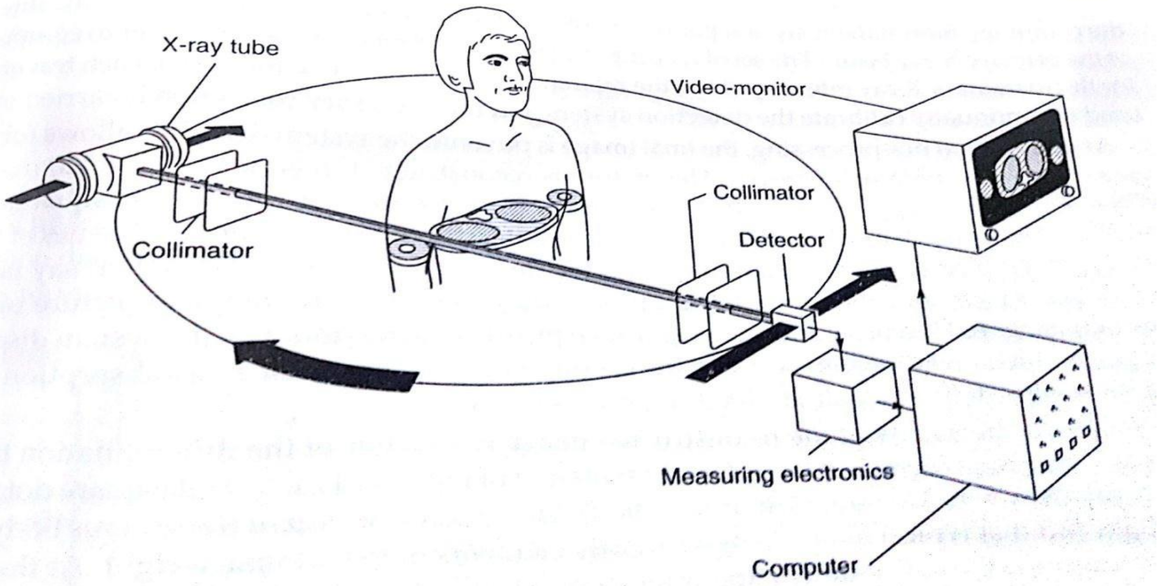


Figure 15: The technique of producing CT images

SYSTEM COMPONENTS

- **Scanning system:** This takes suitable readings for a picture to be reconstructed, and includes X-ray source and detectors.
- **Processing unit:** This converts these readings into intelligible picture information.
- **Viewing part:** It presents this information in visual form and includes other manipulative aids to assist diagnosis.
- **Storage unit:** This enables the information to be stored for subsequent analysis.

MAGNETIC RESONANCE IMAGING & NUCLEAR MEDICINE SYSTEM

- Clinical magnetic resonance imaging (clinical MRI) is an imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body in both health and disease.
- MRI scanners use strong magnetic fields, radio waves, and field gradients to generate images of the organs in the body.
- MRI does not involve x-rays, which distinguishes it from computed tomography (CT or CAT).
- While the hazards of x-rays are now well-controlled in most medical contexts, MRI still may be seen as superior to CT in this regard.
- MRI is widely used in hospitals and clinics for medical diagnosis, staging of disease and follow-up without exposing the body to ionizing radiation.
- MRI often may yield different diagnostic information compared with CT. There may be risks and discomfort associated with MRI scans.
- Compared with CT, MRI scans typically take greater time, are louder, and usually require that the subject go into a narrow, confining tube.
- In addition, people with some medical implants or other non-removable metal inside the body may be unable to undergo an MRI examination safely.
- MRI was originally called 'NMRI' (nuclear magnetic resonance imaging).

- It is based upon the science of nuclear magnetic resonance (NMR).
- Certain atomic nuclei are able to absorb and emit radio frequency energy when placed in an external magnetic field.
- In clinical and research MRI, hydrogen atoms are most often used to generate a detectable radio-frequency signal that is received by antennas in close proximity to the anatomy being examined.
- Hydrogen atoms exist naturally in people and other biological organisms in abundance, particularly in water and fat.
- For this reason, most MRI scans essentially map the location of water and fat in the body. Pulses of radio waves excite the nuclear spin energy transition, and magnetic field gradients localize the signal in space.
- By varying the parameters of the pulse sequence, different contrasts may be generated between tissues based on the relaxation properties of the hydrogen atoms therein.
- To perform a study, the person is positioned within an MRI scanner that forms a strong magnetic field around the area to be imaged.
- In most medical applications, protons (hydrogen atoms) in tissues containing water molecules create a signal that is processed to form an image of the body.
- First, energy from an oscillating magnetic field temporarily is applied to the patient at the appropriate resonance frequency.
- The excited hydrogen atoms emit a radio frequency signal, which is measured by a receiving coil.
- The radio signal may be made to encode position information by varying the main magnetic field using gradient coils.
- As these coils are rapidly switched on and off they create the characteristic repetitive noise of an MRI scan.
- The contrast between different tissues is determined by the rate at which excited atoms return to the equilibrium state.
- Exogenous contrast agents may be given to the person to make the image clearer.
- The major components of an MRI scanner are: the main magnet, which polarizes the sample, the shim coils for correcting inhomogeneities in the main magnetic field, the gradient system which is used to localize the MR signal and the RF system, which excites the sample and detects the resulting NMR signal. The whole system is controlled by one or more computers.

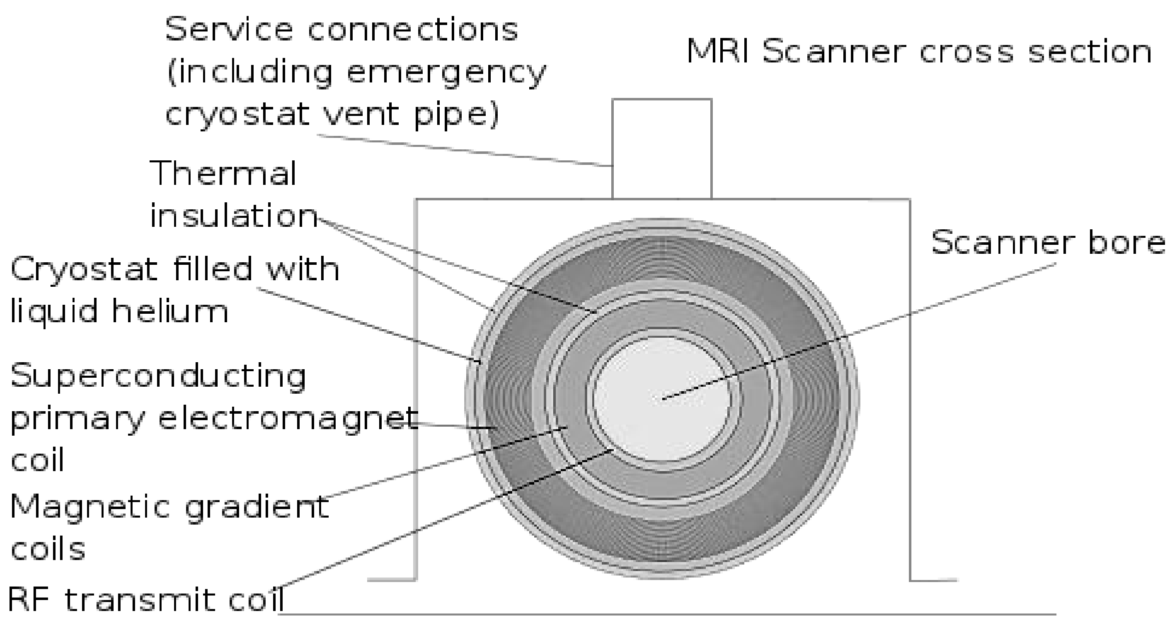
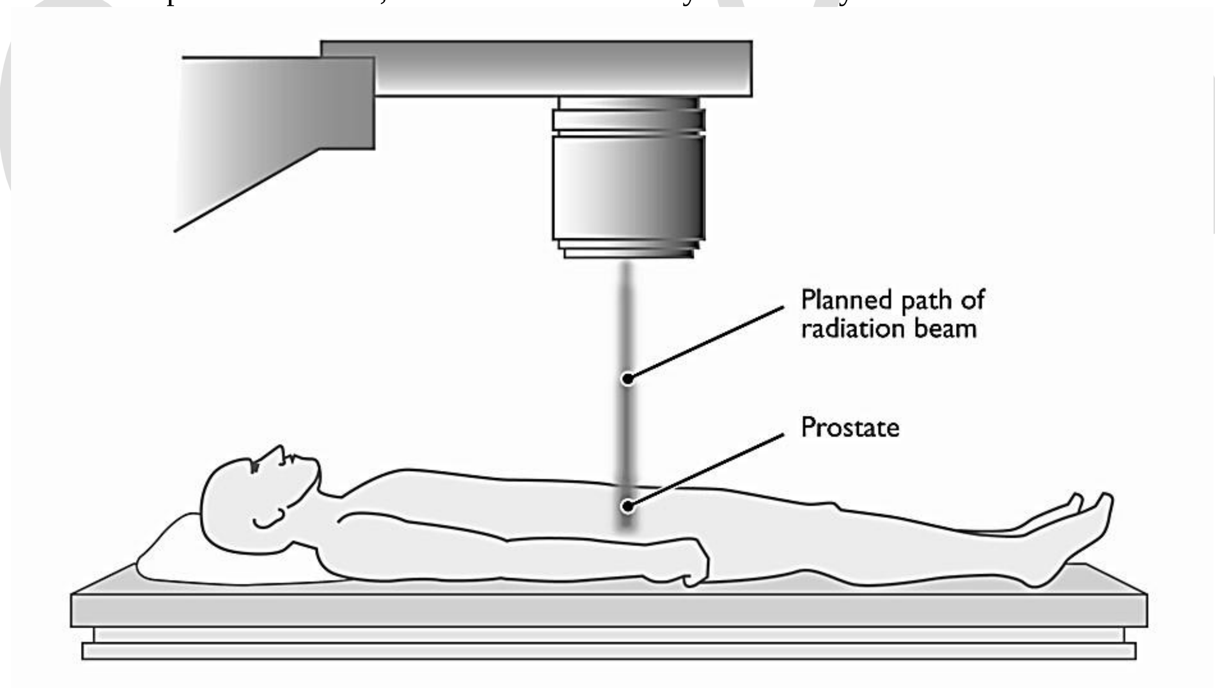


Figure 16: Schematic of construction of a cylindrical superconducting MR scanner.

MODULE 5

RADIATION THERAPY

- In radiation therapy (also called radiotherapy), invisible high-energy rays or beams of subatomic particles are used to damage cancer cells and can stop them from growing and dividing.
- This ultimately can kill the cancer cells treated with radiation.
- A specialist in radiation therapy is called a radiation oncologist.
- Like surgery, radiation therapy can be a local treatment; it affects cancer cells only in the treated area.
- If the area treated is broader, we say it is then a regional treatment.
- Rarely, the whole body is given radiation therapy for a systemic or total-body effect.
- Radiation can come from a machine (external radiation).
- It can also come from an implant (a small container of radioactive material) placed (either temporarily or permanently) directly into or near the tumor (internal or interstitial radiation).
- Some patients receive both kinds of radiation therapy.
- External radiation therapy is usually given on an outpatient basis in a hospital or clinic with specialized equipment 5 days a week for a number of weeks.
- Patients are not radioactive during or after the treatment with external beam radiation therapy.
- For internal radiation therapy, the patient often stays in the hospital for a few days.
- The implant may be temporary or permanent. Because the level of radiation is highest during the hospital stay, patients may not be able to have visitors or may have visitors only for a short time.
- Once an implant is removed, there is no radioactivity in the body.



