Biomedical Instrumentation

(U18PCEC603)

UNIT I

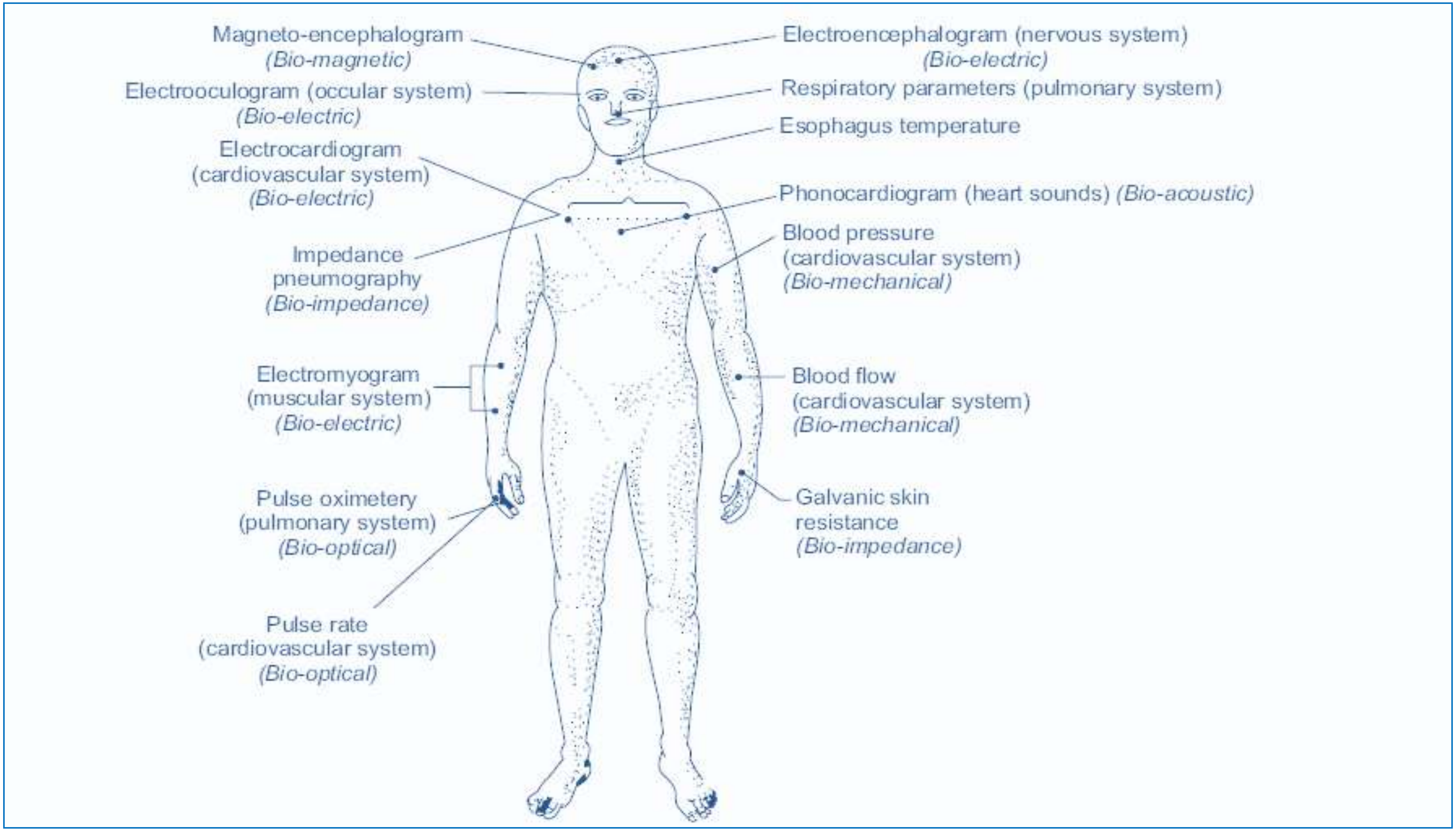
BIO-CHEMICAL AND NON ELECTRICAL PARAMETER MEASUREMENT

Topics

- Introduction
- PH, PO2, PCO2, PHCO3 Measurement
- ELECTROPHORESIS
- Colorimeter
- Photometer
- Auto analyzer
- Blood flow meter
- Cardiac output measurement
- Respiratory measurement
- Blood pressure measurement
- Temperature measurement
- Pulse measurement
- Blood cell counters

INTRODUCTION

Sources of biomedical signals

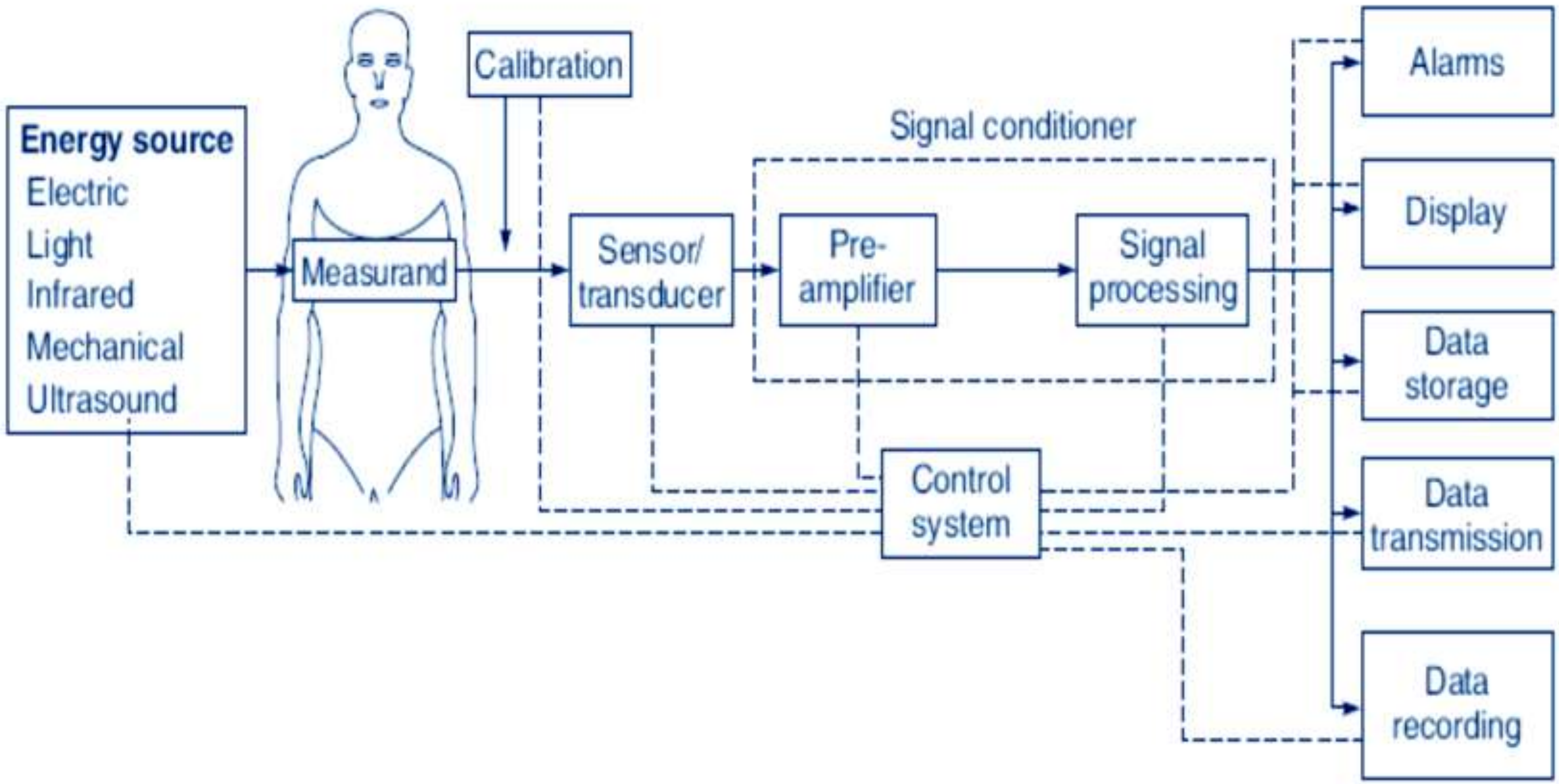


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Biomedical Instrumentation

- Biomedical Instrumentation is the field of creating such instruments that help us to **measure**, **record** and **transmit data** to or from the body.

COMPONENT OF BIOMEDICAL INSTRUMENT SYSTEM

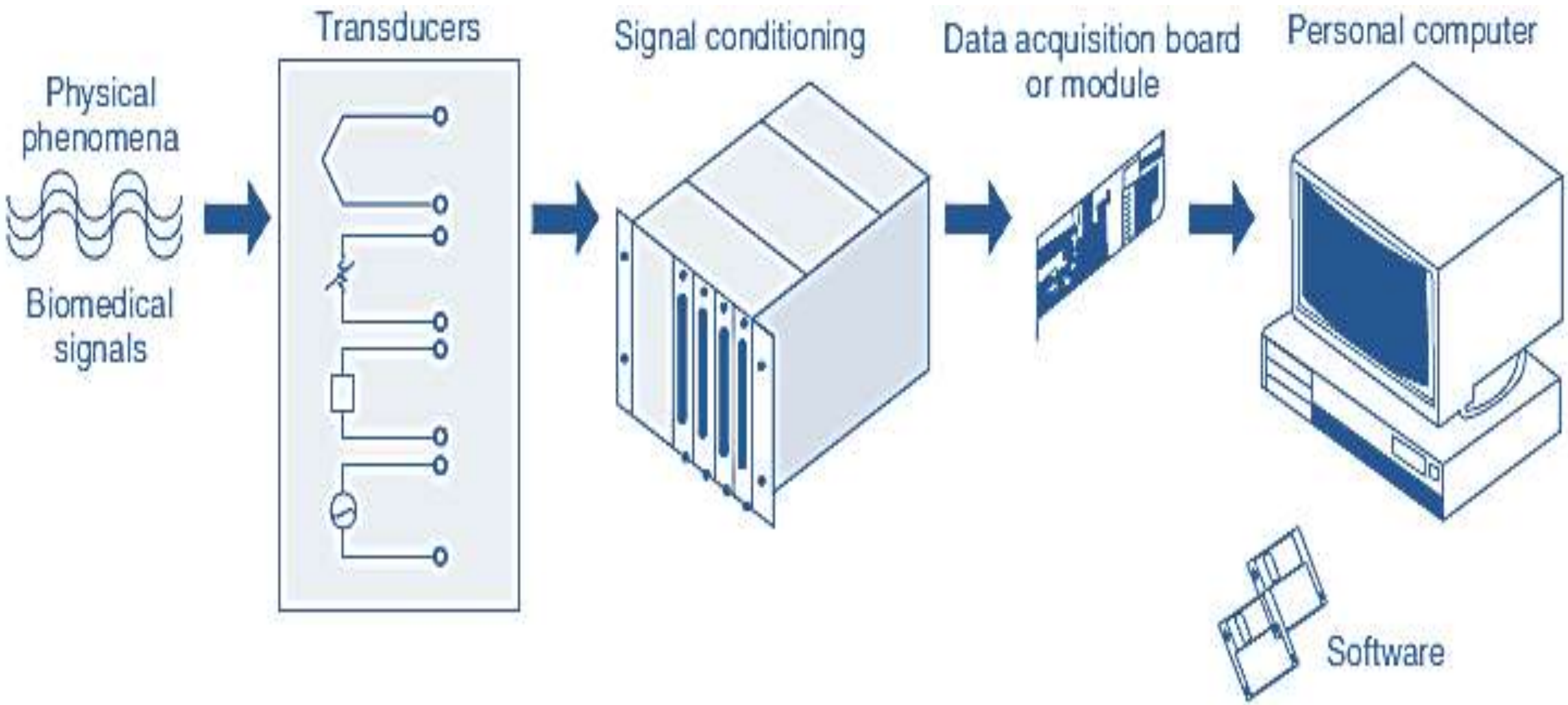


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Objectives of Instrumentation System

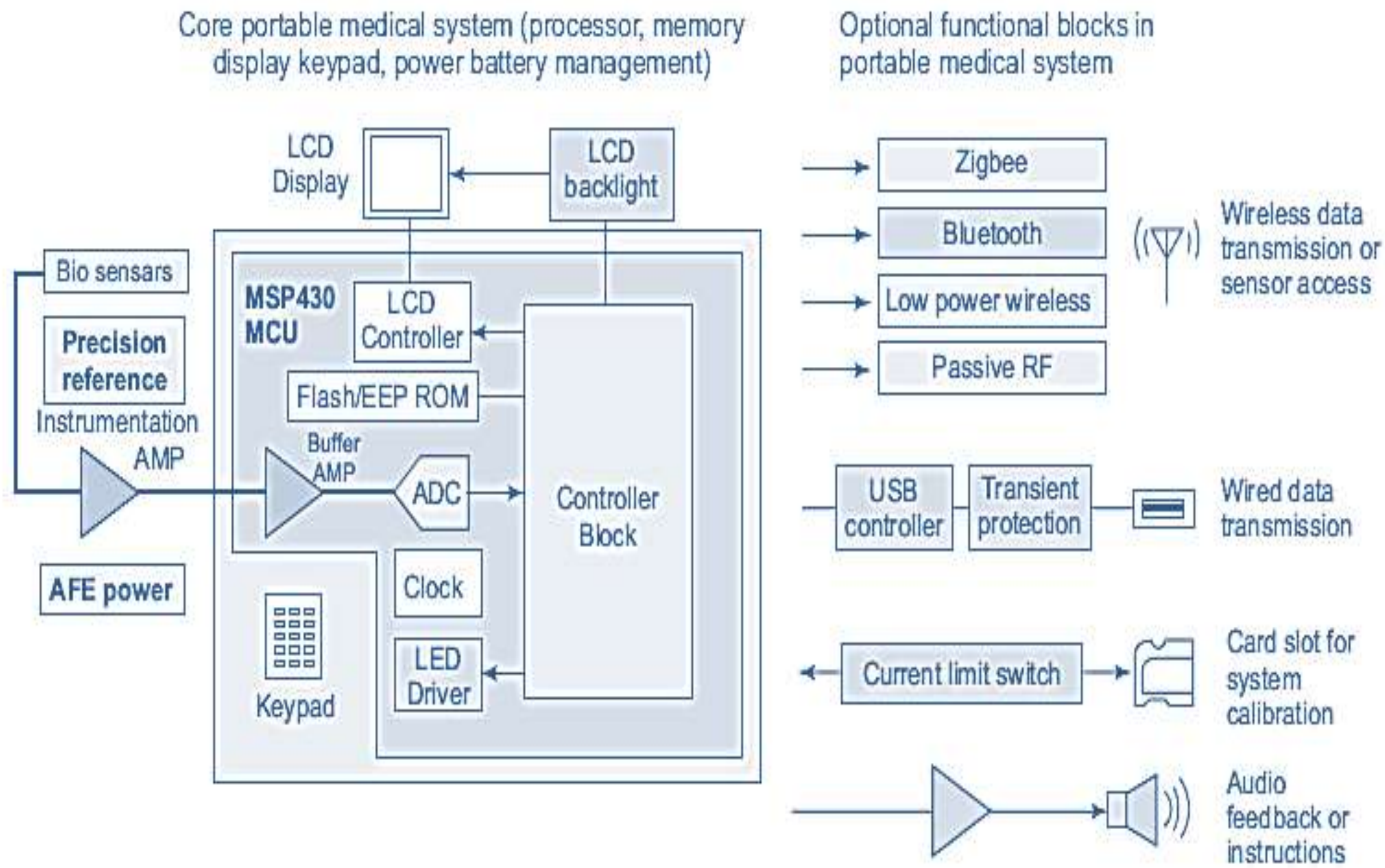
- Data Acquisition
- Diagnosis
- Evaluation
- Monitoring
- Control

PC based medical instrument



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

CONSUMER & PORTABLE MEDICAL EQUIPMENT



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

IMPLANTABLE MEDICAL DEVICES

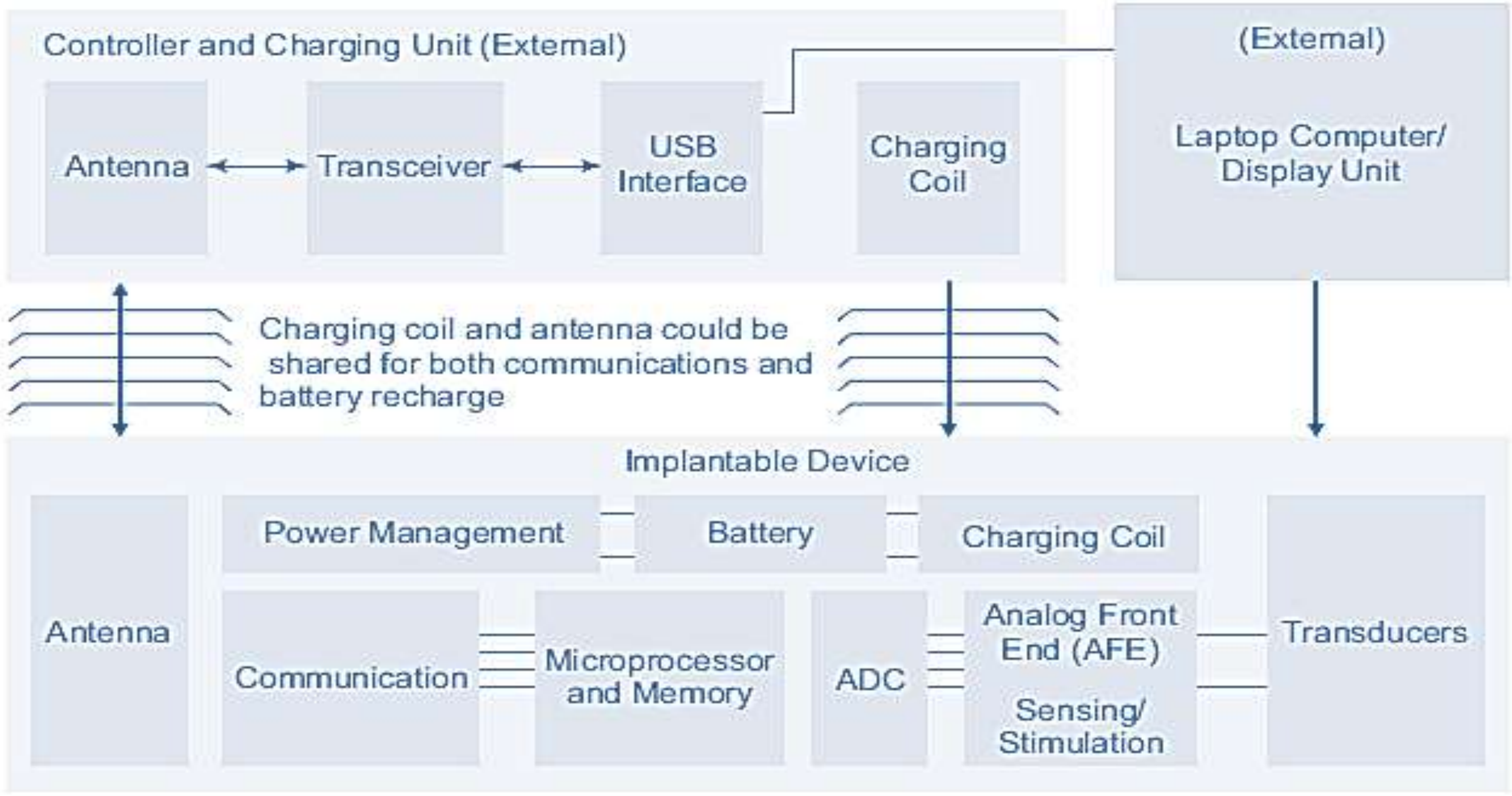
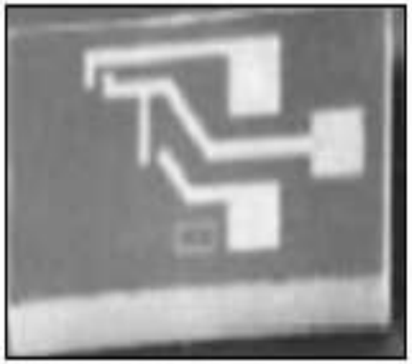


Image Courtesy: Cactus Semiconductor

MICRO-ELECTRO-MECHANICAL SYSTEMS (MEMS)

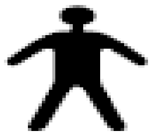
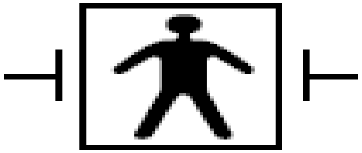
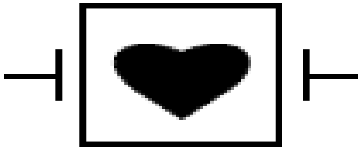
- Micro-Electro-Mechanical Systems (MEMS) are the **integration of mechanical elements, sensors and electronics** on a **common silicon substrate made using micro-fabrication technology**.
- MEMS are a broad set of technologies developed with the goal of **miniaturizing systems through the integration of functions into small packages**.
- Micro-fabricated components are **small sized, light weight, and consume low power**.

Microsensor & Micro-gear



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Types of equipment based on degree of protection

Type B		Non-isolated applied part
Type BF		Isolated applied part
Type CF		Isolated applied part suitable for direct cardiac application
Type F		Food device
Type T		Transportable device

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Types of equipment based on degree of protection (contd..)

Leakage Current	Type B		Type BF		Type CF	
	NC	SFC	NC	SFC	NC	SFC
Earth Leakage current	500uA	1mA	500uA	1mA	500uA	1mA
Enclosure Leakage current	100uA	500uA	100uA	500uA	100uA	500uA
Patient Leakage current	100uA	500uA	100uA	500uA	10uA	50uA

NC = Normal Conditions SFC = Single Fault Conditions

Data Reference& Courtesy : MEAN WELL

Medical device regulatory

- **Indian** authorities overhauled the **medical device** regulatory process in 2017 with the publication of the **Medical Device** Rules.

- The rules came into force in January 2018 and **devices** are **regulated** by the **Central Drugs Standard Control Organization (CDSCO)**, an agency of the Ministry of Health and Family Welfare.

How to Access this

Pls. go to …https://cdsco.gov.in/opencms/opencms/en/Home/

Clinical Instrumentation

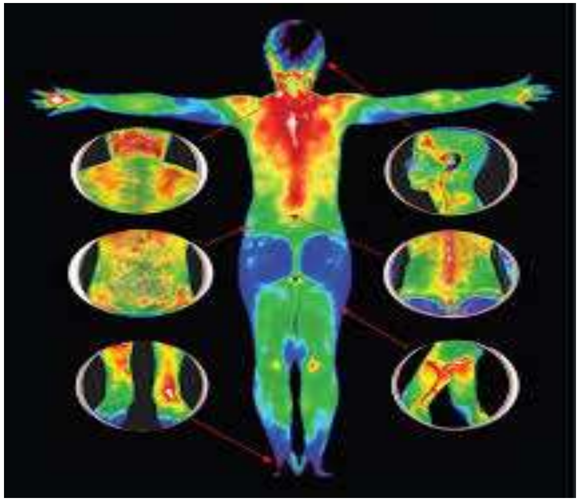
- Diagnosis
- Patient care
- Treatment of Patients (Therapeutic use)

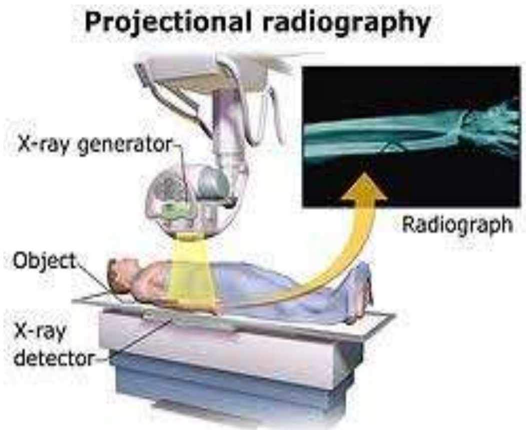
Measuring Instruments

- Audiometer
- Blood cell counter
- Blood Pressure meter
- Stethoscope

Recording Instruments

- Electrocardiograph
- Phonocardiograph (PCG)
- Thermograph
- Radio graph (x-ray)





Monitoring Instruments

- Bed – side monitor
- Bio – monitor

Analysing Instruments

- Colorimeter (The **colorimeter** is used for clinical chemistry, namely for determining haemoglobin concentrations)
- Spectrometer (spectral components of a physical phenomenon)

Data Logging and Controlling Instruments

- **Data Logging**

  Computer

- **Controlling**

➢ Defibrillator

➢ Dialysis instrument

Image courtesy :
Market Research.biz
Los Angeles Times

Medical Classification of BMI

Diagnostic instruments

- Endoscope
- Stethoscope
- Microscope

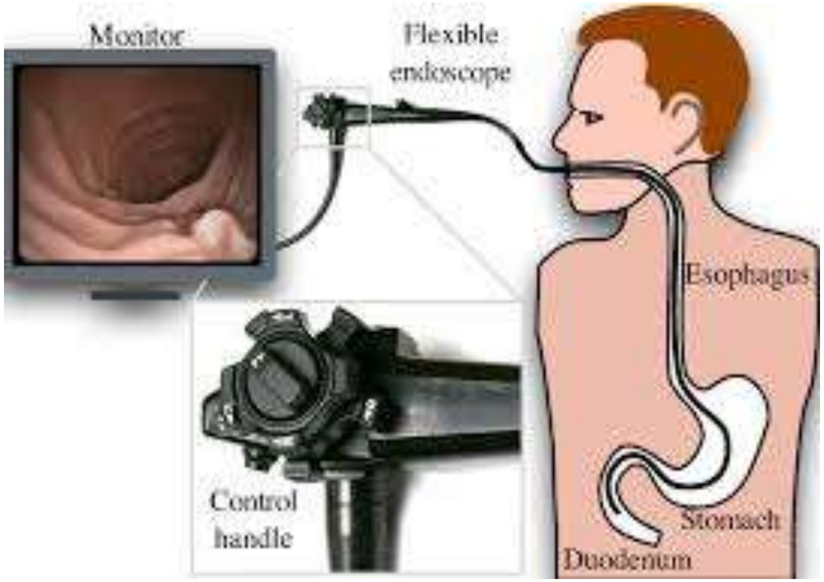


Image Courtesy:
Rob Reilink et al. ,"Image-based flexible endoscope steering", . IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE/RSJ International Conference on Intelligent Robots and Systems ·October 2010

Therapeutic Instruments

- Laser
- Ultrasound therapy
- Electro surgery

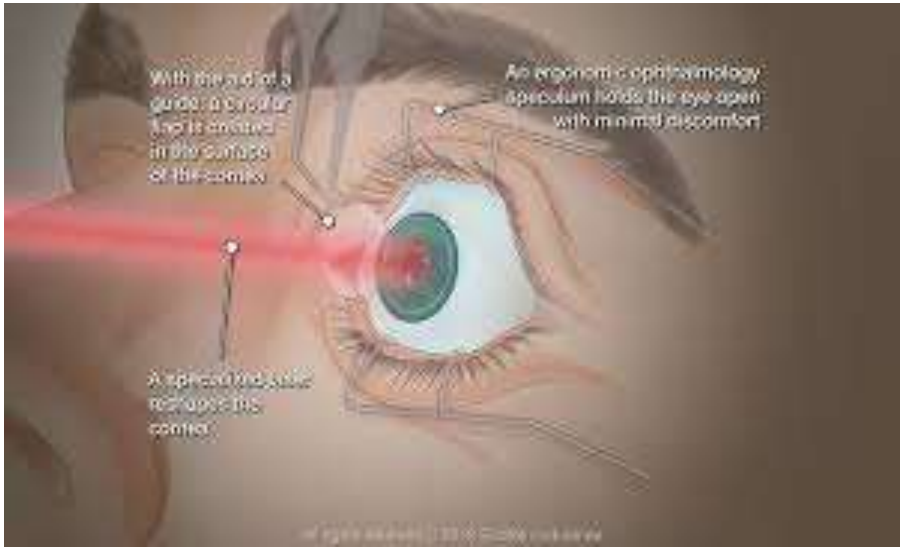


Image Courtesy : Best LASIK Eye Surgery Technology, Andrew Holzman

Image Courtesy : sportsinjuryclinic

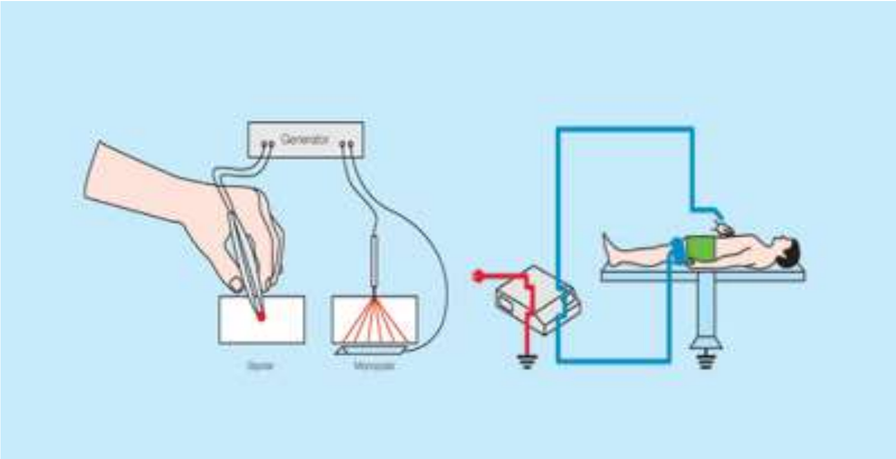


Image courtesy: asianhhm

Supplementary Instruments

- Aid for blind
- Hearing aid
- Pace maker

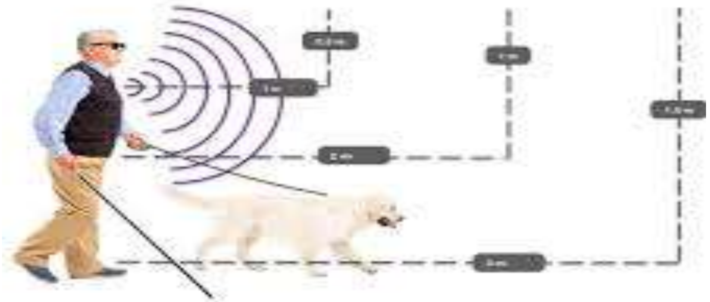


Image Courtesy : Advt. of IMerciv Technologies Private Limited

Image courtesy: www.kenresearch.com

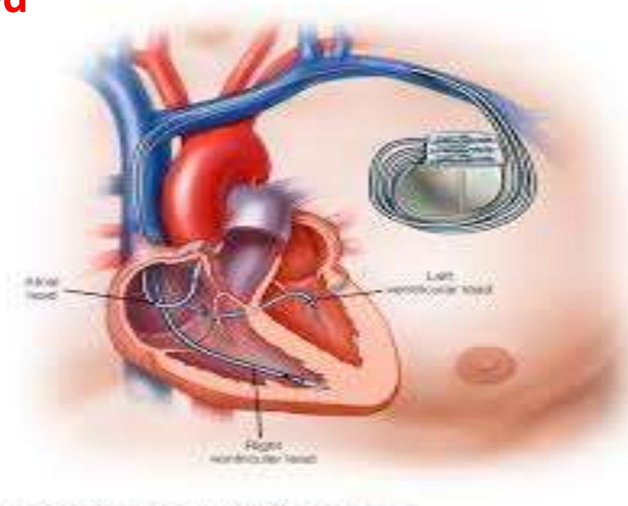


Image courtesy : www.mayoclinic.org

BLOOD pH MEASUREMENT

Blood pH Measurement

- pH is thus a measure of hydrogen ion concentration, expressed logarithmically.
- It is the negative exponent (log) of the hydrogen ion concentration. pH = –log (H+).
- If the number 10^–7 represents the concentration of hydrogen ions in a certain solution, then its pH would be 7.
- As hydrogen ion concentration rises, pH falls because the logarithm gets smaller, and as hydrogen ion concentration falls, pH rises because the logarithm gets larger.
- As we deal in logarithms to base 10, a pH of 7 represents 10 times the number of hydrogen ions.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Blood pH Measurement (Con..)

- Since pure water dissociates into 10–7 mol/l of (H+), a pH of +7 is considered a neutral solution.
- A pH of +6 represents an acid.
- A pH of +8 an alkali.
- Since 10^–6 is a larger number than 10^–8, the former solution has a larger hydrogen ion concentration.
- Thus, a pH of 6 is more acidic than a pH of 8.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Blood pH Measurement (Con..)

- Concentration of atoms is expressed in terms of mols/l
- 1 mol = 6.02 x 10^–23 molecules, known as the Avogadro’s Number.
- Whole blood with a (H+) of 4 x 10^–8 moles/1 would have a pH of 7.4.
- An increase in the (H+) to 1 x 10–7 moles/l would correspond to a decrease in pH to 7.0.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Blood pH Measurement (Con..)

- Electrochemical pH determination utilizes the difference in potential occurring between solutions of different pH separated by a special glass membrane.
- If the pH of one of the solutions is kept constant, so that the potential varies in accordance with the pH of the other solution, then the system can be used to determine pH.
- **The device used for measurement is the glass electrode**.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Blood pH Measurement (Con..)

- Potential (E) of the glass electrode written by the Nernst equation:

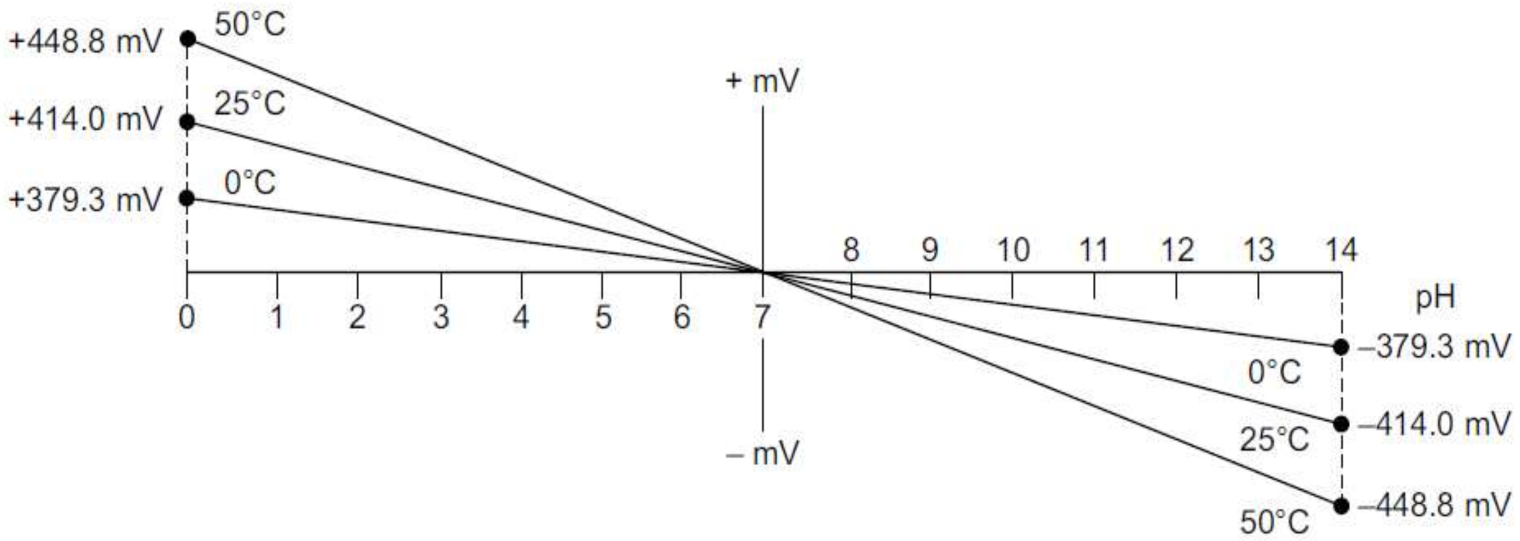
$$E = E_0 - \frac{2.3036\, RT}{F} \cdot \Delta\mathrm{pH}$$

- E0 = standard potential
- R = gas constant
- T = absolute temperature
- F = Faraday constant
- $\Delta\mathrm{pH}$ = pH value deviation from 7.
- The factor –2.3036 is called the slope factor and is clearly dependent upon the solution temperature.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Blood pH Measurement (Con..)

- With a **1°C change in temperature, the changes by 0.2 mV.**
- It is also obvious that the measurement of pH is essentially a measurement of millivolt signals by special methods.



Courtesy: Beckman Instruments Inc., U.S.A.

Blood pH Measurement (Con..)

- The reference electrode provides a constant potential against which the potential of the **indicator or glass electrode** is measured.
- An almost universally employed reference electrode is the saturated **calomel electrode**.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

pH Measurement Procedure

- The solution is taken in a beaker.
- one glass or indicating electrode and the other reference or calomel electrode, are immersed in the solution.
- The voltage developed across the electrodes is applied to an electronic amplifier, which transmits the amplified signal to the display.
- The pH meter is usually equipped with controls for calibration and temperature compensation.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

pH Measurement

- The glass electrode exhibits a high electrical resistance, of the order of 100–1000 MW.
- The emf measurement, necessitates the use of measuring circuits with high input impedance.
- The error caused in pH measurements due to temperature effect can be compensated either manually or automatically.
- In manual adjustment the instrument is calibrated at 25°C. Then the control is simply set to the actual measuring temperature.
- By this adjustment, the output current of the amplifier gets corrected to the desired temperature.

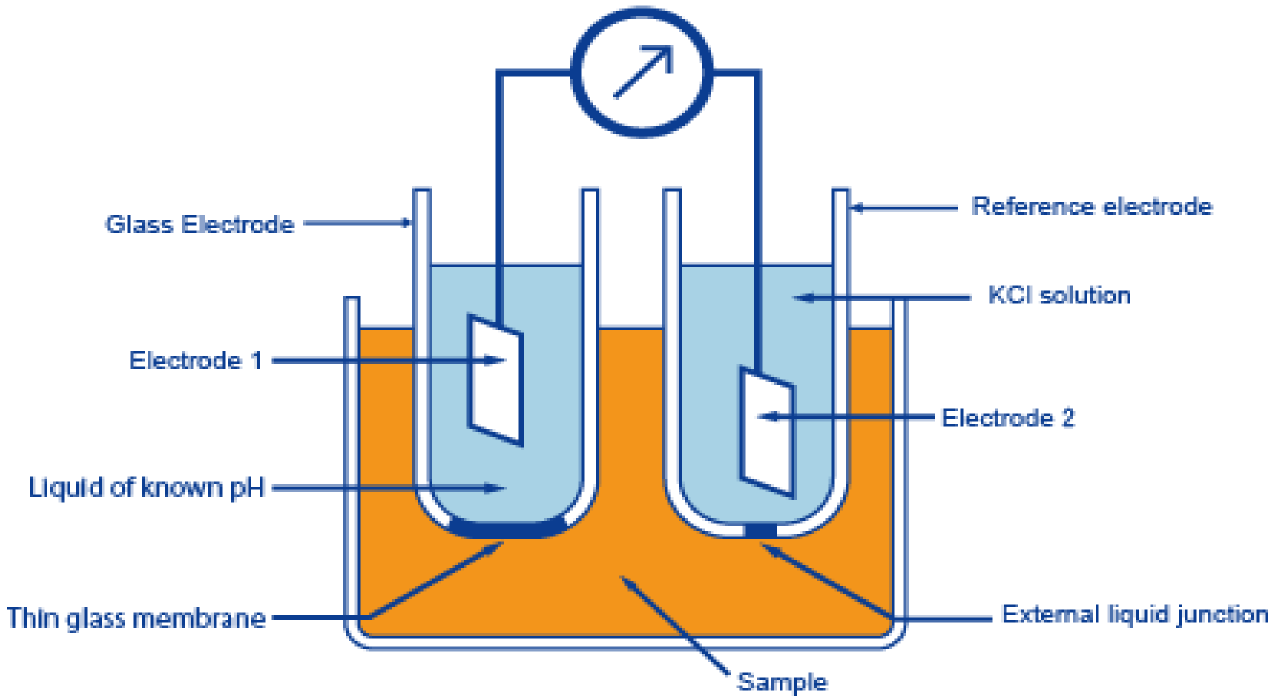
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

pH Measurement

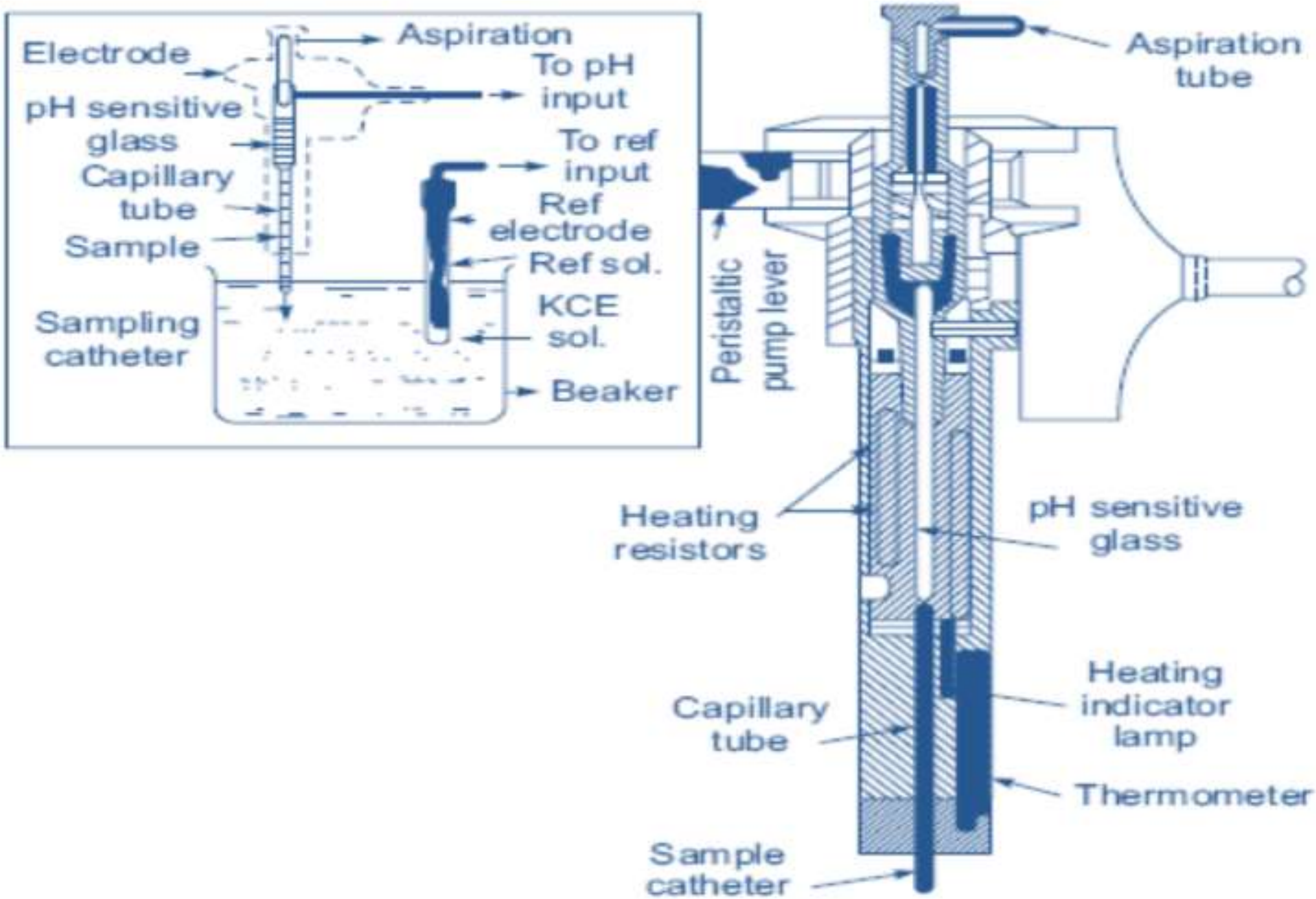
- In automatic adjustment, a variable resistor which is usually a thermistor or wire wound resistance that has an approximate desired resistance temperature coefficient is inserted in the circuit.
- During measurement, it is placed in the test solution.
- The use of an automatic temperature compensator will ensure that the pH meter is operating correct.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

pH Measurement



pH Measurement



Courtesy: Corning Scientific Instruments, U.S.A.

pH Measurement

- Electrodes for Blood pH Measurement:
- Glass electrode type made in different shapes.
- Accept small quantities of blood and yield accurate results.
- a micro-electrode for clinical applications requires only **20–25μl** of capillary blood for the determination of pH.
- The electrode is enclosed in a water jacket with circulating water at a constant temperature of 38°C.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

pH Measurement

Effect of Blood on Electrodes :

- Glass electrodes deteriorate if allowed to remain in contact with blood for a long time.
- This results in a change of the emf-pH slope.
- The poisoning effect appears to be due to protein deposition.
- Therefore, as a precautionary measure, in an apparatus where blood necessarily remains in contact around the electrode for long periods (more than 20 min.).
- The response must be checked frequently against buffer solutions.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

pH Measurement

Buffer Solutions:

- Buffer solutions are primarily used for

  (i) creation and maintenance of a desired, stabilized pH in a solution.

  (ii) standardization of electrode chains for pH measurements.
- A buffer is, therefore, a substance which by its presence in a solution is capable of counteracting pH changes in the solution as caused by the addition or the removal of hydrogen ions.
- Buffer solutions are characterized by their pH value.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Example

- 0.025 molar potassium dihydrogen phosphate with 0.025 molar disodium hydrogen phosphate.