Short-term side effects

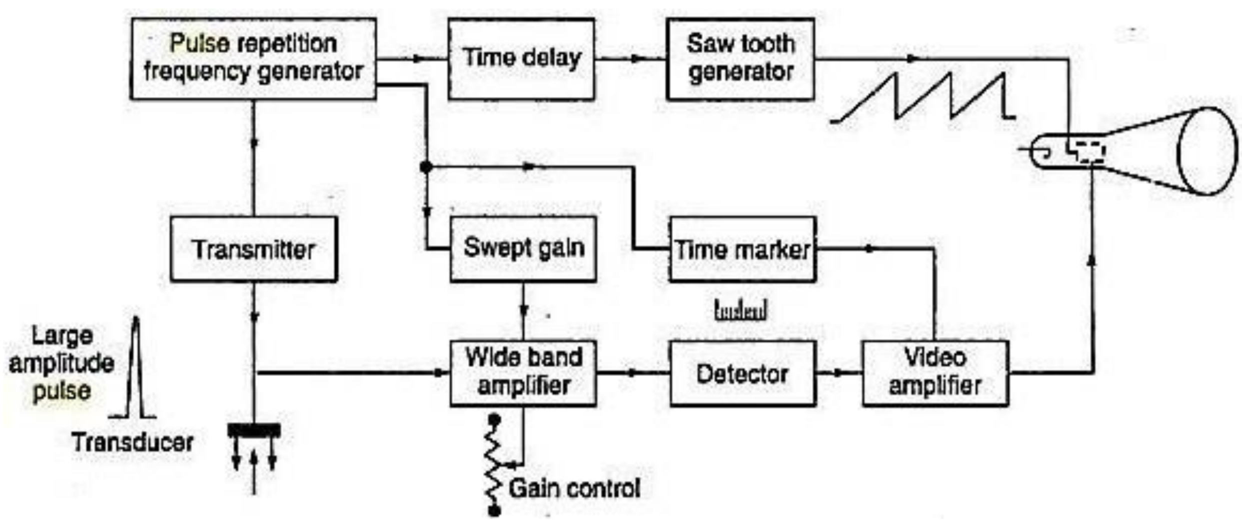
- Short-term effects of radiation treatment can include the following:
- Fatigue or lethargy
- Skin irritation, including swelling, blisters, and a sunburned or tanned appearance
- Effects specific to the area of treatment, such as hair loss, urinary problems, vomiting, and diarrhea
- Tissue inflammation and hepatitis
- Rarely, a drop in the number of white blood cells or platelets

Long-term side effects

- Long-term effects also depend on the site of treatment and can include:
- Stiffening and restricted movement: After neck therapy, for example, the jaw can stiffen. This can occur as a result of tissue scarring. Exercises may be advised after cancer surgery and radiation therapy to help loosen movement.
- Skin effects: These include delayed wound healing and a spidery red or purple appearance caused by dilated capillary blood vessels.
- Diarrhea and bleeding: These can occur as a result of bowel damage when the abdomen receives radiation therapy.
- Hormone problems: These can include hypopituitarism or hypothyroidism, dry mouth, memory loss, and infertility.
- A second cancer caused by radiation exposure: The risk of recurrence of the cancer being treated is higher than the risk of a new cancer being caused by radiation therapy.

ULTRASONIC IMAGING SYSTEMS

- Ultrasound is a form of energy which consists of mechanical vibrations and the frequencies of which are so high that they are above the range of human hearing.
- Most biomedical applications of ultrasound employ frequencies in the range 1 to 15 MHz.
- Velocities of ultrasound in soft tissues and bones are 1570 m/s and 3600 m/s respectively.
- Now-a-days ultrasonic diagnostic aids and ultrasonic therapeutic aids are very popular.
- Ultrasonic diagnostic aids are based on the echo aspect and the Doppler shift aspect.
- Ultrasonic therapeutic aids are based on the thermal effects and cavitation effects developed during the irradiation of ultrasound on the body.
- Ultrasonography is a technique by which ultrasonic energy is used to detect the state of the internal body organs.
- Bursts of ultrasonic energy are transmitted from piezoelectric transducer through the skin and into internal anatomy.
- When this energy strikes an interface between two tissues of different acoustical impedance, reflections (echoes) are returned to the transducer.
- The transducer converts these reflections to an electrical signal.
- This electrical signal is amplified and displayed on an oscilloscope at a distance proportional to the depth of the interface.
- Ultrasonic diagnosis differs from X-ray diagnosis in that no shadow images are normally obtained and the cross sectional or linear images are obtained through parts of the body.
- Ultrasonic imaging is safe since ultrasonography uses mechanical energy at a level which is not harmful to human tissues.
- So the ultrasonography is called a non-invasive technique.



- The transmitter generates a train of short duration pulses at a repetition frequency determined by the Pulse Repetition Frequency (PRF) generator.
- These are converted into corresponding pulses of ultrasonic waves by a piezoelectric crystal acting as the transmitting transducer.
- The echoes from the target or discontinuity are picked up by the same transducer and amplified suitably for display on a cathode ray tube.
- **Probe:**
- The probes are designed to achieve the highest sensitivity and penetration, optimum focal characteristics and the best possible resolution.
- This requires that the acoustic energy be transmitted efficiently into the patient.
- It is thus desirable to reduce the amount of reflected acoustic energy at the transducer-body interface.
- The single quarter wavelength matching layer accomplishes this by interposing a carefully chosen layer of material between the transducer's piezo-electric element and body tissue.
- A material with an acoustic impedance between tissue and piezo-electric ceramic is selected to reduce the level of acoustic mismatch at the transducer body interface.
- **Pulse Repetition Frequency Generator:**
- This unit produces a train of pulses which control the sequence of events in the rest of the equipment.
- The PRF is usually kept between 500 Hz to 3 KHz.
- The width of the output pulse from the PRF generator should be very small, preferably of the order of a micro-second, to generate short duration ultrasonic pulse.
- It is a practice to use one astable circuit to generate a train of pulses with the required frequency and then to use them to trigger a mono-stable multi-vibrator which produces pulses of the required width.
- **Transmitter**
- The transmitting crystal is driven by a pulse from the PRF generator and is made to trigger an SCR circuit which discharges a capacitor through the piezo-electric crystal in the probe to generate an ultrasonic signal.
- **Receiver**
- The function of the receiver is to obtain the signal from the transducer and to extract from it the best possible representation of an echo pattern.
- **Wide band amplifier**
- The echo-signals received at the receiving transducer are in the form of modulated carrier frequency and may be as small as a few microvolts.
- These signals require sufficient amplification before being fed to a detector circuit for extracting modulating signals which carry the useful information.
- This is achieved in a wide-band amplifier, which is wide enough to faithfully reproduce the received echoes.
- **Swept gain control**
- The receiving amplifier can only accept a limited range of input signals without overloading and distortion.
- Abrupt changes in tissue properties that shift the acoustical impedance can cause the echo amplitudes to vary over a wide dynamic range, perhaps 40 to 60.
- In order to avoid this, the amplifier gain is adjusted to compensate for these variations.
- This gain adjustment is controlled with swept gain control.
- **Detector**
- After the amplification, the echo signals are rectified in the detector circuit.
- The detector employed could be conventional diode-capacitor type with an inductive filter to have additional filtering of the carrier frequency.

- In this rectification process, the negative half cycles in the echo voltage waveforms are converted into positive half cycles.
- This is followed by a demodulation circuit.
- The output of the demodulator circuit is in the form of an envelope of the echo signal.
- That output is the information desired, that is the amplitude of the echo signal and its time delay from the transmission pulse.
- **Video amplifier**
- The signal requires further amplification after its demodulation in the detector circuit before it can be given to they-plates of the CRT.
- The output of the detector circuit is typically around 1V, but for display on the CRT, the signal must be amplified to about 100 to 150 V.
- The most commonly used video amplifier is the RC coupled type, having an inductance in series with the collector load.
- **Time delay unit**
- The time delay unit is sometimes required for special applications.
- In special cases, if desired, the start of the trace can be delayed by the time delay unit so that the trace can be expanded to obtain better display and examination of a distant echo.
- **Time marker**
- The time marker produces pulses that are a known time apart and, therefore, correspond to a known distance apart in human tissues.
- **Display**
- After amplification in the video amplifier, the signal is given to the Y plates of the CRT.
- CRT is not only a fast-acting device but also gives a clear presentation of the received echo
- signals.

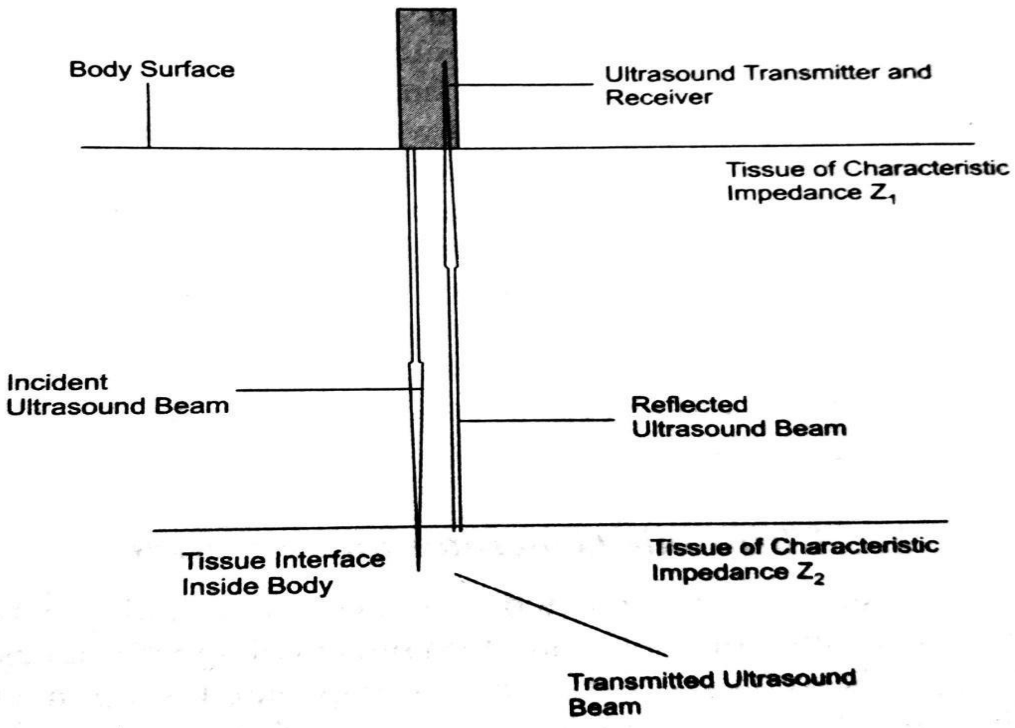


Fig 17: Ultrasonic Reflection and Transmission at Tissue Interface

MODULE 5

APPLICATIONS OF ULTRASONOGRAPHY

- In neurology to find any brain tumour
- In ophthalmology to find any foreign objects in eye
- In cardiology to determine the cross-section of the heart and to determine heart rate.
- In gynaecology to monitor the foetus growth and to indicate the presence of twins
- To identify the breast cancer

Syllabus

Magnetic Resonance Imaging – Basic NMR components, Biological effects and advantages of NMR imaging.
Biomedical Telemetry system: Components of biotelemetry system, application of telemetry in medicine, single channel telemetry system for ECG and temperature.
Patient Safety: Electric shock hazards, leakage current, safety codes for electro medical equipments

I. MAGNETIC RESONANCE IMAGING:

Magnetic Resonance Imaging (MR1) or Nuclear Magnetic Resonance (NMR) Tomography has emerged as a powerful imaging technique in the medical field because of its high resolution capability and potential for chemical specific imaging.

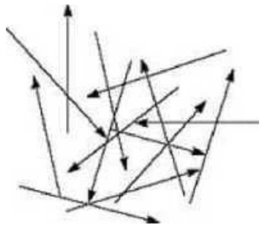
Comparison of NMR system and XRAY and CT

1. Similar to the X-ray computerized tomography (CT), MRI uses magnetic fields and radio frequency signals to obtain anatomical information about the human body as cross-sectional images in any desired direction and can easily discriminate between healthy and diseased tissue.
2. MRI images are essentially a map of the distribution density of hydrogen nuclei and parameters reflecting their motion, in cellular water and lipids.
3. The total avoidance of ionizing radiation, its lack of known hazards and the penetration of bone and air without attenuation make it a particularly attractive non-invasive imaging technique.
4. CT provides details about the bone and tissue structure of an organ whereas NMR highlights the liquid-like areas on those organs and can also be used to detect flowing liquids, like blood.
5. A conventional X-ray scanner can produce an image only at right angles to the axis of the body, whereas the NMR scanner can produce any desired cross-section, which offers a distinct advantage to and is a big boon for the radiologist.