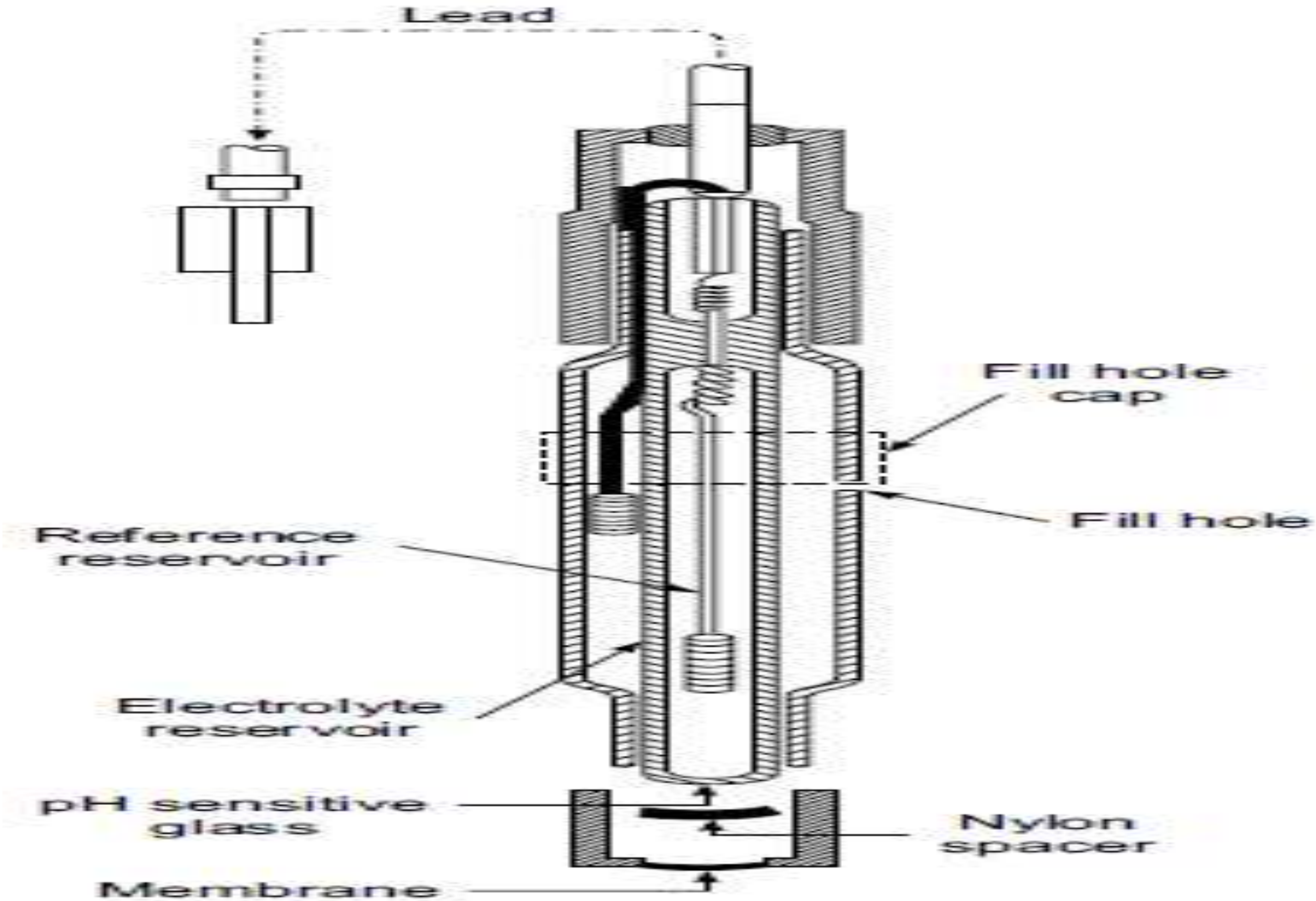
MEASUREMENT OF BLOOD PCO_2

MEASUREMENT OF BLOOD PCO_2

- The blood pCO2 is the partial pressure of carbon dioxide of blood taken.

$$pCO_2 = \text{Barometric pressure} - \text{water vapour pressure} \times \frac{\%CO_2}{100}$$

MEASUREMENT OF BLOOD PCO_2 …



Courtesy: Corning Scientific Instruments, U.S.A.)

MEASUREMENT OF BLOOD PCO_2…

- The CO2 from the blood sample diffuses through the membrane to form H2CO3, which dissociates into (H+) and (HCO– 3) ions.
- **The resultant change in pH is thus a function of the CO2 concentration in the sample**.
- **The emf generated was found to give a linear relationship between the pH and the negative logarithm of pCO2**.

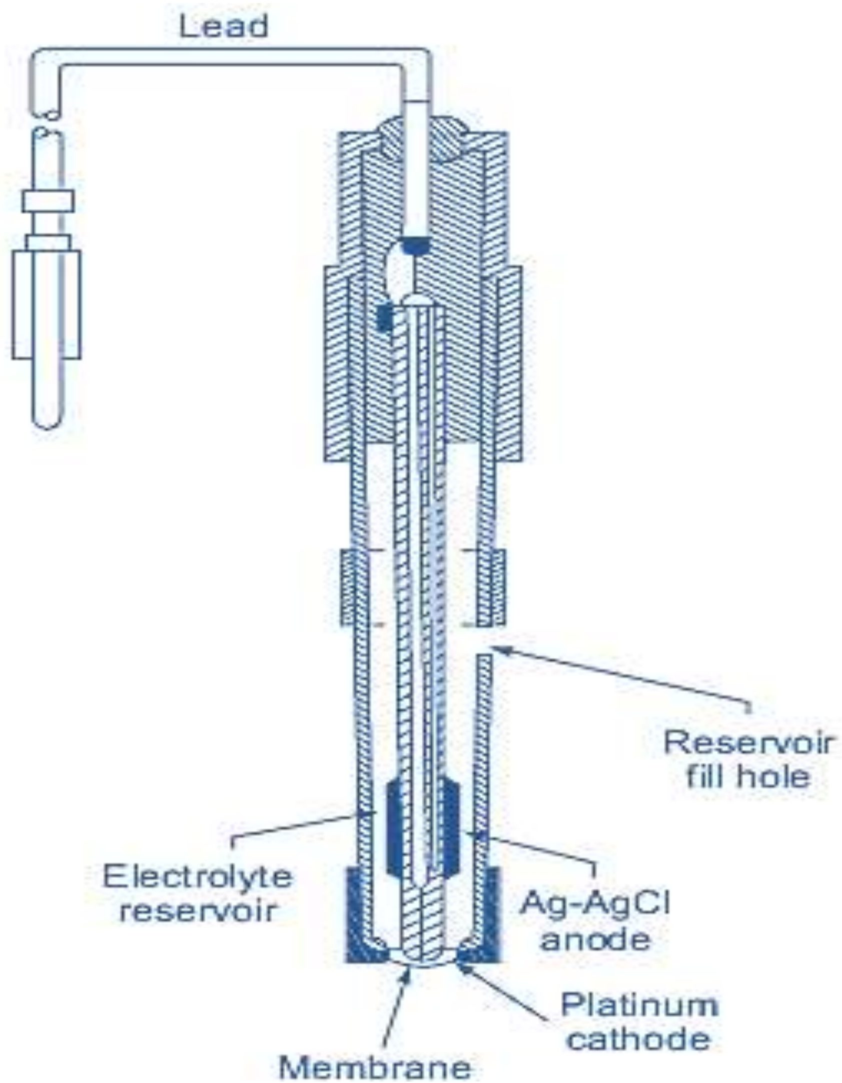
MEASUREMENT OF BLOOD PCO_2…

- The emf generated by a pCO2 electrode is a direct logarithmic function of pCO2.
- It is observed that a change in pCO2 causes the potential to change by 58 ± 2 mV.

BLOOD PO_2 MEASUREMENT

BLOOD PO_2 MEASUREMENT

- The partial pressure of oxygen is usually measured with a polarographic electrode.
- There is a characteristic polarizing voltage at which any element in solution is predominantly reduced and in the case of oxygen, it is 0.6 to 0.9 V.
- In this voltage range, it is observed that the current flowing in the electrochemical cell is proportional to the oxygen concentration in the solution.



Courtesy: Corning Scientific Instruments, U.S.A.

BLOOD PO_2 MEASUREMENT

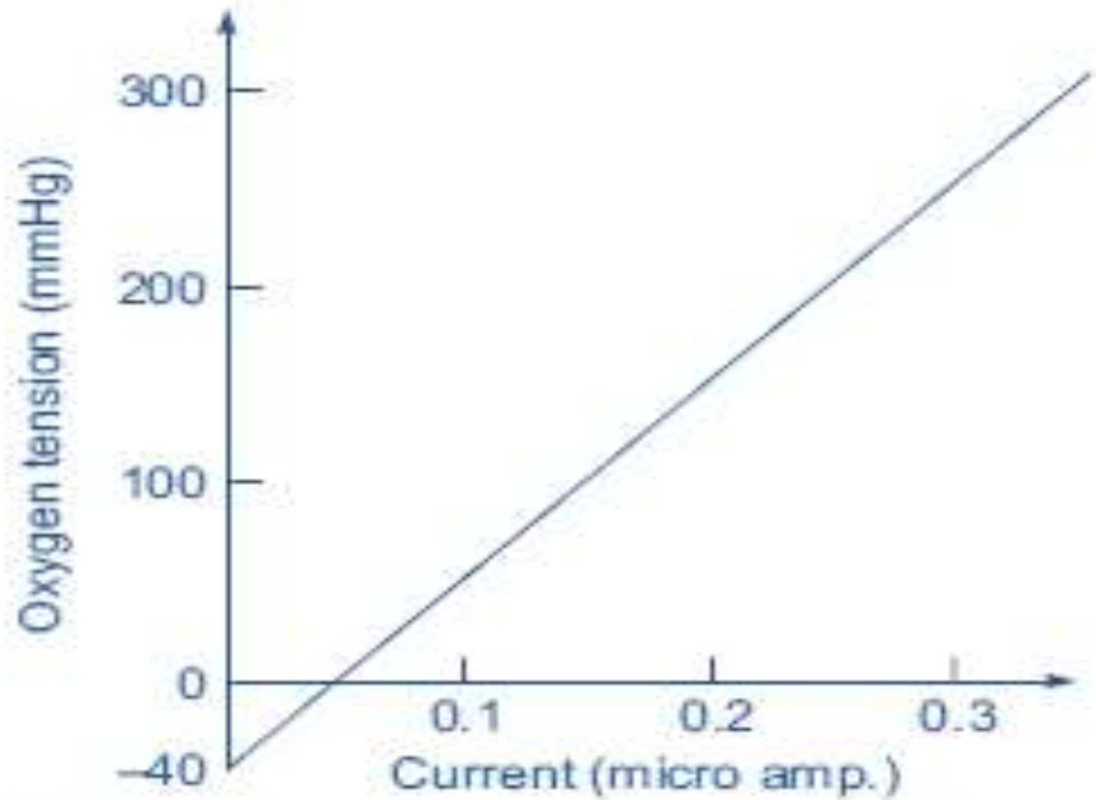
Cathode reaction:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

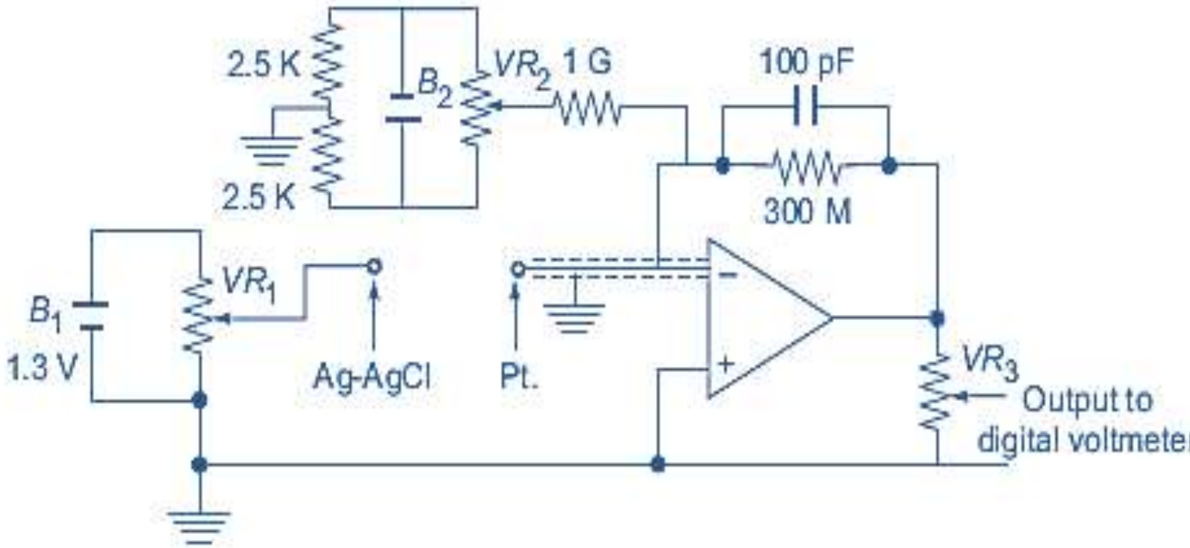
Anode reaction:

$$4Ag^+ \rightarrow 4Ag + 4e^-$$

Calibration curve of PO_2 electrode



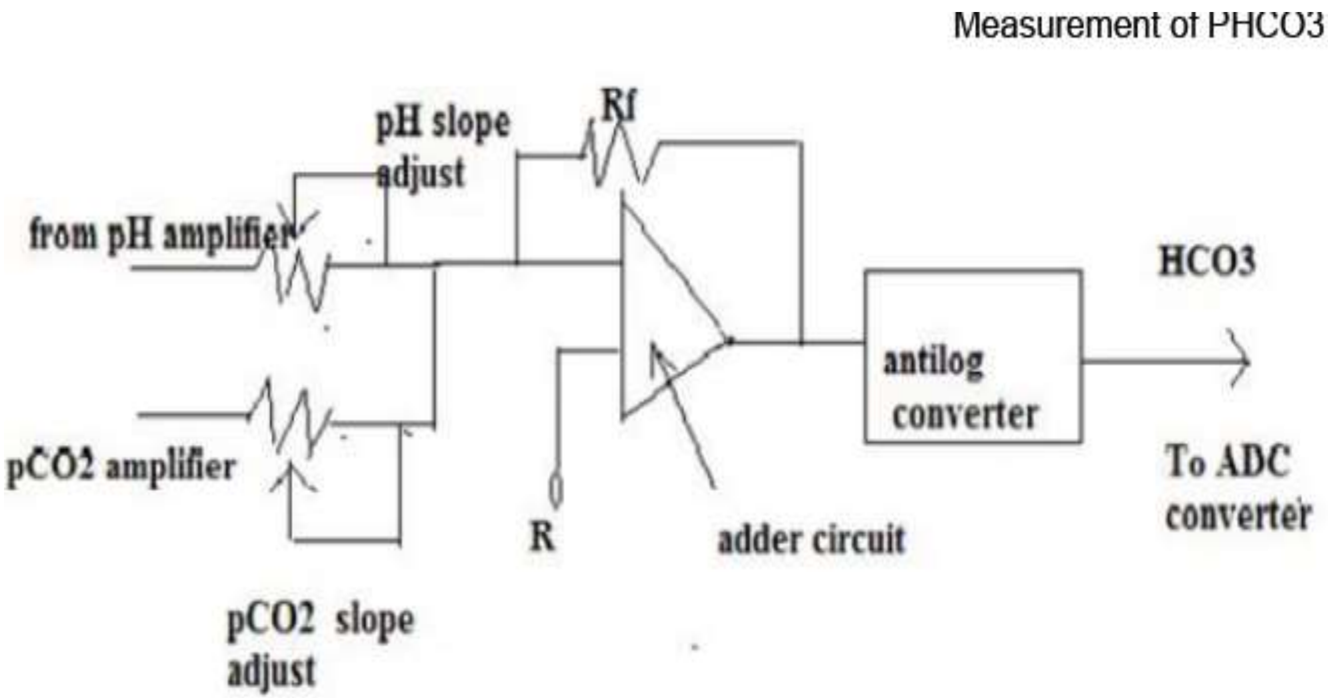
Current Amplifier



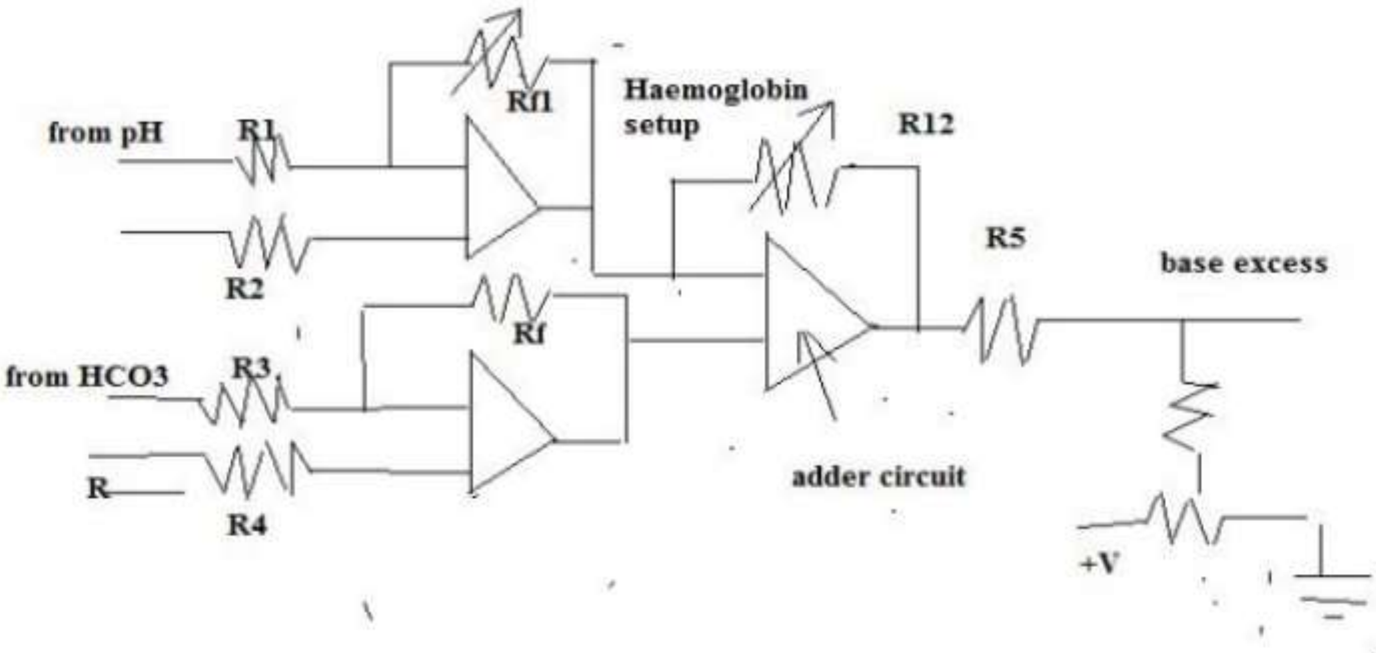
$PHCO_3$ MEASUREMENT

PHCO$_3$ Measurement

- Bicarbonate

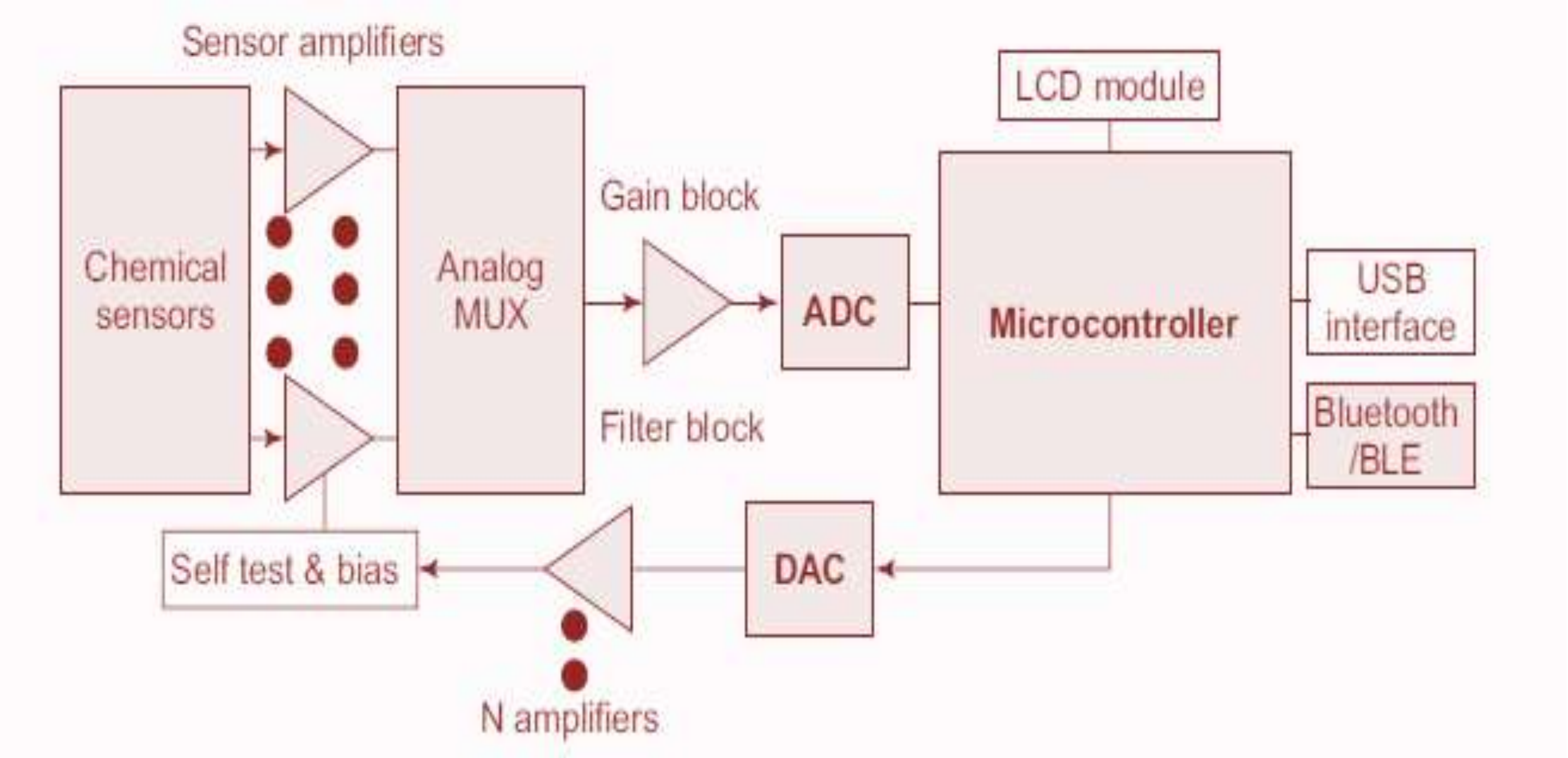


Complete Blood Sample Analysis



A COMPLETE BLOOD GAS ANALYSER

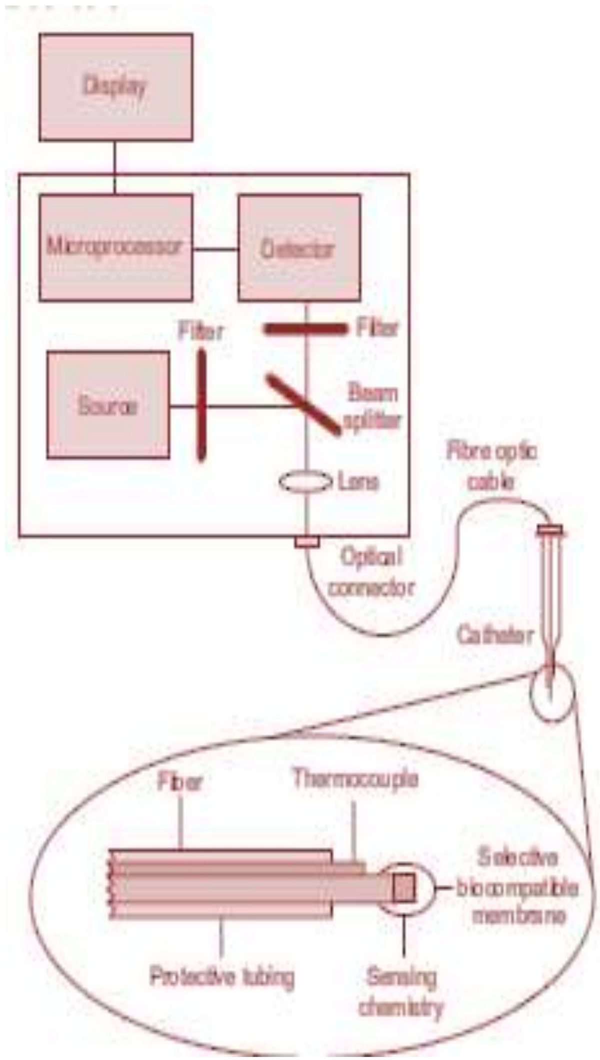
A complete Blood Gas analyser Block Diagram



Adapted from M/s Texas Instruments

FIBRE OPTIC-BASED BLOOD GAS SENSORS

Fibre Optic-based Blood Gas Sensors



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

- To analyse blood gases, a **small, stable, accurate and biocompatible sensor** is required which is **inserted in the blood flow** of an artery (Reference : Miller, 1993) through an arterial cannula and remain in place for several days.
- The sensors are interfaced with an electro-optic monitor.
- The monitor supplies the excitation light, which may be from a monochromatic source such as a diode laser or a broadband source like a xenon lamp whose light is filtered to provide a narrow bandwidth of excitation.

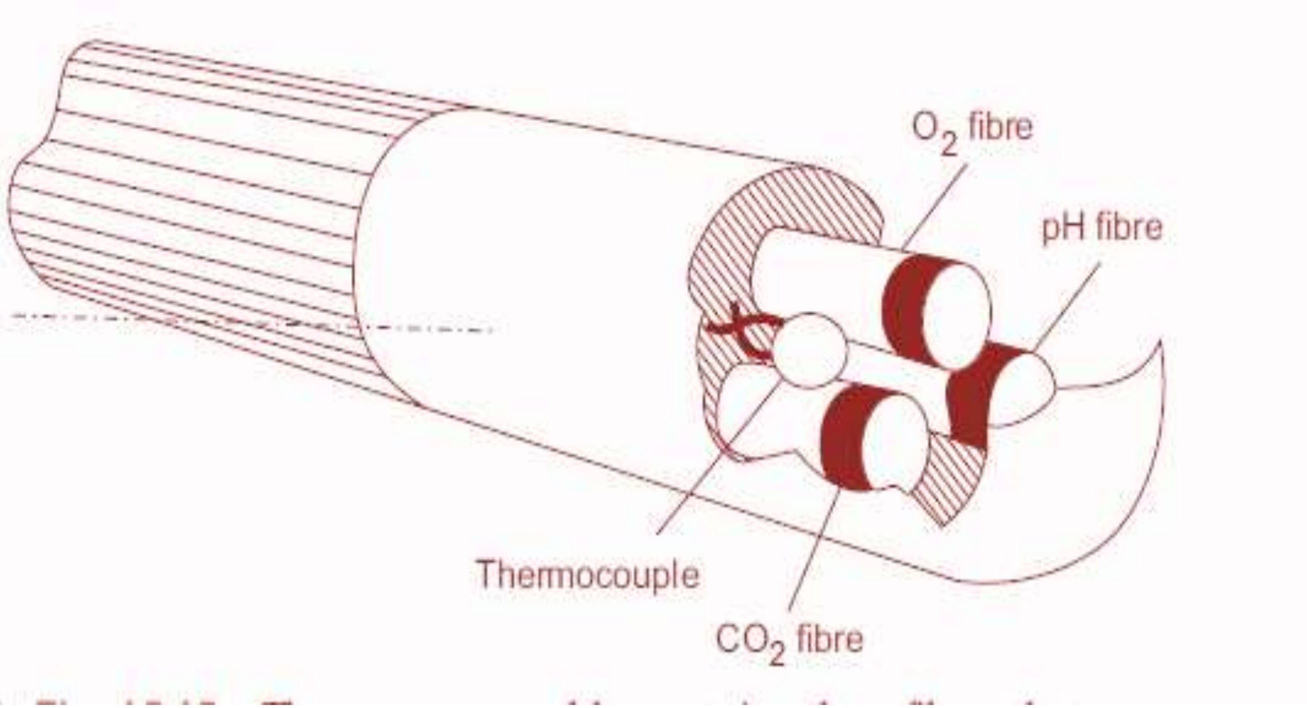
Arterial cannula- Sample Collection

Image Courtesy https://www.sciencephoto.com/

Fibre Optic-based Blood Gas Sensors(Con..)

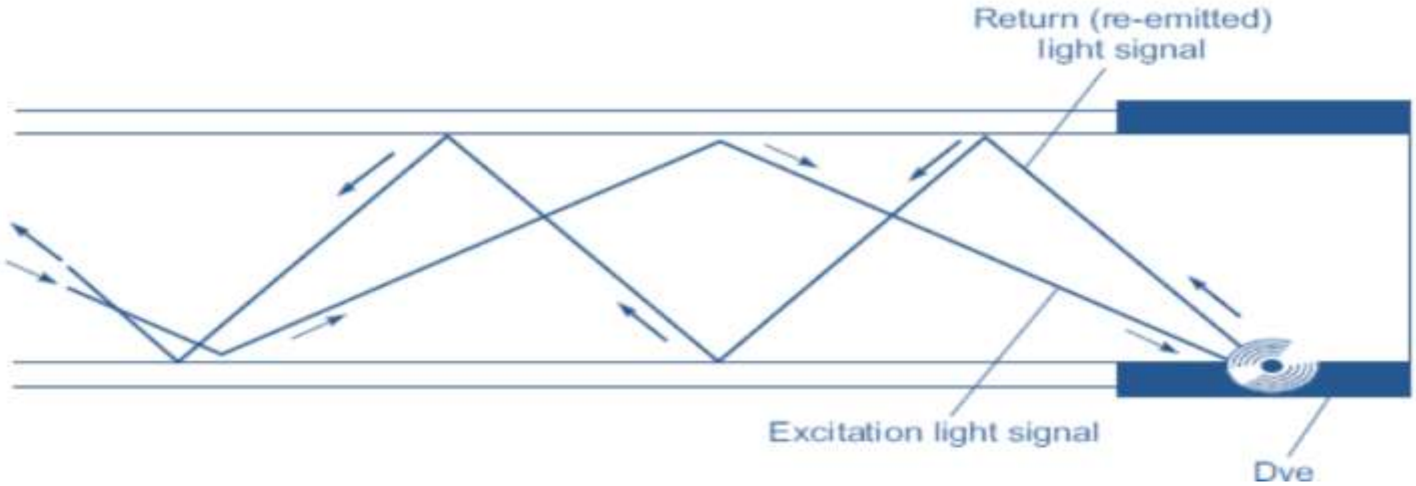
- Two wavelengths of light are provided, **one wavelength is sensitive to changes in the species** to be measured.
- The **other wavelength is unaffected by changes in the analytic concentration**.
- The **unaffected wavelength serves as a reference** and is used to compensate for fluctuations in the source output and detector efficiency.
- The **light output from the monitor is coupled into a fibre optic cable** through appropriate lenses and optical connectors.
- The **cable is sufficiently long to permit easy patient access by allowing the monitor to be placed at a distance**.

Sensor assembly with three fibres (To measure pH, pCO_2 and pO_2)



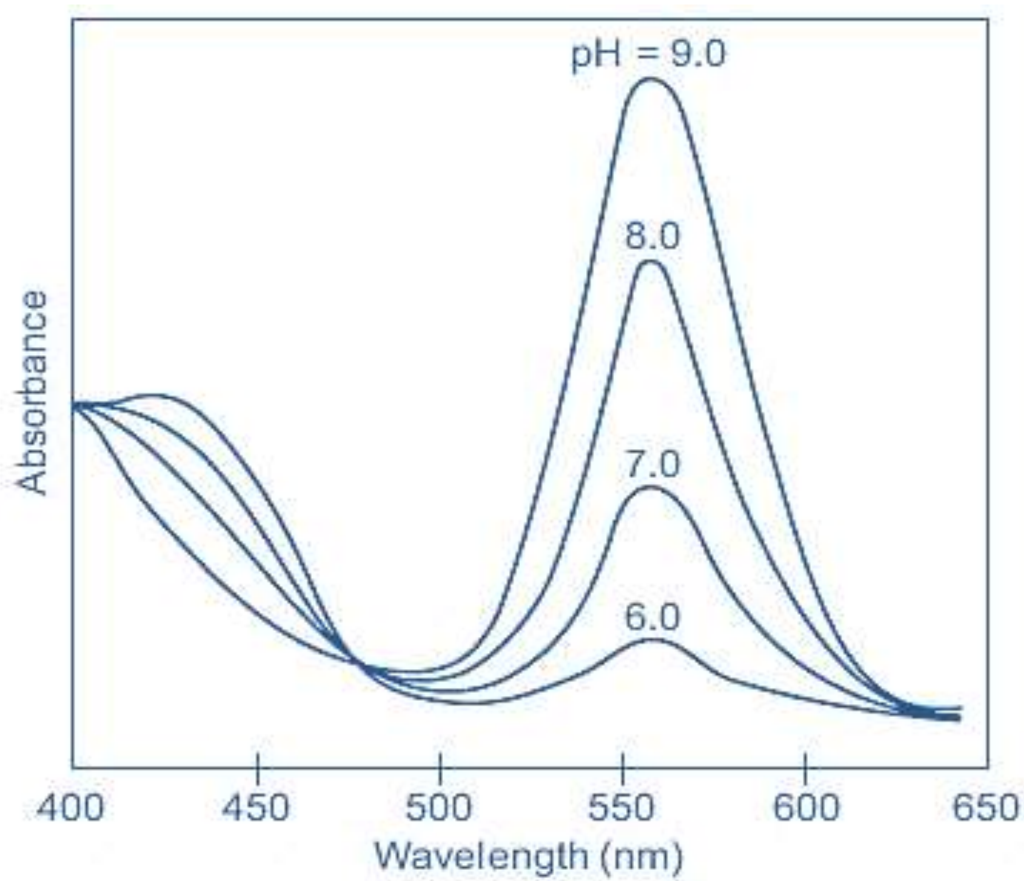
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Fluorescent Emission



- Each fibre is as thin as human hair and coated at the tip with a specific chemical dye , When light of a known wavelength strikes the dye, the dye fluoresces, giving off light of a different wavelength.
- The fluorescent emission changes in intensity as a function of the concentration of the analyte (O2, CO2 or pH) in the blood.
- The emitted light travels back down the fibre to the monitor where it is converted into an electrical signal by using a solid state detector or a photomultiplier.
- The signal is amplified before it is given to a digitizer.
- Signal processing to relate the light intensity to the analyte concentration is achieved using a microprocessor and is digitally displayed.

Absorption spectra of pH sensitive dye (phenol red)



ELECTROPHORESIS

ELECTROPHORESIS

- In clinical laboratories, various devices are used based on the electrophoretic principle.
- These devices are used for the following applications.
- To measure the quantity of protein in plasma, urine, etc.
- To separate enzymes into their components is enzymes.
- To identify antibodies.

ELECTROPHORESIS

Basic principle

- Electrophoresis is defined as the movement of a solid phase with respect to a liquid. The buffer solution is used to carry the current and to maintain the pH value of the solution as a constant one during the migration
- The sample is applied to the medium and under the effect of the electric field, group of particles that are similar in charge, size, and shape migrate at the same rate. So the particles are separated into zones.

Factors Affect the Speed of Migration

Magnitude of charge: The mobility of a given particle is directly related to the net magnitude of the particles charge. Mobility is defined as, the distance in cm, a particle moves in unit time per unit field strength.

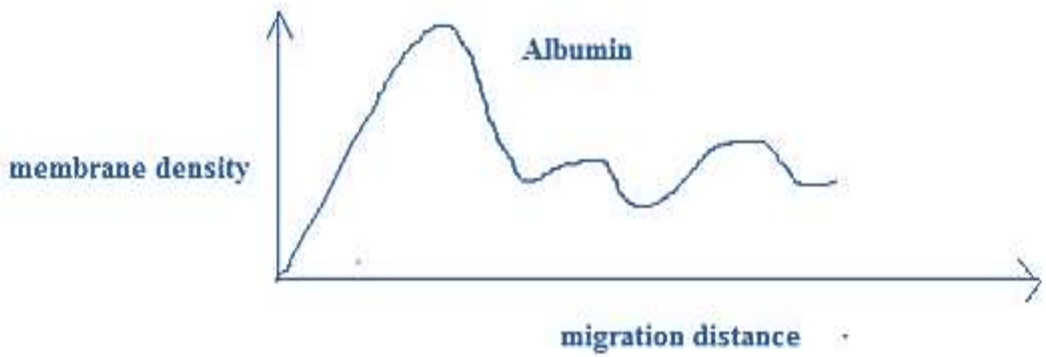
Ionic Strength of Buffer: If the buffer is more concentrated then the migration of the particles is slow. Because, if greater the proportion of buffer ions present, then greater the proportion of the current they carry.

Temperature: Mobility is directly related to temperature. Heat is produced when the current flows through the resistance of the medium. So, the temperature of the medium is increased and resistance is decreased. Finally, the rate of migration is increased.

Time: The distance of migration is related to the time period during which electrophoresis takes place

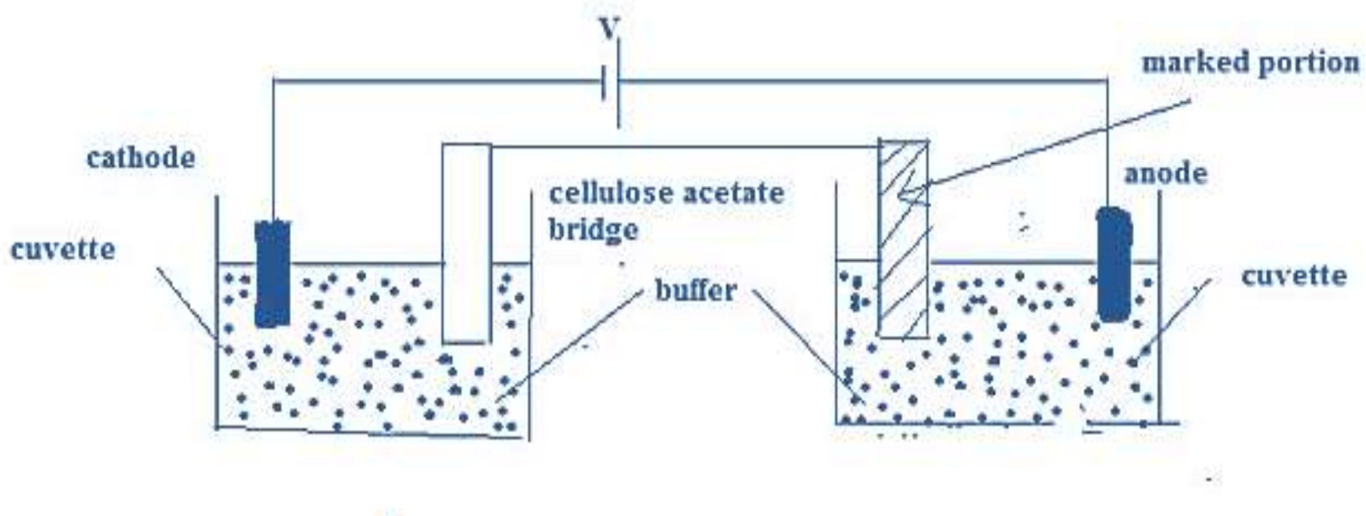
Cellulose Acetate Electrophoresis

- The sample for each test is placed on the strip at a marked location. Then, the constant electric potential(250 V) is applied across the strip 4 – 6 mA of initial current is obtained .
- After 15-20mins, the electric voltage is removed, then, migrated protein band is stained with buffer and it is dried in preparation for densitometry.



Cellulose acetate electrophoresis..

- The membrane is placed in the holder of densitometer.
- The path of the migration of one of the specimen is scanned.
- The low voltage output is amplified and recorded using x-y recorder.



COLORIMETERS

Colorimeters

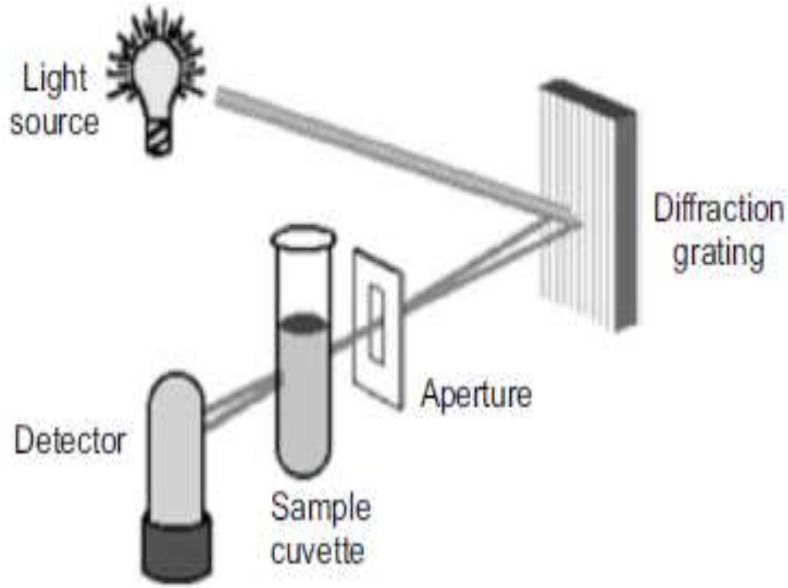
- A colorimetric (photometric) determination is one that involves the **measurement of colour in the visual region of the electromagnetic spectrum** (**400–700 nm**).
- In a colorimeter, **the sample is normally a liquid**.
- The sample compartment of a colorimeter is provided with a holder to contain the cuvette (straight-sided clear container for holding liquid samples).
- The liquid is sample and **reference cuvettes are measured first** and a shutter is moved into or out of the light beam until the readout meter gives a full-scale deflection (100% T-scale reading).
- The sample is then moved into the beam and the light passing through it is measured as a percentage to the reference value.

Colorimeters (con..)

$$\text{Sample concentration} = \text{Standard concentration} \times \frac{\text{Sample reading}}{\text{Reference reading}}$$

- Colorimeters are extremely simple in construction and operation.
- They are used for a great deal of analytical work, where high accuracy is not required.
- The disadvantage is that a range of filters is required to cover different wavelength regions.

Colorimeters (con..)



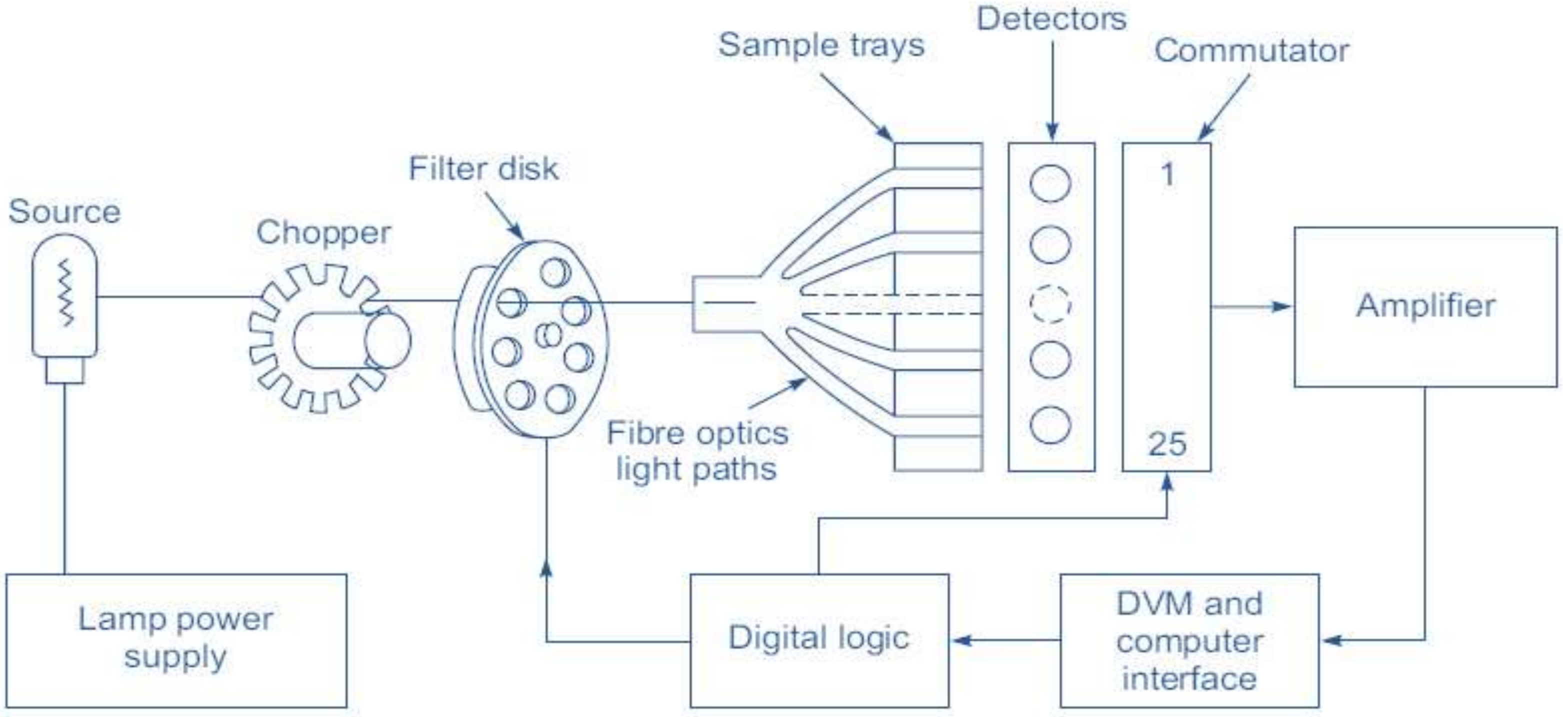
wavelength-selectable, single-beam UV-spectrophotometer

A single wavelength spectrophotometer

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Colorimeters (con..)

- **Multi-channel Colorimeter (Photometer)**



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Colorimeters (con..)

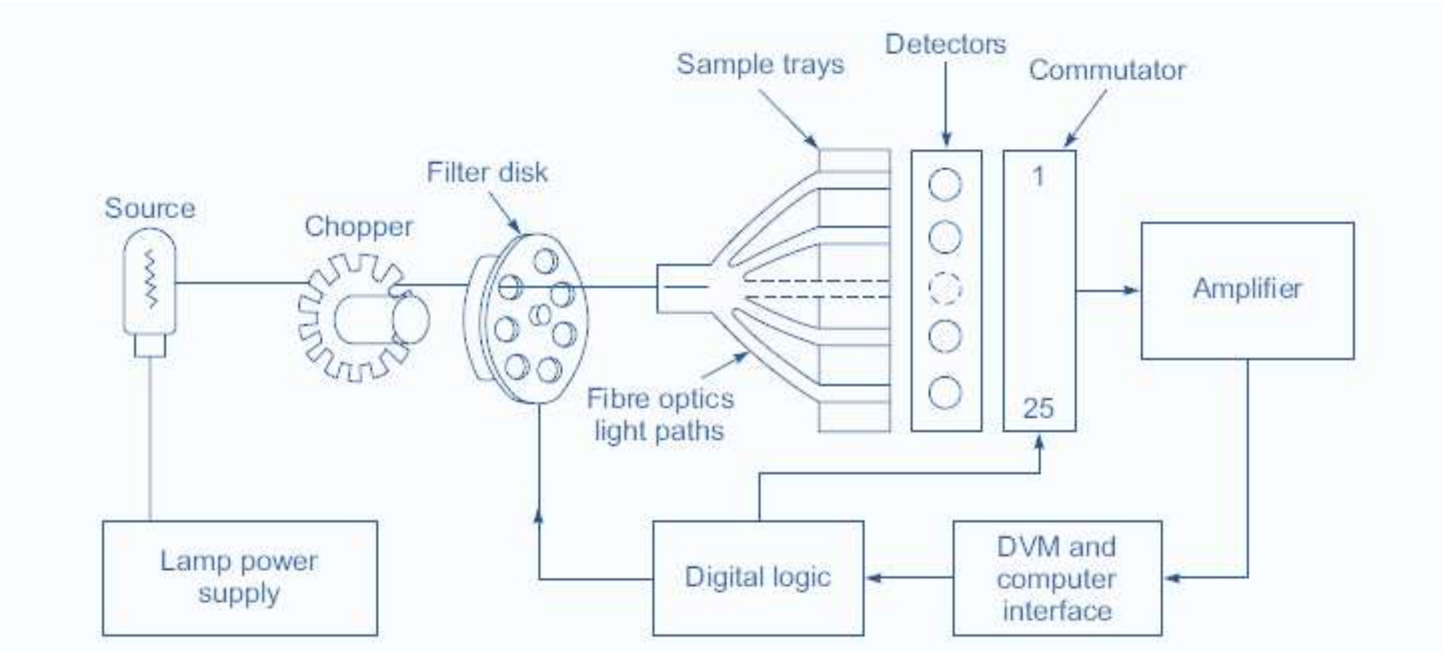
- **In multi-channel photometer:** instead of introducing one sample at a time into a single light path, **a batch of samples is introduced**.
- **Measurements** are carried out **simultaneously**, using a **multiplicity of fiber optic light paths and detectors**, and **then the samples are scanned electronically instead of mechanically**.
- The **24 sample cuvettes are arranged in a rack in a three key eight matrix formation**.
- The **25th channel serves as a reference beam** and eliminates possible source and detector drifts.
- The **time required to place the cuvette rack** into the **measuring position corresponds** to the amount of time necessary to **put one sample into a sample changer**.

PHOTOMETER

Photometer (Multi-channel Colorimeter)

- In a multi-channel photometer, instead of introducing one sample at a time into a single **light path, a batch of samples** is introduced.
- Measurements are carried out simultaneously, using a **multiplicity of fiber optic light paths.**

Photometer (Multi-channel Colorimeter)- Blocks



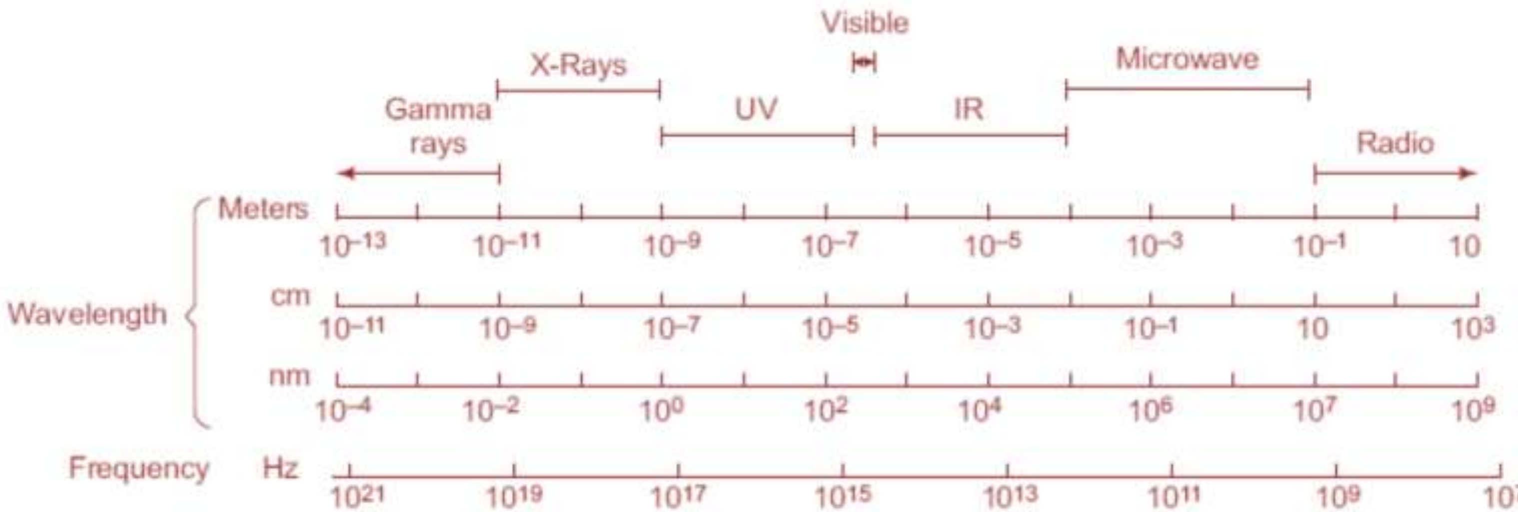
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

SPECTROPHOTOMETRY

SPECTROPHOTOMETRY

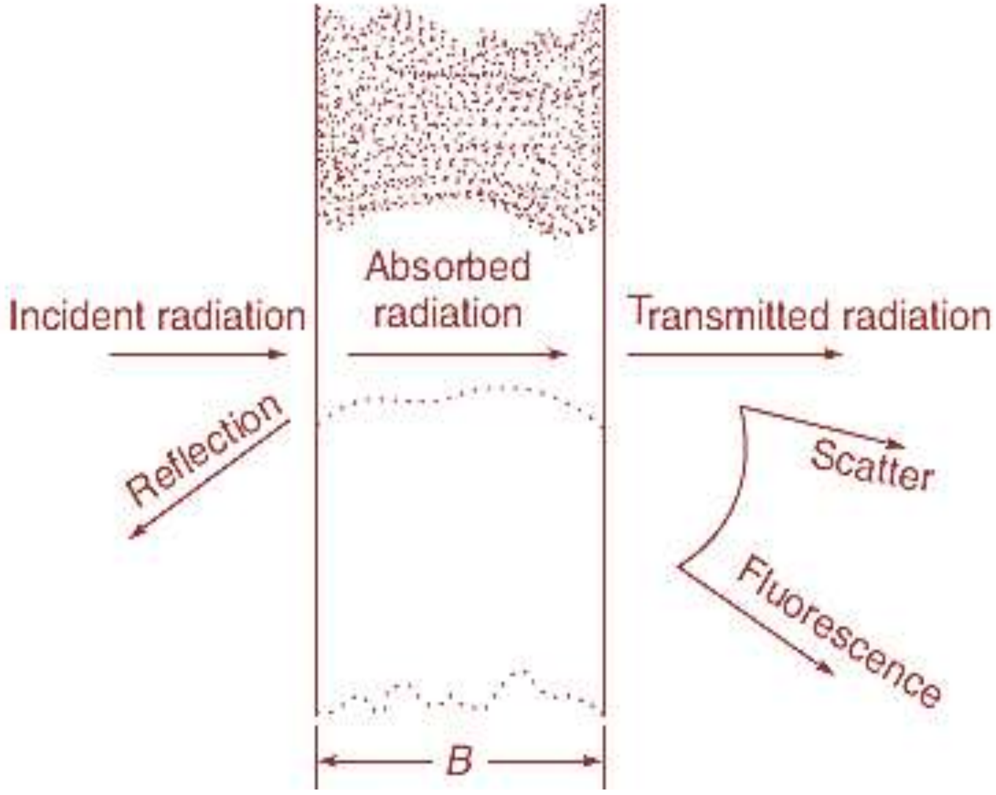
- Spectrophotometry is the most important of all the instrumental methods of analysis in clinical chemistry.
- This method is based on the absorption of electromagnetic radiation in the visible, ultraviolet and infrared ranges.

Electromagnetic Spectrum



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Interaction of radiation with matter



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Interaction of radiation with matter

- Absorption spectrophotometry is based on the principle that the amount of absorption that occurs is dependent on the number of molecules present in the absorbing material.
- The intensity of the radiation leaving the substance may be used as an indication of the concentration of the material.

Interaction of radiation with matter

- P0 is the incident radiant energy and P is the energy which is transmitted.
- The ratio of the radiant power transmitted by a sample to the radiant power incident on the sample is known as the transmittance.

$$\text{Transmittance } T = P/P_0$$

$$\%\ \text{Transmittance} = (P/P_0) \times 100$$

- The logarithm to the base 10 of the reciprocal of the transmittance is known as absorbance.

$$\text{Absorbance} = \log_{10}(1/T)$$
$$= \log_{10}(P_0/P)$$
$$\text{Optical density} = \log_{10}(100/T)$$

Interaction of radiation with matter

- According to the Beer-Lambert Law,

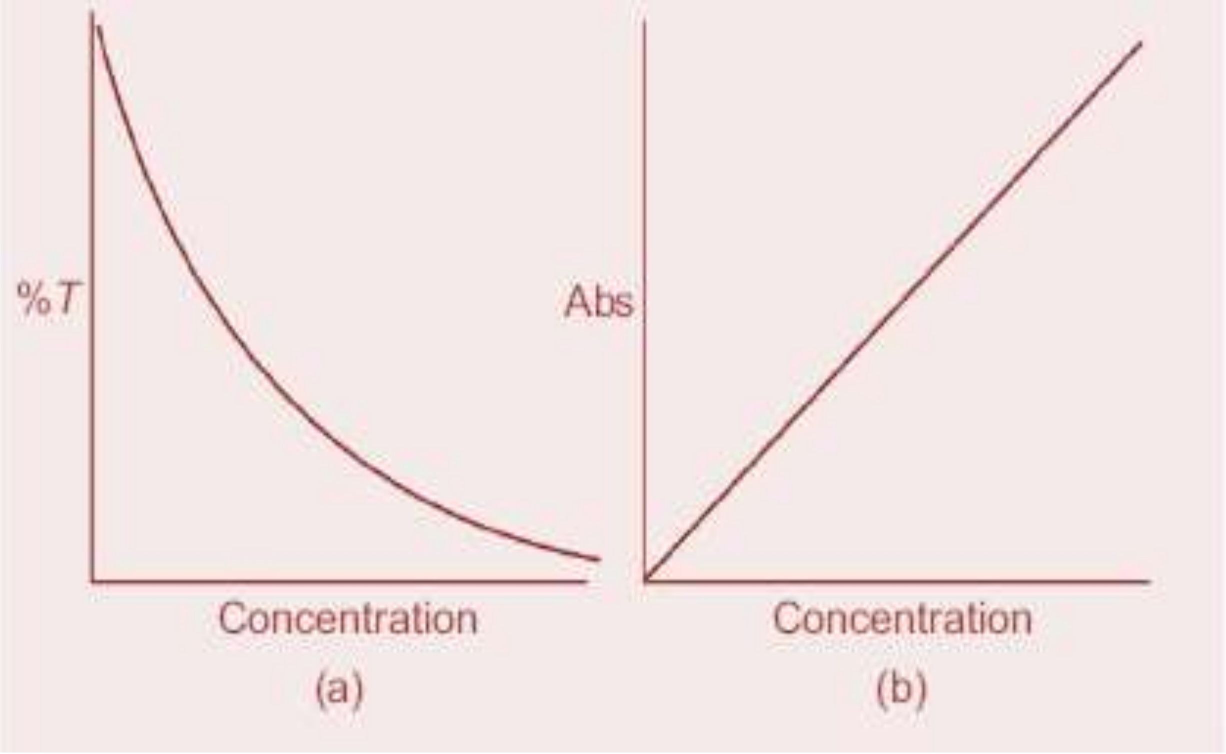
$$P = P_0 10^{-\varepsilon b c}$$

- where c is the concentration, b the path length of light and Ɛ the extinction coefficient.
- The concentration c of the substance is calculated from the absorbance, also called the extinction E, as follows:

$$\text{Absorbance } (E) = \log P_0/P = \varepsilon b c$$

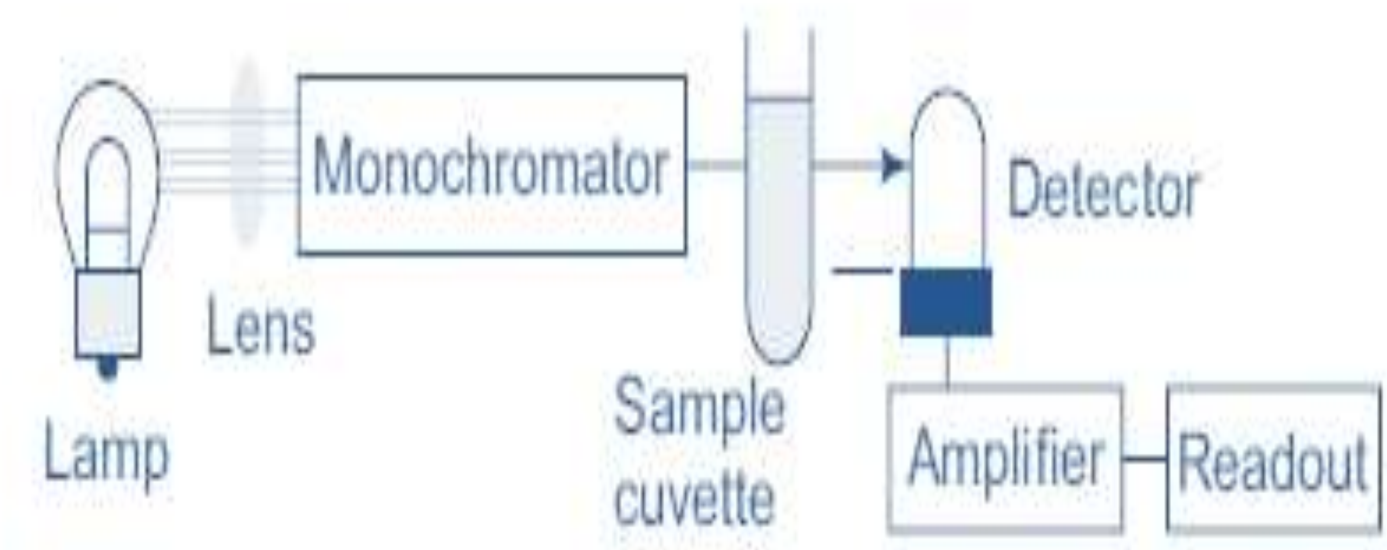
- In spectrophotometric measurements Ɛ and b are nearly constant so that for a particular determination, absorbance (A) varies only with concentration (c).

%T vs concentration & Absorbance vs concentration



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

SPECTROPHOTOMETER TYPE INSTRUMENTS



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

ELEMENTS OF SPECTROPHOTOMETER TYPE INSTRUMENTS

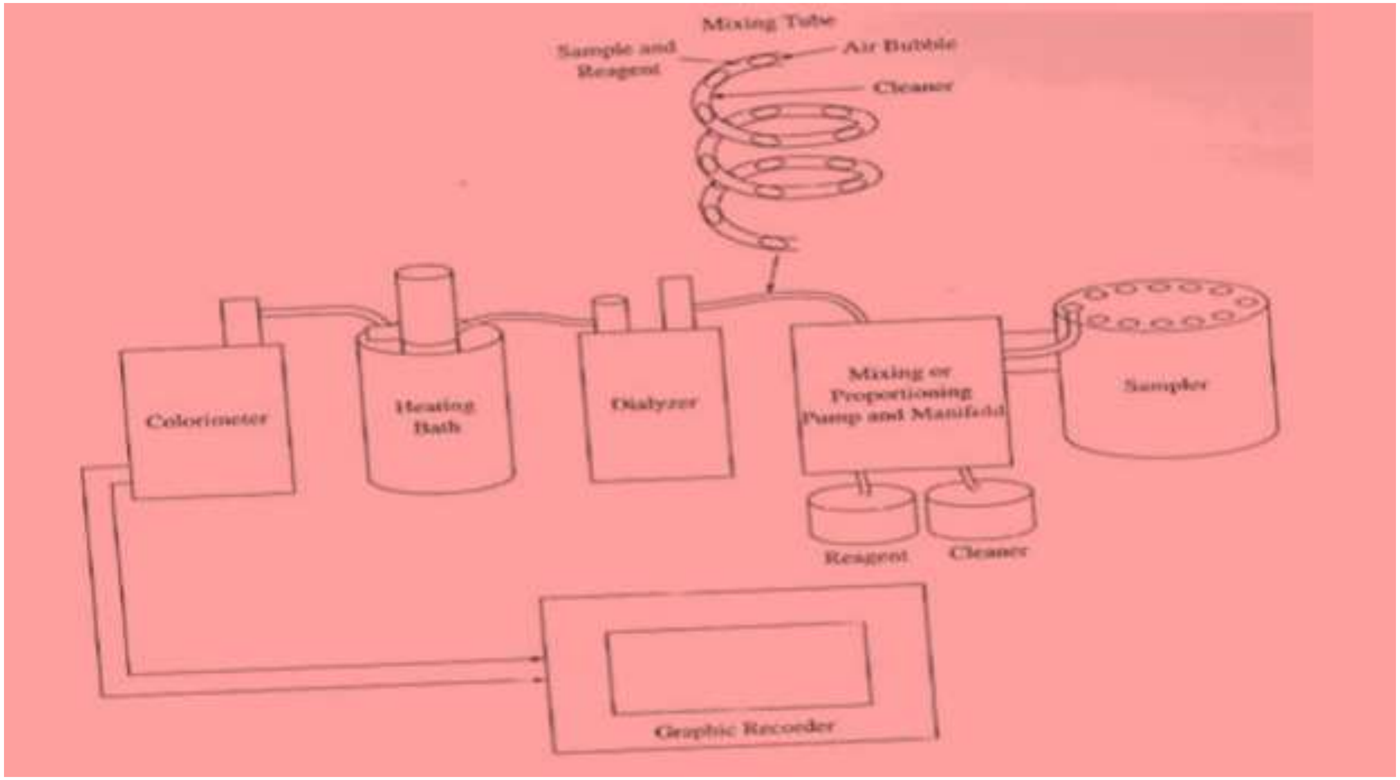
- Source : Such as Tungsten lamp
- Filtering arrangement(such as Prism)
- Detecting system
- Readout system

AUTOANALYZER

AUTOANALYZER…

- An auto analyzer sequentially measures blood chemistry through a series of steps of mixing, reagent reaction and colorimetric measurements.

Block Diagram



Block Diagram…..

- **Sampler:** Aspirates samples, standards, wash solutions into the system.
- **Proportioning pump**: Mixes samples with the reagents so that proper chemical color reactions can take place, which are then read by the colorimeter.
- **Dialyzer:** separates interfacing substances from the sample by permitting selective passage of sample components through a semi permeable membrane.
- **Heating bath:** Controls temperature (typically at 37 °C), as temp is critical in color development.
- **Colorimeter:** monitors the changes in optical density of the fluid stream flowing through a tubular flow cell. Color intensities proportional to the substance concentrations are converted to equivalent electrical voltages.
- **Recorder:** Displays the output information in a graphical form.

BLOOD FLOW METER

Blood flow meter

BLOOD FLOW MEASUREMENT:

- Blood flow is one of the **most important** physiological parameters & one of the **most difficult** to measure accurately.
- Instruments for measuring the flow through blood vessels within the body have to meet certain specifications (e.g. sensitivity and stability)requirements depends on magnitude of flow, location and the diameter of the individual blood vessels.
- The average velocities of blood flow varies range in vessels with diameters ranging from 2 cm to a few millimetres.

Blood flow measurement

- Invasive and non-invasive measurement.
- The most accurate method is to simply piercing the vessel and time the blood flow into a calibrated beaker.
- But this procedure is too radical for most protocols.

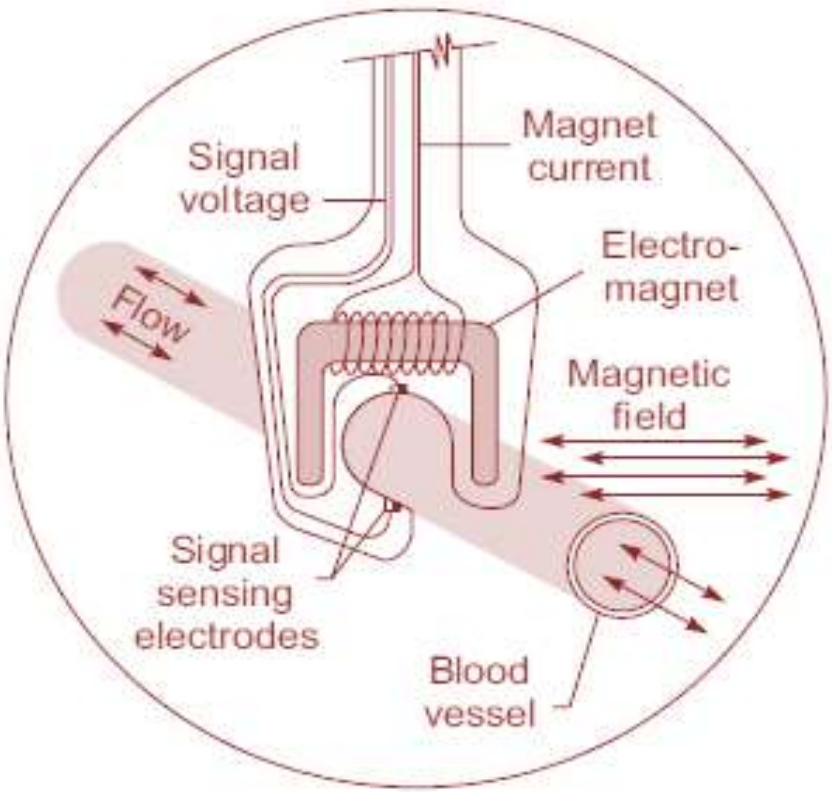
Electromagnetic Blood Flow meter

- Most commonly used instrument for the measurement of blood flow is of the electromagnetic type.
- In this instrument, blood flow can be measured in intact blood vessels without cannulation.
- However, this method requires the blood vessel be exposed .
- The flow head or the measuring probe can be put across it.

Electromagnetic Blood Flow meter

- The operating principle of electromagnetic type flowmeters is based on **Faraday's law of electromagnetic induction.**
- **when a conductor is moved at right angles through a magnetic field in a direction at right angles both to the magnetic field and its length, an emf is induced in the conductor.**
- An electromagnetic assembly provides the magnetic field placed at right angles to the blood vessel in which the flow is to be measured.

Electromagnetic Blood Flow meter



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electromagnetic Blood Flow meter

- The blood stream(which is a conductor) cuts the magnetic field and voltage is induced in the blood stream.
- The induced voltage is picked up by two electrodes incorporated in the magnetic assembly.
- The **magnitude of the voltage** picked up is **directly proportional** to the **strength of the magnetic field, the diameter of the blood vessel and the velocity of blood flow**.

Electromagnetic Blood Flow meter

$e = CHVd$

e = induced voltage

H = strength of the magnetic field

V = velocity of blood flow

d = diameter of the blood vessel

C = constant of proportionality

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electromagnetic Blood Flow meter

- If the **strength of the magnetic field and the diameter of the blood vessel remain unchanged** : The **induced voltage will be a linear function of the blood flow velocity**.

$$e = C_1 V$$

- **C1 is a constant and equal to CHd.**
- The flow rate Q through a tube is given by

$$Q = VA$$

- **A is the area of cross-section of the tube, hence**

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electromagnetic Blood Flow meter

$$e = C_1 \times Q/A = C_2 \times Q$$

- where C2 is a general constant and is given by C1/A.
- This equation shows **the induced voltage is directly proportional to the flow rate through the blood vessel**.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

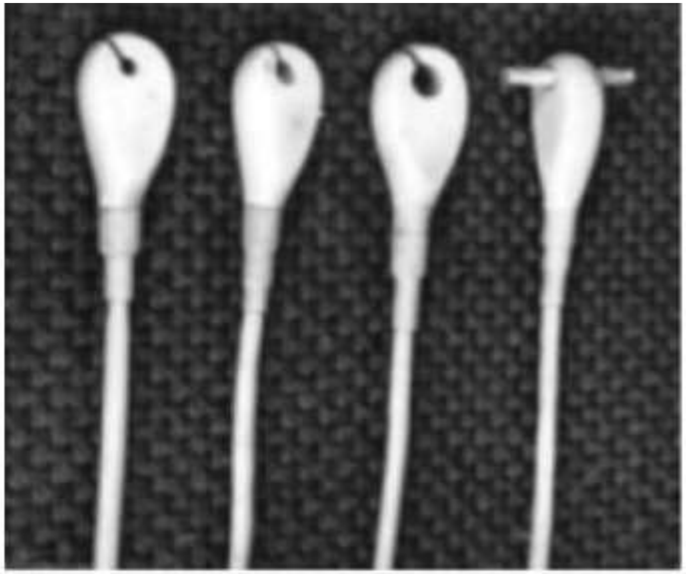
Electromagnetic Blood Flow meter

- The induced voltage picked up by the electrodes is amplified and displayed/recorded on a suitable system.
- The system is calibrated in terms of volume flow as a function of the induced voltage.
- The diameter of the blood vessel is held constant by the circumference of the hole in the probe that surrounds it.

Design of Flow Transducer:

- It is a tube of non-magnetic material to ensure that the **magnetic flux does not bypass the flowing liquid** and go into the walls of the tube.
- The tube is made of a conducting material and generally has an insulating lining to prevent short circuiting of the induced emf.
- The induced emf is picked up by point electrodes made from stainless steel or platinum.

Flow heads



- The flow head contains a slot through which the intact blood vessel can be inserted to make a snug fit.
- Several probes of different sizes must therefore accompany the flowmeter to match the full range of sizes of the blood vessels which have various diameters.
- flow heads having as small as 1 mm external diameter (for small vessels).

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

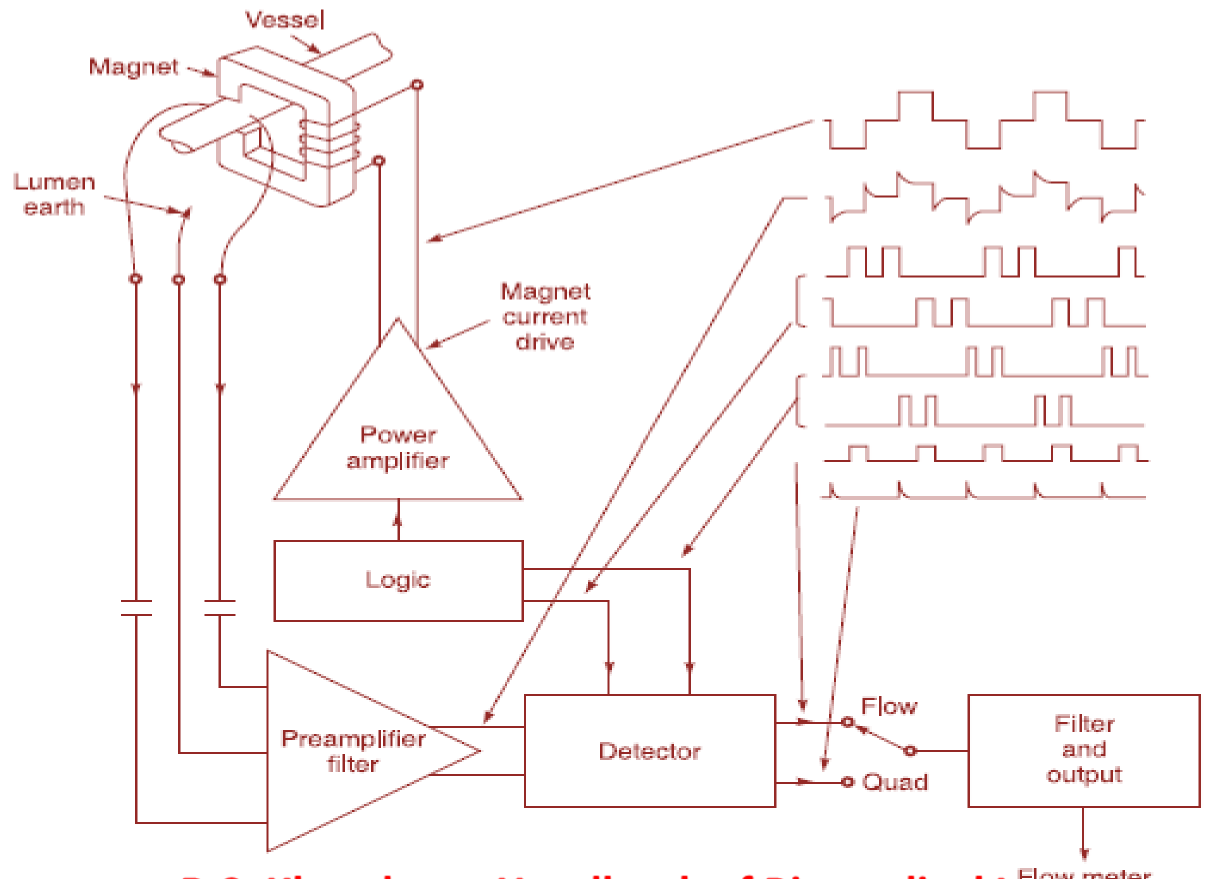
Types of Electromagnetic Flowmeters

- **Sine Wave Flowmeters**
- In sine wave flowmeter, the probe magnet is energized with a sine wave and consequently the induced voltage will also be sinusoidal in nature.
- The major problem encountered with the sinusoidal type of magnetic field is that the blood vessel and the fluid contained in it act as the secondary coil of a transformer when the probe magnet is excited.
- In addition to the induced flow voltage, there is an induced artefact voltage generally referred to as '**transformer voltage**'.

Types of Electromagnetic Flowmeters

- The energizing voltage given to the magnet
- is a square wave and therefore, the induced voltage is also a square wave.
- The square wave flowmeter has less requirements of phase stability than the sine wave type as it can suppress the quadrature voltages relatively easily.

Blocks of square wave flowmeter



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

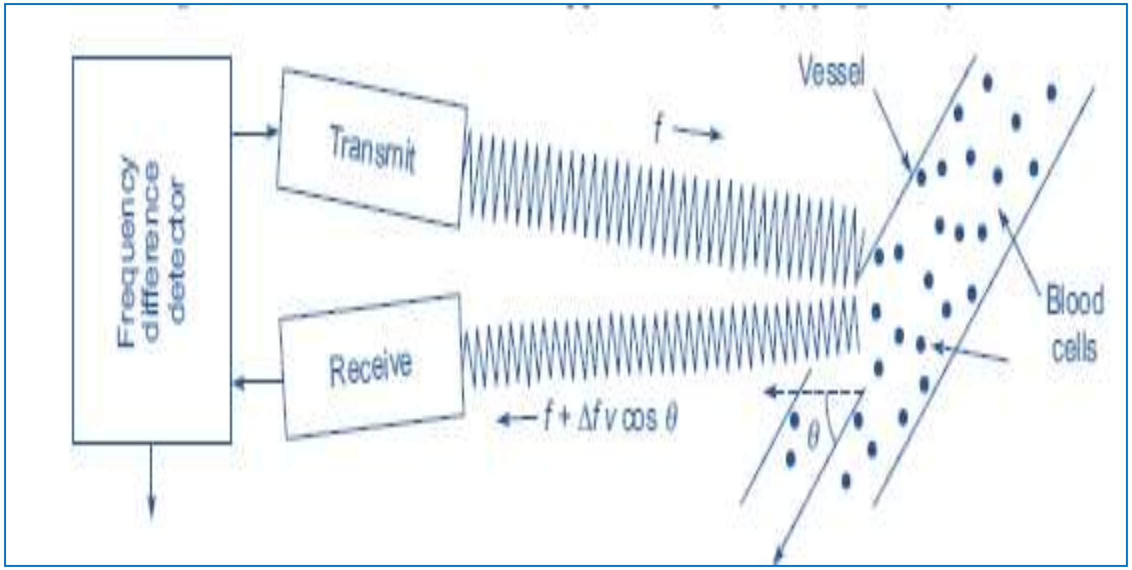
Ultrasonic Blood Flowmeters

Types :

- Transit- time velocity meter.
- Doppler-shift type.

Doppler-shift Flow-velocity Meters

- Non-invasive technique to measure blood velocity in a particular vessel from the surface of the body.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Doppler-shift Flow-velocity Meters

$$f_1 = \frac{(C - v\cos\theta)}{C}$$

f = transmitted frequency

C = velocity of sound in blood

θ = angle of inclination of the incident wave to the direction of blood flow

v = velocity of blood cells

$$f_2 = \left[\frac{C}{(C + v\cos\theta)}\right]$$

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Doppler-shift Flow-velocity Meters

- The resultant Doppler shift

$$\Delta f = f - f_2 = \left[\frac{C}{C + v\cos\theta} \right]$$

Block diagram of Doppler shift blood flowmeter

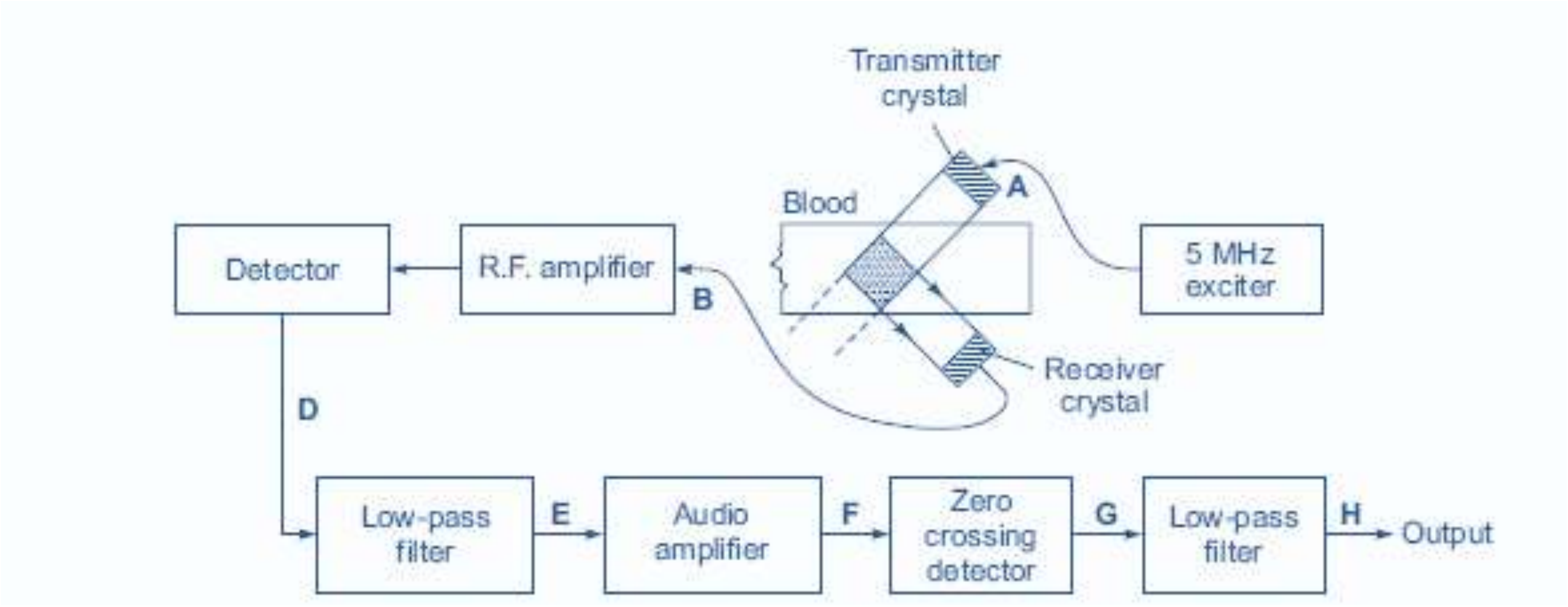
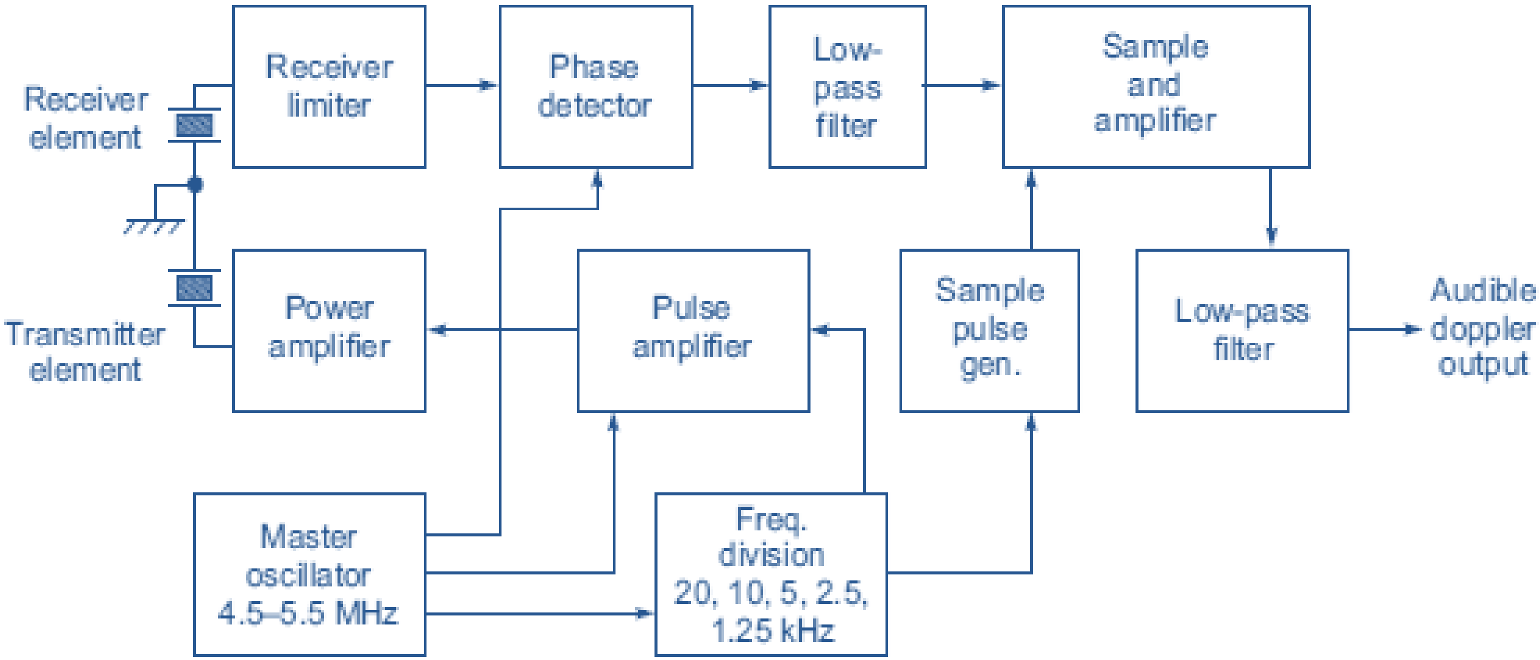


Image Courtesy: Flax et al., IEEE Trans. Biomed. Eng,

Range Gated Pulsed Doppler Flowmeters

- **Reason:** If the return signal is range gated, then the distance to the moving interface (blood vessel diameter) as well as its velocity with respect to the beam can be measured.

Block diagram of a pulsed Doppler flowmeter



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of a pulsed Doppler flowmeter

Transmitter: It comprises a master oscillator whose frequency may vary from 2 to 10 MHz; however 5 MHz is a good compromise for detecting the blood flow in vessels 4-6 cms in depth.

PRF: Pulse Reception frequency

PRF (kHz)	Approximate Depth Range (cm)	Max. Δf Detectable (kHz)
25	3.0	12.5
18	4.3	9.0
12.5	6.0	6.25

Block diagram of a pulsed Doppler flowmeter

Receiver:

- The back-scattered Doppler-shifted signals from a blood vessel range in intensity from 50 dB to more than 120 dB down from the transmitted signal.
- The receivers designed for this purpose have a bandwidth of 3 MHz and gain in excess of 80 dB.
- This is followed by a single side band type quadrature phase detector which separates the upper and lower Doppler side bands for sensing flow direction.
- The detector consists of a phase-shift network, which splits the carrier into two components that are in **quadrature, which means they are 90**°.
- These reference cosine and sine waves must be several times larger than the RF amplifier output.
- The Doppler shift of the received echo, back scattered by the moving blood is detected by **sensing the instantaneous phase difference between the echo and a reference signal** from the **master oscillator**.

Block diagram of a pulsed Doppler flowmeter

- If the flow of blood is in the **same direction as the ultrasonic beam**, then it is considered that the blood is flowing away from the transducer.
- In this case, the **Doppler-shift frequency is lower than that of the carrier** and the phase of the Doppler wave lags behind that of the reference carrier.
- If the flow of blood is **towards the transducer**, then the **Doppler frequency is higher than the carrier frequency** and the phase of the Doppler wave leads the reference carrier.
- By examining the sign of the phase, the direction of flow can be established.

Block diagram of a pulsed Doppler flowmeter

- **Zero-crossing Detectors:**
- In order to measure blood velocity, a frequency meter is needed to analyze the frequency components of the Doppler signal.
- Doppler velocimeters use zero- crossing detectors for this purpose.
- The function of the zero-crossing detector is to convert the audio frequency amplifier output to a proportional analog output signal.
- It emitting a constant area pulse for each crossing of the zero axis from negative to positive.

Block diagram of a pulsed Doppler flowmeter

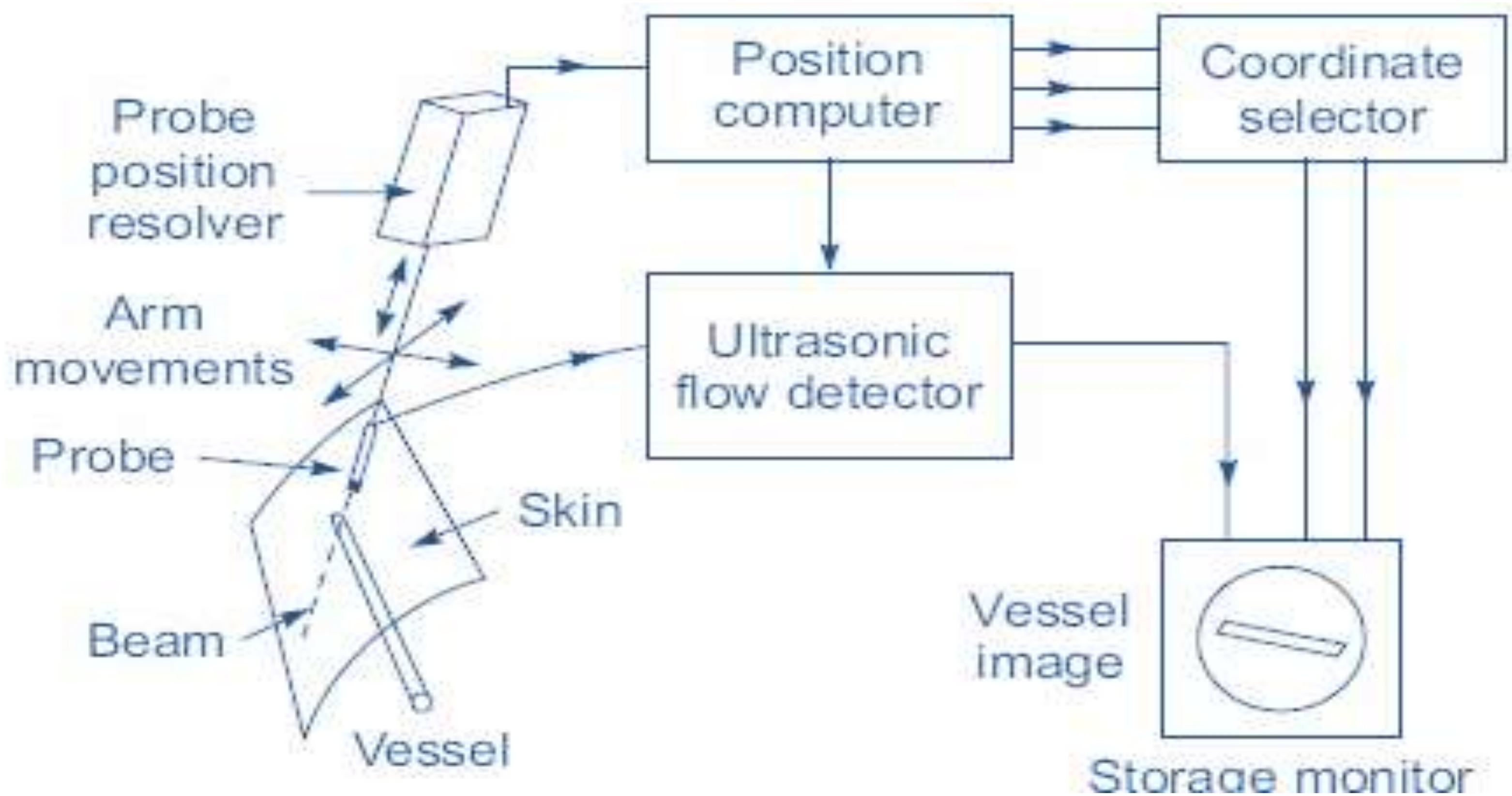
- **Spectrum Analyzers:**
- Because of the limitations of the zero-crossing detector, alternative methods have been employed for the analysis of Doppler signals for velocity measurements.
- For example, spectrum analyzers are used to derive blood flow velocity information from Doppler signals.
- A spectrum analyzer processes short lengths of audio signal to produce spectral displays.