Basic Principle

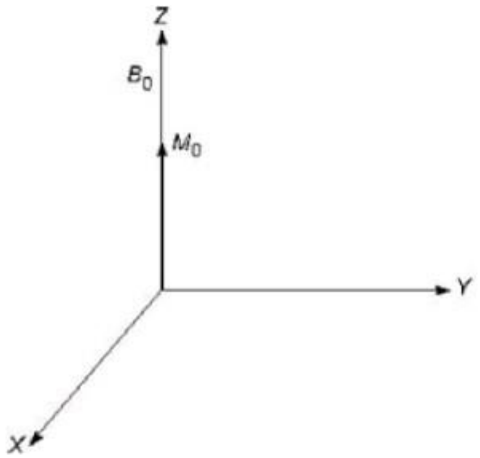
MR1 systems provide highly detailed images of tissue in the body. The systems detect and process the signals generated when hydrogen atoms, which are abundant in tissue, are placed in a strong magnetic field and excited by a resonant magnetic excitation pulse.

All materials contains nucleus that have a combination of protons and neutrons. It possesses a spin and the amount of spin give rise to a magnetic moment. The magnetic moment has a magnitude and direction. In tissues Magnetic moments of nuclei making up the tissue are randomly aligned and net magnetization=0.



Random alignment of magnetic moments of the nuclei making up the tissue, resulting in a zero net magnetization.

When a material is placed in a magnetic field B_0, some of the randomly oriented nuclei experience an external magnetic torque which tends to align the individual parallel or anti-parallel magnetic moments to the direction of an applied magnetic field. This gives a magnetic moment that accounts for the nuclear magnetic resonance signal on which the imaging is based. This moment is in the direction of applied magnetic field Bo. With the magnetic moments being randomly oriented with respect to one another, the components in the X-Y plane cancel one another out while the Z components along the direction of the applied magnetic field add up to produce this magnetic moment M_0 shown in Figure given below.



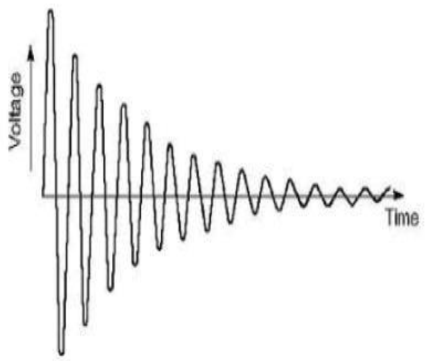
The application of external magnetic field causes the nuclear magnetic moments to align themselves, producing a net moment in the direction of the field B_0.

NMR Resultant Signal Pick up by the Instrument

- When a nucleus with a magnetic moment is placed in an externally applied magnetic field, the energy of the nucleus is split into lower (moment parallel with the field) and higher (anti-parallel) energy levels. The energy difference is such that a proton with specific frequency (energy) is necessary to excite a nucleus from the lower to die higher state.
- The excitation energy E obtained by the application of external RF signal, and is given by the Planck's equation
  $E = h\omega o$ Where h is Planck's constant. This energy is usually supplied by an RF magnetic field. ωo = Frequency of appied RF.
- The excited proton tends to return or relax to its low-energy state with spontaneous decay and re-emissions of energy at a later time Y in the form of radio wave photons. This decay is exponential in nature and produces a "**free induction decay" (FID**)

signal (Fig. below) that is the fundamental form of the nuclear signal obtainable from an NMR system.

- To summarize, if in a static field, RF waves of the right frequency are passed through the sample of interest (or tissue), some of the parallel protons will absorb energy and be stimulated or excited to a higher energy in the anti-parallel direction. Sometime later, the RF frequency absorbed will be emitted as electromagnetic energy of the same frequency as the RF source. The amount of energy required to flip protons from the parallel to the anti-parallel orientation is directly related to the magnetic field strength; stronger fields require more energy or higher frequency radiation. This is picked up by the instrument and then processed.

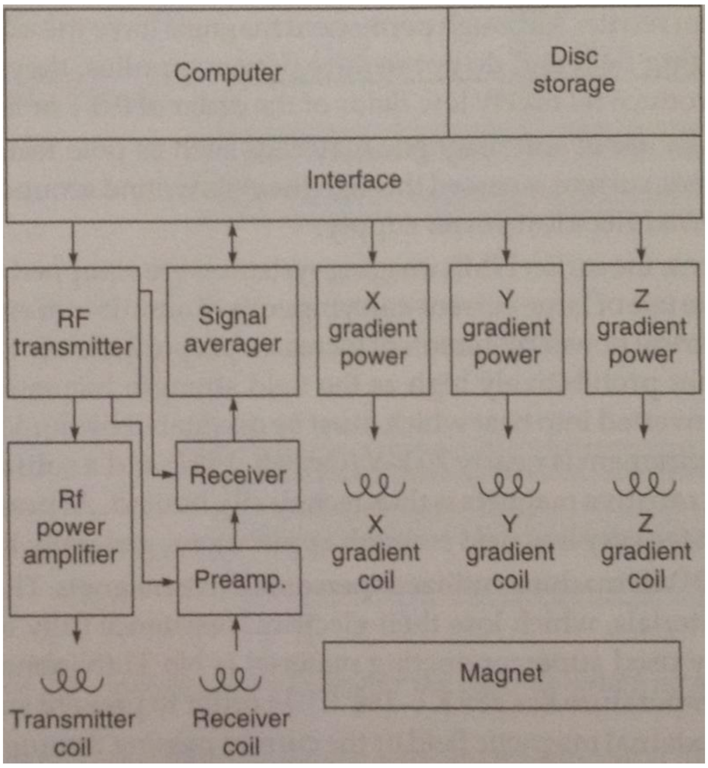


Free induction decay (FID) signal obtained in NMR experiments

BASIC NMR COMPONENTS

The basic components of an NMR imaging system are shown in Fig. These are:

1. **Magnet:** Provides a strong uniform, steady, magnet field B_0.
2. **RF transmitter**, which delivers radio-frequency magnetic field to the sample.
3. **Gradient system**, which produces time-varying magnetic fields of controlled spatial non-uniformity;
4. **Detection System**, which yields the output signal; and
5. **Imager system**, including the computer, which reconstructs and displays the images.



1. Imager System

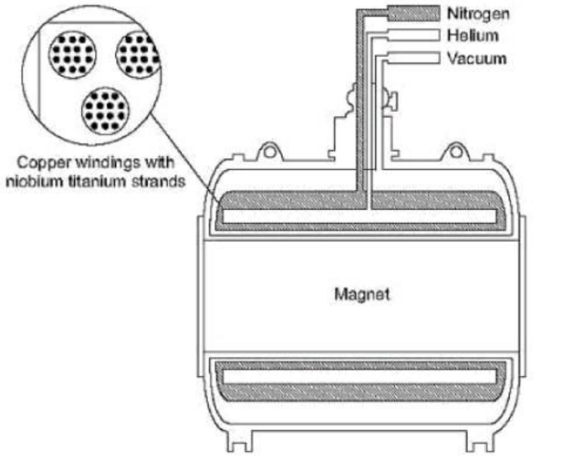
- The imaging sequencing in the system is provided by a computer. Functions such as gates and envelopes for the NMR pulses, blanking for the pre-amplifier and RF power amplifier and voltage waveforms for the gradient magnetic fields are all under software control.

- The computer also performs the various data processing tasks including the Fourier transformation, image reconstruction, data filtering, image display and storage. Therefore, the computer must have sufficient memory and speed to handle large image arrays and data processing, in addition to interfacing facilities.

2. The Magnet:

- In magnetic resonance tomography, the base field must be extremely uniform in space and constant in time as its purpose is to align the nuclear magnets parallel to each other in the volume to be examined.
- Also, the signal-to-noise ratio increases approximately linearly with the magnetic field strength of the basic field, therefore, it must be as large as possible.
- Four factors characterize the performance of the magnets used in MR systems; viz., field strength, temporal stability, homogeneity and bore size.
- The gross non-homogeneities result in image distortion while the bore diameter limits the size of the dimension of the specimen that can be imaged.
- Such a magnetic field can be produced by means of four different ways, viz., permanent magnets, electromagnets, resistive magnets and super-conducting magnets.
- **Permanent Magnet:** In case of the permanent magnet, the patient is placed in the gap between a pair of permanently magnetized pole faces. Permanent magnet materials normally used in MRI scanners include high carbon iron alloys such as alnico or neodymium iron.. Although permanent magnets have the advantages of producing a relatively small fringing field and do not require power supplies, they tend to be very heavy (up to 100 tons) and produce relatively low fields of the order of 0.3 T or less.

- **Electromagnets:** Make use of soft magnetic materials such as pole faces which become magnetized only when electric current is passed through the coils wound around them. Electromagnets obviously require external electrical power supply.
- **Resistive magnets**: make use of large current-carrying coils of aluminium strips or copper tubes. In these magnets, the electrical power requirement increases proportionately to the square of the field strength which becomes prohibitively high as the field strength increases. Moreover, the total power in the coils is converted into heat which must be dissipated by liquid cooling.
- **Superconductive magnets.** Most of the modem NMR machines utilize superconductive magnets. These magnets utilize the property of certain materials, which lose their electrical resistance fully below a specific temperature. The commonly used superconducting material is Nb Ti (Niobium Titanium) alloy for which the transition temperature lies at 9 K (-264°C). In order to prevent superconductivity from being destroyed by



Schematic drawing of the superconducting magnet an external magnetic field or the current passing through the conductors, these conductors must be cooled down to temperatures significantly below this point, at least to half of the transition temperature. Therefore, superconductive magnet coils are cooled with liquid helium which boils at a temperature of 4.2 K (-269°C).

RF Transmitter System

The system consists of an RF transmitter, RF power amplifier and RF transmitting coils.

1. RF Transmitter System
   - In order to activate the nuclei so that they emit a useful signal, energy must be transmitted into the sample. This is what the transmitter does.
   - The RF transmitter consists of an RF crystal oscillator at the Larmor frequency. The RF voltage is gated with the pulse envelopes from the computer interface to generate RF pulses that excite the resonance.

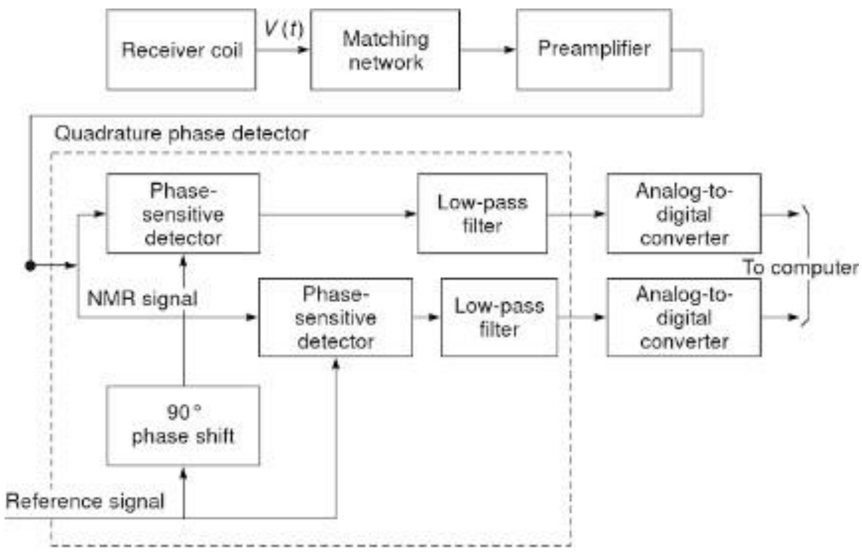
2. RF Power Amplifier

   - These pulses are amplified to levels varying from 100W to several kW and are fed to the transmitter coil.

3. RF Transmitting Coils

   - The coil generates RF field perpendicular to the direction of main magnetic field.
   - Coils are tuned to the NMR frequency and are usually isolated from the remaining system using RF shielding cage.

Detection System



Block diagram of the NMR detection system

- Block diagram is shown in above fig.
- The function of detection system is to detect the nuclear magnetization and generate an output signal for processing by the computer.

- The receiver coil usually surrounds the sample and acts as an antenna to pick up the fluctuating nuclear magnetization of the sample and converts it to a fluctuating output voltage V(i).
- NMR signal is given by

$$V(t) = -\frac{d}{dt} \cdot M(t,x) \cdot B_c(x)\, d_x$$

  Where M(t, x) is the total magnetization in a volume and
  $B_c(x)$ the sensitivity of the receiver coil at different points in space.
  $B_c(x)$ describes the ratio of the magnetic field produced by the receiver coil to the current in the coil.
- The receiver coil design and placement is such that $B_c(x)$ has the largest possible transverse component. The longitudinal component of $B_c(x)$ contributes little to the output voltage and can he ignored.
- The RF signals constitute the variable measured in magnetic resonance tomography. These are extremely weak signals having amplitude in the nV (nano-Volt) range thus requiring specially designed RF antennas. The sensitivity of an MR scanner therefore depends on the quality of its RF receiving antenna. For a given sample magnetization, static magnetic field strengths and sample volume, the signal-to-noise-ratio (SN R)of the RF signal at the receiver depends in the following manner upon the RF-receiving antenna.

$$\text{SNR} \sim K(Q/V_c)$$

Where K is a numerical constant, specific to the coil geometry
Q is the coil magnetization factor, and
V_c is the coil volume.

- This implies that the SNR of an MR scan can be improved by maximizing magnetization to coil volume.
- Some of the commonly available coils are:
- Body Coils: Constructed on cylindrical coils forms with diameter ranging from 50 to 60 cm entirely surround the patient's body.
- Head Coils: Designed only for head imaging, with typical diameter of 28 cm.

- **<u>Surface coils:</u>**
  Orbit/ear coil: flat, planar ring-shaped coil with 10 cm diameter;
  Neck coil: flexible, rectangular shaped surface coil (10 cm x 20 cm) capable of adaptation to the individual patient anatomy; and
  Spine coil: cylindrical or ring-shaped coil with 15 cm diameter.

- **<u>Organ-enclosing coils:</u>**
  Breast coil: cylindrical or ring-shaped coil with 15 cm diameter.

Helmholtz-type coil: a pair of flat ring coils each having 15 cm diameter with distance between the two coils variable from 12 to 22 cm.

Matching Network

- Following the receiver coil is a *matching network which* couples it to the pre-amplifier in order to maximize energy transfer into the amplifier. This network introduces a phase shifty to the phase of the signal.

Pre-amplifier: The pre-amplifier is a low-noise amplifier which amplifies the signal and feeds it to a quadrature phase detector.

Quadrature phase detector

- The detector accepts the RF NMR signal which consists of a distribution of frequencies centred around or near the transmitted frequency *w* and shifts the signal down in frequency by *w*.
- The detector circuit accepts the inputs, the NMR signal *V(t)* and a reference signal, and multiplies them, so that the output is the product of the two inputs. The frequency of the reference signal is the same as that of the irradiating RF pulse. The output of the phase-sensitive detector consists of the sum of two components, one a narrow range of frequencies centred at $2w_0$, and the other, a narrow range centred at zero.
- The low pass filter following the phase-sensitive detector removes all components except those centred at zero from the signal.

ADC

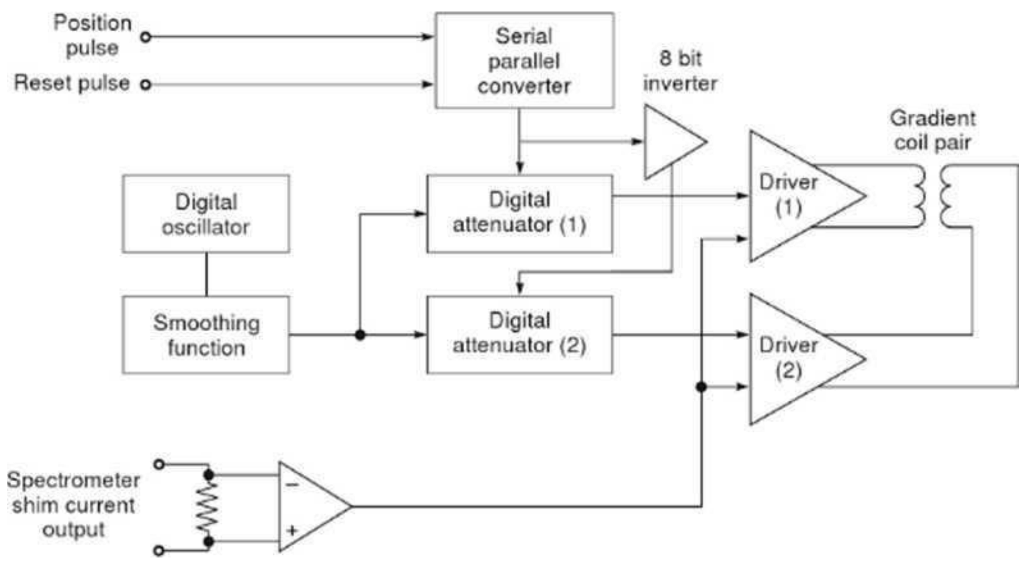
- It is necessary to convert the complex (two-channel) signal to two strings of digital numbers by analog-to-digital converters. The A-D converter output is passed, in serial data form to the computer for processing.

Gradient System for Spatial Coding:

- Spatial distribution information can be obtained by using the fact that the resonance frequency depends on the magnetic field strength. By varying the field in a known manner through the specimen volume, it is possible to select the region of the specimen from which the information is derived on the basis of the frequency of the signal. The strength of the signal at each frequency can be interpreted as the density of the hydrogen nuclei in the plane within the object where the magnetic field corresponds to that frequency.
- . The imaging methods differ mainly in the nature of the gradient time dependence (static, continuously time-depended or pulsed), and in the type of NMR pulse sequence employed.
- Spatial information and therefore images obtained by super-imposing a linear magnetic field gradient on the uniform magnetic field applied to the object to be imaged. When this is done, the resonance frequencies of the processing nuclei will depend primarily on the positions along the direction of the magnetic gradient.

- This produces a one-dimensional projection of the structure of the three- dimensional object. By taking a series of these projections at different gradient orientations, a two or even three-dimensional image can be produced.
- In NMR systems, for spatially resolving the signals emitted by the object, the initially homogeneous magnetic field B_0 is overlaid in all three spatial dimensions, X, Y, Z with small linear magnetic fields-gradient fields G.
- These gradient fields are produced with die aid of current carrying coils and can be switched on or off as desired, both during the application of the RF energy and also in any phase of the measuring procedure.

A block diagram of gradient control system is shown in Fig. given below. The hardware can be broken down into four sub-system.



Block diagram of gradient control system. Each X,Yand Z coil pair has its own control circuit.

1. **<u>Serial Parallel Computer</u>**

- The first sub-system includes the interface between the computer and the gradient control system. Its primary function is to allow the independent positioning of the three planes (X, *Y* and *Z).*

2. **<u>The digital oscillator</u>**

- Consists of a 555 timer followed by shift registers A digital oscillator facilitates varying itis output frequency over an extremely wide range through the use of a single control
- The 8-bit input from the interface circuit is used directly to one attenuator while the same 8-bits are inverted to control the second attenuator. The output of the attenuators is then voltage-amplified by two op amps prior to the driven circuits.
- Current control used to adjust the static field gradients be available for setting the DC levels upon which the alternating gradients are superimposed .

- An op amp serves the differential voltage drop across a dummy load and produces an output which is then DC coupled to the drivers.
- The high current drivers use a conventional design with a single op amp providing the input to a driver and a complimentary pair of power transistors to provide a sufficient current to the gradient coil.
- In typical scanners, gradient coils have an electric resistance of about l Ohm and an inductance of 1 mH. The gradient fields are required to be switched from 0 to 10 mT/ m in about 0.5 ms. The current switches from O to about 100 A in this interval. The power dissipation during the switching interval is about 20 kW. This places very strong demands on the power supply and it is often necessary to use water cooling to prevent overheating of the gradient coils.
- With well-designed coils, errors resulting from non-linear gradients will perhaps not be evident in a medical image since the image will remain clear and will not contain rigidly shaped objects or those with sharp edges for close comparison. But these gradient coils are usually designed to optimize linearity in the central region. Away from the centre, gradient linearity becomes progressively worse. Without restoration, the image will not give accurate information on the outer regions. Therefore, non-linear field gradients result in a geometrical distortion of the image reconstructed from projections.

Imager System:

The imager system includes the computer for image processing, display system and control console. The timing and control of RF and gradient pulse sequences for relaxation time measurements and imaging, in addition to FT image reconstruction and display necessitate the use of a computer.

The computer is the source of both the voltage waveforms of all gradient pulses and the envelopes of the RF pulses. A general purpose mini-computer of the type used for a ('AT scanner is adequate for these purposes.

BIOLOGICAL EFFECTS OF NMR IMAGING

The three aspects of NMR imaging which could cause potential health hazard are:

(i) Heating due to the rf power.
A temperature increase produced in the head of NMR imaging would be about 0.3°C. This does not seem likely to pose a problem.

(ii) Static magnetic field:
No significant effects of the static field with die level used in NMR are known, but the possible side effects of electromagnetic fields are decrease in cognitive skills, mitotic delay in slime moulds, delayed wound healing and elevated serum triglycerides.

(iii) Electric current induction due to rapid change in magnetic field:
It is believed that oscillating magnetic field gradients may induce electric currents strong enough to cause ventricular fibrillation. However, no damage due to NMR

from exposures has been reported. It is suggested that fields should not vary at a rate faster than 3 tesla/s.

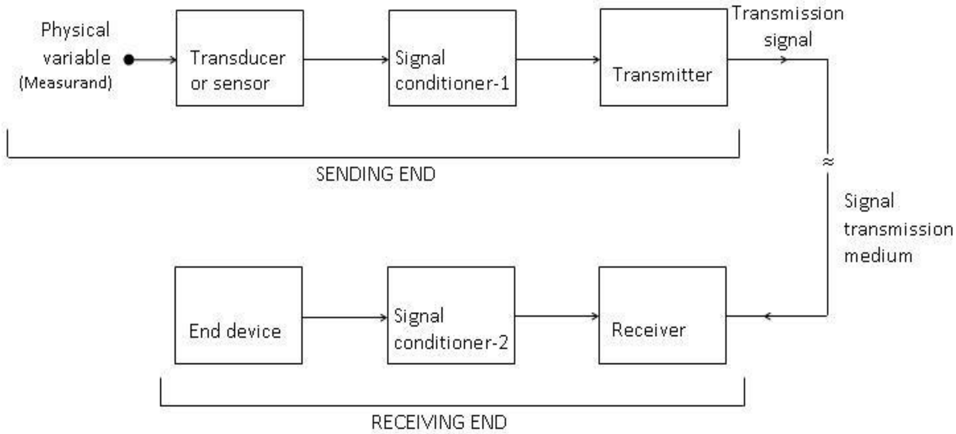
ADVANTAGES OF NMR IMAGING SYSTEM

1. The NMR provides substantial contrast between soft tissues that are nearly identical.
2. NMR uses no ionizing radiation and has minimal hazards for operators of the machines and for patients.
3. Unlike CT, NMR imaging requires no moving parts, gantries or sophisticated crystal detectors.
4. The system scans by superimposing electrically controlled magnetic fields consequently, scans in any pre-determined orientation are possible.
5. With the new techniques being developed, NMR permits imaging of entire three-dimensional volumes simultaneously instead of slice by slice, employed in other imaging systems.
6. In NMR both biochemical (spectroscopy) and spatial information (imaging) can be obtained without destroying the sample.

BIOMEDICAL TELEMETRY SYSTEM

- The term telemetry is derived from the two Greek terms: *"tele"* and *"metron", which mean "remote"* and *"measure".*
- In general, a physical variable or quantity under measurement, whether local or remote, is called a *measurand.*
- Telemetry is a technology that allows the remote measurement and reporting of information of interest to the system designer or operator.
- Literally, biotelemetry is the measurement of biological parameters over a distance.

Elements of Telemetry



Block schematic of basic telemetry system

1. Transducer or Sensor:
    - Converts the physical variable to be telemetered into an electrical quantity.
2. Signal Conditioner-1:
    - Converts the electrical output of the transducer (or sensor) into an electrical signal compatible with the transmitter.
3. Transmitter:

Its purpose is to transmit the information signal coming from the signal conditioner-1 using a suitable carrier signal to the receiving end.