BLOOD FLOW MEASUREMENT THROUGH DOPPLER IMAGING

Blood Flow Measurement through Doppler Imaging

- Doppler ultrasound is **not only used for the measurement of the absolute value of blood velocity and volume flow**.
- It also helps for **direct visualization of the blood vessels** and to **study the blood-velocity/time wave form shapes over the cardiac cycle**.
- The **imaging facility helps to measure beam/vessel angle** to detect the location of the required site of measurement of velocity and flow.

Doppler imaging system-block diagram



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

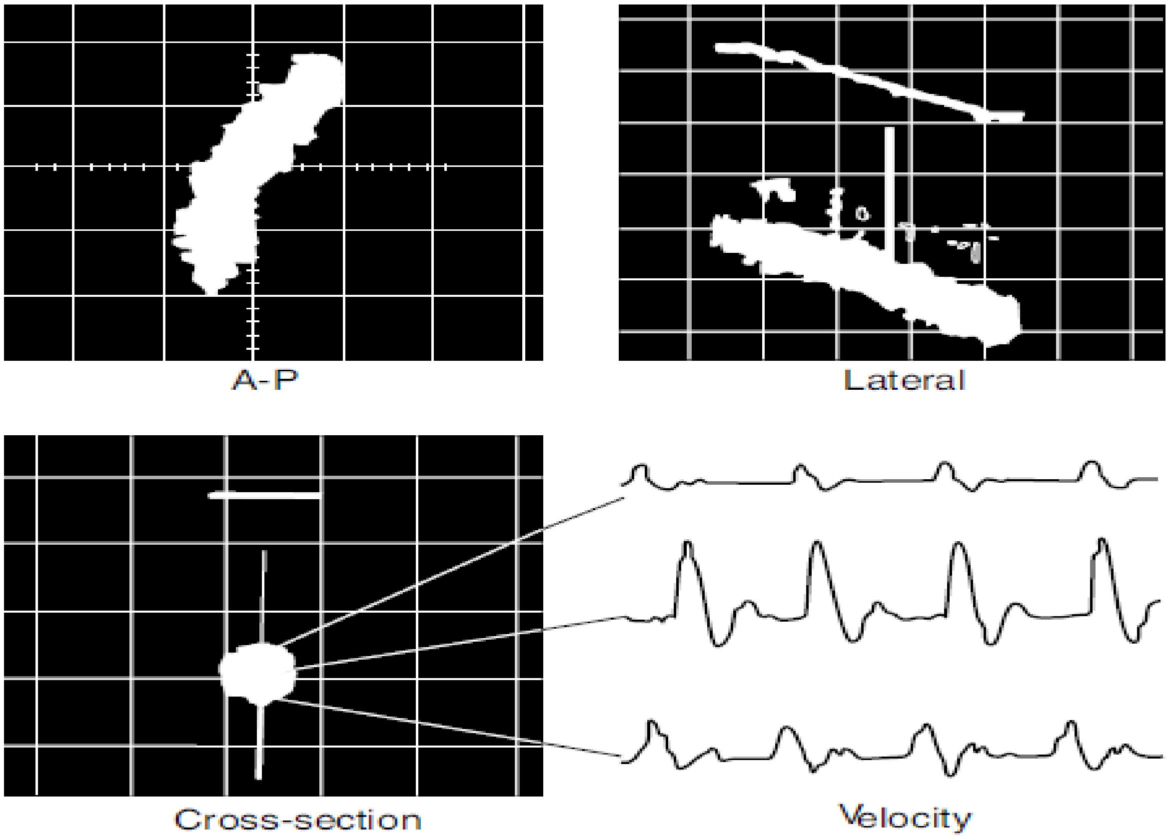
Doppler imaging system-block diagram(con..)

- A vessel is imaged by **moving the probe over the skin surface** & **adjusting the probe/sampling-volume distance until** the sampling volume has been swept through **the section of the vessel of interest**.
- The 3D information about the geometry of the vessel is displayed by selecting, in turn, 02 of the 03 dimensions available for display on the monitor.
- it is possible to construct anterior-posterior, lateral and cross-sectional scans of blood vessels.

Doppler imaging system-block diagram(con..)

- **Time needed** to complete a single cross-sectional scan of a blood vessel is long (**3 min**) **even after the vessel is located.**
- If the flow detector is not direction-resolving, is that of separating the images of contiguous veins and arteries.
- To overcome these issues , Fish (1978) developed a **multi-channel direction-resolving flow detector**.
- It is a **30 channel device** & can determine the direction of the component of flow along the beam.

Lateral, anterior-posterior and cross-section views of Doppler Imaging



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Lateral, anterior-posterior and cross-section views of Doppler Imaging - con….

- From the images, it is quite convenient to see where the measurement is being made.
- It is possible to record velocity profiles over the cardiac cycle, it is possible to compute mean blood flow, peak flow, peak reverse flow by sampling measurements at intervals, say 40 ms.
- The system computes flow information from the velocity profiles and cross-sectional diameter of the blood vessel under investigation.

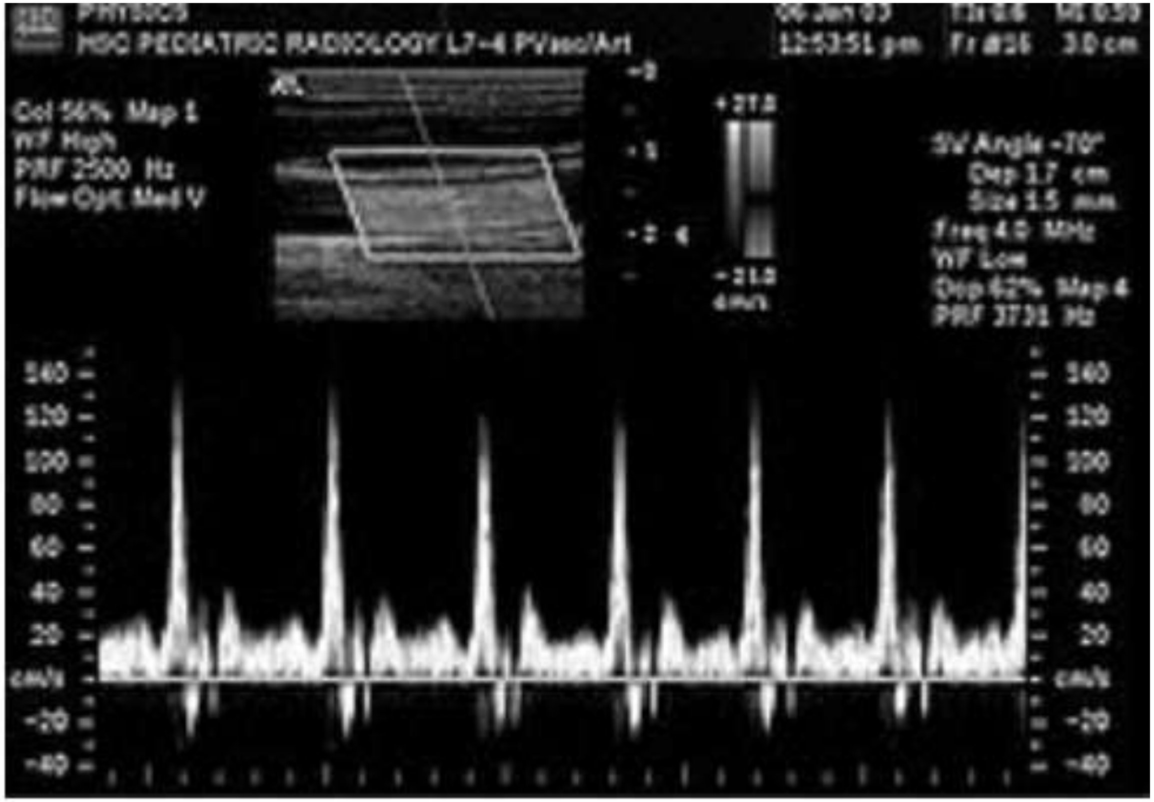
Lateral, anterior-posterior and cross-section views of Doppler Imaging - con….

- The system computes **flow information from the velocity profiles and cross-sectional diameter of the blood vessel** under investigation.
- The **transducer frequency is usually 5 MHz** and it transmits **ultrasound beam focused at 2–4 cm**, which is the **approximate depth of the carotid or femoral artery**.
- The signal processing circuit generates simultaneous forward and reverse flow-velocity channels by the use of a phase-quadrature detection system and **the processor scans the instantaneous blood-velocity spectrum** as it is formed.
- The **circuit rejects low frequency signals** due to **arterial wall movement and noise or transducer movement** by **adjusting the threshold for Doppler signals.**

Lateral, anterior-posterior and cross-section views of Doppler Imaging - con….

- **Colour Doppler** sonography is based on the measurement of the local flow velocity in real time & display the surrounding structures in colour coded form, **together with the section scan of the vessel walls**.
- The colour, **usually red or blue**, indicates the **direction of blood flow**.
- The **colour intensity indicates the local flow velocity**.
- **The brighter the colour intensity, the higher the velocity**.
- The image gives an immediate overview of flow direction and flow dynamics & alterations to the vascular structures.

Spectral Doppler scan of the common carotid artery



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

NMR (NUCLEAR MAGNETIC RESONANCE) BLOOD FLOW METER

NMR (Nuclear magnetic resonance) Blood Flow meter

- Nuclear magnetic resonance principle is a another **non-invasive method** for **measuring blood flow in various organs**.
- This method pertains to a **quantum mechanical phenomenon** related to the **magnetic energy levels of the nucleus** of **some elements and their isotopes**.
- For blood flow measurement, **behavior of two hydrogen atoms** of water is studied, **since blood is approximately 83% water**.
- **Due to the magnetic moment of the hydrogen atom, the nucleus behaves as a micro-miniature magnet** which can be affected by externally applied magnetic fields.
- The **hydrogen nuclei orient themselves** to produce a net parallel alignment **to a steady magnetic field**.

NMR (Nuclear magnetic resonance) Blood Flow meter

- The nuclear magnets precess around the magnetic field lines until they become aligned.
- The angular frequency (Larmor frequency) of this precession is :

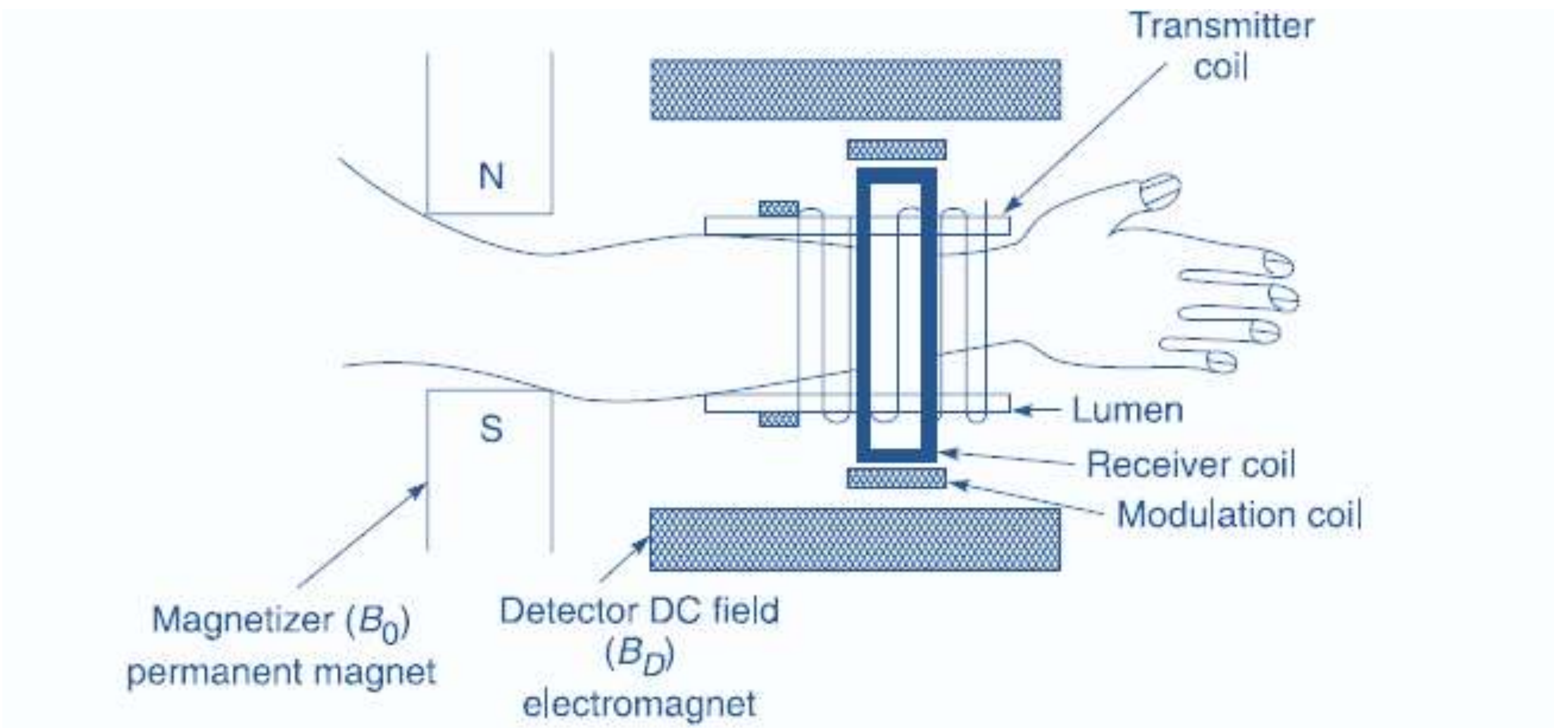
$$W = 2\pi v = rB_0$$

  - r is the ratio of the magnetic moment to the angular momentum
  - B0 is the density of the steady magnetic field
  - v is the frequency of radiation.

NMR (Nuclear magnetic resonance) Blood Flow meter- con…

- When the **frequency of the magnetic field is near the Larmor frequency**, the **nuclear magnets can be rotated** and their **presence detected secondary** to an externally applied radio frequency magnetic field.
- region of **demagnetization can be made** by **disorienting** the **nuclear magnets** with a **radio frequency field very close to the Larmor frequency**.

Measurement of arterial blood flow using NMR principle



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Measurement of arterial blood flow using NMR principle

- The **blood vessel of interest** is positioned in a **uniform steady magnetic field**.
- The **nuclear magnets of the hydrogen atoms**, which before insertion were randomly oriented, now begin to **align themselves.**
- Some begin to align parallel, whereas others commence to align anti-parallel.
- The magnitude of the magnetization can be related to either flow velocity or flow rate.
- Since the magnetization can be changed at some point in a magnetic field, and the change detected at some distal point, it is possible to determine the transport time between the two points.

Measurement of arterial blood flow using NMR principle

- A crossed coil configuration is used to detect the level of magnetization in the limb.
- Two magnets are used, a strong permanent magnet B0 for magnetization and a weaker, homogeneous electromagnet for detection.
- A graph plotted shows that the **magnetization changes proportionally to velocity and thus a measurement of the magnetization can yield velocity information**.
- If a receiver coil is used, **the voltage induced in the coil by the magnetization is proportional to the cross-sectional area of the vessel carrying the blood**.

Measurement of arterial blood flow using NMR principle

- The **NMR signal voltage proportional** to **velocity V, and multiplied by area A, will give a volumetric flow rate Q**.
- The major shortcoming of NMR blood flow meters is the **physical size of the magnets and the sensitivity of the system needed to detect the magnetically tagged** bolus of blood.

LASER DOPPLER BLOOD FLOW METER

Laser Doppler Blood Flow meter

- Laser Doppler Flowmetry (LDF) uses the Doppler effect to measure the speed of red blood cells.
- The incident light in the red wavelength is incident upon the blood vessels.
- The red blood cells absorb the incident light and reflect light with a shifted frequency depending on the flow velocity.
- Optical fibers can be used for this purpose to control the delivery of light.
- Two fibers are typically used with the detected light collected in a different fiber.

Laser Doppler Blood Flow meter

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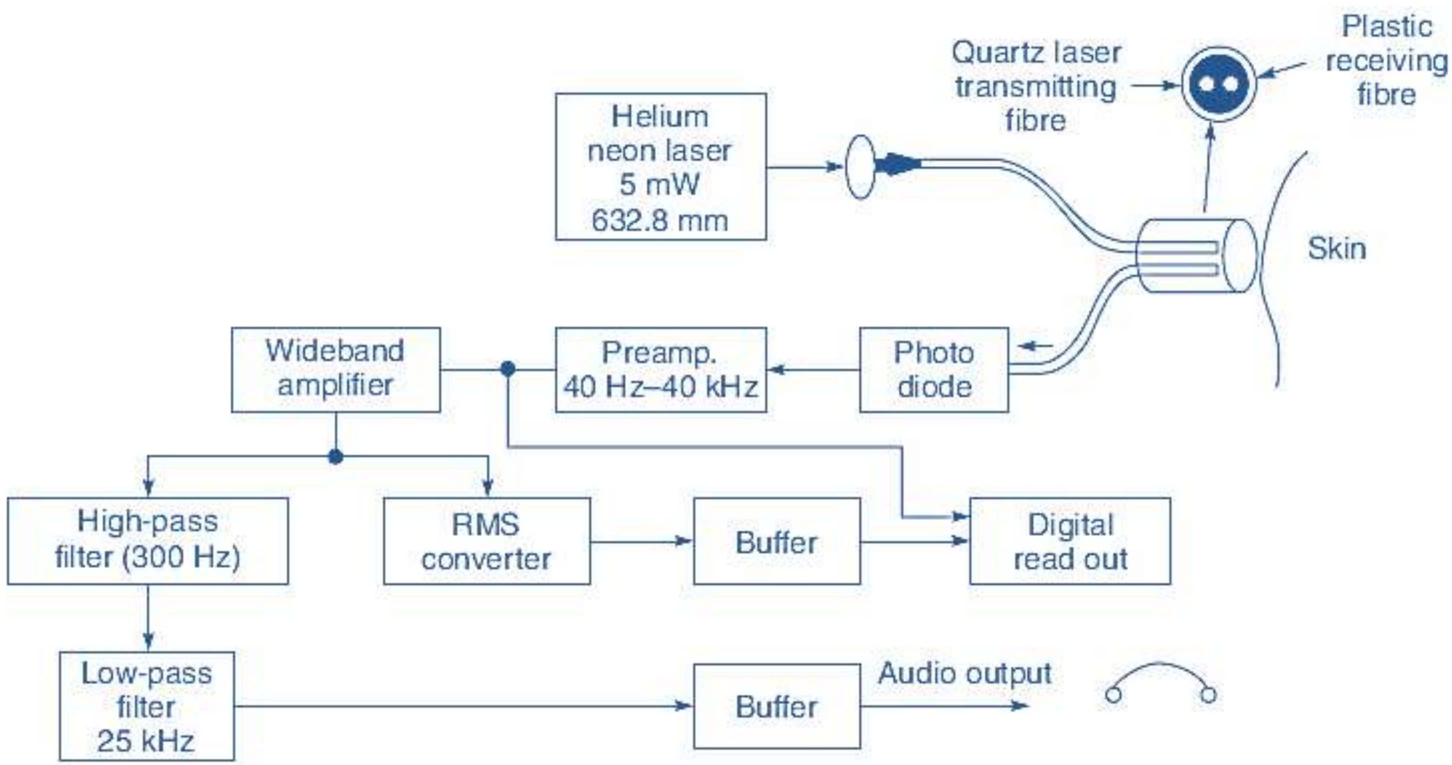
Block diagram of a laser Doppler system for blood flow measurement in skin



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of a laser Doppler system for blood flow measurement in skin

- The light wavelength can be changed within a narrow window to control the depth of penetration depending on the regions of the body.
- **Different wavelengths penetrate at different depths in skin.** Optimal wavelength choice is required if one wants to image surface or deep tissue blood flow.
- Doppler flowmetry has additional techniques to process the detected spectrum to identify the velocity profile.
- Imaging can also be done with less fiber optics if the sample is mounted on a surface.

Wearable laser blood flow meter

- Image courtesy : Higurashi et al., 2003

Wearable laser blood flow meter..

- By **precisely integrating** a laser diode, photodiode, and optical waveguide onto a single chip laser blood flow meter have been downscaled to a tiny device that **can be worn on the wrist**.
- The sensor head, which is placed in contact with a fingertip, consists of optical elements precisely mounted on a chip with 1-micrometer accuracy using advanced micromachining and surface mounting technologies.
- **Measurement data sent wirelessly can be displayed or recorded.**

CARDIAC OUTPUT MEASUREMENT

Cardiac output measurement

- Cardiac output is the **quantity of blood delivered by the heart to the aorta per minute**.
- It is a major determinant of **oxygen delivery to the tissues**.
- A fall in cardiac output may result in **low blood pressure, reduced tissue oxygenation, acidosis, and shock**.
- The direct method of estimating the cardiac output consists in **measuring the stroke volume by the use of an electromagnetic flow probe placed on the aorta and multiplying it by the heart rate.**

Cardiac output measurement

- This method **involves surgery** & **not preferred** in routine applications.
- Another method is the **Fick's method**, which determining the cardiac output by **the analysis of the gas-keeping of the organism**.
- This method is **rather complicated, difficult to repeat, necessitates catheterization**.
- The most popular method is principle of **indicator dilution**.

Indicator Dilution Method

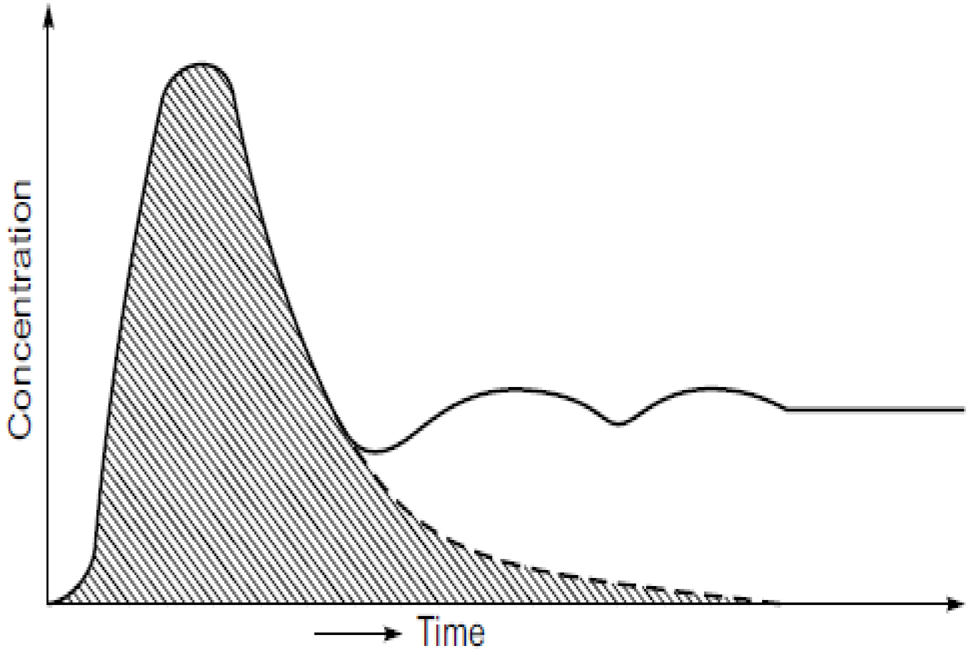
- Indicator dilution principle states that: if we introduce **into or remove from a stream of fluid a known amount of indicator** and **measure the concentration difference** upstream and downstream of the injection (or withdrawal), we can estimate the volume flow of the fluid.
- Two methods are generally employed for introducing the indicator in the blood stream (it may be injected at a constant rate)
- The **method of continuous infusion suffers** from the disadvantage that **most indicators re-circulate, and this prevents a maxima from being achieved**.

Indicator Dilution Method

- In the injection method, **a small known quantity of an indicator such as a dye or radioisotope** is directed into the circulation.
- It is **injected into a large vein** or **preferably into the right heart itself**.
- After passing through the right heart, lungs and the left heart, the **indicator appears in the arterial circulation**.
- The **presence of an indicator in the peripheral artery is detected by a suitable (photoelectric) transducer** and is **displayed on a chart recorder**.

Indicator Dilution Method

The dilution curve



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Indicator Dilution Method

The dilution curve

- During the first circulation period, the indicator would mix up with the blood and will dilute just a bit.
- When passing before the transducer, it would reveal a big and rapid change of concentration. This is shown by the rising portion of the dilution curve.
- Had the circulation system been an open one, the maximum concentration would have been followed by an exponentially decreasing portion so as to cut the time axis as shown by the dotted line.

Indicator Dilution Method

The dilution curve

- When the **indicator is completely mixed up with blood, the curve becomes parallel with the time axis**.
- The **amplitude of this portion depends upon the quantity of the injected indicator** & **the total quantity of the circulating blood**.

calculate the cardiac output from the dilution curve:

$$Q = \frac{M}{\begin{array}{l}\text{average concentration of indicator per} \\ \text{litre of blood for duration of curve}\end{array} \times \begin{array}{c}\text{curve duration} \\ \text{in seconds}\end{array}} .1/\text{s}$$

$$= \frac{M \times 60}{\text{area under the curve}} 1/\text{min}$$

M = quantity of the injected indicator in mg, Q = cardiac output

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Indicator Dilution Method

calculate the cardiac output from the dilution curve: Example

- **If 10 mg of the indicator was injected and the average concentration as calculated from the curve was 5 mg/l for a curve duration of 20 s; then Q = 6**
- The evaluation of the dilution curve is simplified by replotting the curve on a semilogarithmic scale paper.
- The indicator concentration (Y-axis) is plotted on a logarithmic scale and the time (X-axis) on a linear scale.
- The decreasing exponential portion of the curve appears as a straight line, which is projected downwards to cut the time axis.

Dye Dilution Method

- The most commonly used indicator substance is a dye.
- Fox and Wood (1957) suggested the use of Cardio green dye for recording the dilution curve.
- It is preferred because of **its property of absorbing light in the 800 nm region** of the spectrum where **both reduced and oxygenated haemoglobin have the same optical absorption**.
- While using the dyes, it was necessary to have the patient breath oxygen.
- The concentration of cardio green can be measured with the help of infra-red photocell transducer.

Dye Dilution Method

- The procedure consists in injecting the dye into the right atrium.
- Usually 5 mg of cardio green dye is injected in a 1 ml volume.
- The quantity used may be 2.5 mg in the case of children.
- A motor driven syringe constantly draws blood from the radial or femoral artery through a cuvette.
- The curve is traced by a recorder attached to the densitometer.
- After the curve is drawn, an injection of saline is given to flush out the dye from the circulating blood.

A densitometer for quantitative measurement of dye concentration

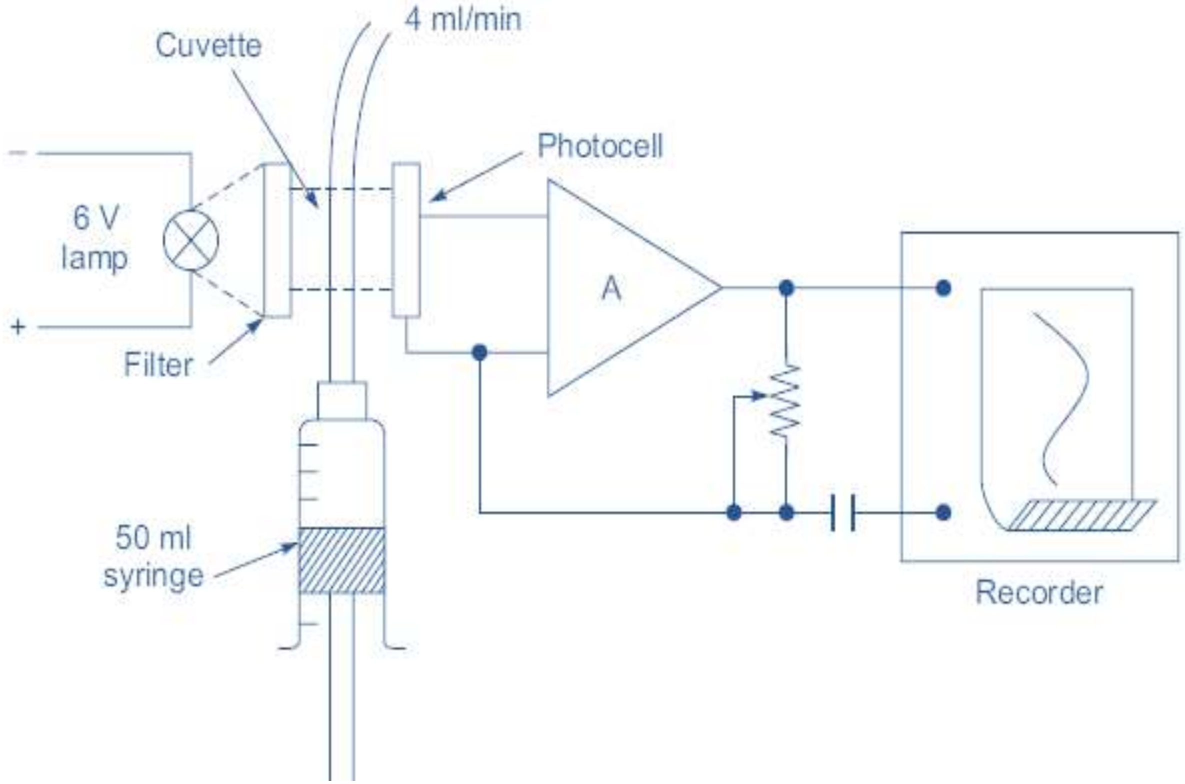


Image courtesy : Jarlov and Holmkjer, 1972; Med. & Biol. Eng.

A densitometer for quantitative measurement of dye concentration

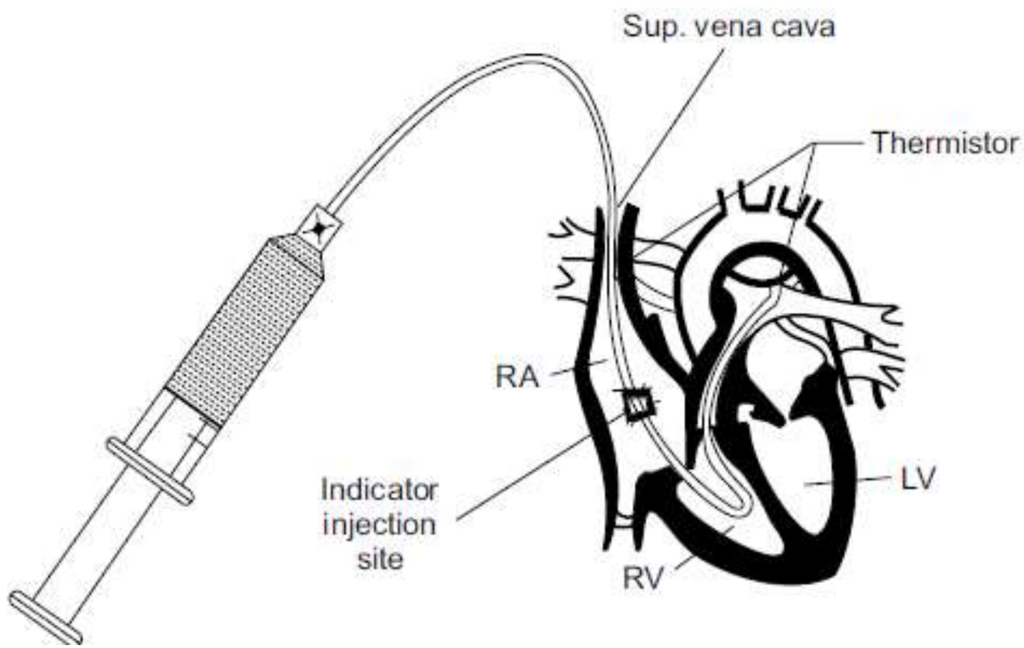
- The photometric part consists of a source of radiation and a photocell and an arrangement for holding the disposable polyethylene tube constituting the cuvette.
- An interference filter with a peak transmission of 805 nm is used to permit only infrared radiation to be transmitted.
- This wavelength is the isobestic wavelength for haemoglobin at various levels of oxygen saturation.
- In order to avoid the formation of bubbles, the cuvette tubing should be flushed with a solution of silicone in ether.
- A flow rate of 40 ml/min is preferred in order to get as short a response time as possible for the sampling.
- The sampling syringe has a volume of 50 ml/min.
- The output of the photocell is connected to a low drift amplifier. It has a high input impedance and low output impedance.
- The amplification is directly proportional to the resistance value of the potentiometer R.
- A potentiometric recorder records the amplifier signal on a 200 mm wide recording paper and a paper speed of 10 mm/s

Thermal Dilution Techniques

- A thermal indicator of known volume introduced into either the right or left atrium will produce a resultant temperature change in the pulmonary artery.
- The integral of which is inversely proportional to the cardiac output.

$$\text{Cardiac output} = \frac{\text{"a constant"} \times (\text{blood temp.} - \text{injectate temp.})}{\text{area under dilution curve}}$$

cardiac output thermal dilution set up



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

cardiac output thermal dilution set up

- A solution of **5% Dextrose in water at room temperature** is injected as a **thermal indicator into the right atrium**.
- It mixes in the right ventricle, and is detected in the pulmonary artery by means of a **thermistor mounted at the tip of a miniature probe**.
- The injectate temperature is also sensed by a thermistor & the temperature difference between the injectate and the blood circulating in the pulmonary artery is measured.
- The reduction in temperature in the pulmonary artery (due to the passage
- of the Dextrose) is integrated with respect to time & the blood flow in the pulmonary artery is then computed by a computer which also applies correction factors.
- A meter provides a direct reading of cardiac output after being muted until integration is complete so as to avoid spurious indications during a determination.

cardiac output thermal dilution set up

- The system calibration is based upon the use of an injection of 10 ml of 5% Dextrose olution at a temperature in the range of 18–28°C.
- In this range, the injectate temperature is measured to an accuracy of ± 0.2°C, & also displayed on a meter.

Calculation

$$V D_i S_i (T_i - T_b) = Q D_b S_b \int \Delta T \, dt$$

which, when rearranged gives

$$Q = \frac{V(T_i - T_b)}{\int DT \, dt} \cdot \frac{D_i S_i}{D_b S_b}.$$

where: Q = volumetric flow

V = volume of injectate

T = temperature

ΔT = incremental temperature of the blood injectate mixture

D = density

S = specific heat

i and b refer to the injectate and blood respectively.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Calculation

$$\text{Cardiac output} = \frac{(1.08)\,(C)\,(60)\,(V)\,(T_i - T_b)}{\int DT\,dt}$$

where: 1.08 is the ratio of the products of specific heats and specific gravities of 5% dextrose in water and blood

C = 0.827 for 10 ml injectate at ice temperature (0 to 2°C)

= 0.747 for 5 ml injectate at ice temperature

= 0.908 for 10 ml injectate at room temperature (22 to 26°C)

= 0.884 for 5 ml injectate at room temperature

V = volume of injectate (ml)

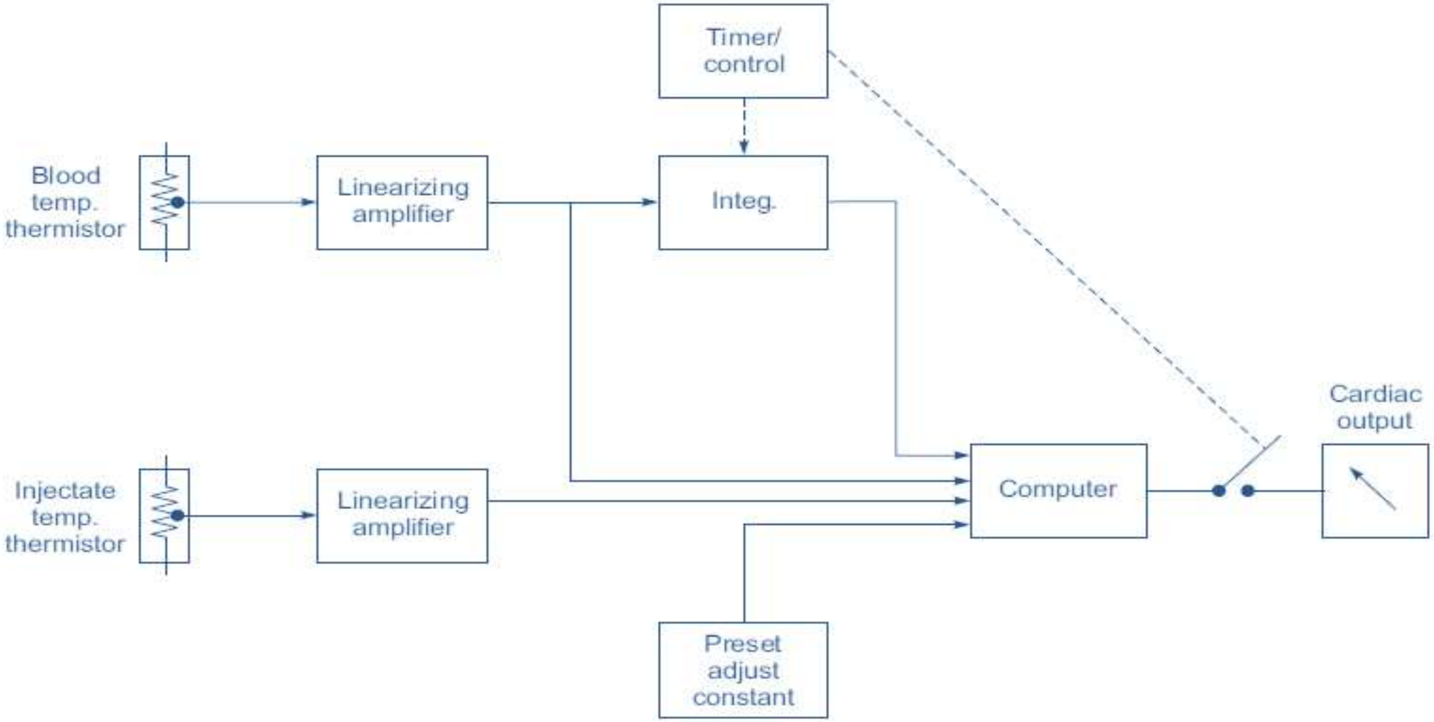
T_b = initial temperature of blood (°C)

T_i = initial temperature of injectate (°C)

$\int DT\,dt$ = integral of blood temperature change (°C.s).

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of the thermal dilution system



Measurement of Continuous Cardiac Output Derived from the Aortic Pressure Waveform

- For critically ill patients, to estimate cardiac output on a beat to- beat basis.
- Thermal dilution measurements can be repeated more frequently than the other methods, but even then the measurements can only be made at certain intervals.
- The technique also requires the presence of well-trained operators for obtaining reliable measurements.
- The method is based on the analysis of the aortic pressure wave, and estimates the left ventricular stroke volume from the pulse contour.

Measurement of Continuous Cardiac Output Derived from the Aortic Pressure Waveform

$$\text{Stroke volume} = \frac{1}{Z_{ao}} \int_{To}^{T_E} (P_{ao} - P_{ed})\, dt$$

- This equation shows that the area 'A' under the systolic portion of the aortic pressure wave is integrated.
- This area 'A' is divided by the patient calibrator (Zao: aortic characteristic impedance) to obtain a quantity approximating the left venticular stroke volume.
- changes in this area 'A' reflect corresponding changes in stroke volume.

Measurement of Continuous Cardiac Output Derived from the Aortic Pressure Waveform

- Cardiac output is computed for each beat as the instantaneous product of stroke volume and heart rate:

$$\text{Stroke volume (SV)} = \frac{A}{Z_{ao}} \ (\text{cm}^3)$$

$$\text{Heart rate} = \frac{60}{T} \ (\text{bpm})$$

$$\text{Cardiac output} = \frac{(SV)(HR)}{1000} = \frac{60 \cdot A}{1000 \cdot Z_{ao} T} \ (\text{l/min})$$

The cardiac output computer consists of three modules:

(i) The pressure transducer amplifier

(ii) The cardiac output computer

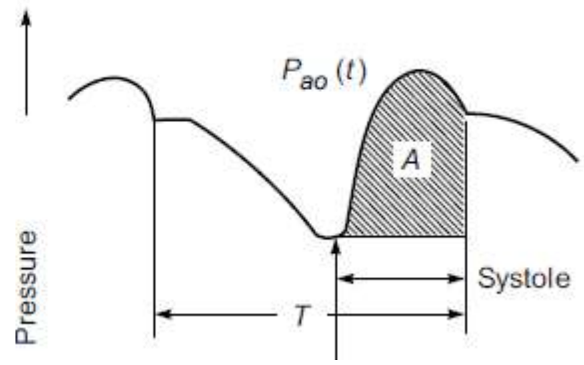
(iii) Dual numerical display and alarm limits.

Two parameters must be set initially for each patient:

(i) patient age

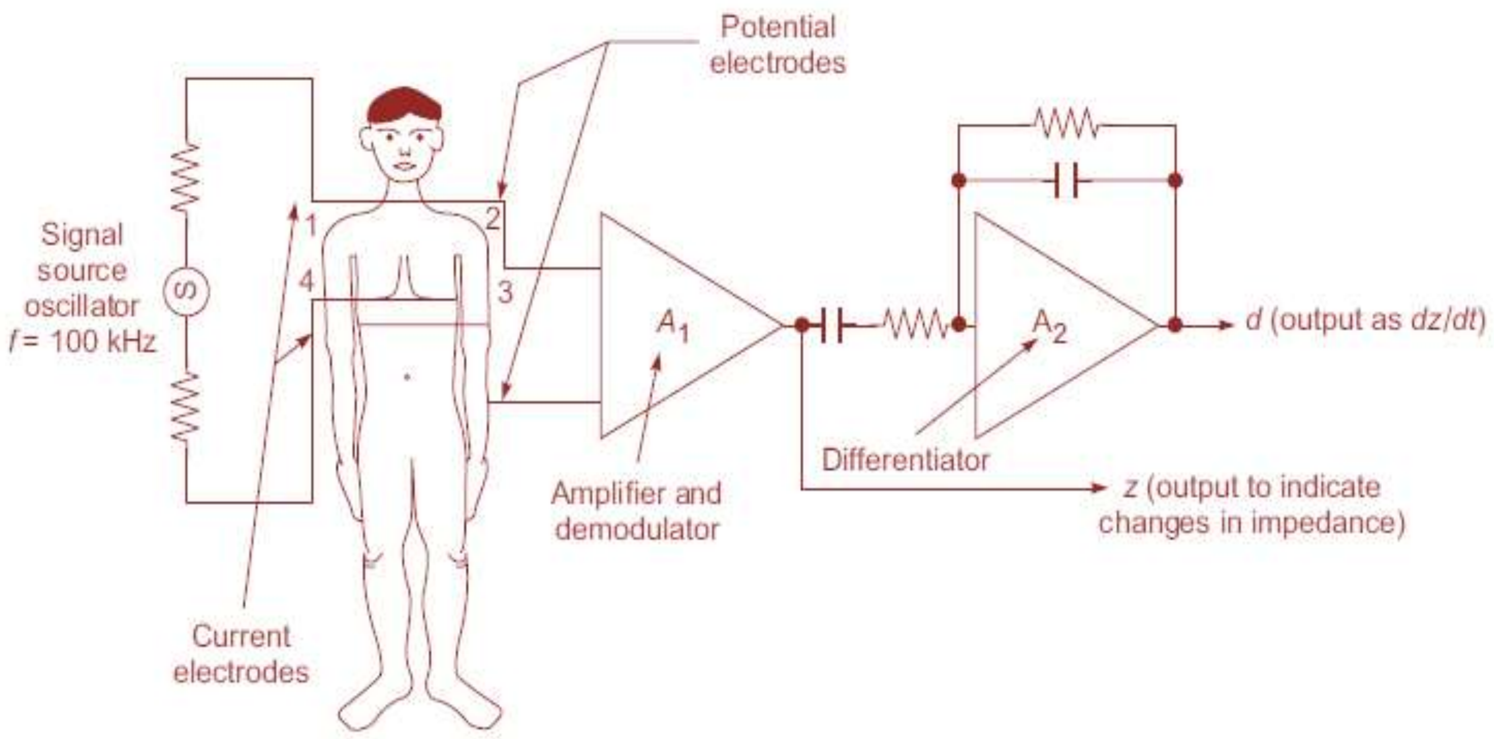
(ii) The patient calibrator Zao.

Cardiac Output



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Impedance Technique



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Impedance Technique

- If Ρ is the resistivity, the resistance between two sensing electrodes (2 and 3) is given by

$$R_0 = \frac{\rho L}{A}$$

where L is the separation between the electrodes and A is the cross-sectional area

$$dV = \left[\frac{L^2}{R_0^2}\right] dR$$

$$dV = \left[\frac{L^2}{Z_0^2}\right] \cdot T \cdot \left[\frac{dz}{dt}\right]_{max}$$

Ultrasound Method

- Ultrasound can be used to measure the velocity of blood flow in the ascending aorta by the application of the Doppler principle.
- Blood flow =velocity * area

$$= cm^3/sec = ml/sec \times L/100\ ml \times 60\ sec/min$$
$$= L/min$$

Cardiac output measurement devices based on ultrasound actually measure the stroke volume during the cardiac cycle as per the relationship given below:

$$SV = CSA \times \int^{VET} V(t)\,dt$$

where SV = stroke volume
CSA = cross-sectional area of the aorta
VET = ventricular ejection time
V = blood velocity

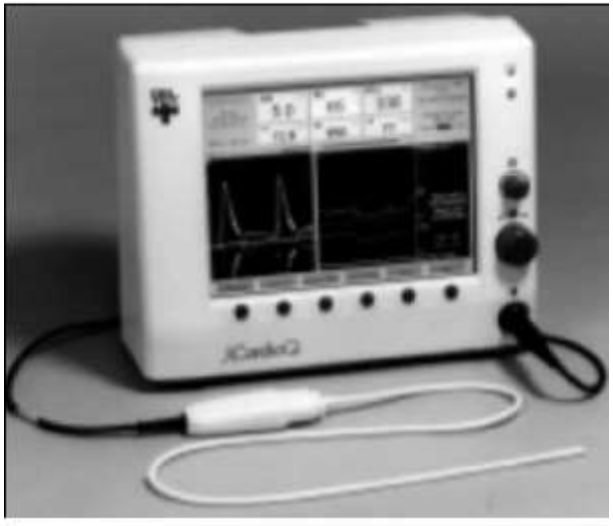
Ultrasound Method

- The blood velocity V calculated from the Doppler equation is as follows:

$$V = \frac{C^2 F_d}{2F_o \times \cos\theta}$$

where: C = speed of sound
F_d = frequency shift
F_o = frequency of the emitted sound
θ = angle between the emitted sound and the moving object

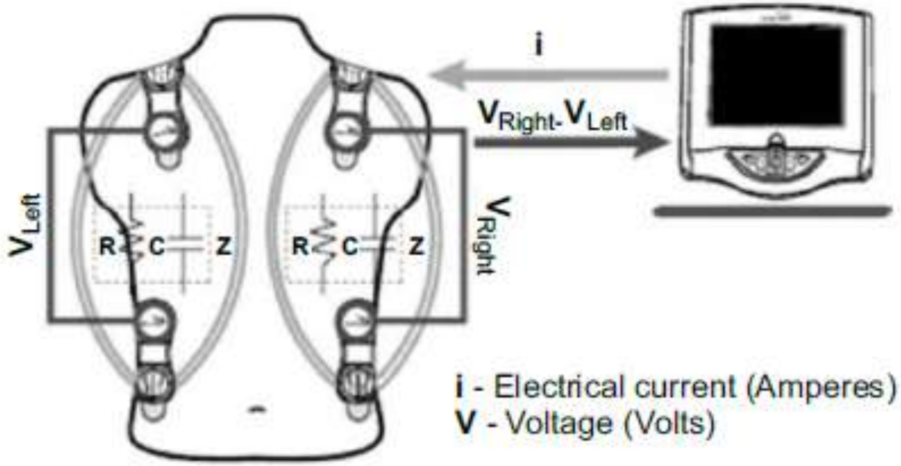
Display system



Bioreactance Method

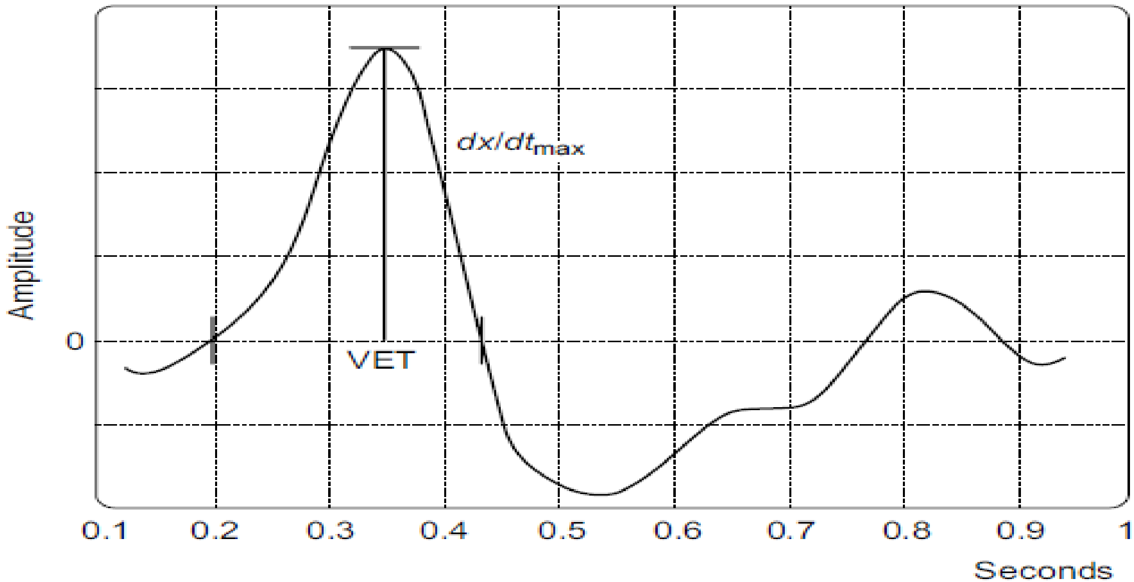
- It is a method for **non-invasive monitoring** based on Bioreactance, or the **Phase Shifts that occur** when an **alternating current is passed** through the thorax.
- The thorax **consists of resistance elements which create opposition to the passage of an AC current** and **reactance elements which oppose the change of the electric voltage** .
- **Resistance and reactance together create a time delay** between the **current and the voltage**, **resulting in the Phase Shift**.
- When an **alternating current (AC) is applied**, the **blood flow through the large arteries causes** the **amplitude of the applied voltage to change**.
- In addition, it **causes a time delay or Phase Shift between the applied current and the measured voltage**.
- Phase Shifts are **tightly correlated** with stroke volume.

Bioreactance Method



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Computing Stroke volume from flow signal
(Image courtesy: www.cheetah-medical. com)



Once dX/dt and VET(Ventricular Ejection Time) are both measured, the stroke volume (SV) can be calculated as:

$$SV = dX/dt \times VET$$

Cardiac Output (CO) is simply the multiplication of the SV and heart rate. So, CO=SV×HR

Carbon Dioxide Rebreathing Method..

- Oxygen uptake in the lungs is entirely transferred to the blood.
- Cardiac output can be calculated as the ratio between **oxygen consumption (VO2)** and **arteriovenous difference in oxygen** (AVDO2).

Fick equation: $$\text{Cardiac output (CO)} = \frac{VO_2}{AVDO_2}$$

- A carbon dioxide sensor (infrared light absorption), a disposable airflow sensor and a pulse oximeter used for measurement.

Carbon Dioxide Rebreathing Method

- The sensor is placed into the ventilator circuit between the patient elbow and ventilator.
- The rebreathing valve is automatically controlled by the monitor.
- If the valve is activated, the flow of the inspired and expired gas is diverted through a rebreathing Loop.
- When the valve is deactivated, this additional rebreathing volume is bypassed and normal ventilation resumes.
- Every three minutes, a baseline, rebreathing and stabilization phase occurs.
- A non-invasive cardiac output calculation is made following the end of each three minute cycle.
- The calculation is based on the changes induced in CO_2 elimination and end tidal CO_2 in response to the rebreathing volume.

RESPIRATORY MEASUREMENT

Measurement of Respiration Rate

- Primary functions of the respiratory system are to **supply oxygen and remove carbon dioxide from the tissues**.
- The action of breathing is controlled by a muscular action.
- The **volume of the lung is increase and decrease** to effect a precise and sensitive control of the tension of carbon dioxide in the arterial blood.
- This is rhythmic action.

Displacement Method

- **The respiratory cycle changes** can be **sensed by means of a displacement transducer** incorporating a **strain gauge or a variable resistance element**.
- The **transducer is held by an elastic band**, which goes **around the chest**.
- The respiratory movements result in resistance changes of the strain gauge element connected as one arm of a WS bridge circuit.
- Bridge output varies with chest expansion and yields signals corresponding to respiratory activity.

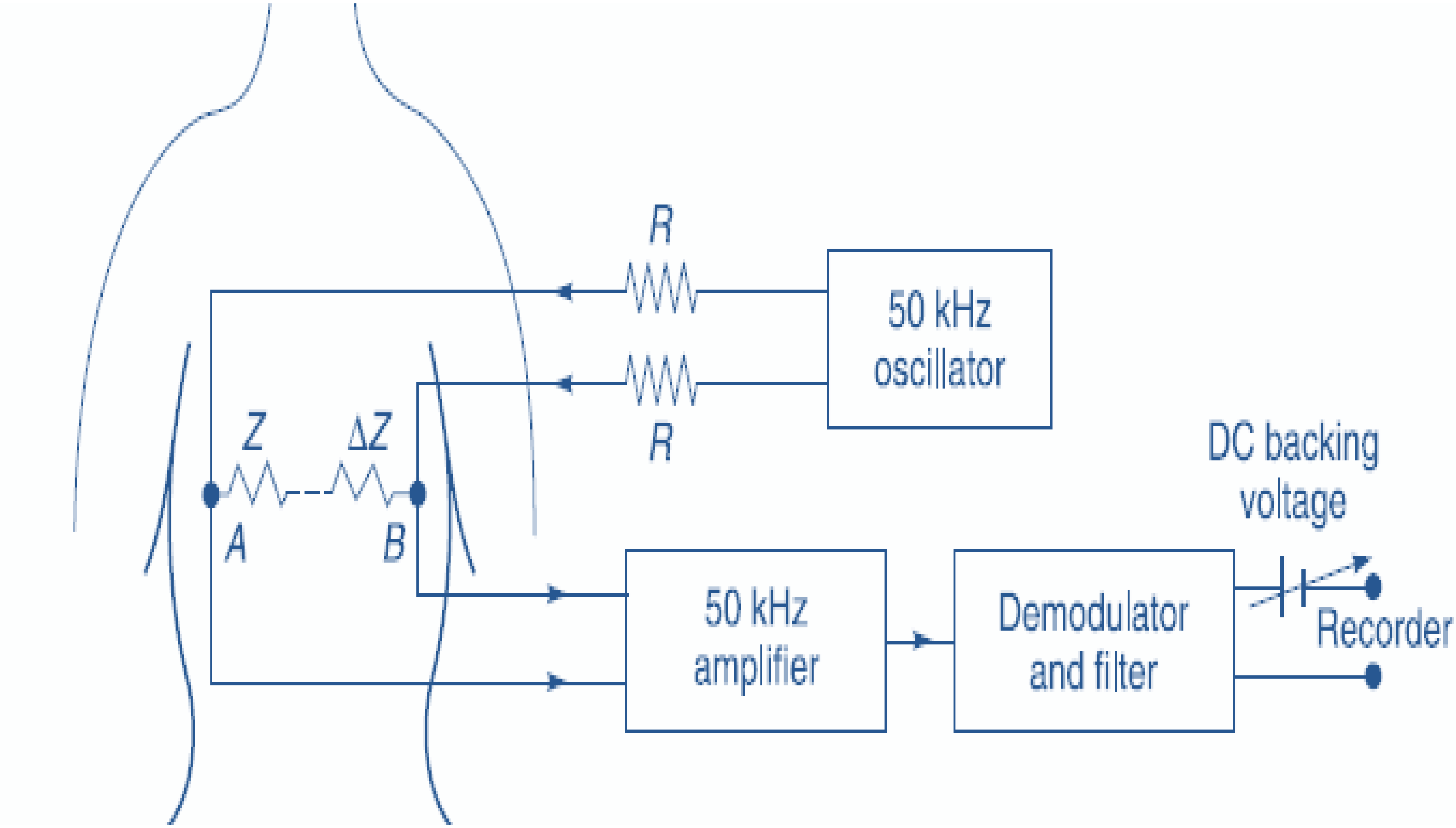
Displacement Method

- **Changes in the chest circumference** can also be **detected by a rubber tube filled with mercury**.
- With **the expansion of the chest during an inspiratory** Phase: **the rubber tube increases in length & the resistance of the mercury** varies.
- Resistance changes measured by sending constant current & measuring the changes in voltage developed with the respiratory cycle.

Thermistor Method

- Air is warmed during its passage through the lungs .
- There is a detectable **difference** of **temperature between inspired and expired air**.
- This difference of temperature can be sensed by using a thermistor placed in front of the nostrils by a suitable holding device.
- The thermistor is placed as part of a voltage dividing circuit / bridge circuit whose unbalance signal can be amplified to obtain the respiratory activity.

Impedance Pneumography



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Impedance Pneumography

- **Indirect technique** for the measurement of respiration rate.
- Using externally applied electrodes, the impedance pneumograph measures relationship between respiratory depth and impedance change.
- Impedance method :**passing a high frequency current** through the appropriately placed **electrodes on the surface of the body &** detecting the modulated signal**.**
- The signal is modulated by changes in the body impedance, accompanying the respiratory cycle.

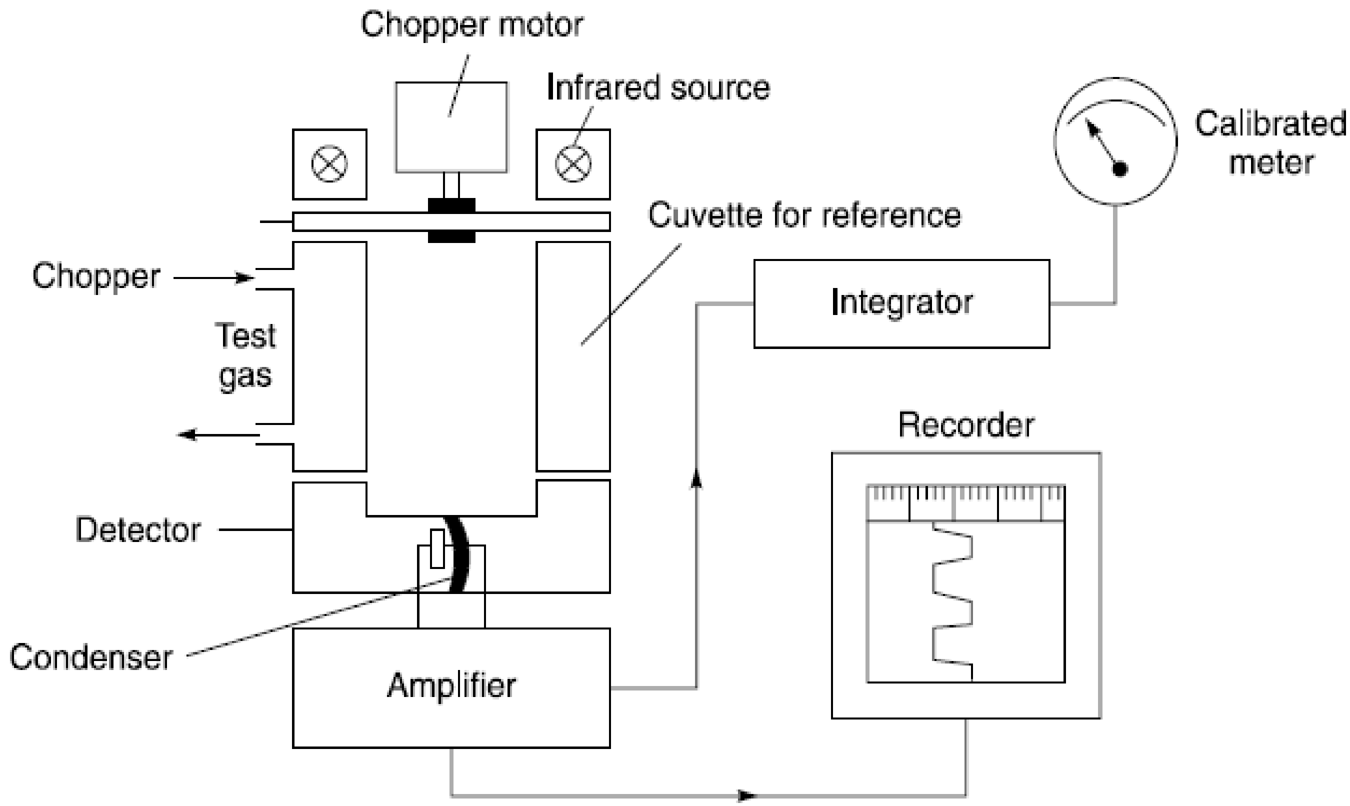
Impedance Pneumography

- The electrodes offer an impedance of 150 to 200.
- The change in impedance to each respiratory cycle is of the order of 1% of the base impedance.
- Frequency greater than 5 kHz must be used for the measurement of physiological events by impedance.
- Frequencies lower than 5 kHz are particularly hazardous

CO_2 Method of Respiration Rate Measurement

- The measurement is based on the absorption property of infrared rays by certain gases.
- When infrared rays are passed through the expired air containing CO_2, some of the radiations are absorbed by it.
- Suitable filters are required to determine the concentration of specific gases (CO_2, CO..)

CO_2 Method of Respiration Rate Measurement

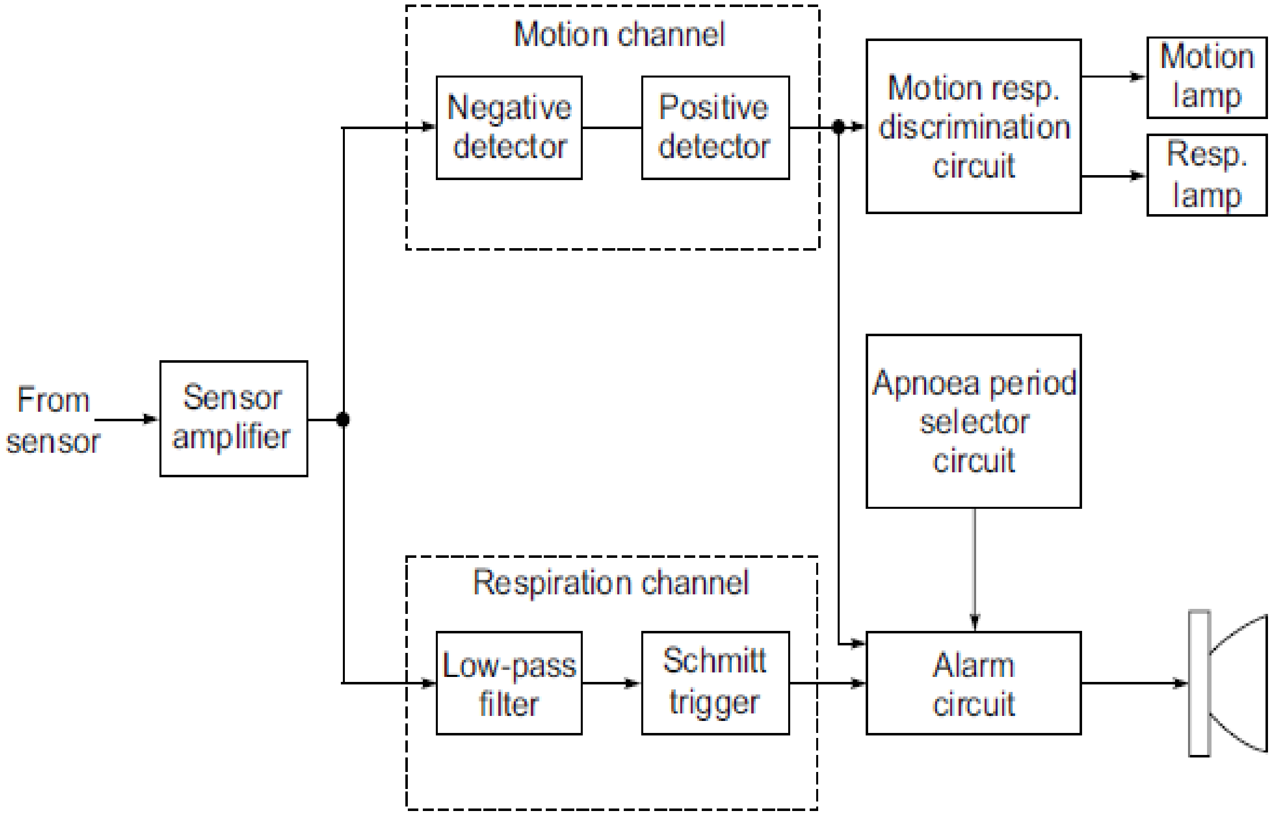


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Apnoea Detectors

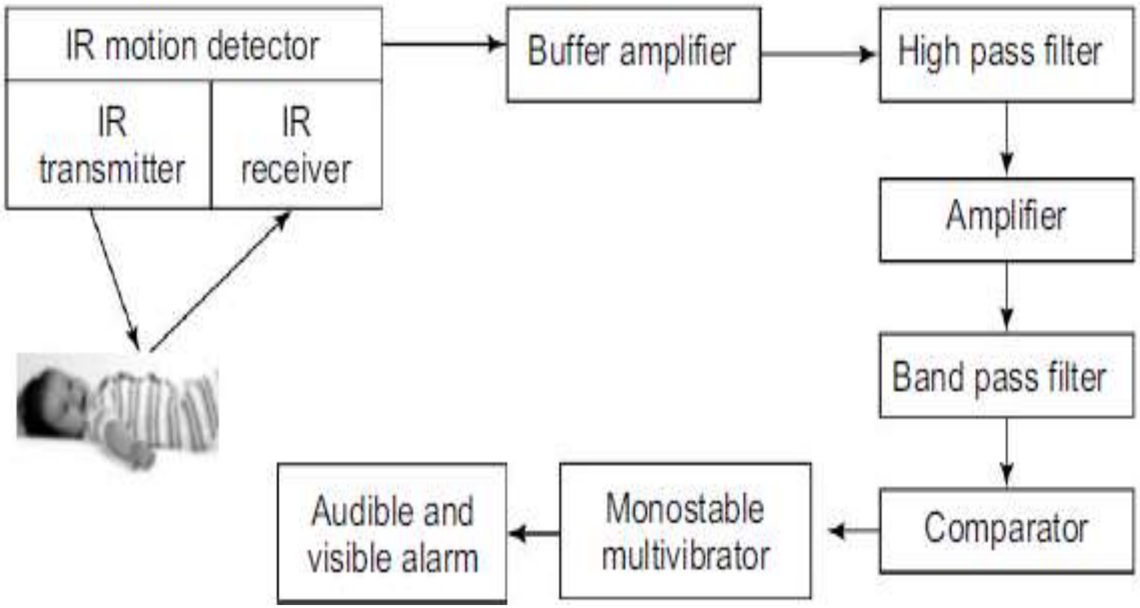
- Arrest of the heart and circulation in several clinical situations such as head injury, drug overdose, anesthetic complications and obstructive respiratory diseases.
- Apnoea may also occur in premature babies during the first weeks of life because of their immature nervous system.
- Apnoea monitors are particularly useful for monitoring the respiratory activity of premature infants.

Apnoea Detectors



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Contactless Apnoea monitor



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

BLOOD PRESSURE

Blood pressure

- Blood pressure is the **most often measured and the most intensively studied parameter** in **medical /physiological practice**.
- Determination of its **maximum and minimum levels during each cardiac cycle s**upplemented by information about other physiological parameters (**vascular condition** and certain other aspects of **cardiac performance**).
- Blood is **pumped by the left side of the heart into the aorta**.
- Due to the **load resistance of the arterioles** it **loses its pressure** and **returns to the heart at a low pressure** via highly distensible veins.

Blood pressure

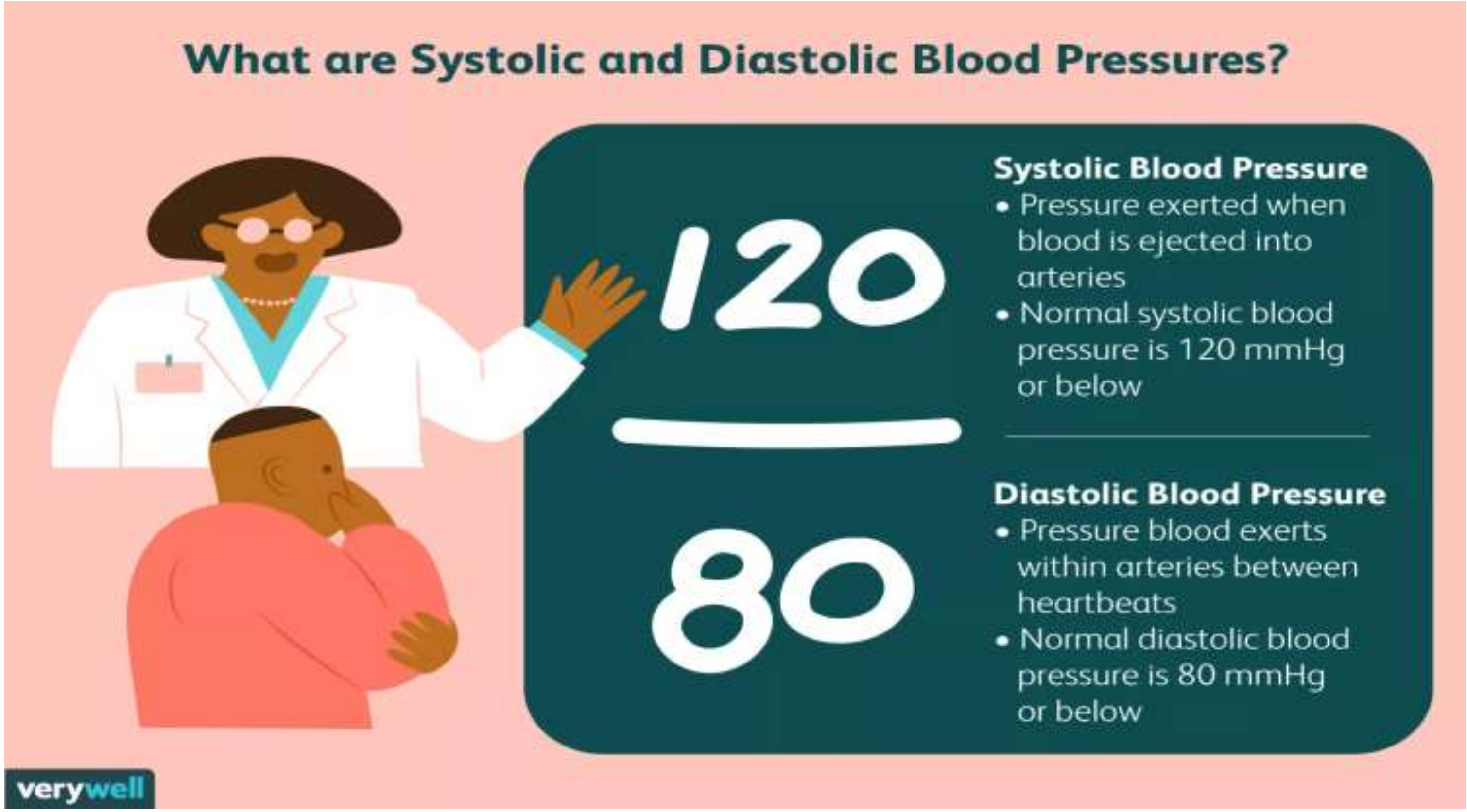
- The **maximum pressure reached during cardiac ejection is systolic pressure**& the **minimum pressure occurring at the end of a ventricular relaxation is diastolic pressure (Normal BP level: 120/80 mm Hg**).
- All **blood pressure measurements are made with reference to the atmospheric pressure (mmHg)**.

➢ Arterial system 30–300 mmHg

➢ Venous system 5–15 mmHg

➢ Pulmonary system 6–25 mmHg

Systolic & Diastolic Pressure



Blood pressure Values in Circulatory system

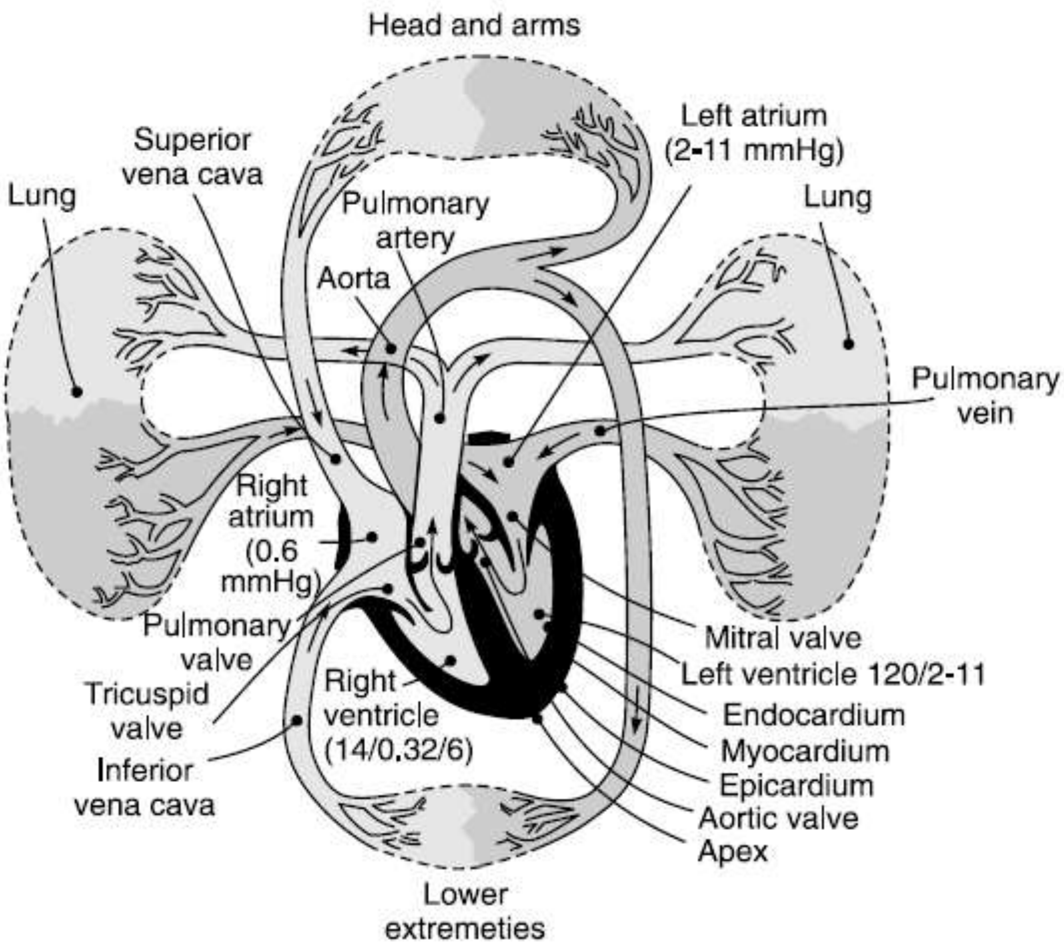


Image Courtesy: Hewlett Packard, U.S.A.)

Direct Methods of Monitoring Blood Pressure

- Direct method of pressure measurement is used when the highest degree of absolute accuracy, dynamic response and continuous monitoring are required.
- Used to measure the pressure in deep regions inaccessible by indirect means.
- A **needle type probe** is **inserted through a vein** or artery to the area of interest.

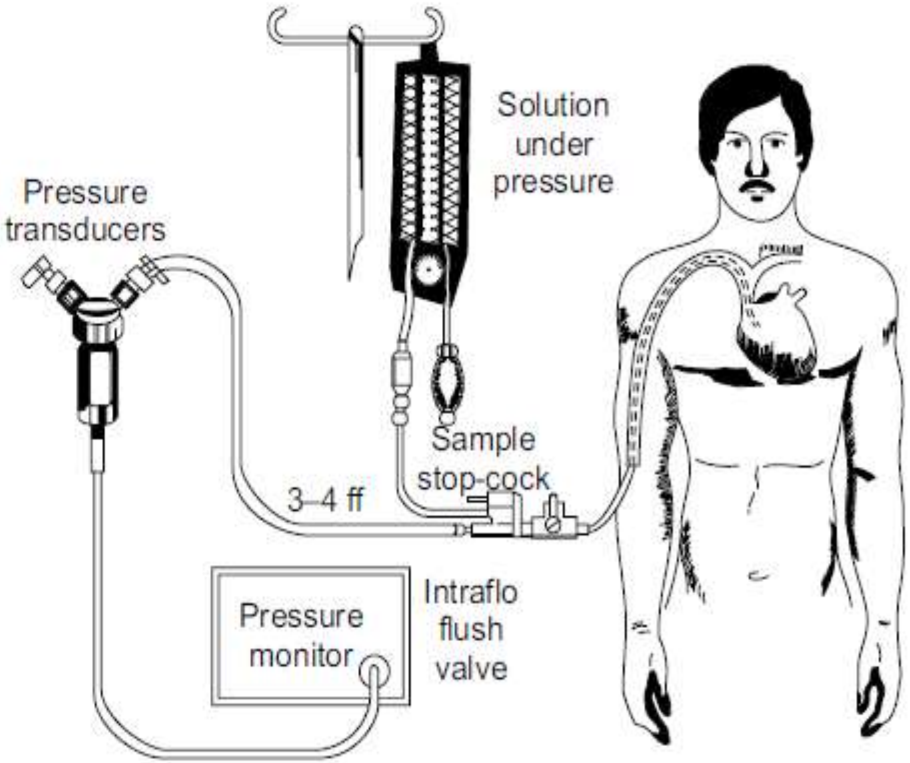
Direct Methods of Monitoring Blood Pressure

- Two types of probes used:
- One type is the **catheter tip probe** in which the sensor is mounted on the tip of the probe and the pressures exerted on it are converted to the proportional electrical signals.
- The other is the **fluid-filled catheter type**, which transmits the pressure exerted on its fluid-filled column to an external transducer.
- This transducer converts the exerted pressure to electrical signals.
- The electrical signals can then be amplified and displayed or recorded.
- **Fluid-filled type systems require careful adjustment** of the catheter dimensions to obtain an optimum dynamic response.

Direct Methods of Monitoring Blood Pressure

- Also a visualization of the **pulse contour ,stroke volume, duration of systole, ejection time and other variables also possible.**
- Once an arterial catheter is in place, it is also convenient for drawing blood samples to determine the cardiac output (dye dilution curve method), blood gases and other chemistries.
-

Pressure measuring system by direct method

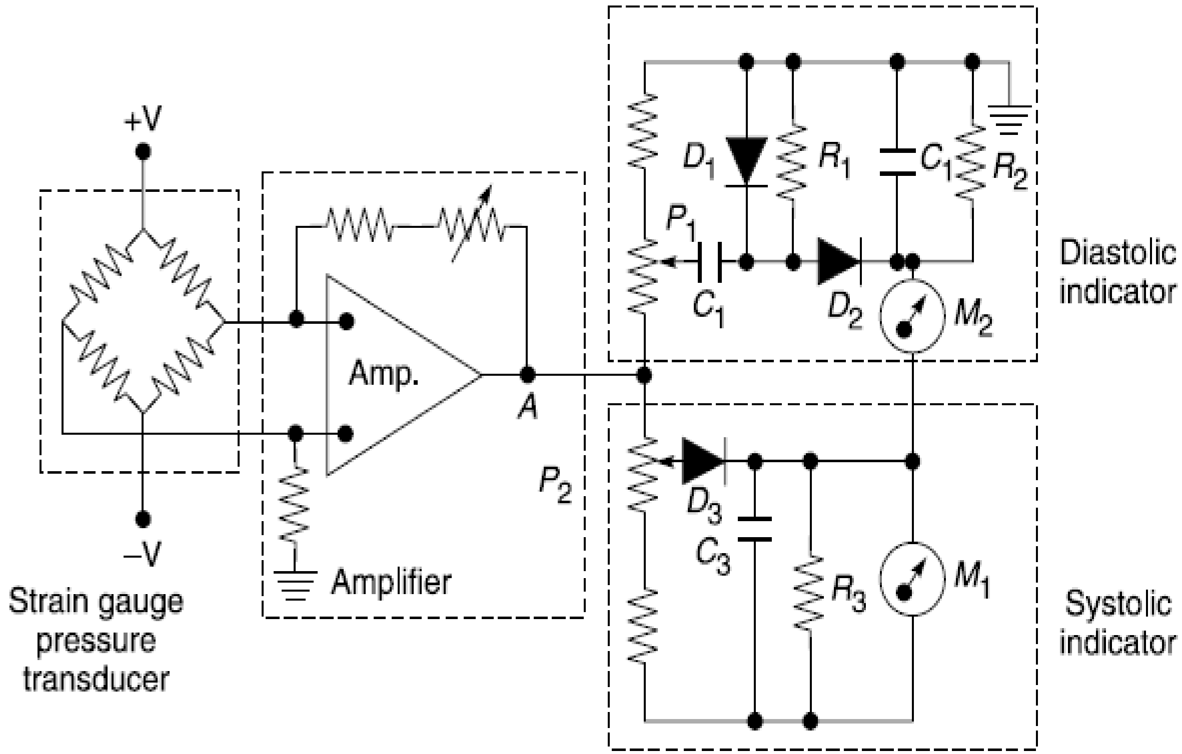


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Pressure measuring system by direct method

- Before inserting the catheters into the blood vessel it is important that the fluid-filled system should be thoroughly flushed.
- A steady flow of sterile saline is passed through the catheter to prevent blood clotting in it.
- As air bubbles dampen the frequency response of the system, the system is free from them.

Circuit diagram : Measurement of systolic & diastolic blood pressure



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Circuit diagram : Measurement of systolic & diastolic blood pressure

- Processing the electrical signals received from the pressure transducer for measuring arterial pressure.
- The transducer is excited with a 5 V dc excitation.
- The electrical signals corresponding to the arterial pressure are amplified in an operational amplifier / carrier amplifier.
- The excitation for the transducer comes from an amplitude controlled bridge oscillator through an isolating transformer, it provides an interconnection between the floating and grounded circuits.

Circuit diagram : Measurement of systolic & diastolic blood pressure

- secondary winding in the transformer is used to obtain isolated power supply for the floating circuits.
- For measurement of systolic pressure, a conventional peak reading type meter is used.
- When : a positive going pressure pulse appears at A, diode D3 conducts and C3 charged.
- The value of diastolic pressure is derived in an indirect way.
- A clamping circuit consisting of C1 and D1 is used to develop a voltage equal to the peak-to-peak value of the pulse pressure.
- Diode D2 conduct and charge capacitor C2 to the peak value of the pulse signal.

Circuit diagram : Measurement of systolic & diastolic blood pressure

- The diastolic pressure is indicated by a second meter M2.
- M2 shows: The difference between the peak systolic minus the peak-to-peak pulse pressure signal.

Catheter tip pressure transducer

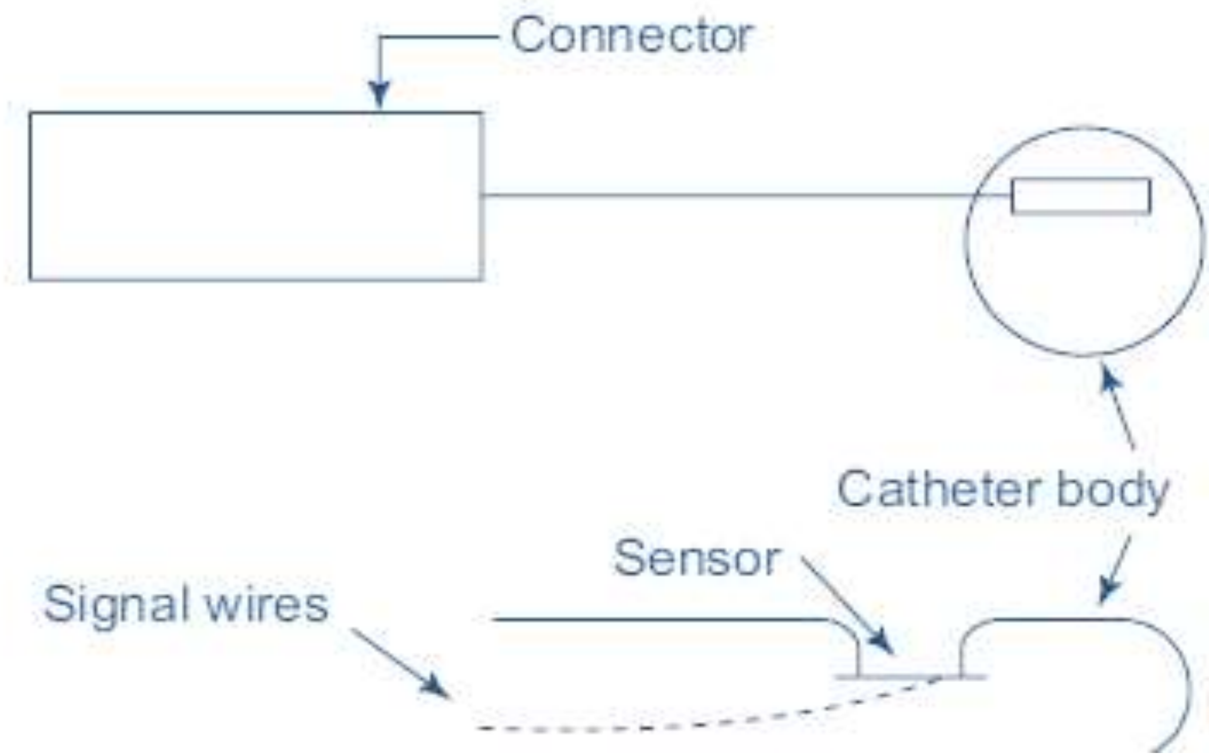


Image Courtesy: M/S Miller, U.S.A.

MEMS based catheter tip pressure sensor

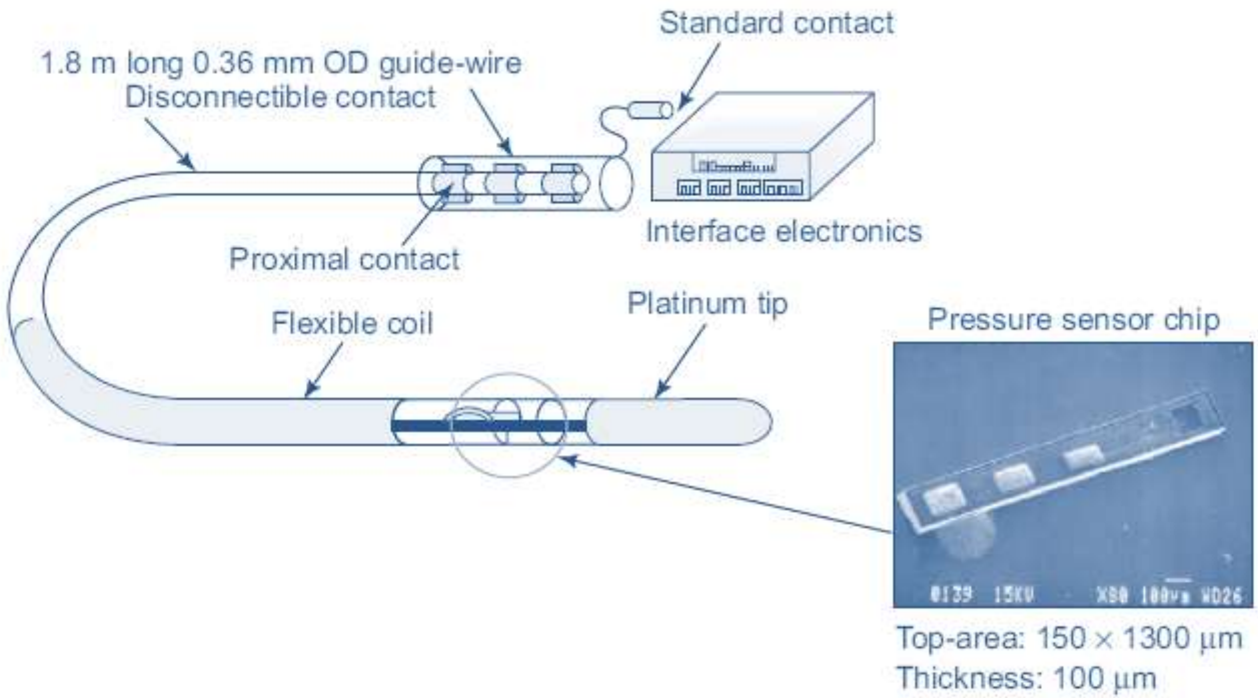


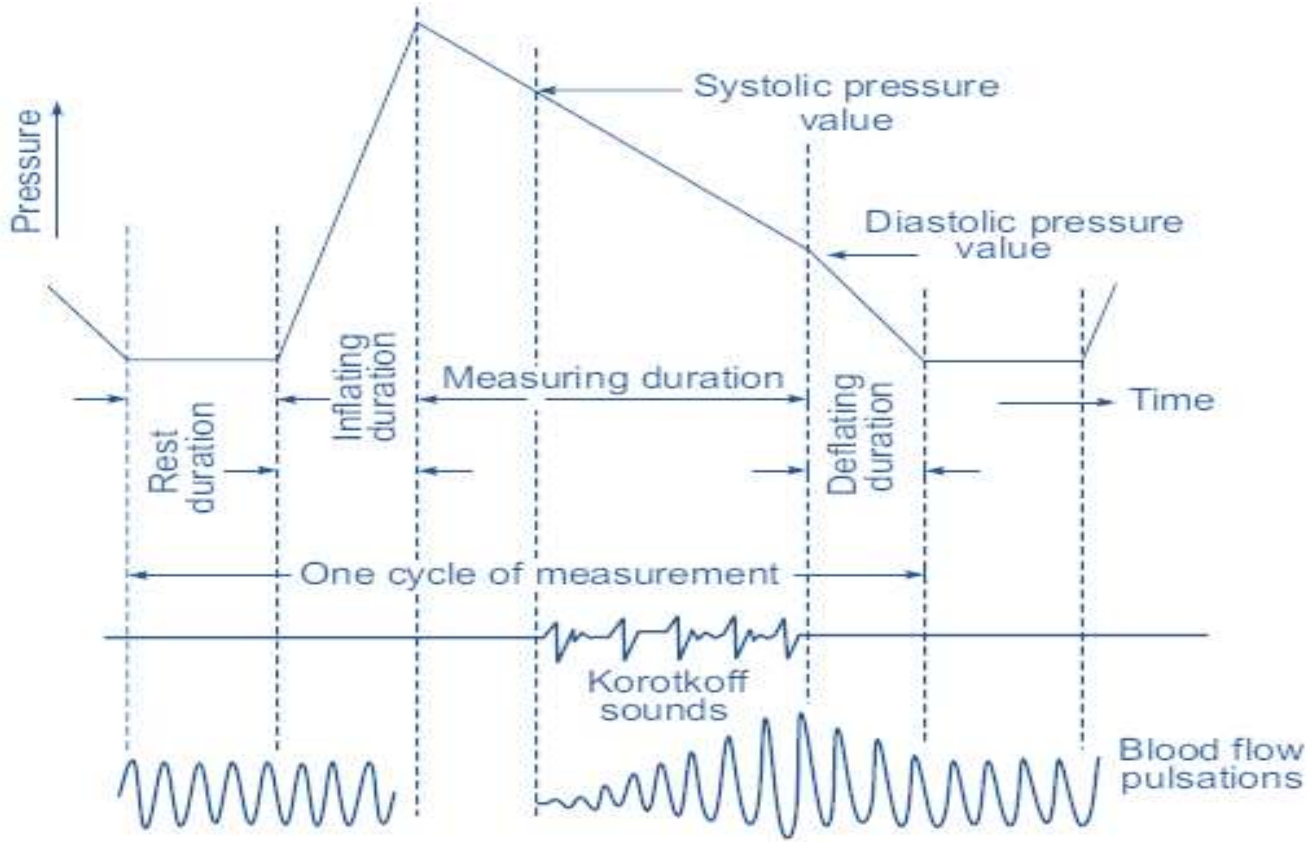
Image Courtesy: M/s ACREO

Indirect Methods of Blood Pressure Measurement

- The classical method of making an indirect measurement of blood pressure is by the use of a cuff over the limb(artery).
- Initially, the **pressure in the cuff is raised** to a level well **above the systolic pressure** so that the flow of blood is completely terminated.
- Pressure in the cuff is then released at a particular rate.
- When it reaches a level, which is below the systolic pressure, a brief flow occurs.
- The problem here finally reduces to determining the exact instant at which the artery just opens and when it is fully opened.