- The **transmitter may perform** one or more of the following functions:
- (i) **Modulation**: Modulation of a carrier signal by the information signal.
- (ii) **Amplification**: As and if required for the purpose of transmission.
- (iii) **Signal Conversion**: As and if required for the purpose of transmission.
- (iv) **Multiplexing**: If more than one physical variables need to be telemetered simultaneously from the same location, then either frequency-division multiplexing (FDM) or time-division multiplexing (TDM) is used.
- **Receiver:** Its purpose is to **receive the signal(s) coming from the transmitter** (located at the sending end of the telemetry system) via the signal transmission medium and recover the information from the same.
- It may perform one or more of the following functions:

1. **Amplification**
2. **Demodulation:**
3. **Reverse Signal Conversion**

De-multiplexing

- **Signal Conditioner-2**: Processes the receiver output as necessary to make it suitable to drive the given end device.
- **End Device**: The element is so called because it appears at the end of the system.
- **End device may be performing** one of the following functions:

1. Analog Indication:
2. Digital Display

Digital Storage

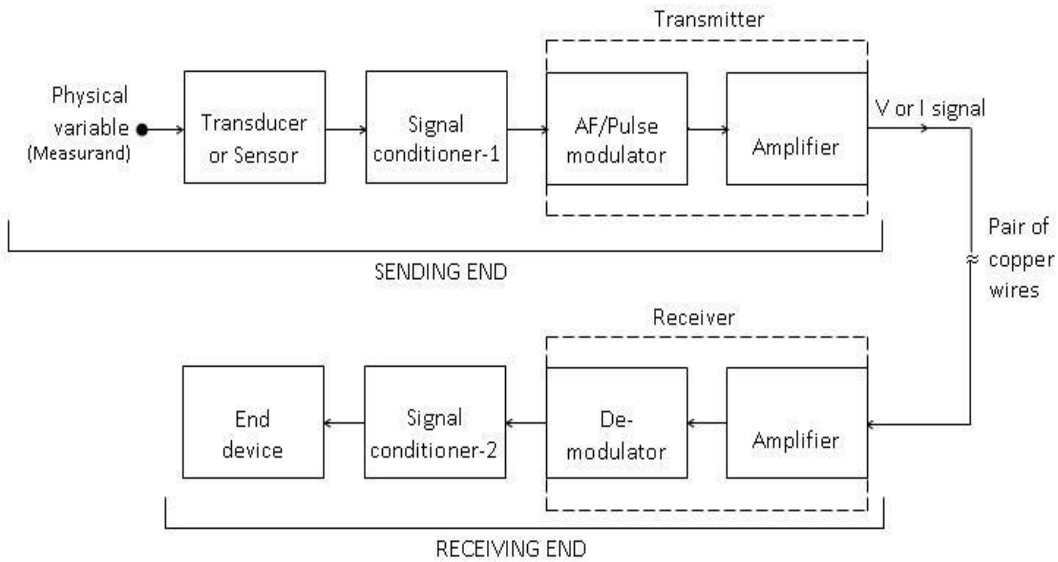
<u>Telemetry Classification Based on Transmission Medium</u>

Divided into 2

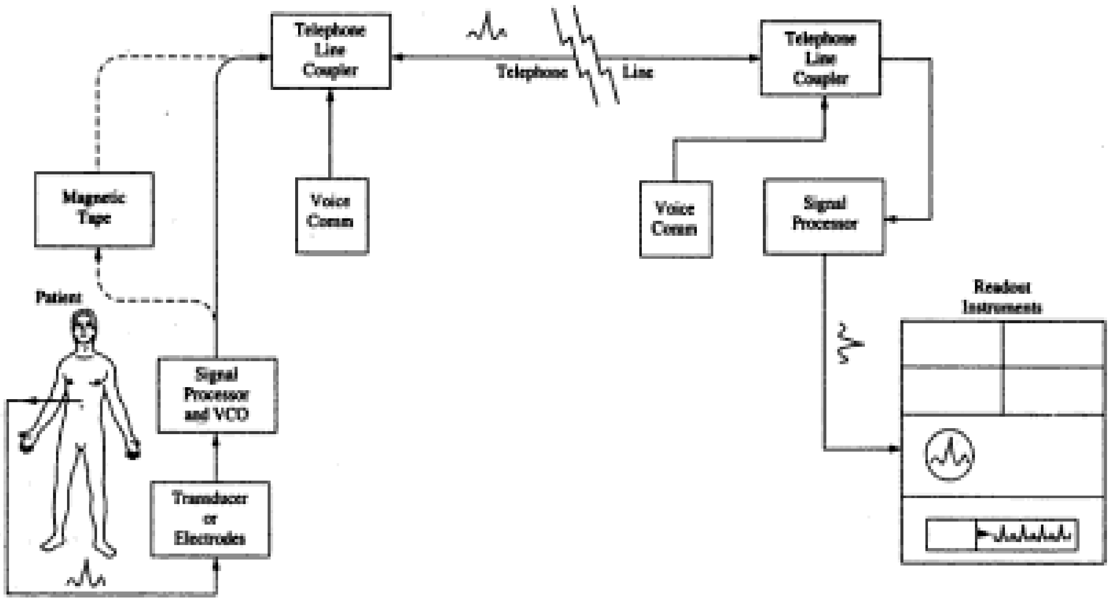
1. Wired Telemetry 2. Wireless Telemetry

COMPONENTS OF WIRED BIOTELEMETRY SYSTEM

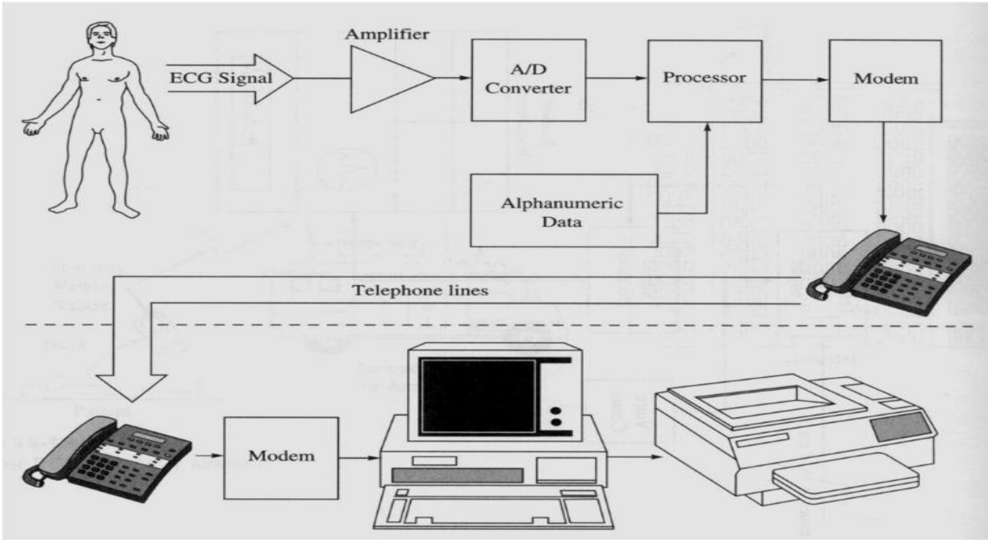
General Block Diagram



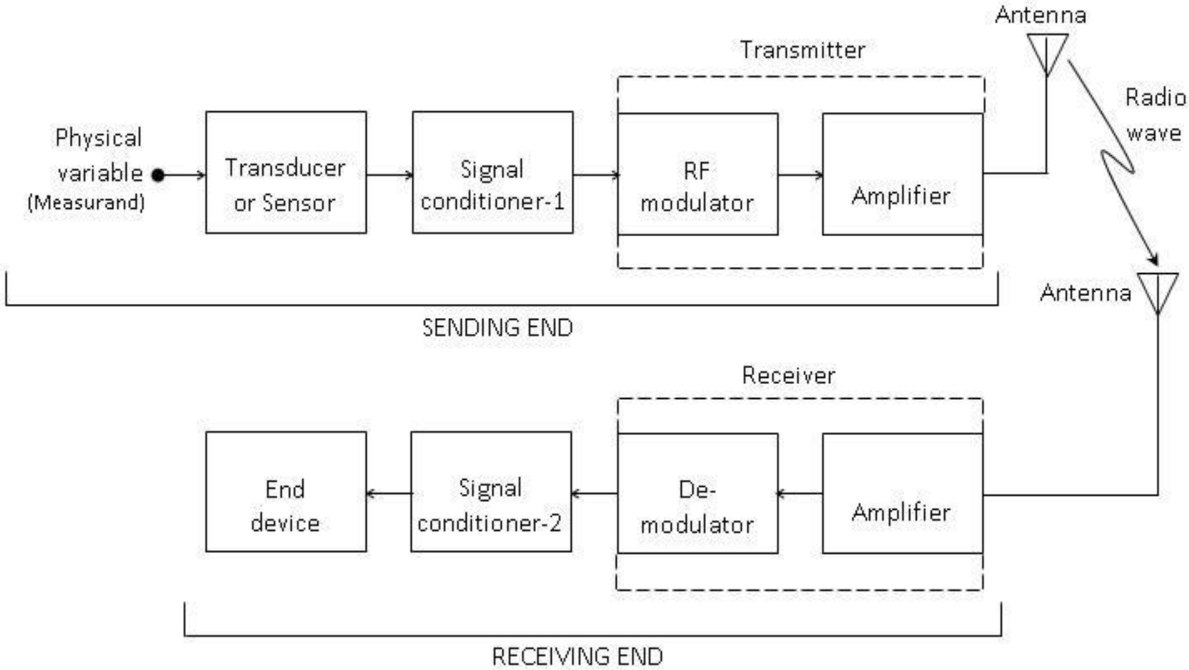
ANALOG SYSTEM [WIRED]



DIGITAL SYSTEM [WIRED]



Elements of Wireless Bio-Telemetry

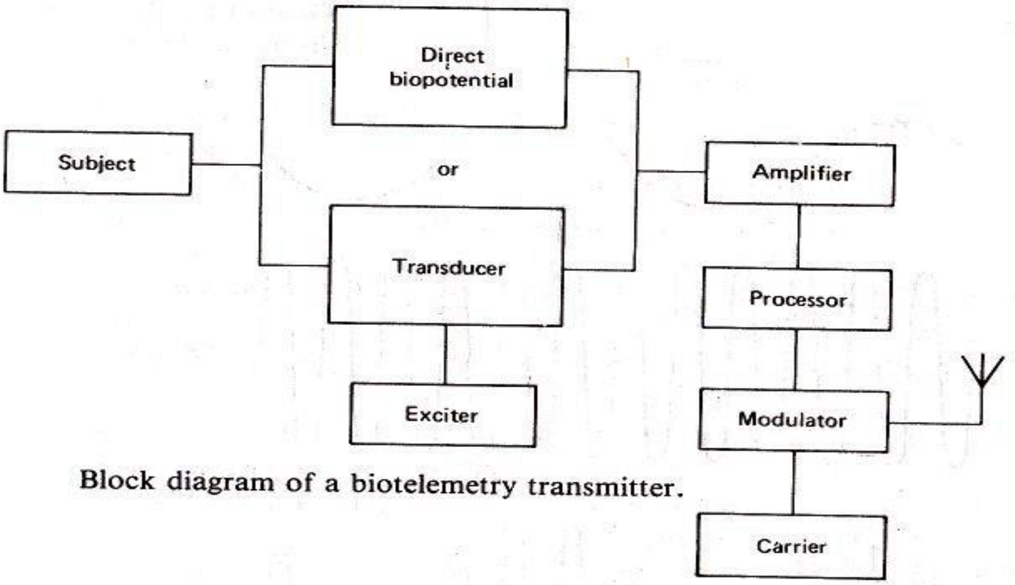


Block schematic of radio telemetry and short-range radio telemetry systems

ELEMENTS OF WIRELESS BIO-TELEMETRY

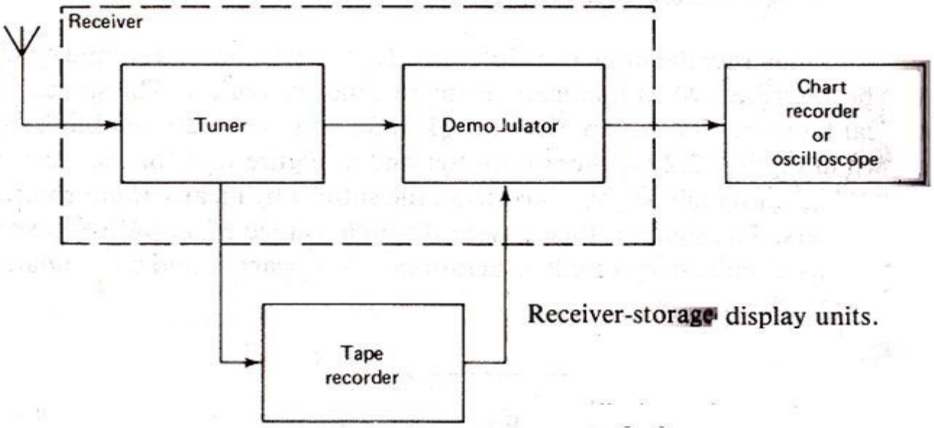
- A typical biotelemetry system comprises:
    1. Sensors appropriate for the particular signals to be monitored
    2. Battery-powered, Patient worn transmitters
    3. A Radio Antenna and Receiver
    4. A display unit capable of concurrently presenting information from multiple patients

1. **Wireless Bio-telemetry Transmitter**



Block diagram of a biotelemetry transmitter.

2. Wireless Bio-telemetry Receiver



Receiver-storage display units.

- Physiological signals are obtained from the subject by means of appropriate transducers. The signal is then passed through a stage of amplification and processing circuits that include generation of a subcarrier and a modulation stage for transmission.
- The circuitry which generates the carrier and modulates it constitutes the transmitter. Equipment capable of receiving the transmitted signal and demodulating it to recover the information comprise the receiver. By tuning the receiver to the frequency of the desired RF carrier, that signal can be selected while others are rejected.
- The range of the system depends upon a number of factors, including the power and frequency of the transmitter, relative locations of the transmitting and receiving antennas, and the sensitivity of the receiver.
- The receiver consists of a tuner to select the transmitting frequency, a demodulator to separate the signal from the carrier wave, and a means of displaying or recording the

signal. The signal can also be stored in the modulated state by the use of a tape recorder, as shown in the block diagram.

- The biotelemetry system use two modulators. The physiological signals are used to modulate a low-frequency carrier called sub-carrier in the audio frequency range. The RF carrier is then modulated by the sub-carrier and transmitted. The double modulation gives better interference free performance in transmission and enables the reception of low frequency biological signals. The sub modulator can be FM or PWM but the final modulator is practically always FM system.
- If several physiological signals are to be transmitted simultaneously, each signal is placed on a sub-carrier of a different frequency using FM or AM. The sub-carriers are added together to give a composite signal in which none of the parts overlap in frequency. The composite signal modulates the RF carrier by the same or different method. This process of transmitting many channels of data on a single RF carrier is called frequency division multiplexing (FDM). This is more efficient and less expensive than employing a separate transmitter for each channel.
- At the receiver, a multiplexed RF carrier is first demodulated to recover each of the separate sub-carriers which are then demodulated to retrieve the original physiological signals. Both FM/AM (sub-carrier is frequency modulated and RF carrier is amplitude modulated) and FM/FM systems are used in biotelemetry, the later more extensively.
- The modulation system is selected based on the size, complexity, noise transmission and other operational problems.

APPLICATION OF TELEMETRY IN MEDICINE

1. Telemetry of ECGs from Extended Coronary Care patients

- To make monitoring possible for the cardiac patients, some hospitals have extended coronary-care units equipped with patient-monitoring systems that include telemetry. In this arrangement, each patient has ECG electrodes taped securely to his chest.
- The electrodes are connected to a small transmitter unit that also contains the signal-conditioning equipment. The transmitter unit is fastened to a special belt worn around the patient’s waist.
- Batteries for powering the signal conditioning equipment and transmitter are also included in the transmitter package. These batteries must be replaced periodically.
- The output of each receiver is connected to one of the ECG channels of the patient monitor.

2. Telemetry for ECG Measurements During Exercise

- For certain cardiac abnormalities, such as ischemic coronary artery disease, diagnostic procedures require measurement of the electrocardiogram while the patient is exercising, usually on a treadmill or a set of steps. Although such measurements can be made with direct-wire connections from the patient to nearby instrumentation, the connecting cables are frequently in the way and may interfere with the performance of the patient. For this reason, telemetry is often used in conjunction with exercise ECG measurements.

- The transmitter unit used for this purpose is similar to that described earlier for extended coronary care and is normally worn on the belt. Care must be taken to ensure that the electrodes and all wires are securely fastened to the patient, to prevent their swinging during the movement of the patient.

3. Telemetry for Emergency Patient Monitoring

- In many areas ambulances and emergency rescue teams are equipped with equipment to allow electrocardiograms and other physiological data to be transmitted to a nearby hospital for interpretation.
- Two-way voice transmission is normally used in conjunction with the telemetry to facilitate identification of the tele-metered information and to provide instructions for treatment.
- Through the use of such equipment, ECGs can be interpreted and treatment begun before the patient arrives at the hospital of this type requires a much more powerful transmitter than the two applications previously described. Often the data must be transmitted many miles and sometimes from a moving vehicle.
- To be effective, the system must be capable of providing reliable reception and reproduction of the transmitted signals regardless of conditions.

4. Telephone Links

One application involves the transmission of ECGs from heart patients and (particularly) pacemaker recipients. In this case the patient has a transmitter unit that can be coupled to an ordinary telephone. The transmitted signal is received by telephone in the doctor's office or in the hospital. Tests can be scheduled at regular intervals for diagnosing the status and potential problems indicated by the ECGs.

SINGLE CHANNEL TELEMETRY SYSTEM FOR ECG AND TEMPERATURE

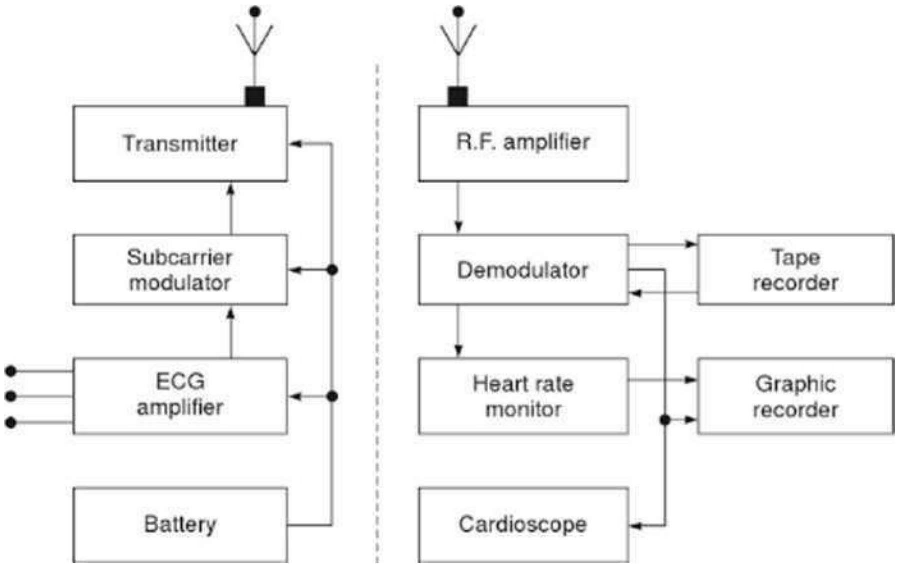
In a majority of the situations requiring monitoring of the patients by wireless telemetry, the parameter which is most commonly studied is the electrocardiogram. Therefore, we shall first deal with a single channel telemetry system suitable for the transmission of an electrocardiogram.

ECG Telemetry System

Figure shows the block diagram of a single channel telemetry system suitable for the transmission of an electrocardiogram.

There are two main parts:

- The Telemetry Transmitter which consists of an ECG amplifier, a sub-carrier oscillator and a UHF transmitter along with dry cell batteries.
- Telemetry Receiver consists of a high frequency unit and a demodulator to which an electrocardiograph can be connected to record, a cardioscope to display and a magnetic tape recorder to store the ECG. A heart rate meter with an alarm facility can be provided to continuously monitor the beat-to-beat heart rate of the subject.



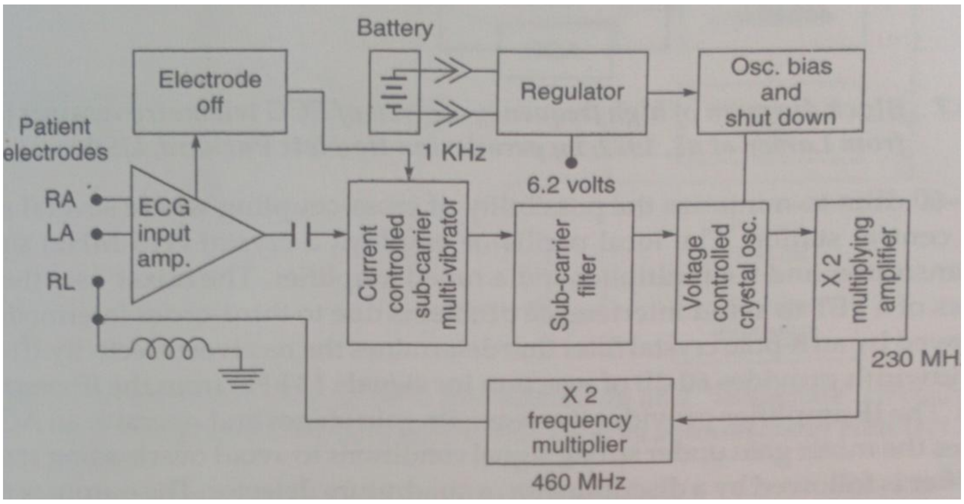
Block diagram of a single channel telemetry system

For distortion-free transmission of ECG, the following requirements must meet.

•The subject should be able to carry on with his normal activities while carrying the instruments without the slightest discomfort. He should be able to forget their presence after some minutes of application.
•Motion artefacts and muscle potential interference should be kept minimum.
•The battery life should be long enough so that a complete experimental procedure may be carried out.
•While monitoring paced patients for ECG through telemetry, it is necessary to reduce pacemaker pulses. The amplitude of pacemaker pulses can be as large as 80 mV compared to 1-2 mV, which is typical of the ECG.

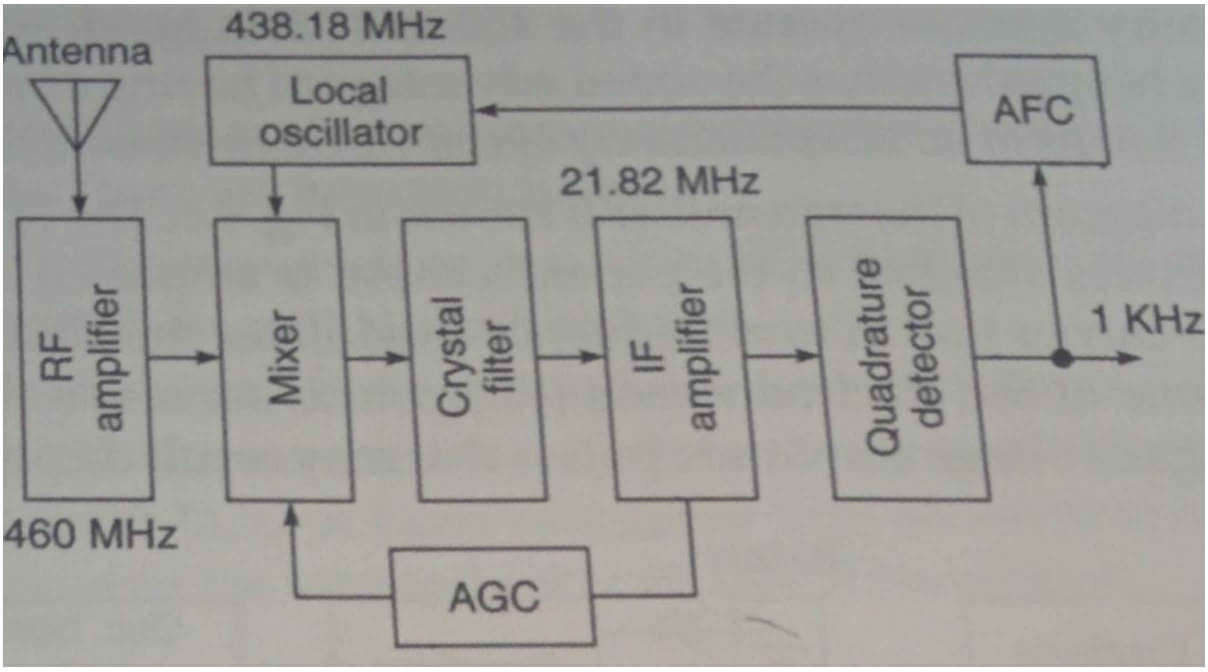
Components

1. Transmitter



- A block diagram of the transmitter is shown in Fig. The ECG signal, picked up by three pre-gelled electrodes attached to the patient's chest, is amplified and used to frequency modulate a 1 kHz sub-carrier that in turn frequency-modulates the UHF carrier. The resulting signal is radiated by one of the electrode leads (RL), which serves as the antenna. The input circuitry is protected against large amplitude pulses that may result during defibrillation.
- ECG input amplifier is ac coupled to the succeeding stages The coupling capacitor not only eliminates dc voltage that results from the contact potentials at the patient-electrode interface, it also determines the low-frequency cut-off of the system which is usually 0.4 Hz.
- The subcarrier oscillator is a current-controlled multi-vibrator which provides ±320 Hz deviation from the 1 kHz centre frequency for a full range ECG signal.
- The sub-carrier filter removes V square-wave harmonic and results in a sinusoid for modulating the RF carrier.
- The carrier is generated in a crystal-controlled oscillator operating at 115 MHz.