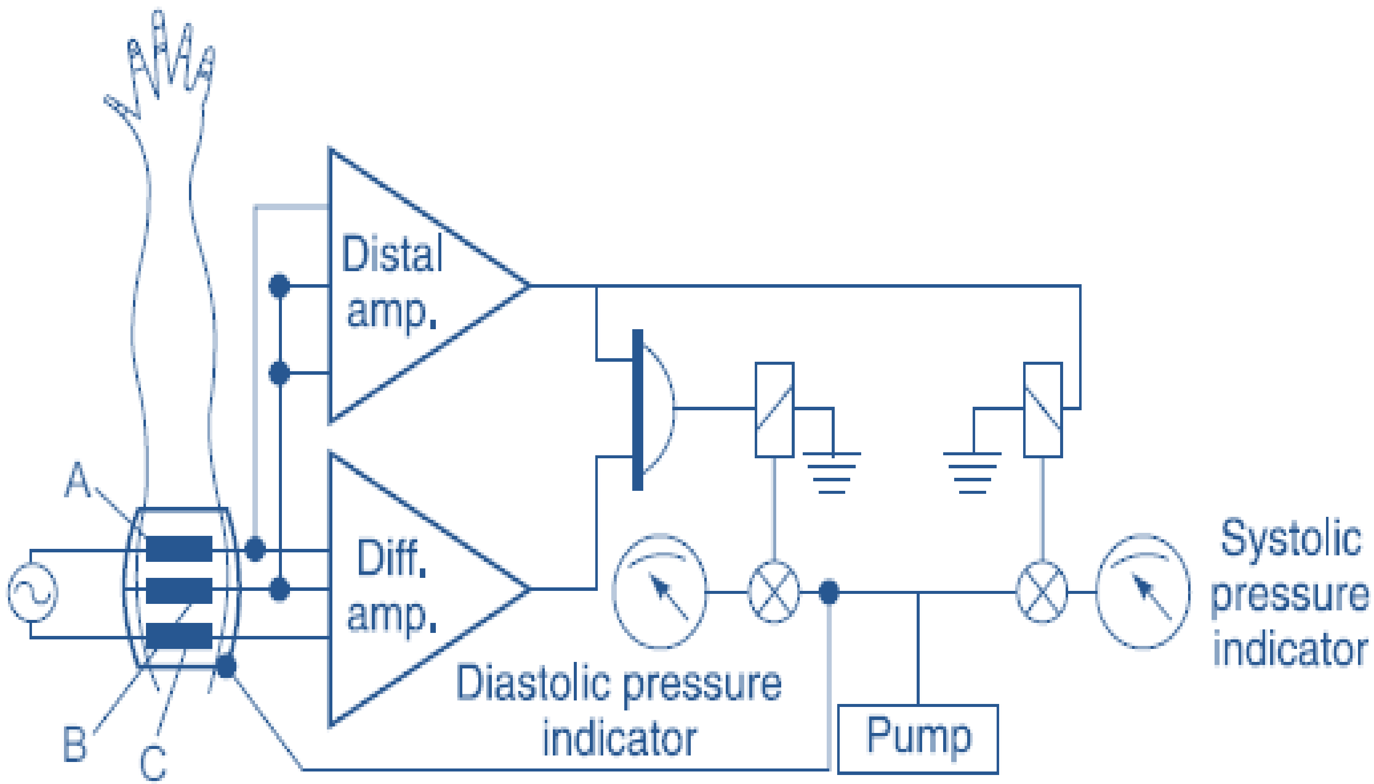
Indirect Methods..

Principle of blood pressure measurement based on Korotkoff sounds



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Rheographic method of indirect blood pressure measurement



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

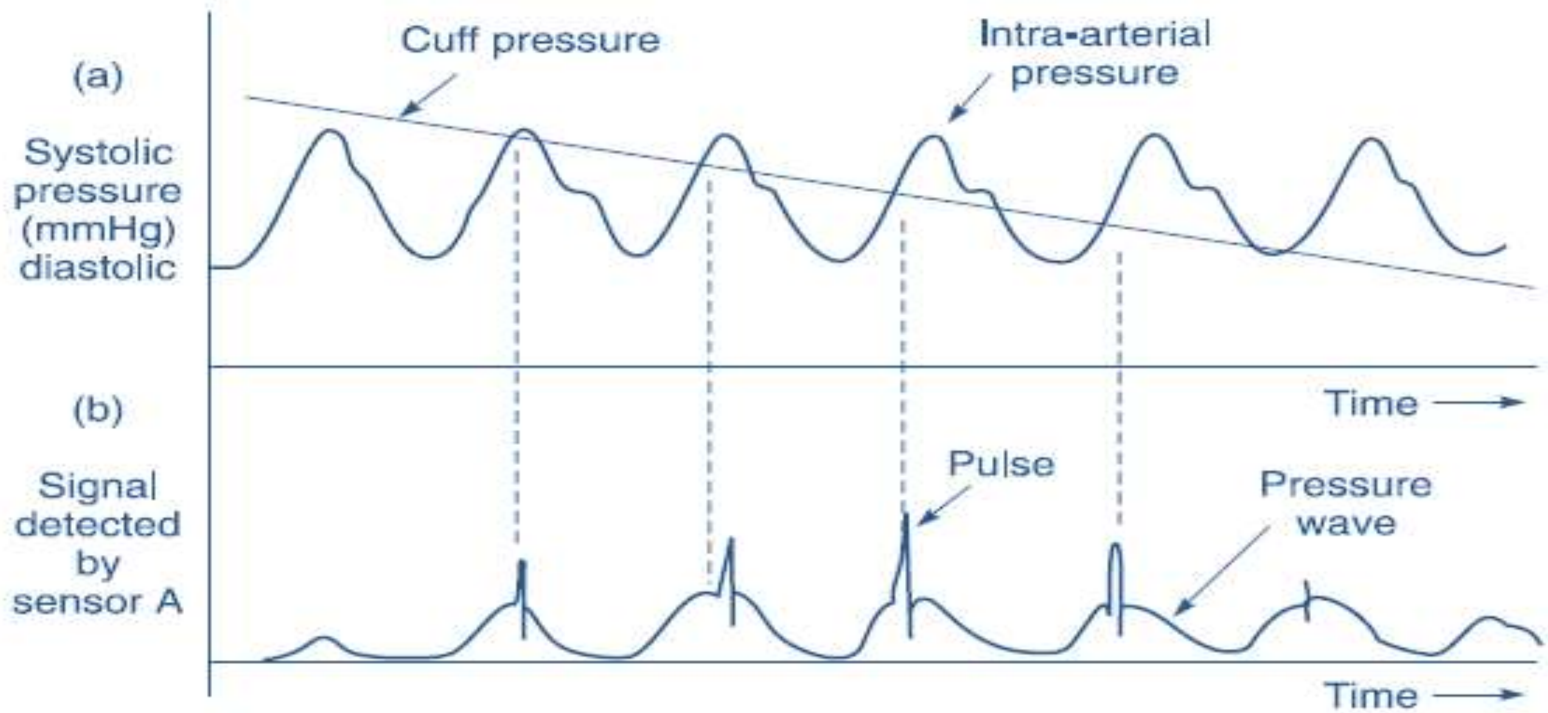
Rheographic method of indirect blood pressure measurement

- When the cuff is inflated above the systolic value, no pulse is detected by the electrode A.
- The pulse appears when the cuff pressure is just below the systolic level.
- As long as the pressure in the cuff is between the systolic and diastolic values, differential signal exists between the electrodes A and C.
- The pulse appearing at the electrode A is time delayed from the pulse appearing at C.
- When the cuff pressure reaches diastolic pressure, the arterial blood flow is no longer impeded and the differential signal disappears.
- A command signal is then initiated and the diastolic pressure is indicated on the manometer.

Differential Auscultatory Technique

- The "differential auscultatory technique" is a non-invasive method for accurately measuring blood pressure.
- A special cuff-mounted sensor consisting of a pair of pressure sensitive elements, isolates the signal created each time the artery is forced open.

Relationship between cuff pressure & intra-arterial pressure, Signal created by the relative pressure changes

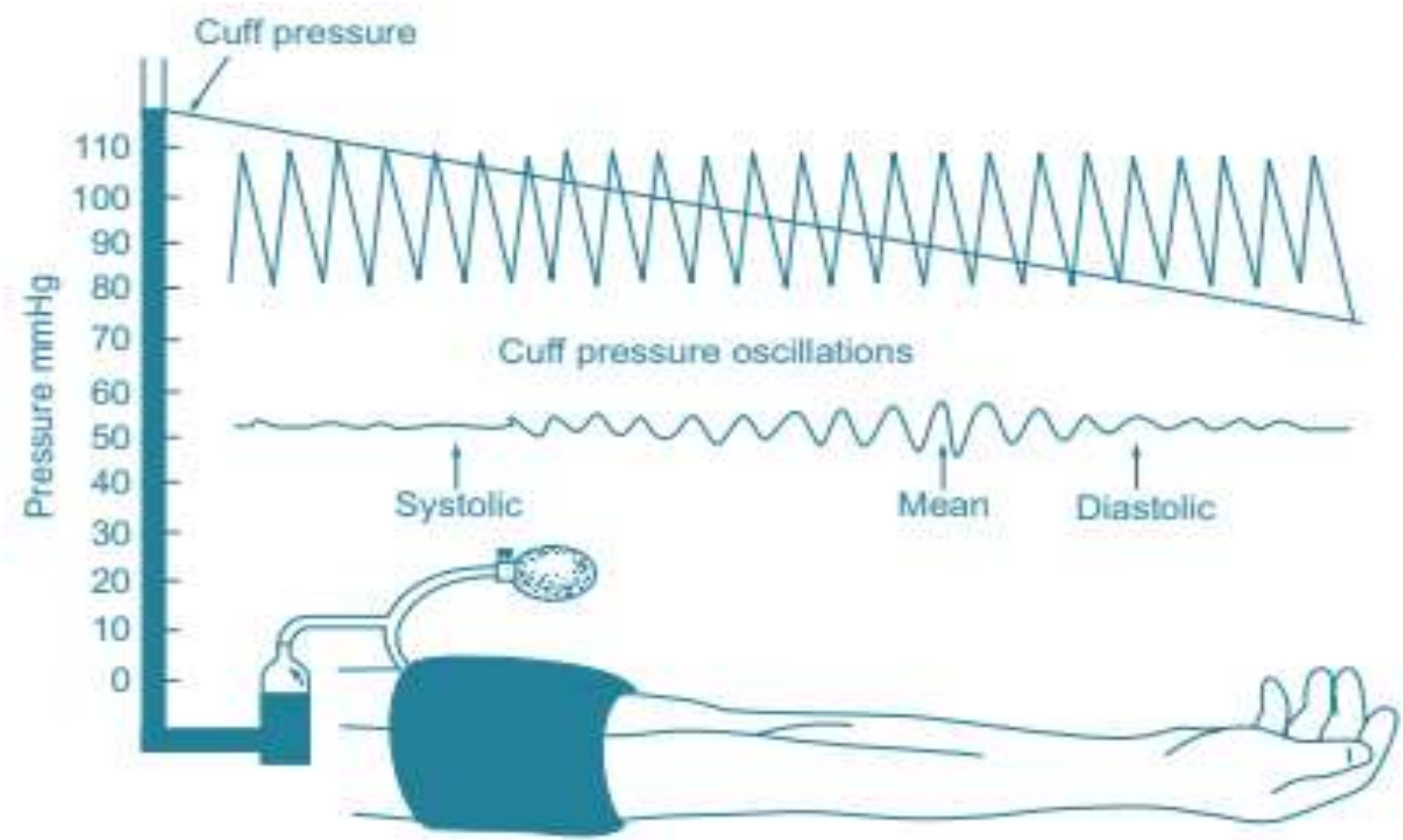


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Oscillometric Measurement Method

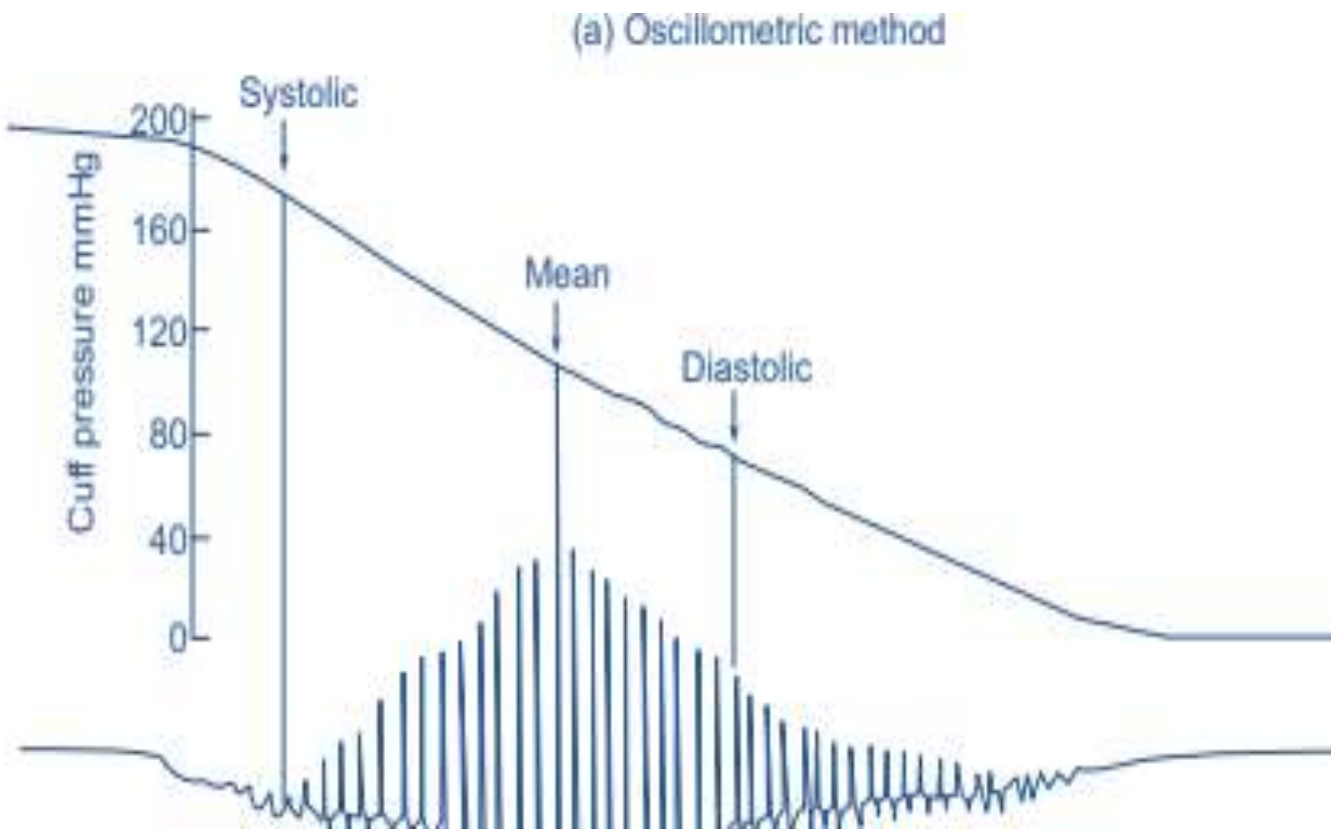
- Automated oscillometric method of non-invasive blood pressure measurement.
- cuff pressure reaches, a **level above the systolic pressure**, the artery **walls begin to vibrate / oscillate** as the blood flows turbulently through the partially occluded artery.
- The vibrations will be sensed in the transducer system monitoring cuff pressure.
- The pressure in the cuff further decrease, the oscillations increase to a maximum amplitude and then decrease until the cuff fully deflates and blood flow returns to normal.
- Oscillations begin to rapidly increase in **amplitude correlates with the diastolic pressure.**

Oscillometric method of blood pressure measurement



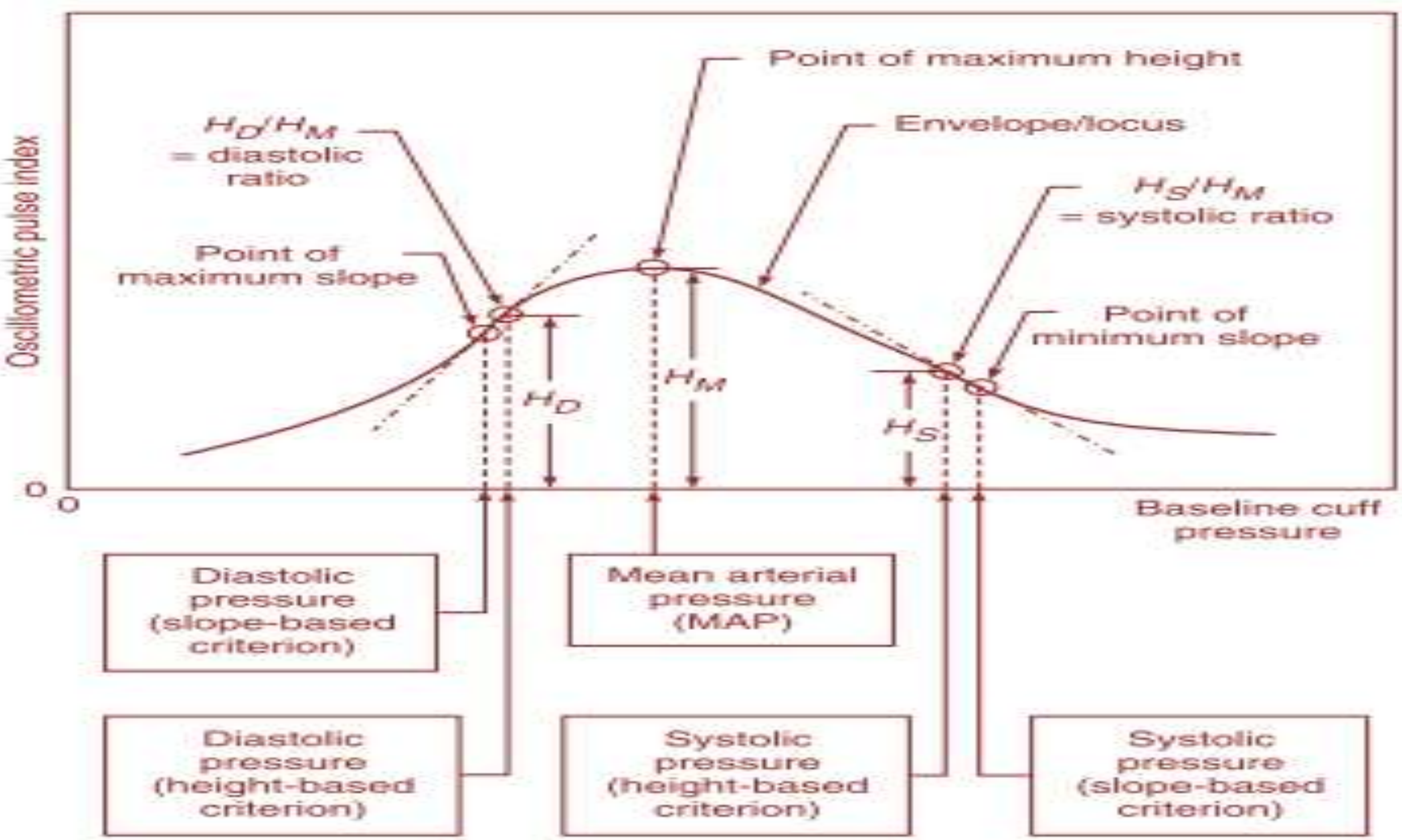
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Oscillations in cuff pressure



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Criteria for oscillometric blood pressure determination



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

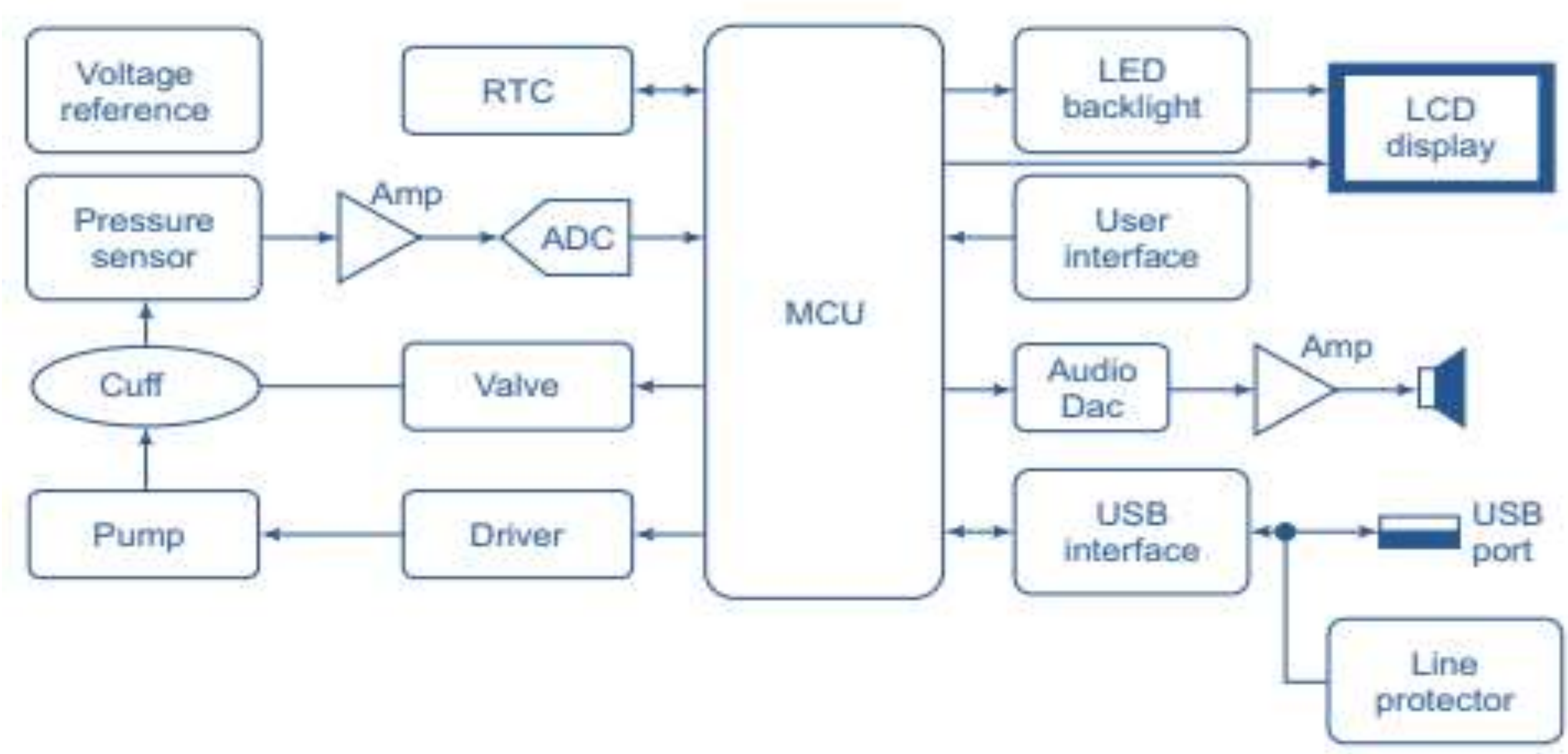
Diastolic pressure can be related to systolic pressure and MAP

$$\text{Mean BP} = \frac{\text{Systolic BP} + (2 \times \text{Diastolic BP})}{3}$$

$$\text{Diastolic BP} = \frac{(3 \times \text{Mean BP}) - \text{Systolic BP}}{2}$$

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Non-invasive blood pressure monitor



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Ultrasonic Doppler Shift Method

- Based on the ultrasonic detection of arterial wall motion.

$$\Delta f = \frac{2V_t}{\lambda_c}$$

where Δf = Doppler frequency (Hz)

V_t = velocity of the object (m/s)

λ_c = carrier wavelength (m)

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Ultrasonic Doppler Shift Method

- For blood pressure measurement, the **artery is the object from where the ultrasound gets reflected**.
- **Arterial movement produces the Doppler frequency shift**.

$$\lambda_c = \frac{V_c}{f_c}$$

where λ_c = wavelength (in metres) of the carrier frequency in the medium
V_c = velocity of the carrier frequency in the medium (1480 m/s in water)
f_c = carrier frequency in the medium (2 MHz)

$$\lambda_c = \frac{1480}{2 \times 10^6} = 0.74 \times 10^{-3}\ \mathrm{m}$$

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Ultrasonic Doppler Shift Method

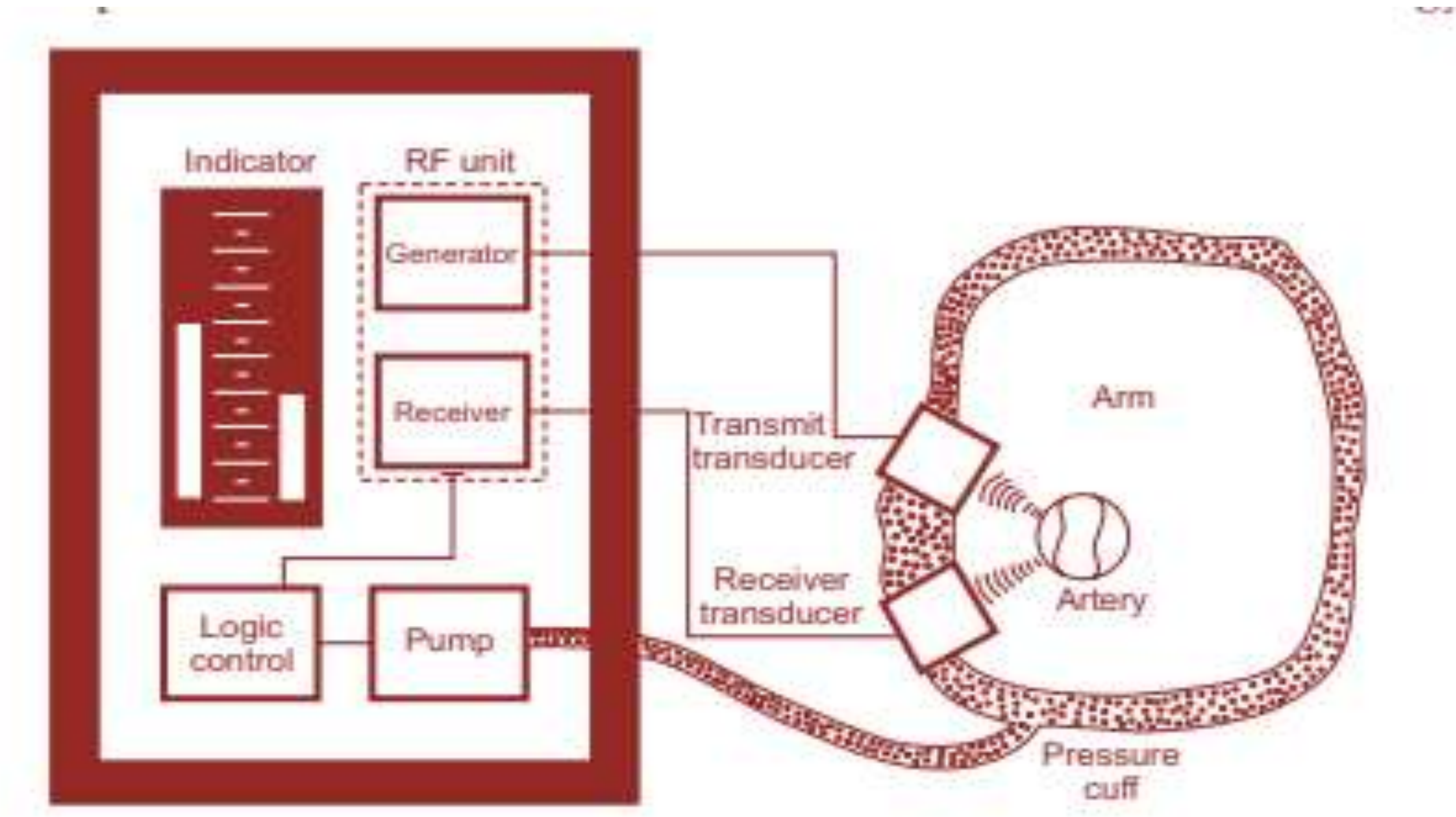
$$\Delta f = \frac{2V_t}{0.74 \times 10^{-3}} = 2.7 \times 10^3 V_t (\text{Hz})$$

$$V_t = \frac{\Delta d}{\Delta t} = \frac{5 \times 10^{-3}}{0.1} = 50 \times 10^{-3} \text{ m/s}$$

$$\Delta f = 2.7 \times 10^3 V_t = 2.7 \times 10^3 \times 50 \times 10^{-3} = 135 \text{ Hz}$$

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Measurement of blood pressure using ultrasonic Doppler-shift principle



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

TEMPERATURE MEASUREMENT

Temperature measurement

- **Classical method:**

  Mercury-in-glass thermometer.

- **Disadvantages:**

➢ Slow

➢ Difficult to read

➢ Susceptible to contamination.

Temperature measurement

Electronic Thermometers:

- It use probes incorporating a **thermistor/ thermocouple sensor** which have rapid response characteristics.
- Probes are **reusable** and their covers are **disposable**.
- Thermocouples are used for surface **skin temperature measurement**.
- **Resistance thermometers** are used for **body temperature measurement**.

Temperature measurement

- The resistance thermometer /thermistor measure absolute temperature, whereas thermocouples generally measure relative temperature.

Thermocouples

- Two wires of different materials are joined together at either end, forming two junctions(maintained at different temperatures)
- A thermo-electromotive force (emf) is generated causing a current to flow around the circuit.
- The junction at the **higher temperature is the measuring junction** & the lower temperature (cold) is reference junction.
- The cold junction is usually kept at 0°C.
- The thermal emf & the current produced is proportional to the temperature difference existing between the junctions.

Thermocouples

Measurement Procedure :

- Insert one junction in or on the surface of the medium whose temperature is to be measured.
- Keep the other at a lower and constant temperature (usually 0°C-inside a vacuum flask containing ice)

Thermal emf for Various Types of Thermocouples

Type	Thermocouple	Useful range °C	Sensitivity at 20°C ($\mu V/°C$)
T	Copper-constantan	–150 to +350	45
J	Iron-constantan	–150 to + 1000	52
K	Chromel-alumel	–200 to +1200	40
S	Platinum-platinum (90%) Rhodium (10%)	0 to +1500	6.4

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Emf versus temperature characteristics

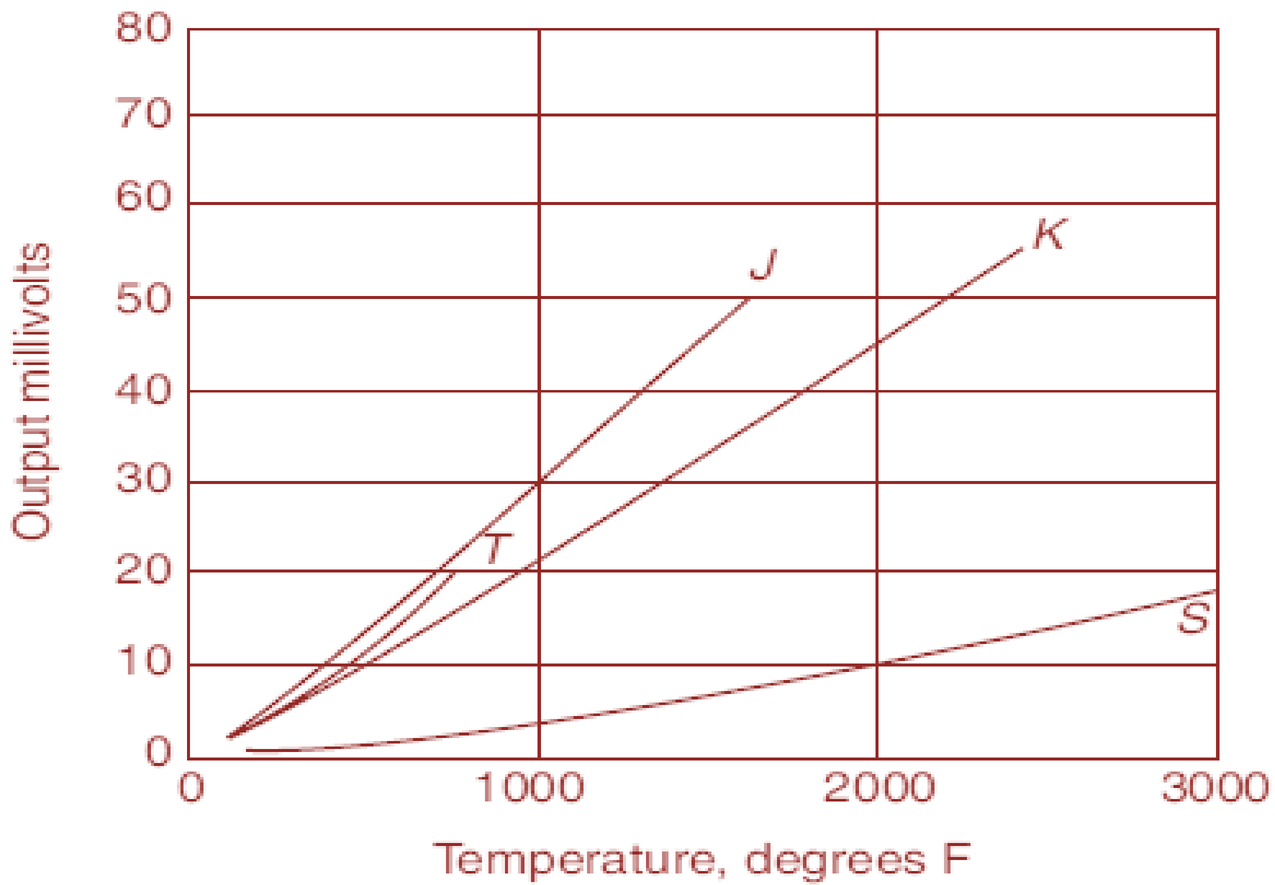


Image Courtesy: Gould Inc., U.S.A.

Emf versus temperature characteristics

- Each type of thermocouple has a unique, non-linear response to temperature.
- Most recording or display devices are linear.
- There is a need to linearize the output from the thermocouples .
- The displayed output correlated with actual temperature.
- In medical applications: a copper-constantan combination is usually preferred.
- With the reference junction at 0°C and the other at 37.5°C, the output from this thermocouple is 1.5 mV.

Reference junction compensator

- A simpler method is to use a reference-temperature compensator which generates an emf that exactly compensate for variations in the reference-junction temperature.

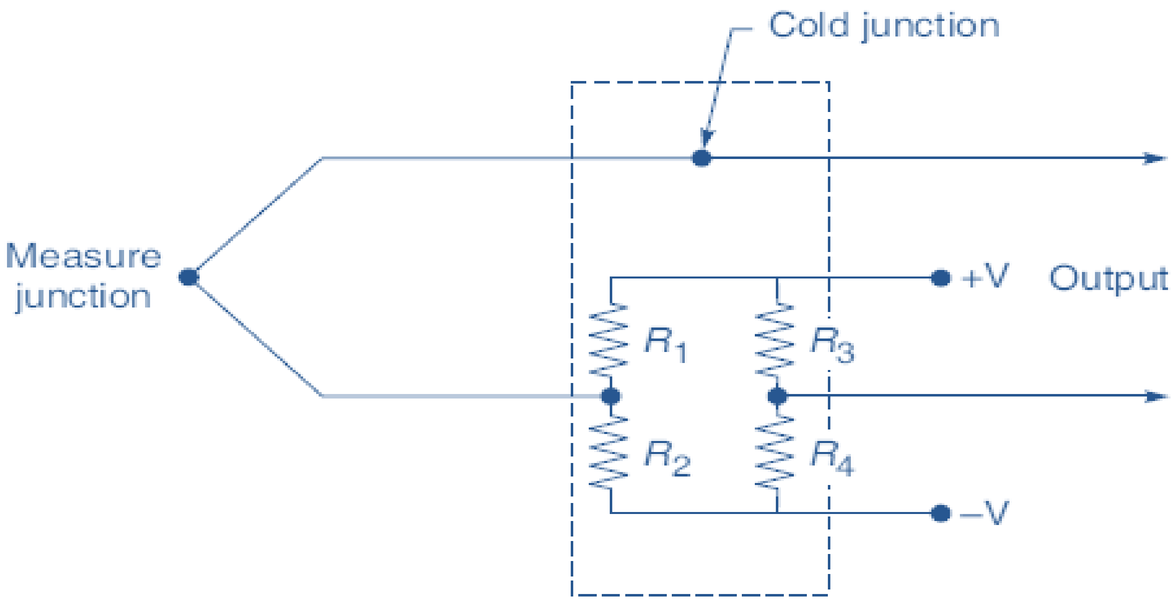


Image Courtesy: Gould Inc., U.S.A.

Electrical Resistance Thermometer

- The **temperature dependence of resistance of certain metals** makes it to construct a temperature transducer.
- The resistance R_t of a metallic conductor at any temperature t is

$$R_t = R_o(1 + \alpha t)$$

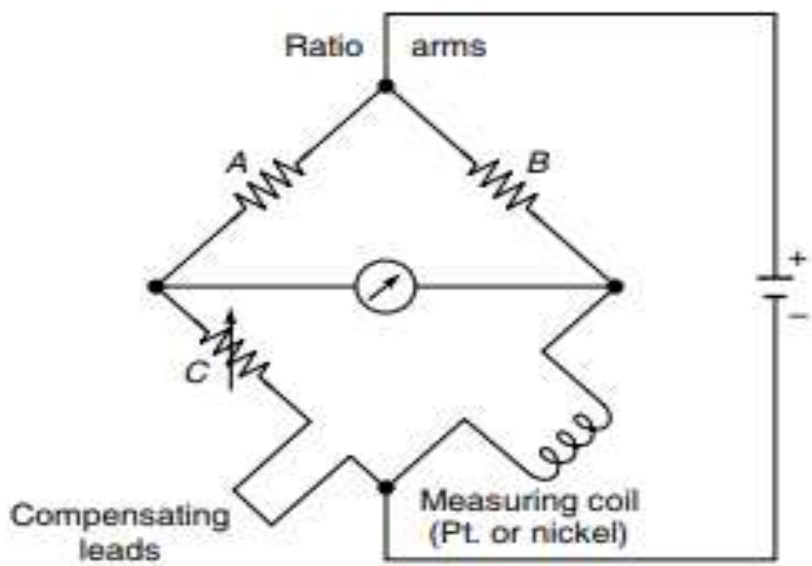
where R_o = resistance at 0°C and

α = temperature coefficient of resistivity

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electrical Resistance Thermometer

- Platinum or nickel are used for resistance thermometry (Reason: they can be readily obtained in a pure form and are comparatively stable)
- Thermometers constructed from a coil of these metals have been used for the measurement of all temperature categories.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electrical Resistance Thermometer

- A and B are fixed resistances.
- C is variable resistance (made from constantan which has a very low temperature coefficient of resistance).
- The measuring coil and its connecting leads are placed in one arm of the bridge circuit & a dummy pair of leads connected in the opposite arm.
- Changes in resistance of the coil leads with ambient temperature are cancelled out by the corresponding changes in the dummy or compensating leads.

Thermistors

- **Principle: Resistance of the thermistor decreases** when **temperature increases**.
- The general resistance-temperature relation for a thermistor :

$$R = Ae^{B/T}$$

where R = resistance of the thermistor in Ω

T = absolute temperature

A and B are constants

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Thermistors

Types of Thermistors:

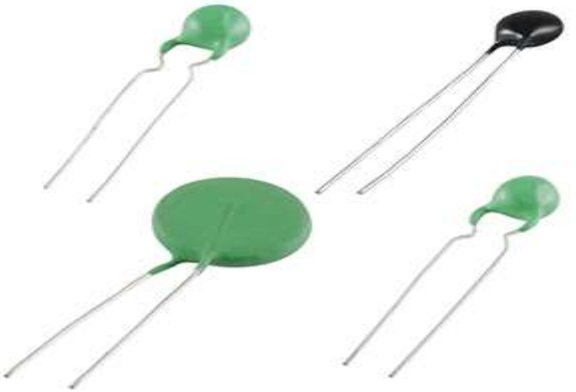
- **NTC (negative temperature coefficient)**

  Materials that experience a decrease in electrical resistance when their temperature is raised.
- **PTC (positive temperature coefficient)**

  Resistance increases with increasing temperature.

Advantages:

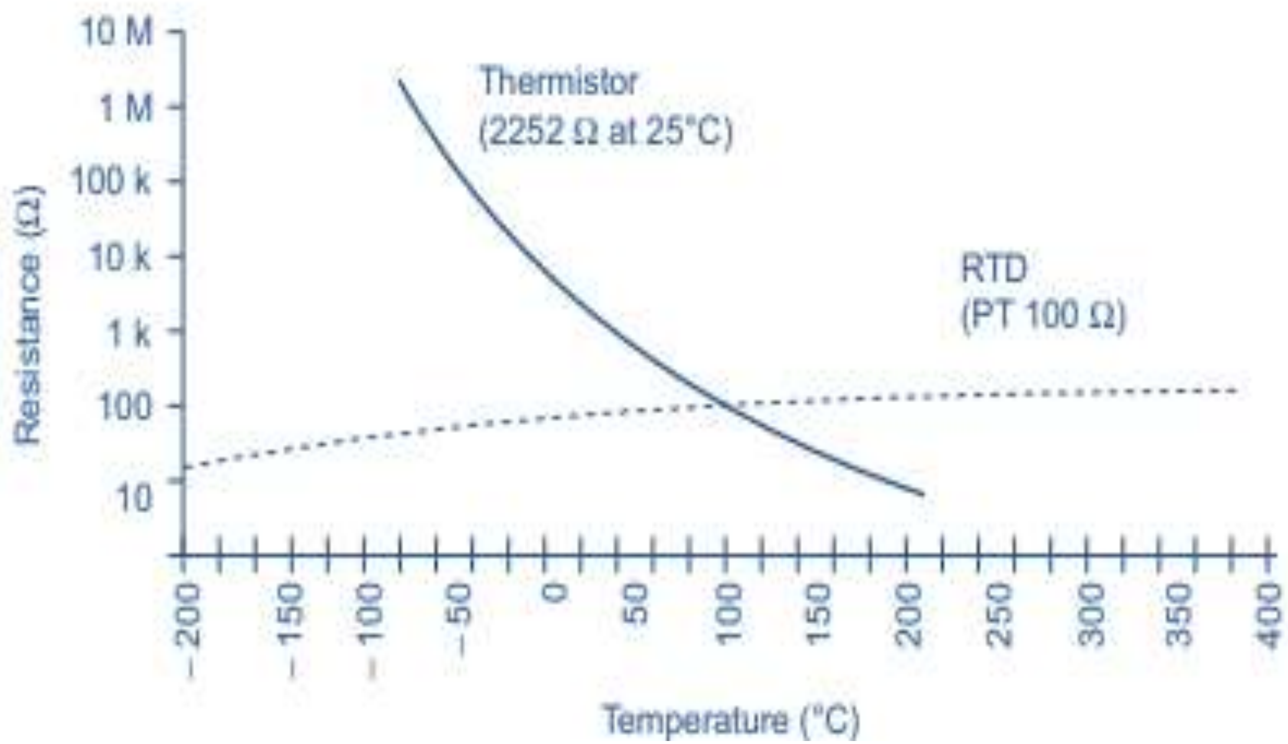
- High sensitivity
- No compensating required
- Quick measurement
- Small in size



Different shapes of thermistor probes

Image Courtesy: Yellow Springs Instruments Co., U.S.A.)