2. **Receiver**

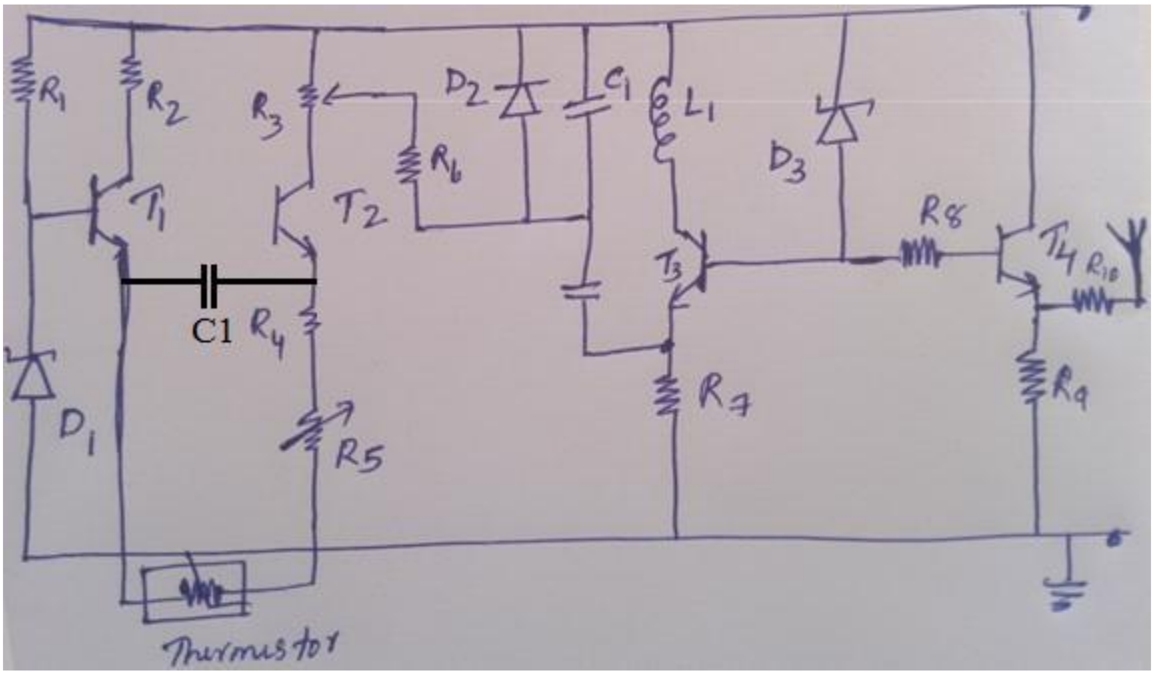


- The receiver uses an omni-directional receiving antenna which is a quarter-wave monopole, mounted vertically over the ground plane of the receiver top cover. This arrangement works well to pick up the randomly polarized signals transmitted by moving patients.
- Receiver comprises of an RF amplifier, which provides a low noise figure, RF filtering and image frequency rejection. In addition to this, the RF amplifier also suppresses local oscillator radiation to -60 dBm to minimize the possibility of cross-coupling where several receivers are used in one central station.
- The local oscillator employs a crystal (115 MHz) similar to the one in the transmitter and x 4 multiplier and a tuned amplifier.

- The mixer is followed by an 8-pole crystal filter that determines the receiver selectivity.
- The IF amplifier provides the requisite gain stages and operates an AGC amplifier which reduces the mixer gain under strong signal conditions to avoid overloading at the IF stages.
- The IF amplifier is followed by a discriminator, a quadrature detector. The output of the discriminator is the 1 kHz sub-carrier. This output is averaged and fed back to the local oscillator for automatic frequency control.
- The 1 kHz sub-carrier is demodulated to convert frequency-to-voltage to recover the original ECG waveform.

<u>Temperature Telemetry System</u>

Systems for the transmission of alternating potentials representing such parameters as ECG, EEG and EMG are relatively easy to construct. Telemetry systems which are sufficiently stable to telemeter direct current outputs from temperature, pressure or other similar transducers continuously for long periods present greater design problems. In such cases, the information is conveyed as a modulation of the mark/space ratio of a square wave. A temperature telemetry system based on this principle is illustrated in the circuit shown in Fig.



- Temperature is sensed by a thermistor having a resistance of 100 Ohm (at 20°C) placed in the emitter of transistor T_1.
- Transistors T_1 and T_2 form a multi-vibrator circuit timed by the thermistor, R4, R5 and C1.
- R5 is adjusted to give 1:1 mark/space ratio at midscale temperature (35 - 41 °C). The multi-vibrator produces a square wave output at about 200 Hz.

- Its frequency is chosen keeping in view with the available bandwidth, required response time, the physical size of the multi-vibrator, timing capacitors and the characteristics of the automatic frequency control circuit of the receiver.
- This is fed to the variable capacitance diode D_2 via potentiometer $\boldsymbol{R_3}$**.** D_2 is placed in the tuned circuit of a RF oscillator [L1C1] constituted by T_3.
- Transistor T_3 forms a conventional 102 MHz oscillator circuit, whose frequency is stabilized against supply voltage variations by the *Zener* diode D_3 between its base and the collector supply potential.
- T_4 is an untuned buffer stage between the oscillator and the aerial. The aerial is normally taped to the collar or harness carrying the transmitter.
- On the receiver side, a vertical dipole aerial is used which feeds a FM tuner, and whose output, a 200 Hz square wave, drives the demodulator.
- In the demodulator, the square wave is amplified, positive dc restored and fed to a meter where it is integrated by the mechanical inertia of the meter movement.
- Alternatively, it is filtered with a simple RC filter to eliminate high ripple content and obtain a smooth record on a paper. A domestic FM tuner can be used for this purpose.
- Temperature measurements in this scheme were made with a thermistor probe.

Patient Safety

- Electric shock burns and fire hazards result from the careless use of electricity. When electricity is relied upon to support life with devices like external pacemakers, respirators, etc. power failure is a continuous threat.
- Shock resulting from electric power is a common experience. Disruption of physiologic function by leakage current applied internally remains sometimes hidden and mysterious. While faulty electric cords and appliances contribute to the former, lack of concept and faulty design are responsible for the latter.

Electric current can flow through the human body either accidentally or intentionally. Electrical currents are administered intentionally in the following cases:

(i) for the measurement of respiration rate by impedance method, a small current at high frequency is made to flow between the electrodes applied on the surface of the body,

(ii) high frequency currents are also passed through the body for therapeutic and surgical purposes,

(iii) when recording signals like EGG and EEG, the amplifiers used in the preamplifier stage may deliver small currents themselves to the patient. These are due to bias currents.

Accidental transmission of electrical current can take place because of a defect in the equipment; excessive leakage currents due to defect in design; operational error (human error) and simultaneous use of other equipment on the patient which may produce potentials on the patient circuit.

ELECTRIC SHOCK HAZARDS

Hazards due to electric shock are also associated with equipment other than that used in hospitals. Some such special situations are as follows:

(i) A patient may not be usually able to react in the normal way. He is either ill, unconscious, anaesthetized or strapped on the operating table. He may not be able to withdraw himself from the electrified object, when feeling a tingling in his skin, before any danger of electrocution occurs.
(ii) The patient or the operator may not realize that a potential hazard exists. This is because potential differences are small and high frequency and ionizing radiations are not directly indicated.
(iii) A considerable natural protection and barrier to electric current is provided by human skin. In certain applications of electromedical equipment, the natural resistance of the skin may be by-passed. Such situations arise when the tests are carried out on the subject with a catheter in his heart or on large blood vessels.
(iv) Electro-medical equipment, e.g. pacemakers may be used either temporarily or permanently to support or replace functions of some organs of the human body. An interruption in die power supply or failure of the equipment may give rise to hazards, which may cause permanent injuries or may even prove fatal for the patient.

(v) Several times there are combinations of high power equipment and extremely sensitive low signal equipment. Each of these devices may be safe in itself, but can become dangerous when used in conjunction with others.

(vii) The environmental conditions in hospitals, particularly in the operating theatres, cause an explosion or fire hazards due to die presence of anaesthetic agents, humidity and cleaning agents, etc.

There are two situations which account for hazards from electric shock.

They are (i) Gross shock and (ii) Micro-current shock.

- In the case of gross shock, the current flows through the body of the subject, e.g. as from arm to arm.
- The other case is that of micro-current shock in which the current passes directly through the heart wall. This is the case when cardiac catheters may be present in the heart chambers. Here, even very small amounts of currents can produce fatal results.

1. Gross Shock

Gross shock is experienced by the subject by an accidental contact with the electric wiring at any point on the surface of the body. The majority of electric accidents involve a current

pathway- through the victim from one upper limb to the feet or to the opposite upper limb and they generally occur through intact skin surfaces. In all these cases, the body acts as a volume conductor at the mains frequency.
For a physiological effect to take place, body must become part or an electric circuit. Current must enter the body at one point and leave at some other point. In this process, three phenomena can occur. These are:

(i) Electrical stimulation of the excitable tissues nerves and muscles
(ii) Resistive heating of tissue
(iii) Electro-chemical burns and tissue damage for direct current and very high voltages.

The value of electric current, flowing in the body, which causes a given degree of stimulation, varies from individual to individual. Typical threshold values of current produce certain responses where the current flows into the body from external contacts (e.g. hand to hand) and these have been investigated.
For a given voltage present on the surface of the body, the value of current passing through it would depend upon the contact impedance.
Besides this, it depends on many other factors such usage, sex, condition of skin (dry or wet, smooth or rough, etc.), frequency of current. duration of current and the applied voltage.

Effects of Electric Current on the Human Body

Threshold of Perception: Bruner (1967) states that the threshold of perception of electric shock is about 1 mA. At this level a tingling sensation is felt by the subject when there is a contact with an electrified object through the intact skin. The threshold varies considerably among individuals and with the measurement conditions. The lowest threshold could be 0.5 mA when the skin is moistened at 50 Hz. Threshold for dc current are2 to 10mA.

Let-go Current: As the magnitude of alternating current is increased the sensation of tingling gives way to the contraction of muscles. The muscular contractions increase as the current is increased and finally a value of current is reached at which the subject cannot release his grip on the current carrying conductor. The maximum current at which the subject is still capable of releasing a conductor by using muscles directly stimulated by that current is called "let-go current".

Physical Injury and Pain: At current levels higher than the ‘let-go current’, the Subject loses the ability to control his own muscle actions and he is unable to release his grip on the electrical conductor. Such currents are very painful and hard to bear. This type of accident is called the 'hold-on-type accident, and is caused by currents in the range of20-100mA.