Thermistors

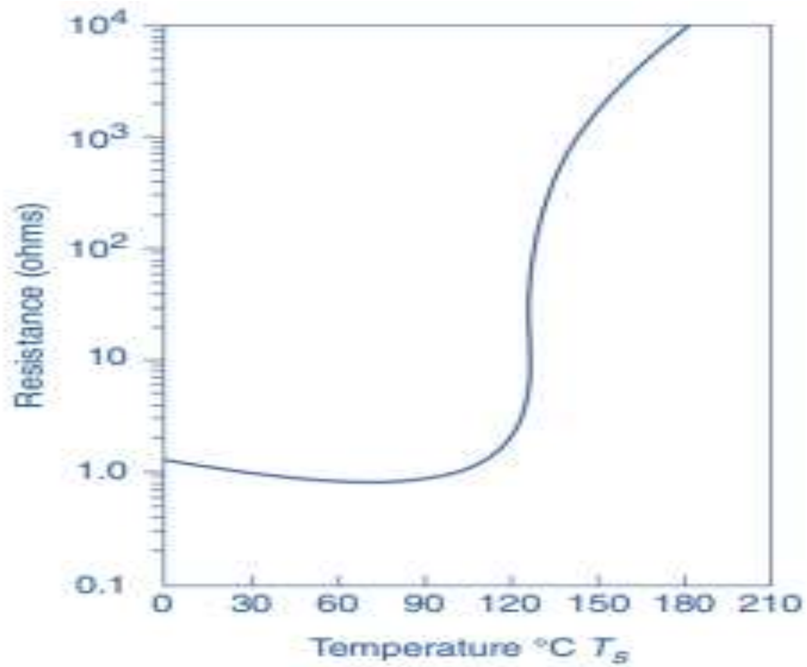


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Resistance-temperature graph

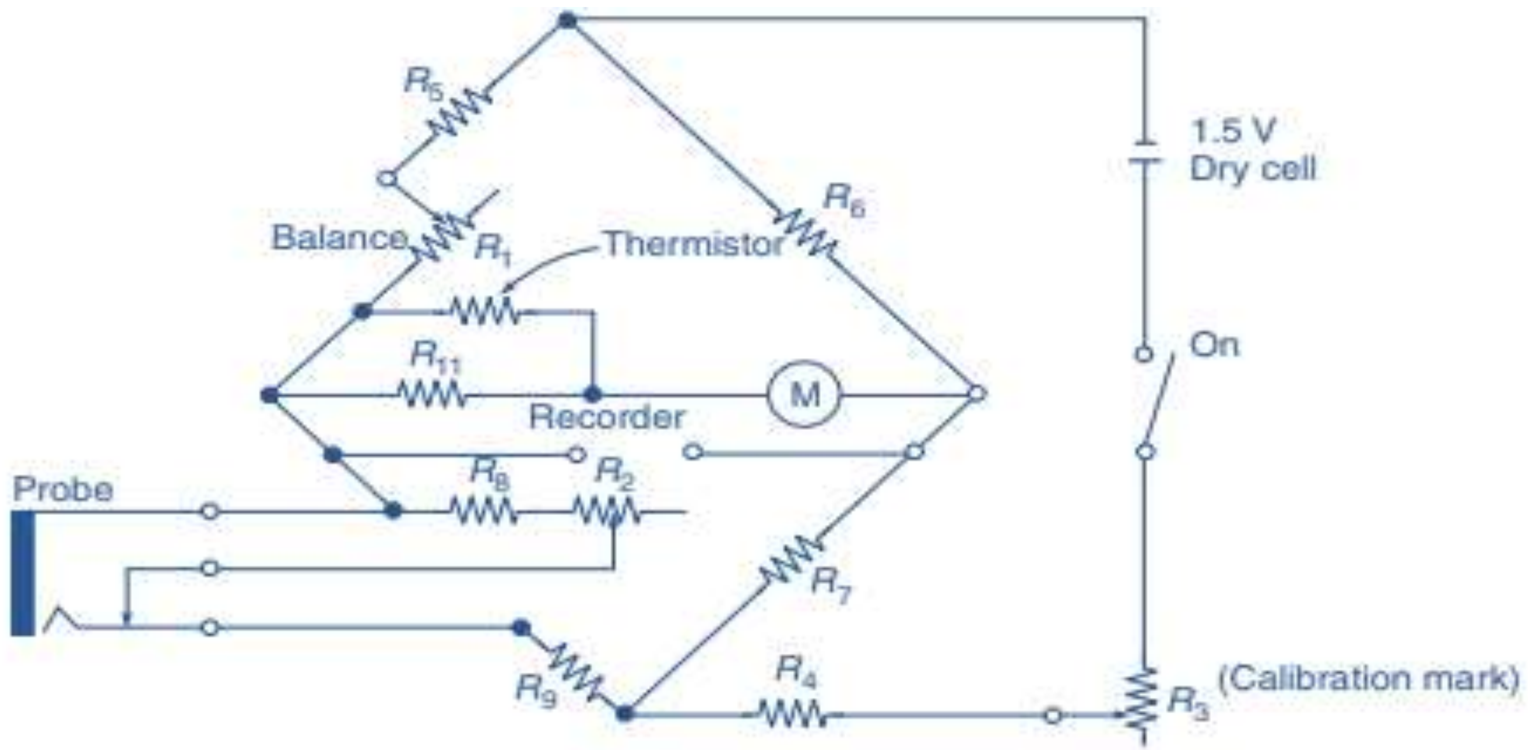
Image Courtesy: Keystone Carbon Co., U.S.A.

- A PTC thermistor switches abruptly when heated to the switching temperature.
- Resistance changes by four decades.



Circuit diagram of a Thermometer

Image Courtesy: Yellow Springs Instruments Co. U.S.A.



Radiation Thermometery

- Material placed above absolute zero temperature emits electromagnetic radiation from its surface.
- Both the amplitude and frequency of the emitted radiation depends on the temperature of the object.
- **Infrared thermometers** measure the magnitude of infrared power (flux), typically from 4 to 14 micrometers spectral range.
- No contact with the object measured.
- The emitted infrared radiation is detected by thermopiles.
- A pyroelectric sensor(other type) , it develops an electric charge that is a function of its temperature gradient.
- Infrared thermometers –advantages

Comparison of Temperature Measurement Methods

	RTD	*Thermistor*	*Thermocouple*	*Radiation*
Accuracy	0.01° to 0.1°F	0.01° to 1°F	1° to 10°F	0.2°F
Stability	Less than 0.1% drift in 5 years	0.2°F drift/year	1° F drift/year	Same as thermocouple
Sensitivity	0.1 to 10 ohms/°F	50 to 500	50 to 500 μvolts/°F	Same as Thermocouple
Features	Greatest accuracy over wide spans; greatest stability	Greatest sensitivity	Greatest economy highest range easiest to use	Fastest response no contaminations

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

OXIMETERS

Oximetery

- **Oximetry:-** determination of the percentage of oxygen saturation of the circulating arterial blood.

$$\text{Oxygen saturation} = \frac{[HbO_2]}{[HbO_2]+[Hb]}$$

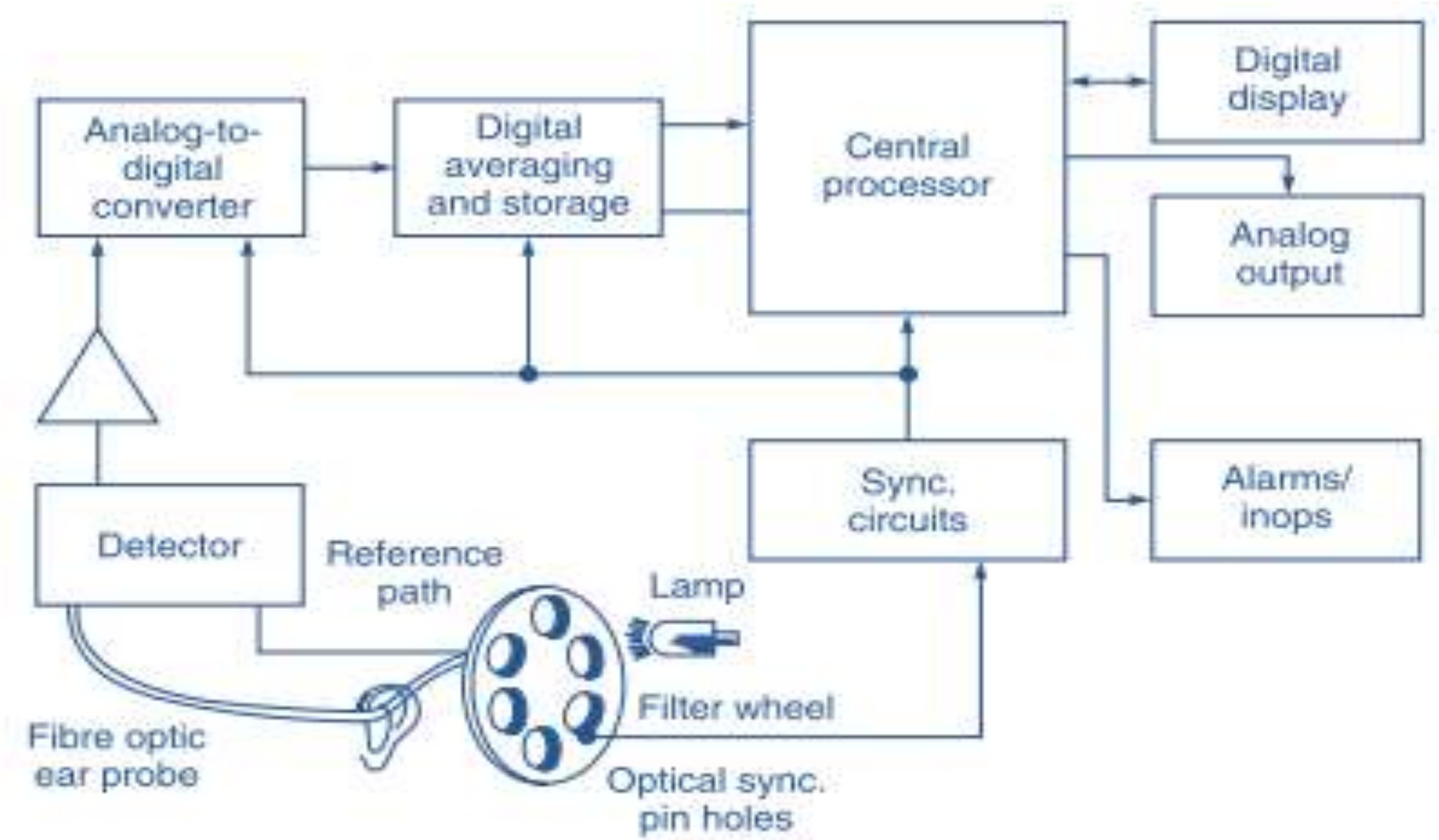
- $[HbO_2]$ is the concentration of oxygenated haemoglobin.
- [Hb] is the concentration of deoxygenated haemoglobin.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

EAR OXIMETER

- Ear oximeters use the transmission principle to measure the arterial oxygen saturation.
- Blood in the ear made similar to arterial blood in composition.
- Increasing the flow through the ear without increasing the metabolism.
- Maximum dilatation is achieved by keeping ear warm.
- It takes about 5 /10 min for the ear to be dilated.
- **Merrick and Hayes (1976)**

Block diagram of ear oximeter



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of ear oximeter..

- The light source is a **tungsten-iodine lamp**.
- lens system collimates the light beam and directs it through thin-film interference filters that provide wavelength selection.
- The filtered light beam enters a fibre optic bundle which carries it to the ear.
- Another fibre optic bundle carries the light passing through the ear back to a detector.
- A second light path is developed with a beam splitter in the path of the collimated light beam near the source.
- This path also passes through the filter.

Block diagram of ear oximeter..

- The detector **receives two light pulses for each wavelength**.
- The **processor takes the ratio of two pulses as the measured value**.
- The **current developed at the photodetector is only 0.5 nA or less during a light pulse**.
- It is **amplified in a high gain amplifier** and then converted to a 16-bit digital signal.
- Computation of percent oxygen saturation is accomplished in a central processor using ADC.

PULSE OXIMETER

Pulse oximetry

- **It is non-invasive method allowing the monitoring of the saturation of a patient's haemoglobin.**
- It is based on **arterial oxygen saturation determinations using two wavelengths.**
- Two wavelengths (**two absorbers are present**) (i) **oxyhaemoglobin (HbO_2)** & (ii) **reduced haemoglobin (Hb).**
- **Light passing through** ear/finger will be absorbed by skin pigments, tissue, bone, **arterial blood, venous blood**.

PULSE OXIMETER..

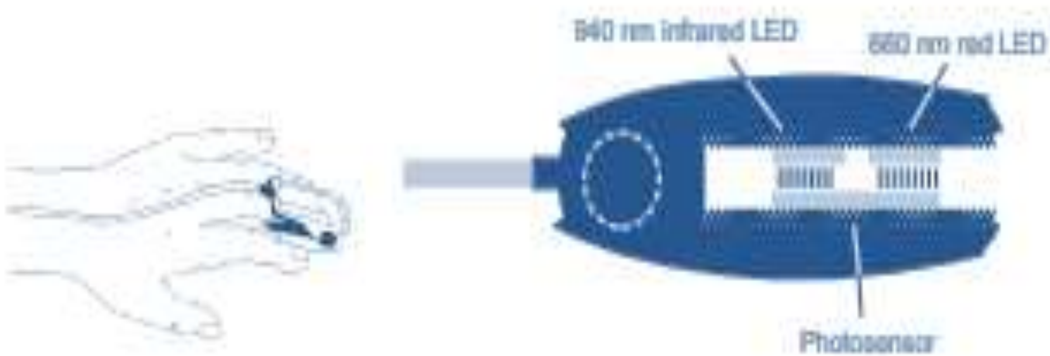
- The absorbance are additive & obey the **Beer-Lambert law**:

$$A = -\log T = \log I_o / I = \varepsilon D C$$

- Io and I are incident and transmitted light intensities
- ε is the extinction coefficient,
- D is the depth of the absorbing layer
- C is concentration

- Most **absorbance are fixed &do not change with time**.
- **Even blood** in the capillaries and veins under steady state metabolic circumstances is constant in composition and flow, at least over short periods of time.
- Only the blood flow in the arteries /arterioles is pulsatile.
- Measuring the absorbance due to arterial blood makes possible the determination of **arterial oxygen saturation (SaO_2)**.

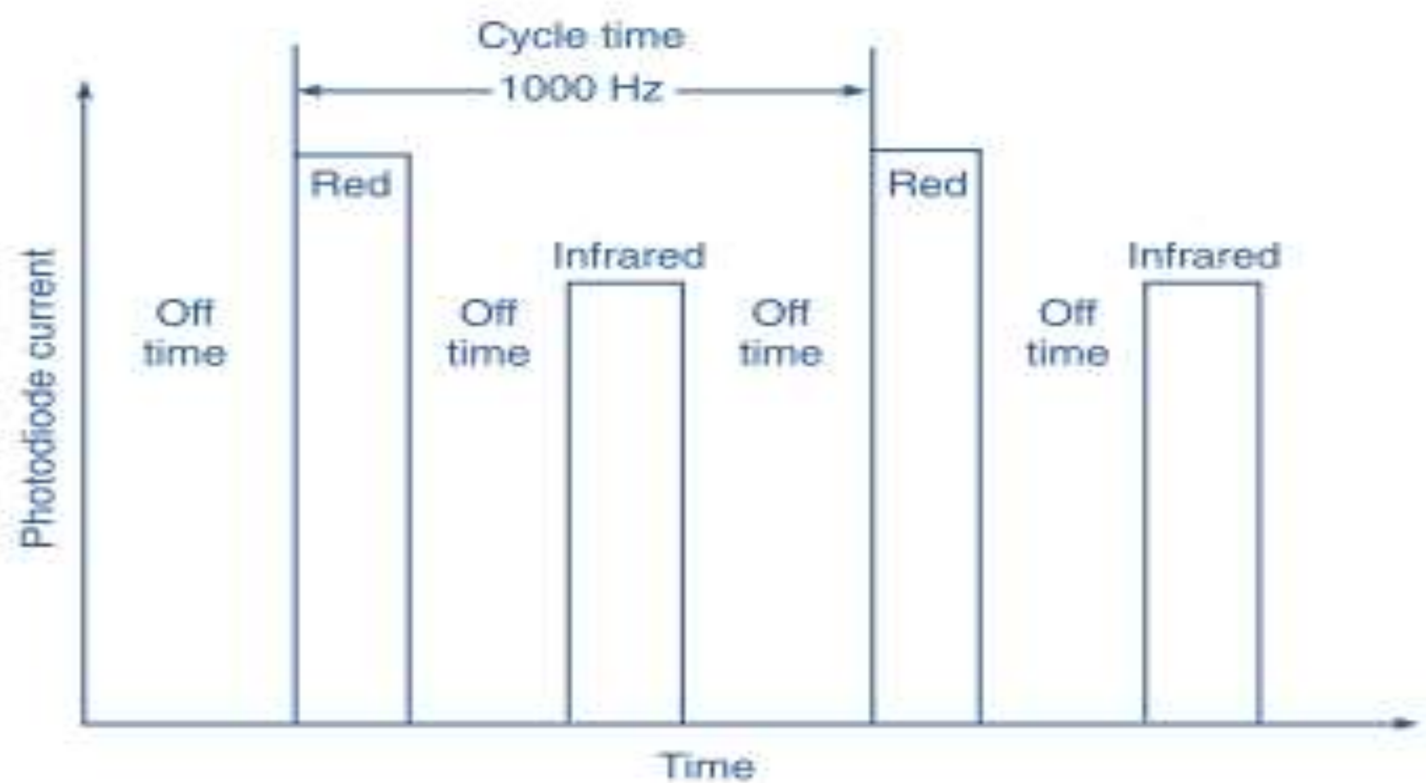
A typical finger tip pulse oximeter probe
&
Components of a pulse oximeter probe



- Pulse oximeter Probes have a **photodetector (Photodiode - PIN-diode).**
- Relative absorption of **red (absorbed by deoxygenated blood)** & **infrared (absorbed by oxygenated blood) correlates to arterial blood oxygen saturations**.

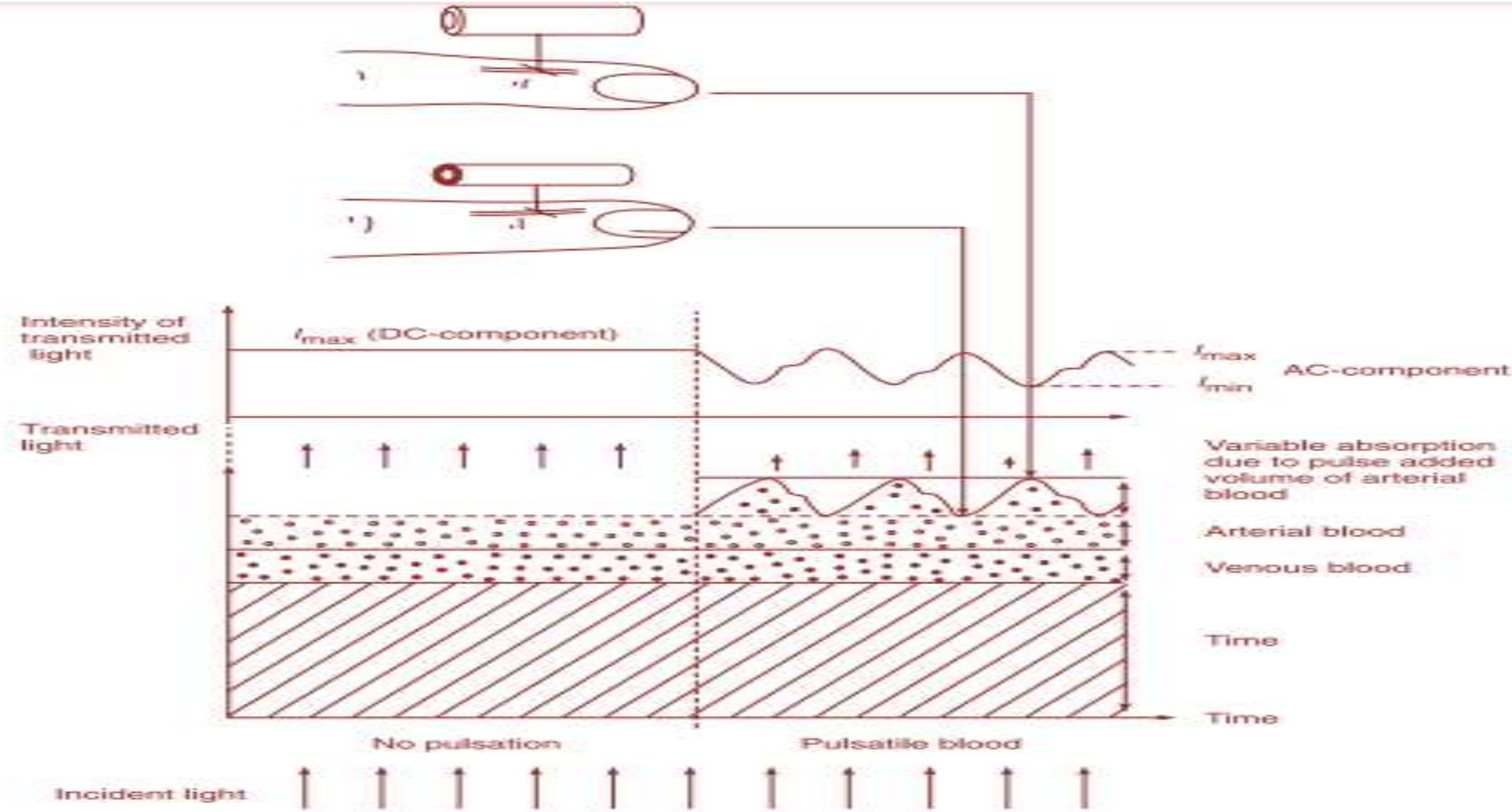
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Typical pulsing of red and infrared light emitting diodes by a pulse oximeter



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Infrared light absorption in the finger



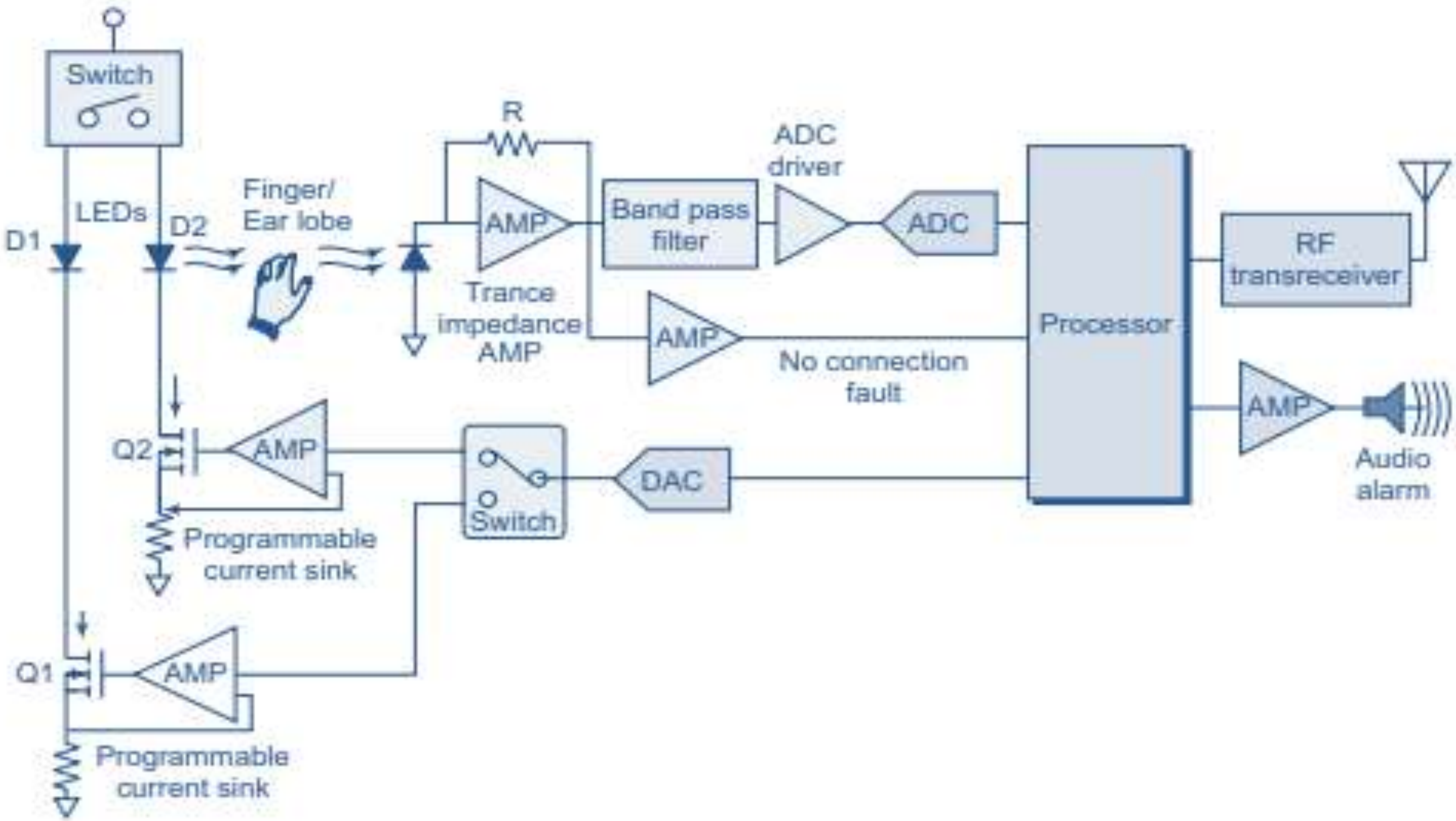
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Infrared light absorption in the finger..

- One signal represents the absorption of red light (660 nm).
- one represents infrared light (940nm).
- **Oxygenated haemoglobin absorbs more infrared light** and allows more red light to pass through.
- **Deoxygenated hemoglobin** allows more infrared light to pass through and **absorbs more red light**.
- The **AC signal is due to the pulsing of arterial blood**.
- DC signal is due to all **non-pulsing absorbers in the tissue**.
- Oxygen saturation is estimated from the **ratio (R)** of **pulse-added red absorbance at 660 nm** to the **pulse-added infrared absorbances at 940 nm.**

$$R = \frac{ac\,660\,/\,dc\,660}{ac\,940\,/\,dc\,940}$$

Block diagram for a pulse oximeter (Reference : Ardizzoni, 2009)



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Finger tip pulse oximeter

Image Courtesy: ttps://wexnermedical.osu.edu/

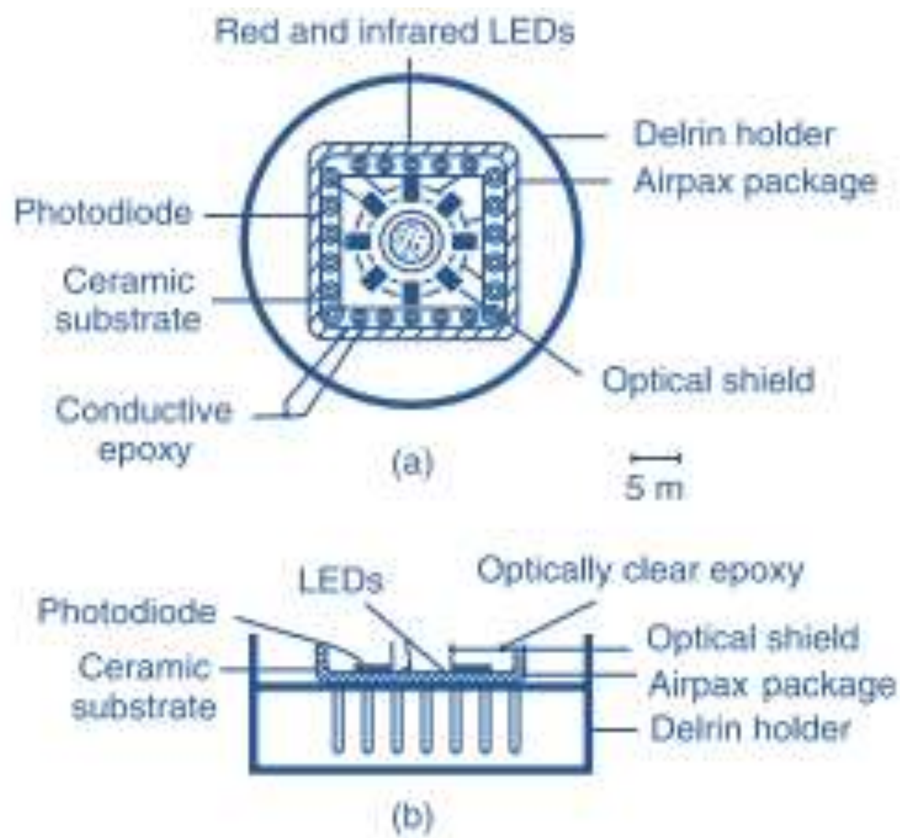
For infants, the pulse oximetry band is attached to their foot

Image Courtesy: https://www.hopkinsmedicalproducts.com/

SKIN REFLEECTANCE OXIMETERS

- Monitoring of **backscattered light** from living tissue in two wavelengths.
- **Backscattered light shows** blood’s relative oxygen saturation.

Schematic diagram of the reflectance oximeter sensor (Reference: Mendelson et al, 1988)



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Schematic diagram of the reflectance oximeter sensor…

- A pair of **red and infrared light emitting diodes is used as the light source**.
- Emission **wavelengths of 665 nm (red) and 935 nm (infrared)**.
- The **reflected light from the skin at these two wavelengths is detected by a silicon diode**.
- These detected signals are processed in the form of photo-plethysmographs to determine SO2.

INTRAVASCULAR OXIMETER

- Optical fibres used to guide the light signal inside the vessel & the reflected light from the red blood cells back to the light detector.

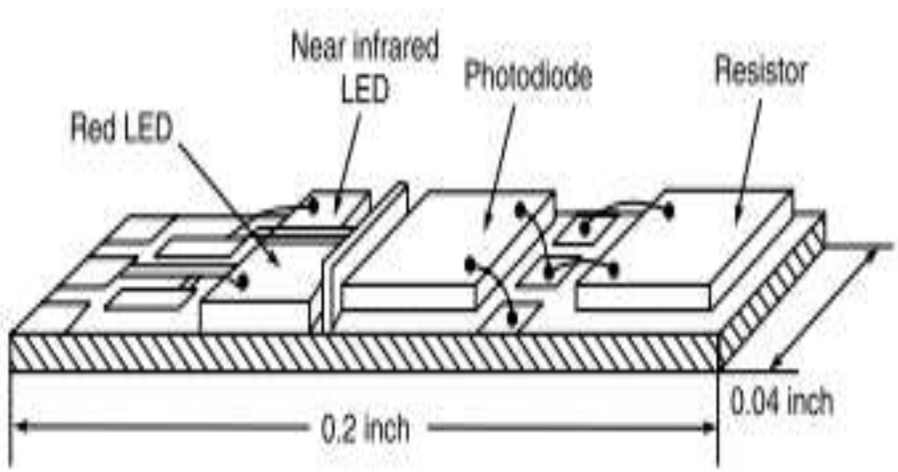
$$SO_2 = A + B\,(R\lambda_1 / R\lambda_2)$$

- where A and B are the constants that depend upon the fiber geometry and physiological parameters of blood.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Catheter-tip hybrid circuit oximeter for intravascular measurement

- One of the problems in fibre optic oximeters is **damage to optical fibers result in severe measurement error.**
- In order to overcome this, catheter tip type oximeters using hybrid type miniature sensors



INTRAVASCULAR OXIMETER- Applications

- Intravasacular oximeters are used to measure: Mixed venous saturation (from which the status of the circulatory system can be deduced).
- Mixed venous saturation varies in reflecting the changes of oxygen saturation, cardiac output, haemoglobin content and oxygen consumption.

BLOOD CELL COUNTERS

Types of Blood Cells

- **Red Blood Cells (Erythrocytes)**
- **White Blood Cells (Leucocytes)**
- **Platelets (Thrombocytes)**
- **Red blood cells, which carry oxygen.**
- **White blood cells, which fight infection.**
- **Platelets, which help with blood clotting**
- A **complete blood count (CBC)** is a blood test used to evaluate your overall health and detect a wide range of disorders, including anemia, infection and leukemia.

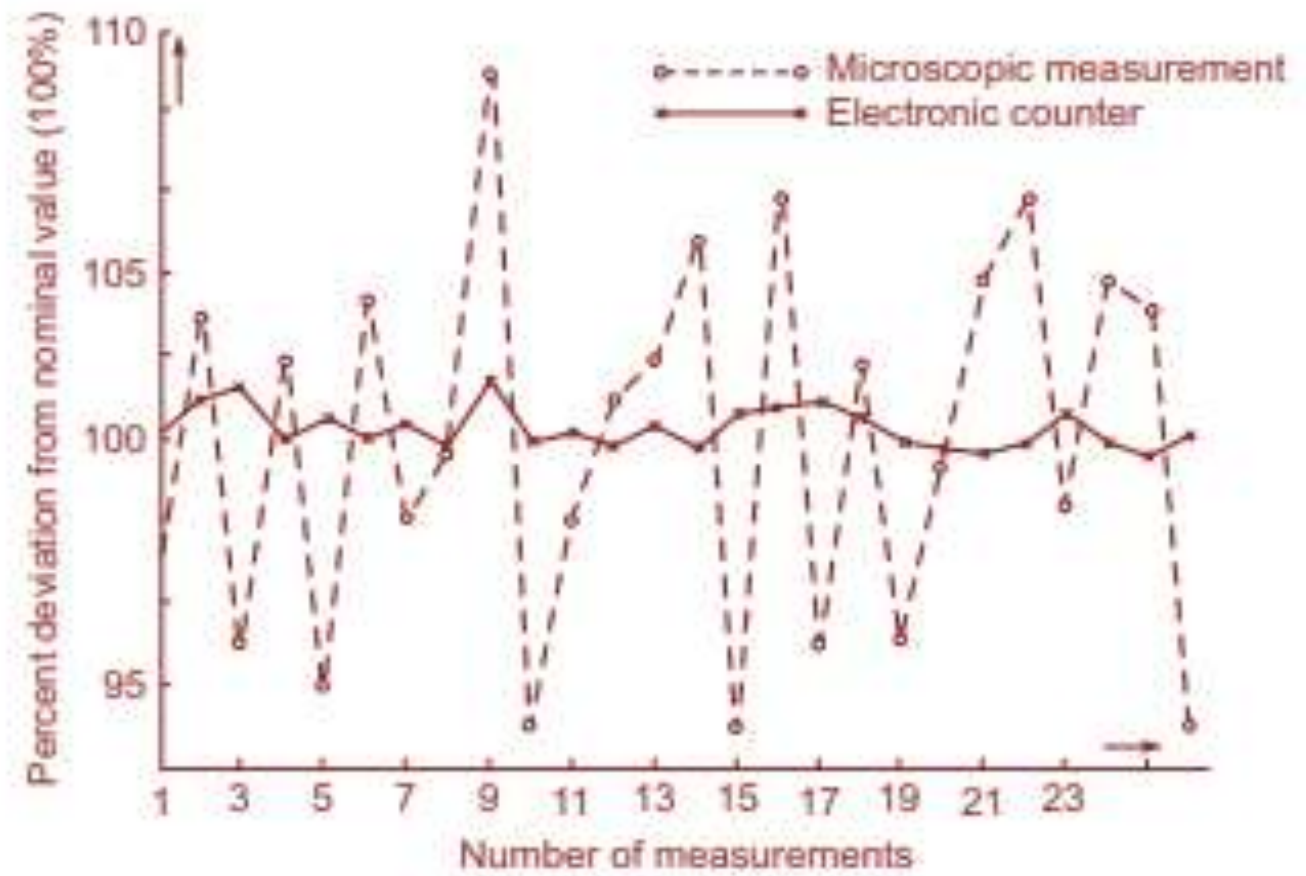
About Blood Cell Count

- The blood constitutes 5–10% of the total body weight.
- For an average adult, it amounts to 5–6 litres.
- Blood consists of corpuscles suspended in a fluid alled plasma in the proportion of 45 parts of corpuscles (cells) to 55 parts of plasma.
- The percentage of cells in the blood is called the haematocrit value or **packed cell volume** (PCV).
- **Mean Cell Volume (MCV)** is calculated from the PCV and the number of red cells present per litre of blood.
- **Mean Cell Haemoglobin (MCH)** is calculated from the Hb and red cell count.
- **Mean Cell Haemoglobin Concentration (MCHC)** It can be calculated if PCV and Hb per dl are known.
- **Mean Platelet Volume (MPV)** is the ratio of the integrated platelet volume to the platelet count and is expressed in femolitres.

Microscopic Method- Blood cell counter

- The diluted sample is visually examined and the cells counted.
- Commonly known as the counting chamber technique.
- Apart from the inherent system error(10%), an additional subjective error of ±10%.
- The lengthy procedure involved results in the rapid tiring of the person making the examination.

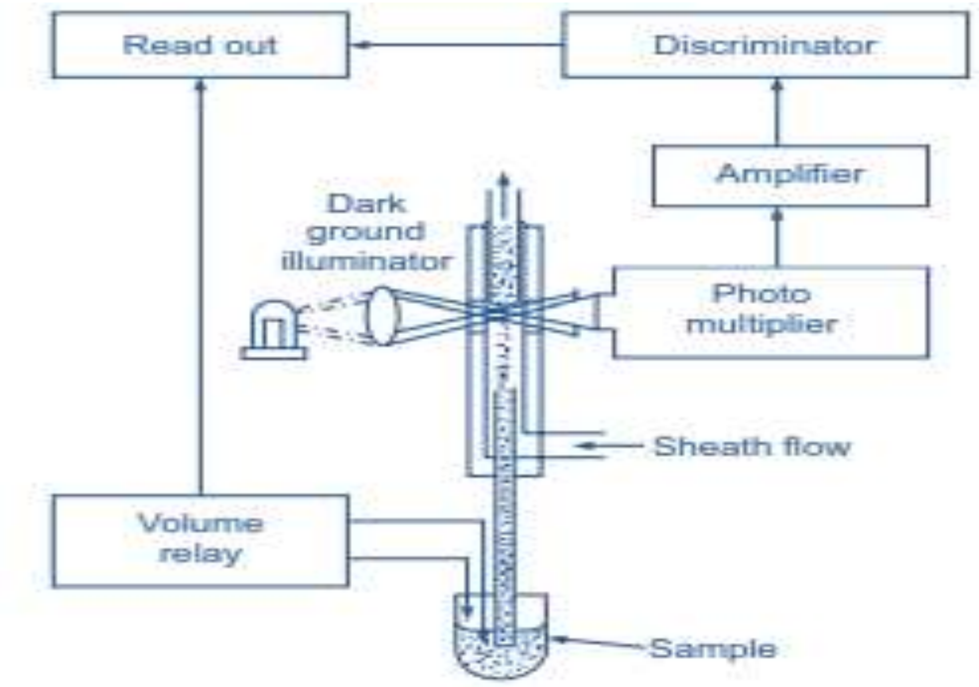
Comparison with Electronic Count



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Automatic Optical Method

- Collecting scattered light from the blood cells and converting it into electrical pulses for counting.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Automatic Optical Method..

- A sample of dilute blood (1:500 for white cells and 1:50,000 for red cells) is taken in a glass container.
- It is drawn through a counting chamber.
- A sample optical system provides a dark field illuminated zone on the stream and the light scattered in the forward direction is collected on the cathode of a photomultiplier tube.
- Pulses are produced in the photomultiplier tube corresponding to each cell.
- These signals are amplified in a high input impedance amplifier and fed to an adjustable amplitude discriminator.
- The discriminator provides pulses of equal amplitude, which are used to drive a digital display.
- This technique take about 30 s for completing the count.
- The instruments require about 1 ml of blood sample.

Electrical Conductivity Method

- **The principle of conductivity change.** (**Coulter principle**)
- **Blood is a poor conductor** of electricity whereas certain diluents are good conductors.
- For a cell count, therefore, blood is diluted and the suspension is drawn through a small orifice.
- By means of a constant current source, a direct current is maintained between two electrodes located on either side of the orifice.
- As a blood cell is carried through the orifice, it displaces some of the conductive fluid and increases the electrical resistance between the electrodes.
- A **voltage pulse of magnitude proportional to the particle volume is produced**.
- The resulting series of pulses are electronically amplified, scaled and displayed on a suitable display.

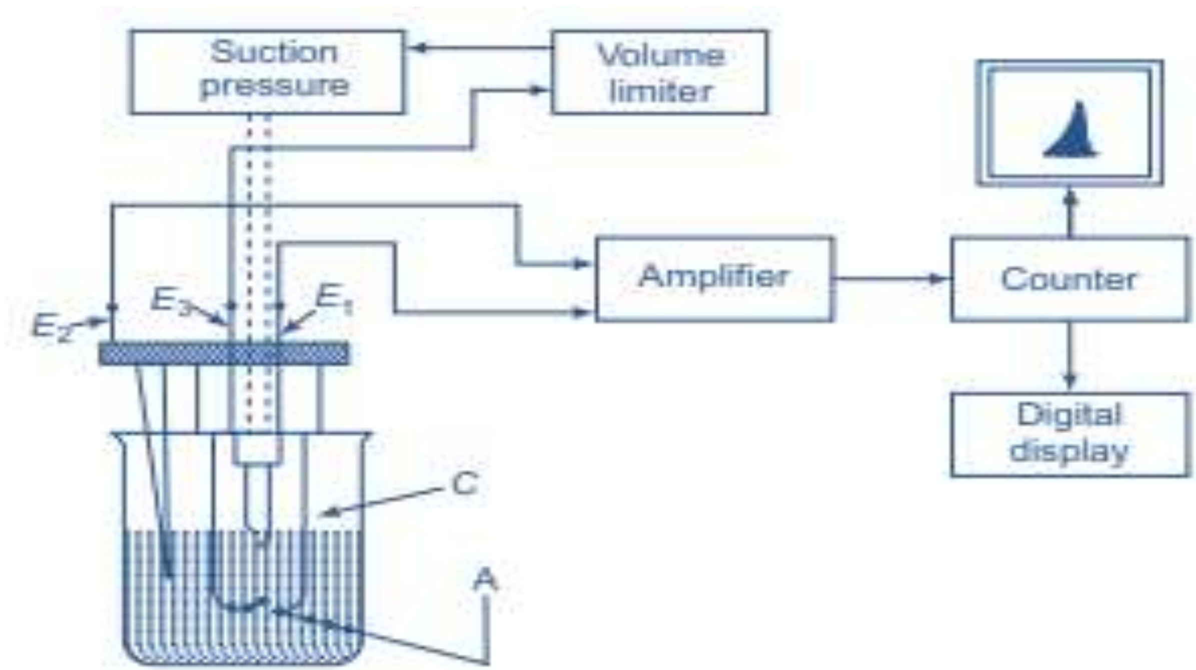
Electrical Conductivity Method..

- The instrument based on **Coulter principle** must follow the **Condition**
- **$D/50 \le d \le D/2$**
- d = maximum particle size
- D = diameter of the measuring aperture

COULTER COUNTERS

- These instruments range from the small counters (red & white cell counts) in very small hospitals and clinics to the multi-parameter microprocessor controlled instrument featuring fully automatic diluting of samples and printing of results.

Block diagram of blood cell Coulter counter



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of blood cell Coulter counter..

- A glass measuring tube C provided with an aperture ‘A’ is immersed into the suspension.
- The pressure difference created between the two sides of the aperture draws the suspension to flow through the aperture.
- A constant current is normally passed between the electrodes E1 and E2.
- The electric resistance of the liquid measured between these two electrodes changes rapidly when a particle having electric conductance differing from the conductance of the electrolyte passes through the aperture.
- This results in the generation of a voltage pulse, which is amplified in a preamplifier of high gain and low noise level.
- The output signal of this stage goes to a discriminator, which compares the amplitude of the pulse arriving at its input with the preset triggering level.
- If the input signal exceeds the triggering level, the discriminator gives out a pulse of constant shape and amplitude.
- These pulses go to a counting circuit for the display of the measured parameter.

Sample Calculation (Blood Cell count)

- The number of particles N in a unit volume is

$$N = \frac{HLE}{V}$$

where

H = factor of dilution

L = scaling factor of the counter

V = measured volume

E = result displayed on the digital display.

Example: if the diluting factor is 63,000 (typical for red cell count in this instrument) and 520 appears on the display; L being 60, and V equal to 0.378 cm3 , then N is:

$$N = \frac{(6.3 \times 10^4)(60)(5.20 \times 10^2}{(3.78 \times 10^2)}$$

$$= 5.20 \times 10^6 \text{ per mm}^3$$

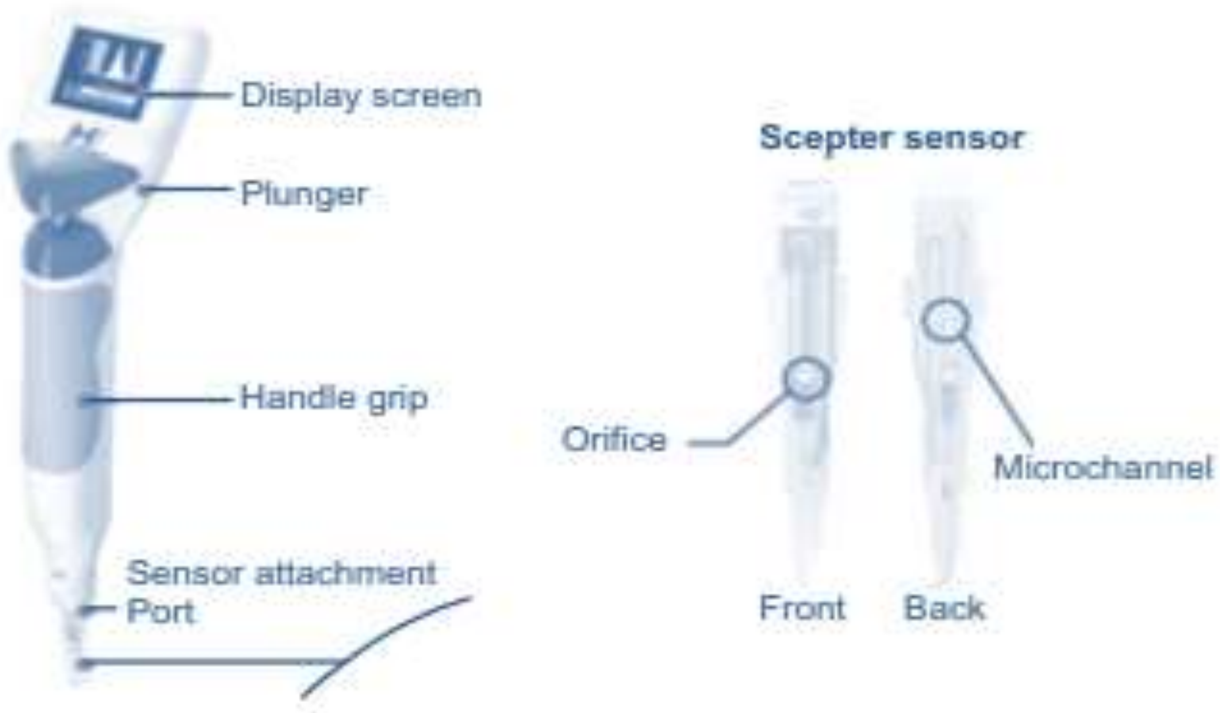
5.2 million blood cells per cubic millimetre

Errors in Electronic Counters

- Aperture errors
- Uncertainty of Discriminator Threshold
- Coincidence Error
- Settling Error
- Statistical Error
- Error in Sample Volume
- Error due to Temperature Variation
- Biological Factors
- Dilution Errors
- Error due to External Disturbances

PORTABLE COULTER COUNTERS

- Handheld automated blood cell counter (Image Courtesy : M/s Millipore)



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

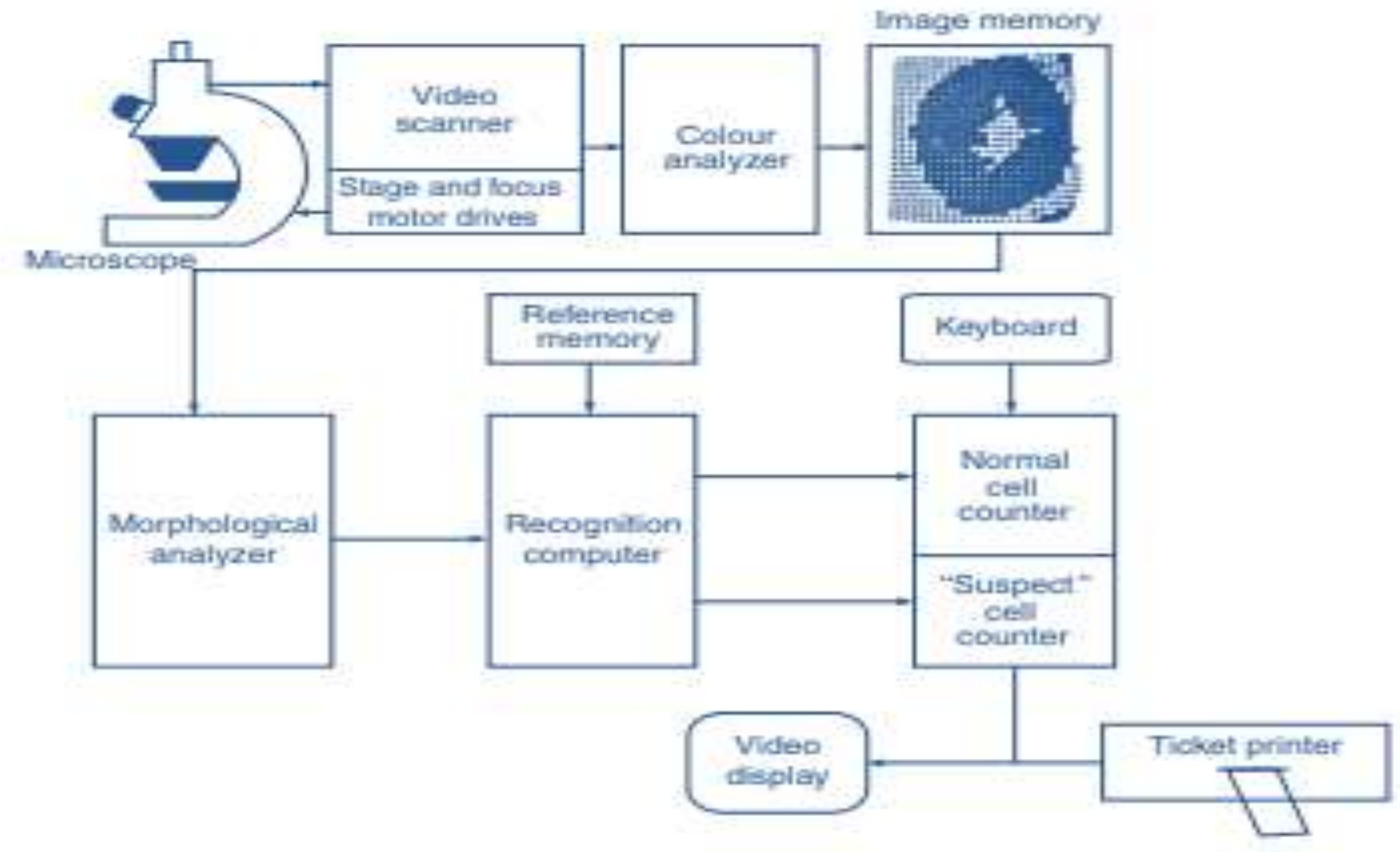
Handheld automated blood cell counter…..