Ventricular Fibrillation: If current comes in contact with intact skin and passes through the trunk at about 100 mA and above, there is a likelihood of pulling the heart into ventricular fibrillation. In this condition, the rhythmic action of the heart ceases, pumping action slops and the pulse disappears. Ventricular fibrillation occurs due to the derangement of function of the heart muscles rather than any actual physical damage to it. Ventricular fibrillation is a serious cardiac emergency because once it starts; it practically never stops spontaneously, even when the current that triggered it is removed.

Sustained Myocardial Contraction: At currents in the range of 1 to 6 A. the entire heart muscle contracts. Although the heart stops beating while the current is applied, it may revert to a normal rhythm if the current is discontinued in time, just as in fibrillation. The damage is reversible if the shock duration is only of a few seconds.

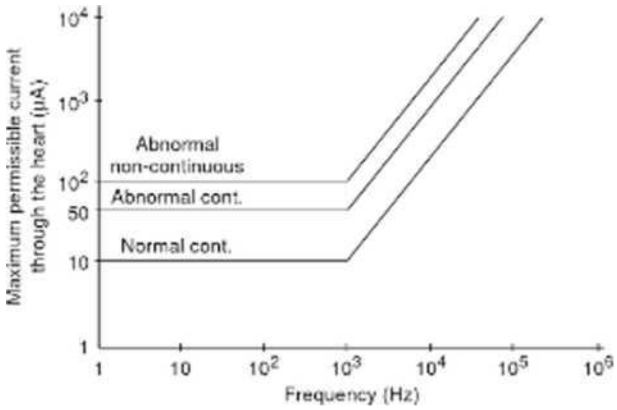
Burns and Physical Injury: At very high currents of the order of 6 amperes and above there is a danger of temporary respiratory paralysis and also of serious burns. Resistive heating causes burns, usually on the skin at the entry points, because skin resistance is high. The brain and other nervous tissue loose all functional excitability when high currents pass through them.

- Gross shock hazards arc usually caused by electrical wiring failures, which allow personal contact with a live wire or surface at the power line voltage. This type of hazard is dangerous not only to the patient but also to the medical and attending staff. The most vulnerable part in the system of electrical safety is the cord and plug. Their use can result in fatal accidents. Broken plugs, faulty sockets and defective power cords must be immediately replaced.

<u>Micro-current Shock</u>

The threshold of sensation of electric currents differs widely between currents applied arm to arm and currents applied internally to the body. In the latter case, a far greater percentage of the current may flow via the arterial system directly through the heart, thereby requiring much less current to produce ventricular fibrillation. Such situations arc commonly encountered in hospitals;

For example, The patients in the catheter laboratory or in the operating room, with a catheter in the heart, would have very little resistance 10 electric currents. A cardiac catheter connected to an electrical circuit for the measurement of pressure provides a conductive fluid connection directly to the heart. This makes the patient highly vulnerable to electric shock because the protection he would have had from layers of intact skin and tissue between his heart and the outside electrical environment has now been by-passed by the wire of fluid column within his heart or blood vessels.



Maximum permissible leakage-current through the heart versus frequency

Electrophysiology of Ventricular fibrillation

Current passing through the human body can prove hazardous as it can induce circulatory arrest. The primary cause of circulatory arrest induced by low voltage electric shock is ventricular fibrillation.

The shock hazards described above lead to the classification of patients in hospitals into three categories:

.

(i) A critical patient will have a direct electrically conductive path to any part of the heart. Based on this classification, the type of leakage current associated w nh each category can be worked out.

LEAKAGE CURRENTS

- Currents of extremely small magnitude can be fatal to a patient when a direct, localized electrical path exists to the heart.
- Patients in coronary care units recovering from heart diseases are especially vulnerable since their hearts are already in an irritable state.
- In such cases, the amount of electrical stimulation necessary to induce a life threatening arrhythmia is greatly reduced. Accidents of this nature can occur in unpredictable circumstances.

  The major source of potentially lethal currents is the Leakage Current

  - Leakage current by definition is an inherent flow of non-functional current from the live electrical parts of an instrument to the accessible metal parts. Leakage currents usually flow through the third wire connection to the ground. They occur by the presence of a finite amount of insulation impedance, which consists of two parts: capacitance and resistance.

- The magnitude of the leakage current is determined by the value of the capacitance present therein.
- The resistive component of leakage current arises because no substance is a perfect insulator and some small amount of current w ill always flow through it.

Types of Leakage Current

Leakage currents are divided according to the current path into the following types:

1. **Enclosure Leakage Current:**

The enclosure leakage current is the current which flaws, in normal condition, from the enclosure or part of the enclosure through a person (or an external conductive part other than the earth connection) in contact with an accessible part of the enclosure to earth or another part of the enclosure. This current becomes significant when the person touching the equipment is connected to earth either directly or via a large capacitance.

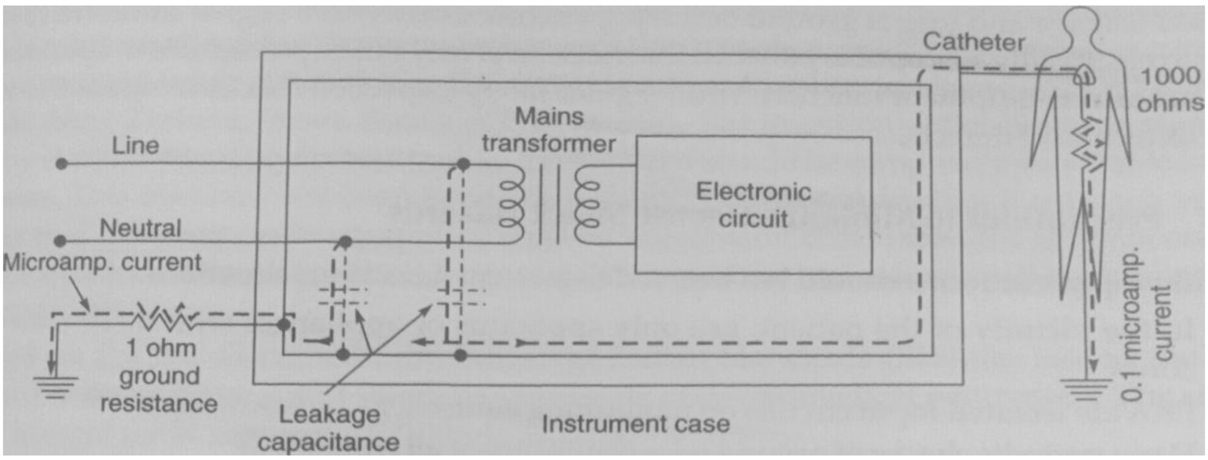
2. **Earth Leakage Current**

'The earth leakage current is the current which flows, in normal condition, to earth from the mains parts of an apparatus via the earth conductor.

3. Patient Leakage Current

The patient leakage current is the current which flows through the patient from or to the applied part of the patient circuits. This current does not include any functional patient current.

Consider electrical equipment connected to the power line.



Path of leakage current in a normal case, i.e. the ground wire intact

A leakage current of 100 microA can be assumed to be flowing through the ground wire. If the chassis of this equipment is connected to the patient who is grounded, then very little of this current will flow through him.

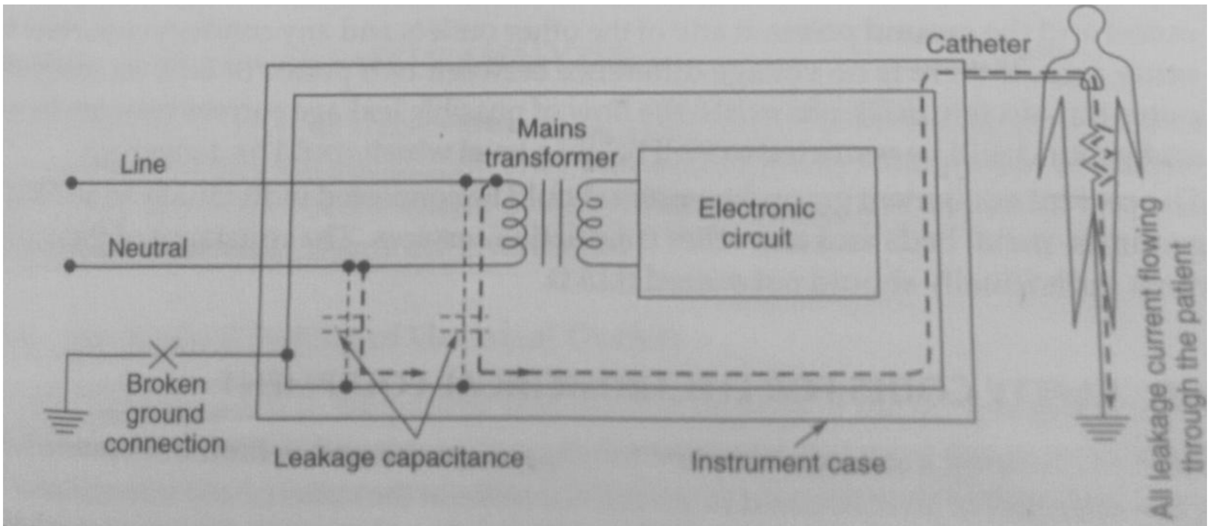


Fig. 18.8 *Path of leakage current in case of discontinuous ground (redrawn by permission of Hewlett Packard, USA)*

- In the above case the patient offers a resistance of 1000 ohm to the ground and the ground connection from the instrument has 1 ohm of series resistance. The current division shall be such that only 0.1 microA of current shall pass through the patient, the rest will flow to the ground.
- If by chance the ground connection breaks, the full leakage current will flow through the patient. This is a very hazardous situation particularly if the current goes through internal electrodes in the vicinity of the patient's heart.

<u>Precautions to Minimize Electric Shock Hazards</u>

The following precautions should be observed to prevent hazardous situations:

•In the vicinity of the patient, use only apparatus or appliances with three-wire power cords.

•Provide isolated input circuits on monitoring equipment.

•Have periodic checks of ground wire continuity of all equipment.

•No other apparatus should be put where the patient monitoring equipment is connected.

•Staff should be trained to recognize potentially hazardous conditions.

•Connectors for probes and leads should be standardized so that currents intended for powering transducers arc not given to the leads applied to pick up physiologic electric impulses.

•The functional controls should be clearly marked and the operating instructions be permanently and prominently displayed so that they can be easily familiarized.

•Many of the portable medical equipment such as dialysis units, hypothermia units, physiotherapy apparatus, respirators and humidifiers are used with adapter plugs that do not ensure a proper grounding circuit.

•The operating instructions should give directions on the proper use of the equipment, hi fact, for electro-medical equipment, the operating instructions should be regarded as an integral pail of the unit.

•The mechanical construction of the equipment must be such that the patient or operator cannot he injured by the mechanical system of the equipment, if properly operated.

• The patient equipment grounding point should be connected ind ividu ally to all receptacle grounds, metal hods and any other conductive services.

SAFETY CODES FOR ELECTROMEDICAL EQUIPMENT

The problem of ensuring a safe environment for the patients as well as for the operators has been engaging the attention of all concerned in several countries at the national and international levels.

Various countries laid down codes of practice for equipments used in hospitals.

- The intention of the common standard is that any electromedical equipment built to the standard should be completely acceptable in all IEC countries. This standard has been adopted in many countries. Adopting a common standard implies that construction of equipment shall be universally acceptable, the leakage and earth resistance paths will be assessed in identical manners and the mains leads will be coloured to the same code, etc.
- Based on the IEC Document, the Bureau of Indian Standards (BIS) has issued the IS:8607 standard to cover general and safety requirements of electromedical equipment. The standard *issued in* eight parts, covers the following aspects:
-

PartI	General
Part II	Protection against electric shock
Part III	Protection against mechanical hazards
Part IV	Protection against unwanted or excessive radiation
Part V	Protection against explosion hazards
Part VI	Protection against excessive temperature, fire and other hazards
Part II	Construction
Part VIII	Behavior and reliability v

This standard applies to all medical electrical equipment except or otherwise stated in the individual specification for the particular medical equipment for which additional or modified equipments have been specified.

Individual standards on different electromedical equipment have also been issued by the BIS. Some of the important standards issued are: Radiofrequency diathermy apparatus (IS.7583), ectrocardiograph (IS:8048), Cardiac Defibrillators (IS:9286), Diagnostic medical X-ray equipment 5:7620), and Electromyograph (IS:8885).