- When Cells flow through the aperture in the sensor, resistance increases.
- The increase in resistance causes a subsequent increase in voltage
- voltage changes are recorded as spikes with each passing cell.
- Spikes of the same size are bucketed into a histogram and counted.
- This histogram gives you quantitative data on cell morphology that can be used to examine the quality and health of your cell culture.

Handheld automated blood cell counter…….

- The cell counter's screen displays:
- Cell concentration
- Average cell size
- Average cell volume
- Histogram of size or volume distribution
- Precise volumes are drawn into the Scepter sensor

AUTOMATIC RECOGNITION AND DIFFERENTIAL COUNTING OF CELLS



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Diff-3 System

- The diff3 was named for differentiating the three major groups of blood cells circulating throughout the body.
- **This technique was Developed by** M/s Perkin-Elmer, USA.
- The system electronically examines conventional microscope blood smear slides and employs optical pattern recognition techniques to achieve the following:
- Counts and differentiates seven important categories of red blood cells (erythrocytes); three based on size, two on colour, one on shape and one covering red cells with nucleii (nucleated red cells).
- Enumerates white blood cells (leucocytes) and differentially classifies them into the 10 most significant medical categories and estimates their total number.
- Surveys platelets (thrombocytes) cell size and sufficiency.

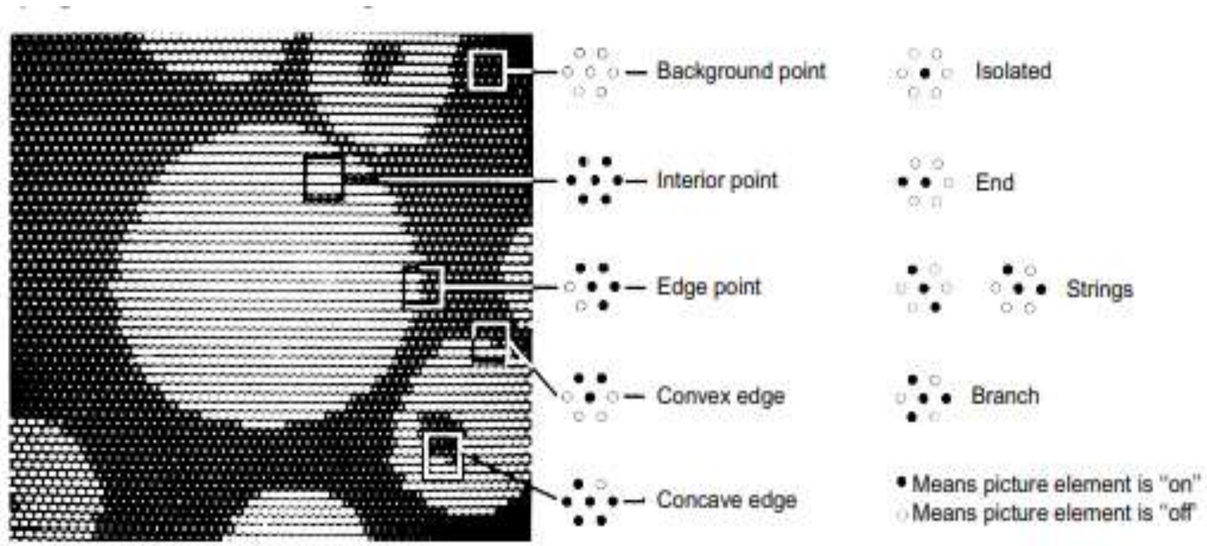
Diff-3 System..

- **Image Processor:** The system uses two computers.
- **A general purpose computer** operates and controls the system.
- The second computer is a special purpose pattern recognition computer (the Golay Logic Processor (Golay, 1969)) which enables the system to transform cell pattern recognition information into differential results.
- It enables the system to ‘see’ a cell in much the same way as a technologist does.
- Image recognition is performed.

Image of a band neutrophil and surrounding red cells as stored in video picture memory

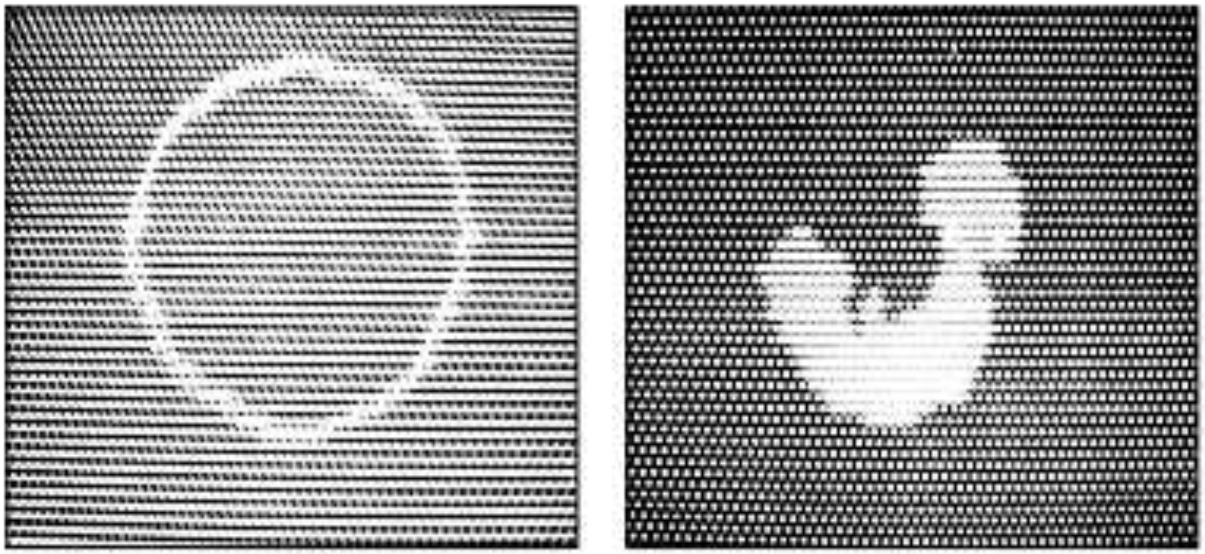
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Examples of points identified by the logic processor



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Examples of points identified by the logic processor



(a) (b)

(a) Outline of whole cell made by turning on only edge points in picture of the whole cell. (b) Picture of the nucleus generated by turning on only interior points of the necleus

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

END OF UNIT I

Biomedical Instrumentation

(U18PCEC603)

UNIT II
ELECTRO-PHYSIOLOGY AND BIO-POTENTIAL RECORDING

Topics

- The origin of Bio-potentials
- Bio-potential electrodes
- Biological amplifiers
- ECG
- EEG
- EMG
- PCG
- EOG
- Lead systems and recording methods
- Typical waveforms and signal characteristics

ORIGIN OF BIO-POTENTIALS

Introduction

- 18th century: Galvani demonstrated that most of the physiological processes were accompanied with electrical changes.
- The **action of living tissues in terms of bioelectric potentials**.
- The **human body**, which is composed of living tissues, can be considered **as a power station** generating **multiple electrical signals** with two internal sources: muscles & nerves.
- **Muscular contraction** is associated with the **migration of ions** which generates **potential differences** measurable with **suitably placed electrodes**.

Introduction

- Heart and the brain produce characteristic patterns of voltage variations which when recorded and analyzed are useful in both clinical practice and research.
- Potential differences are also generated by the electrochemical changes accompanied with the conduction of signals along the nerves to or from the brain.
- These signals are in few **microvolts** and give rise to a complicated pattern of electrical activity when recorded.
- **Bioelectric potentials are generated at a cellular level and the source of these potentials is ionic in nature**.

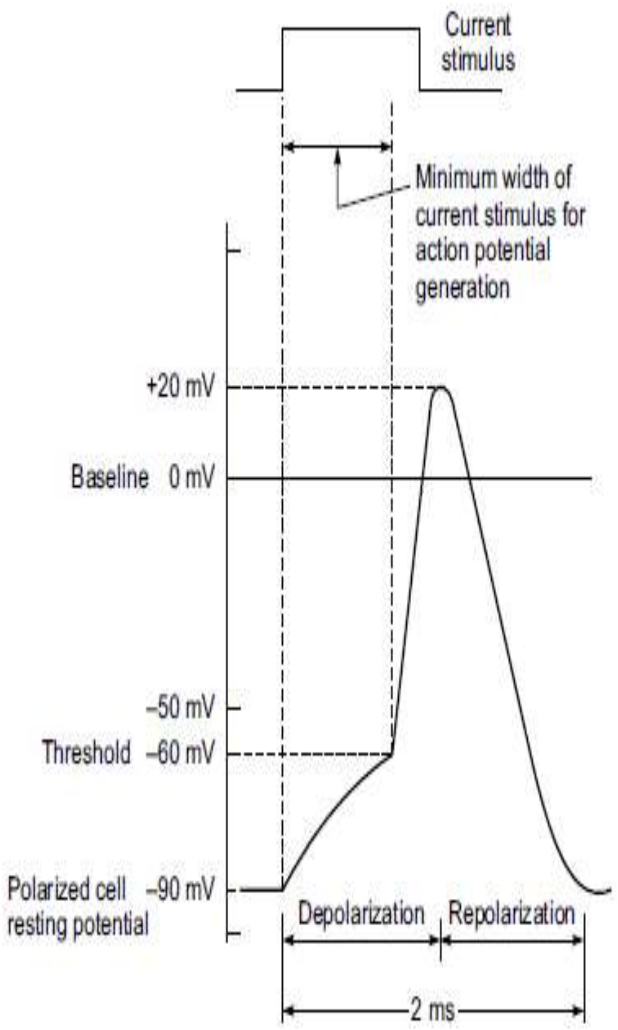
Introduction

- All **living matter is composed of cells** of different types.
- Human cells may vary from **1 micron to 100 microns in diameter**, from **1 mm to 1 m in length**, and membrane **thickness of 0.01 micron**.
- **Surrounding** the cells of the body are **body fluids (**conducting medium for electric potentials).
- **Principal ions producing cell potentials** are **sodium (Na^+), potassium (K^+) and chloride (Cl^-)**.
- Membrane of excitable cells **permits the K^+ and Cl^-** but **obstruct the flow of Na^+.**
- Hence**, concentration of the sodium ion more on the outside** of the cell membrane than on the inside.
- **sodium is a positive ion**, in its resting state, a cell has a **negative charge along the inner surface** of its membrane and a **positive charge along the outer portion**.

Introduction

- The unequal charge distribution resulting certain electrochemical reactions /processes within the living cell & the potential due to this is called the **resting potential**.
- The **cell in this condition is called as polarized**.
- A decrease in this resting membrane potential difference is called depolarization.
- Due to this **distribution of positively charged ions on the outer surface** & **negatively charged ions inside the cell** membrane **results in the difference of potential across it** & the **cell becomes a tiny biological battery.**

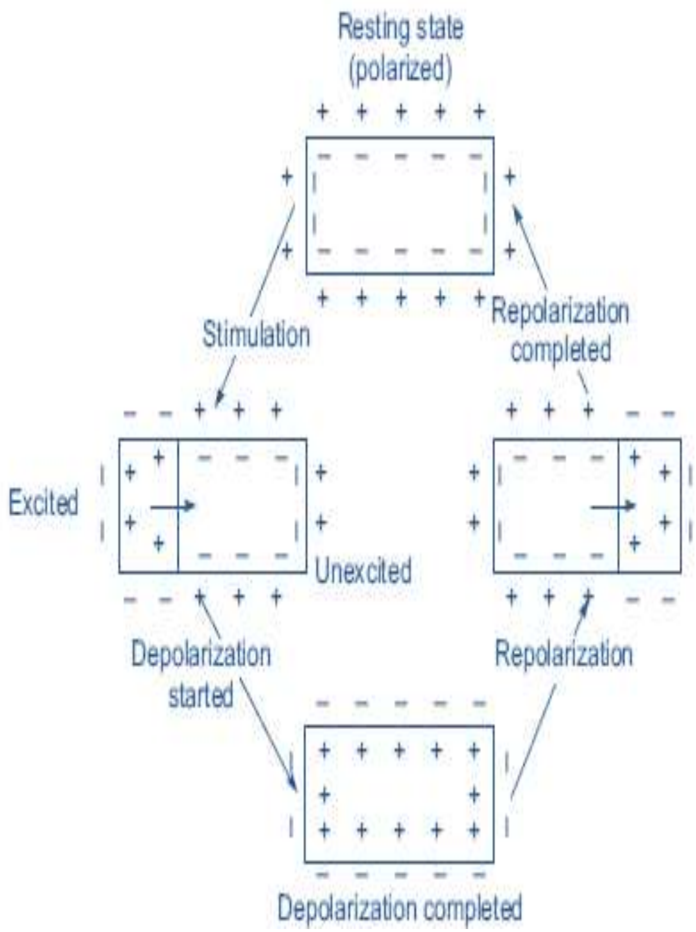
Typical cell potential waveform



- The internal resting potential within a cell is approx.–90 mV with reference to the outside of the cell.
- When the cell is excited or stimulated, the outer side of the cell membrane becomes momentarily negative with respect to the interior.
- This process is called depolarization and the cell potential changes to approximately +20 mV.
- Repolarization takes place a short time later when the cell regains its normal state in which the inside of the membrane is again negative with respect to the outside.
- Repolarization is necessary in order to re-establish the resting potential.
- This discharging and recharging of the cell produces the voltage waveforms which can be recorded by suitable methods using microelectrodes.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electrical activity associated with one contraction in a muscle



- contraction (movement) of a muscle results in the production of an electric voltage.
- Moving muscle section is always negative with respect to its surroundings.
- These voltages are called action potentials because they are generated by the action of the muscles.
- After complete contraction, repolarization takes place resulting in the relaxation of the muscle and its returning to the original state.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electrical activity associated with one contraction in a muscle

- Bioelectric currents are due to positive and negative ion movement within a conductive fluid.
- The ions possess finite mass and encounter resistance to movement within the fluid for they have limited speeds.
- The cell action potential shows a finite rise time and fall time.
- Unless a stimulus above a certain minimum value is applied, the cell will not be depolarized and no action potential is generated. This is known as the stimulus threshold.
- After a cell is stimulated, a finite period of time is required for the cell to return to its pre-stimulus state. This period is known as refractory period

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Bioelectric Signals

Parameter	*Primary signal characteristics*	*Transducer required*
Electrocardiography (ECG)	Frequency range: 0.05 to 120 Hz Signal amplitude: 0.1 – 5 mV Typical signal: 1 mV	Surface electrodes
Electroencephalograph (EEG)	Frequency range: 0.1 to 50 Hz Signal amplitude: 2 – 200 µV Typical signal: 50 µV	Scalp electrodes
Electromyography (EMG)	Frequency range: 5 to 2000 Hz Signal amplitude: 0.05 to 5 mV	Needle electrodes
Electroretinography (ERG)	Frequency range: dc to 20 Hz Signal amplitude: 0.5 µV to 1 mV Typical signal: 0.5 mV	Contact electrodes
Electrooculography (EOG)	Frequency range: dc to 100 Hz Signal amplitude: 10 to 3500 µV Typical signal: 0.5 mV	Contact electrodes

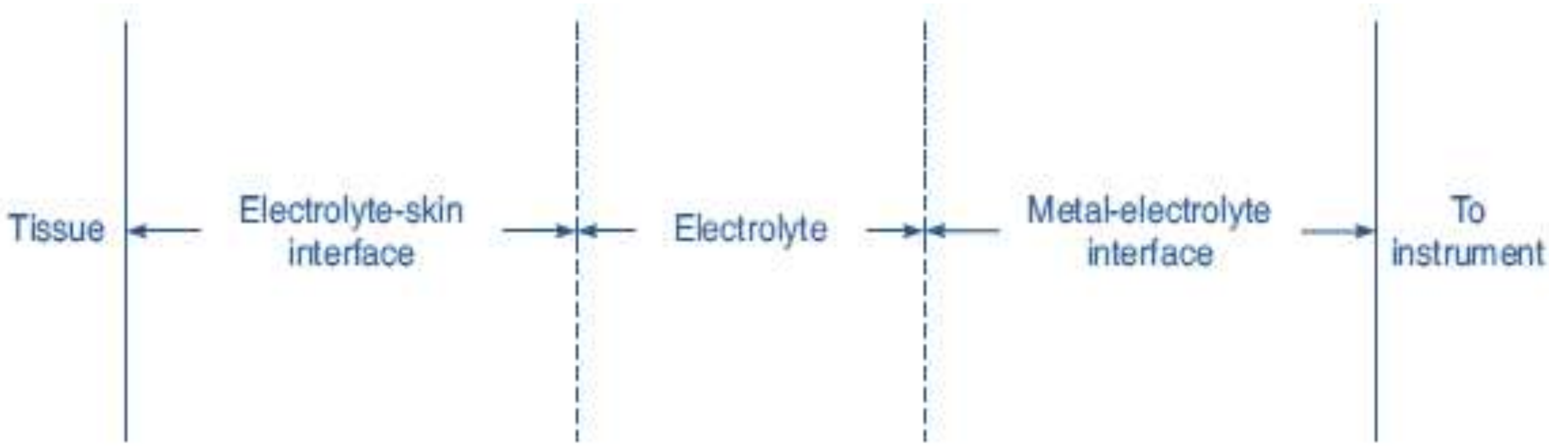
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

BIO-POTENTIAL ELECTRODES

Bio-potential Electrodes

- Bioelectric events captured from the surface of the body using electrodes.
- Electrodes transfer from the ionic conduction in the tissue to the electronic conduction.
- Two types of electrodes are used in practice-(i) surface electrodes (ii) Deep-seated electrodes.
- Surface electrodes picked up the potential difference from the tissue surface without damaging the live tissue.
- Deep-seated electrodes indicate the electric potential difference arising inside the live tissue or cell.

Electrode-Tissue Interface

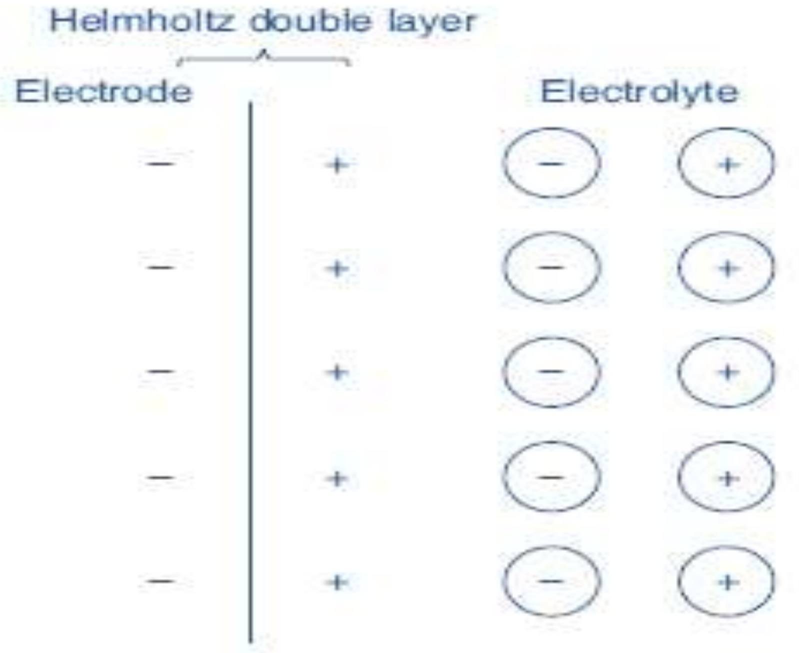


The characteristic of a **surface electrode composed of a metal electrode** and attached to the surface of the body through an electrolyte (electrode jelly) are dependent upon the conditions at the metal-electrolyte interface, the electrolyte-skin interface and the quality of the electrolyte.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

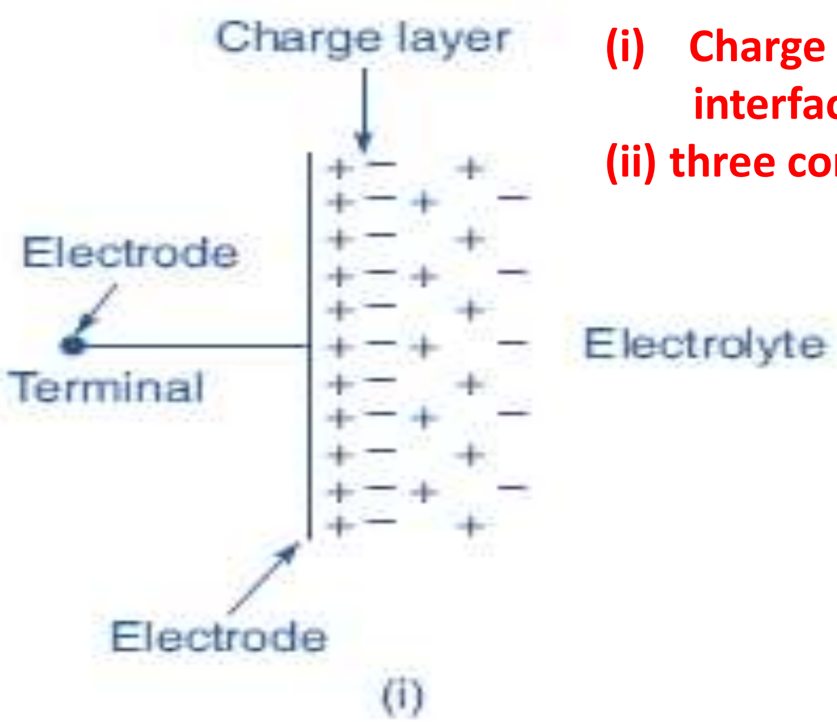
Electrode-Tissue Interface…

- **The electrode tissue interface circuit involves transfer of electrons from the metal phase to an ionic carrier in the electrolyte, a charge double layer (capacitance) forms at the interface.**

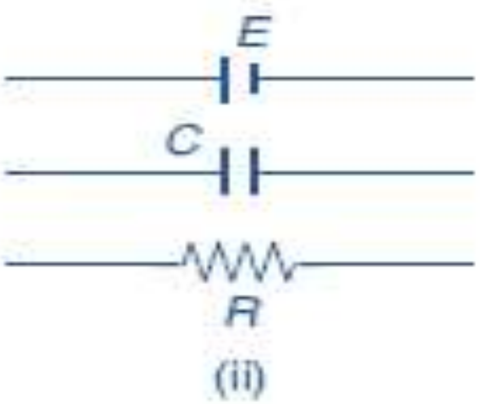


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Metal-Electrolyte Interface



(i) Charge distribution at electrode-electrolyte interface
(ii) three components representing the interface



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electrode Potentials of Some Metals with Respect to Hydrogen

Metal	*Ionic symbol*	*Electrode potential*
Aluminium	Al^{+++}	–1.66 V
Iron	Fe^{++}	–0.44 V
Lead	Pb^{++}	–0.12 V
Hydrogen	H^{+}	0
Copper	C^{++}	+0.34 V
Silver	Ag^{+}	+0.80 V
Platinum	Pt^{+}	+1.2 V
Gold	Au^{+}	+1.69 V

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

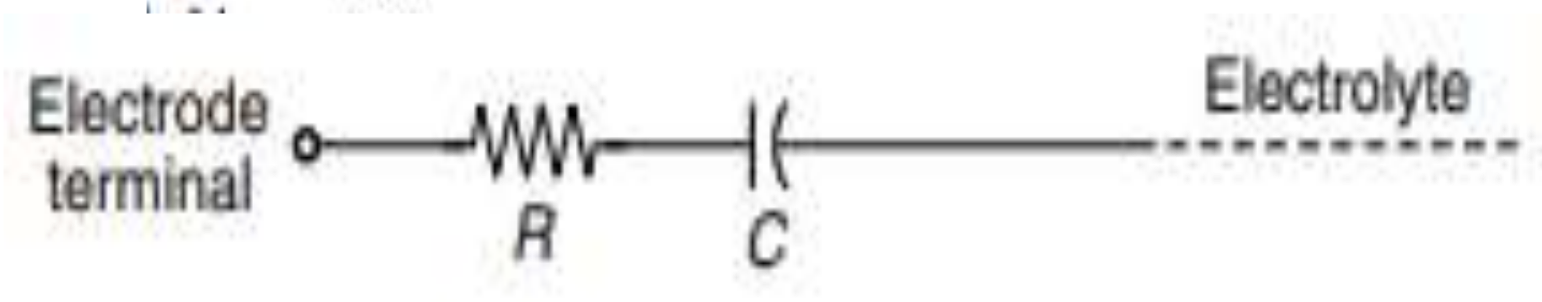
Potential between Electrodes in Electrolytes (Reference: Geddes and Baker, 1975)

Electrode metal	*Electrolyte*	*Potential difference between electrodes*
Stainless steel	Saline	10 mV
Silver	Saline	94 mV
Silver-silver chloride	Saline	2.5 mV
Silver-silver chloride(11 mm disc)	ECG paste	0.47 mV
Silver-silver chloride (sponge)	ECG paste	0.2 mV

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Warburg equivalent for an electrode-electrolyte interface

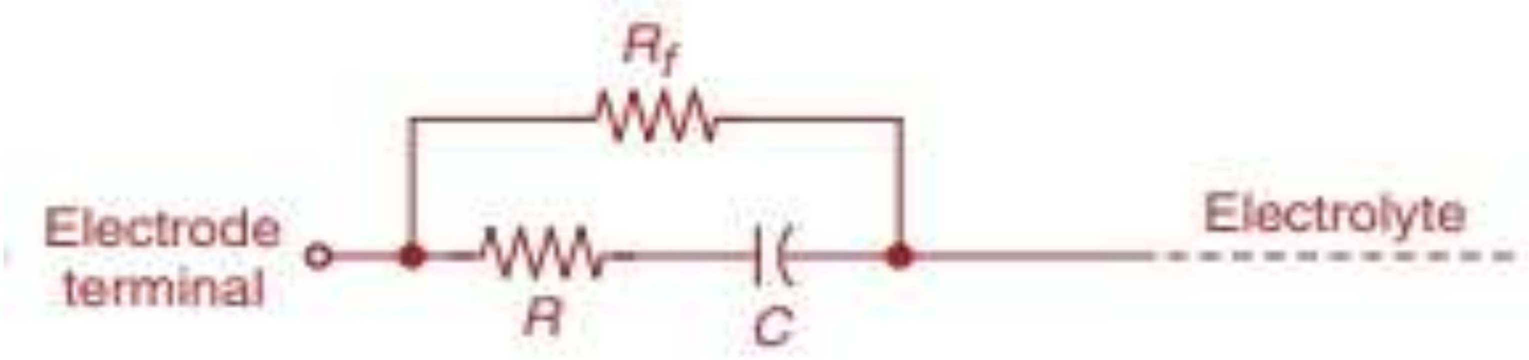
- Warburg (1899) discovered that a **single electrode/electrolyte interface** can be **represented by a series capacitance C and resistance R.**
- C & R are unlike real capacitors , resistors (their values are frequency and current density dependent).
- These components are called the **polarization capacitance and resistance**.
- low current density, the reactance X of C equals R; both varied almost inversely as the square root of frequency
- $R = X = k/\sqrt{f}$, where k is a constant.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Warburg equivalent…

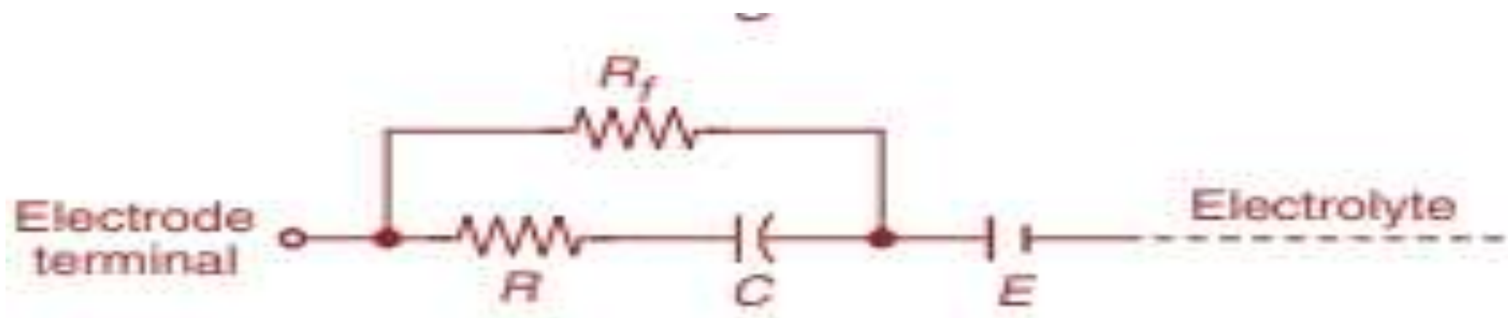
- In Warburg CKT, RC equivalent not adequately represent the behaviour of an electrode/electrolyte interface as this equivalent does not truly account for the very low-frequency behaviour of the interface.
- Therefore, a resistance R_f placed in parallel with the Warburg equivalent.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Warburg equivalent...

- To complete the equivalent circuit of an electrode/electrolyte interface, it is necessary to add the **half-cell potential E**.
- This is the **potential developed at the electrode/electrolyte interface**.
- The **value of E depends on the species of metal and the type of electrolyte, its concentration and temperature**.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

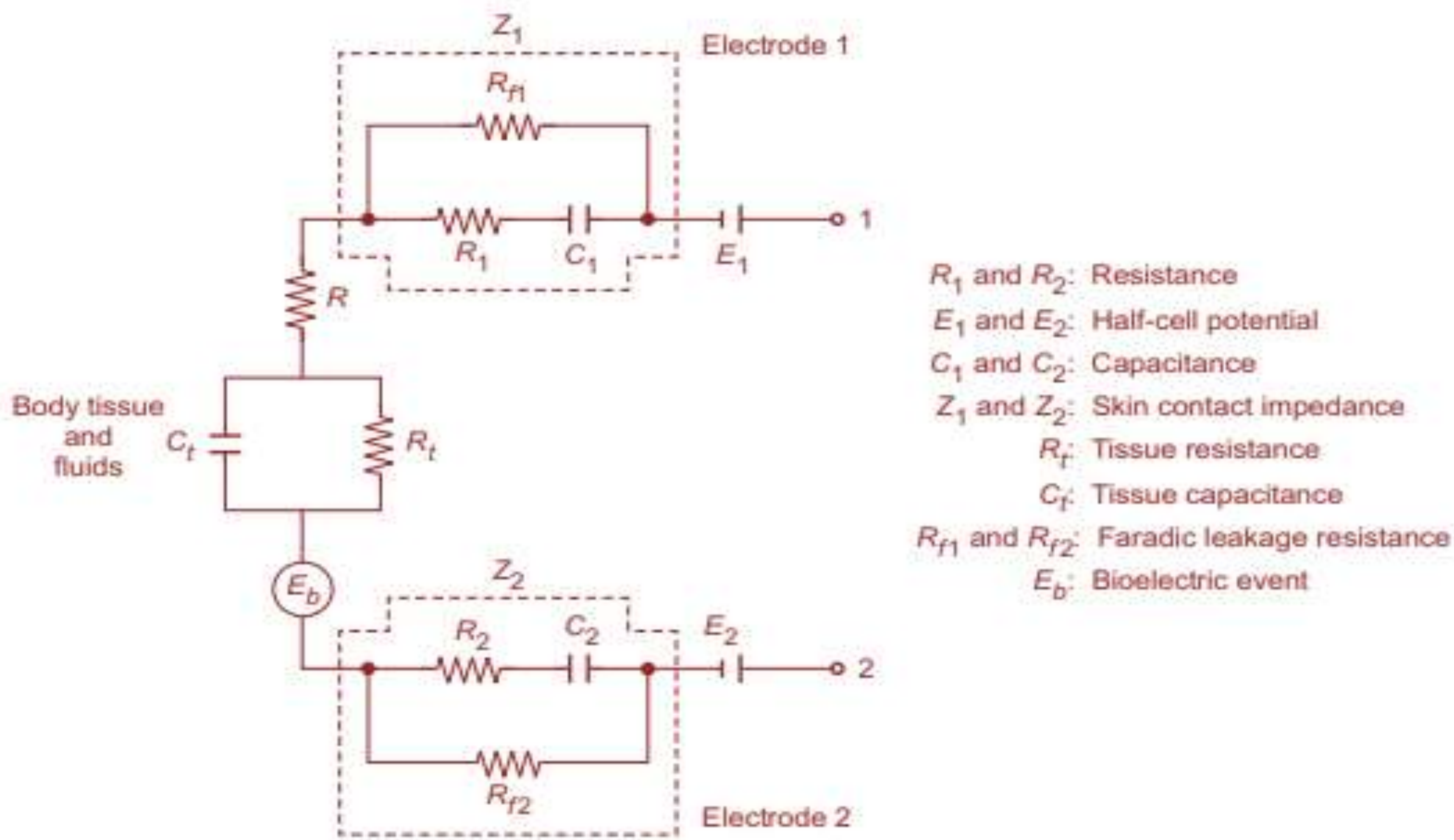
Electrolyte-Skin Interface

- Skin acts as a diaphragm between two solutions (electrolyte & body fluids) of different concentrations containing the same ions, which is bound to give potential differences.
- Equivalent representation be as a voltage source in series with a parallel combination of a capacitance and resistance.
- The capacitance represents the charge developed at the phase boundary whereas the resistance depends upon the conditions associated with ion-migration along the phase boundaries and inside the diaphragm.
- These voltages are called contact potentials.

Electrolyte-Skin Interface

- The electrical equivalent circuit of the surface electrode suggests that the **voltage presented to the measuring instrument from the electrode** consists of **two main components**.
- One is **the contact potential** & **the other is the biological signal of interest**.
- The **contact potential** is found to be a function of the type of **skin, skin preparation and composition of the electrolyte.**

Equivalent circuit for a pair of electrodes (1, 2) on a subject represented by R, R_t , C_t . Embedded in the subject is a bioelectric generator E_b



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

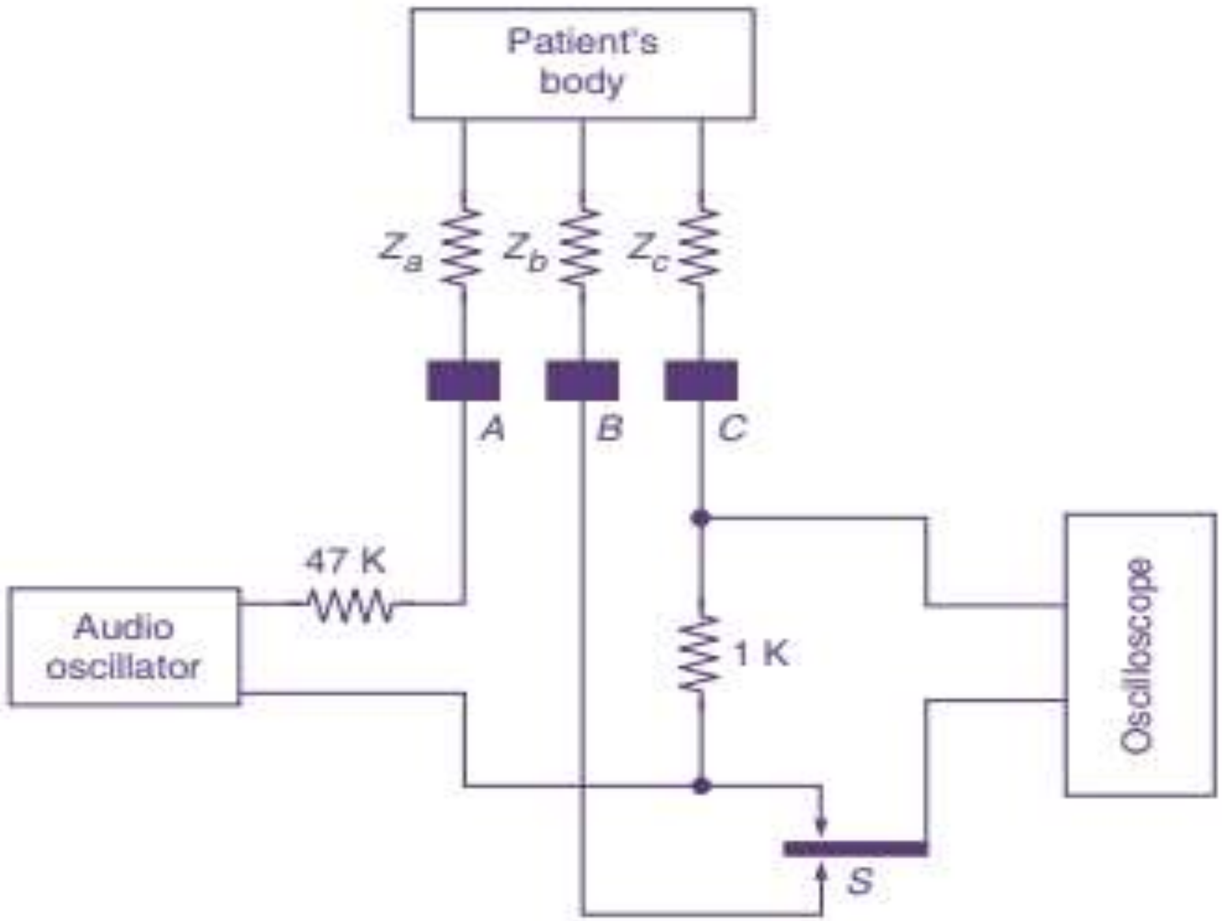
Polarization

- If low voltage is applied to two electrodes placed in a solution, the electrical double layers are disturbed.
- Depending on the metals constituting the electrodes, a steady flow of current may or may not take place.
- In some metal/liquid interfaces, the electrical double layer gets temporarily disturbed by the externally applied voltage ,and a very small current flows after the first surge, thus indicating a high resistance.
- This type of electrode will not permit the measurement of steady or slowly varying potentials in the tissues.
- They are said to, be polarized or nonreversible.

Skin Contact Impedance

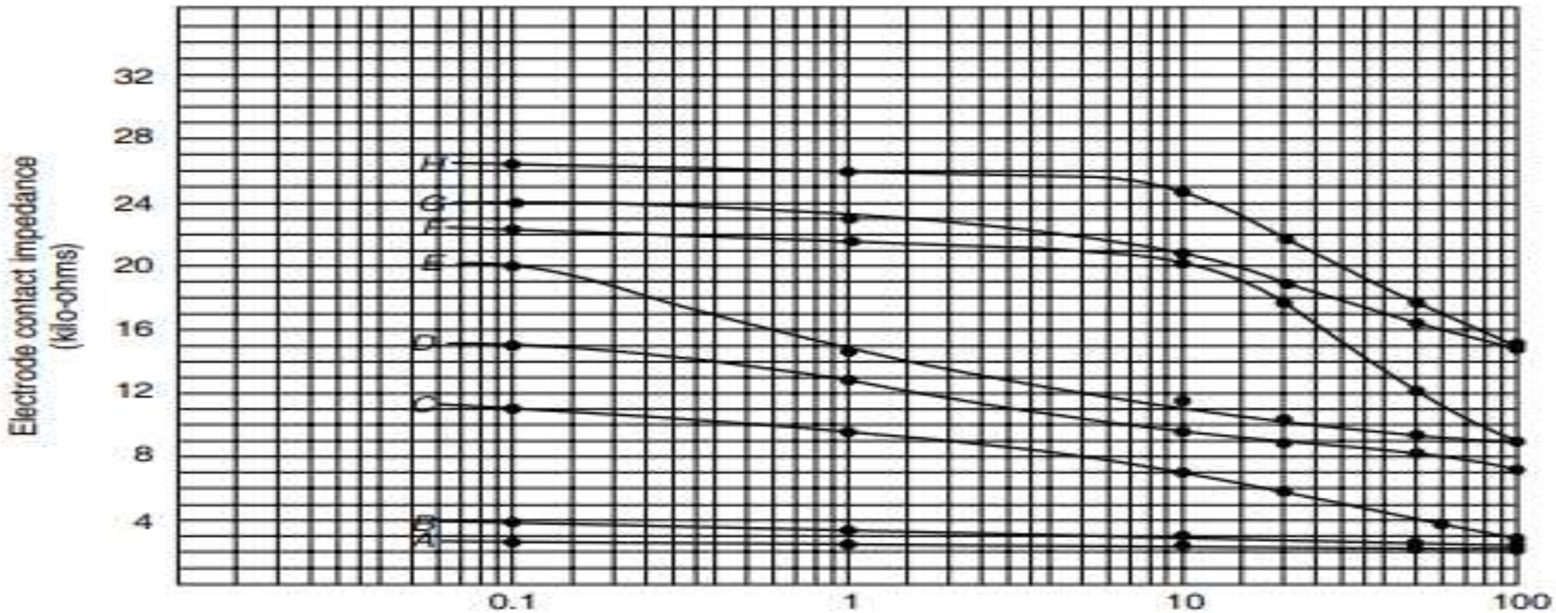
- Impedance at the electrode-skin junction comes in the overall circuitry of the recording machine and, therefore, has significant effect on the final record.
- Skin electrode impedance is known as the contact impedance and is of a value much greater than the electrical impedance of the body tissue as measured beneath the skin.

Arrangement for measurement of electrode skin-contact impedance for surface electrodes



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Electrode skin-contact impedance versus signal frequency for different types of electrodes



A Plastic cup self-adhesive electrodes (Boter *et al.*, 1966)
B Metal plate limb electrodes used with conducting jelly
C Metal plate electrodes used with conducting plastic (Jenkner, 1967)
D Dry multi-point limb electrodes (Lewes, 1966)
E Dry multi-point suction chest electrodes
F Self-adhesive multi-point chest electrodes used with conducting jelly
G Self-adhesive gauze electrodes
H Self-adhesive dry multi-point chest electrodes (Lewes and Hill, 1967)

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Motion Artefacts

- **Motion artifact** is a patient-based **artifact** that occurs with voluntary or involuntary patient **movement** during data acquisition.
- The problem is greatest in cardiac stress laboratories where the exercise ECG is recorded.
- The problem is also serious in coronary care units where patients are monitored for relatively longer periods.
- Motion of the subject under measurement creates artefacts which may even mask the desired signal or cause an abrupt shift in the baseline.
- These artefacts may result in a display being unreadable, a recording instrument exceeding its range, a computer yielding incorrect output or a false alarm being triggered by the monitoring device.

BIOLOGICAL AMPLIFIERS

Biological Amplifiers

What is Bio Amplifiers or Biomedical Amplifiers?

- Biological/bioelectric signals have low amplitude.
- To increase the amplitude level of biosignals amplifiers are designed.
- Outputs from these amplifiers are used for further analysis and they appeared as ECG, EMG, any bioelectric waveforms.

Biological Amplifiers..

Basic Requirements

- **Biological amplifier** should have a **high input impedance** (2 MΩ to10 MΩ) to reduce distortion of the signal.
- Bio-amplifier should have a **small output impedance**.
- Bio-amplifier should consist of **isolation and protection circuits**, to prevent the patients from electrical shocks.
- The **voltage gain** value of the amplifier should be **higher than 100dB**.
- Good bio-amplifier should be free from drift and noise.
- **Common Mode Rejection Ratio (CMRR)** of amplifier should be greater than 80dB to reduce the interference from common mode signal.
- The gain of the bio-amplifier should be calibrated for each measurement.

Biological Amplifiers..

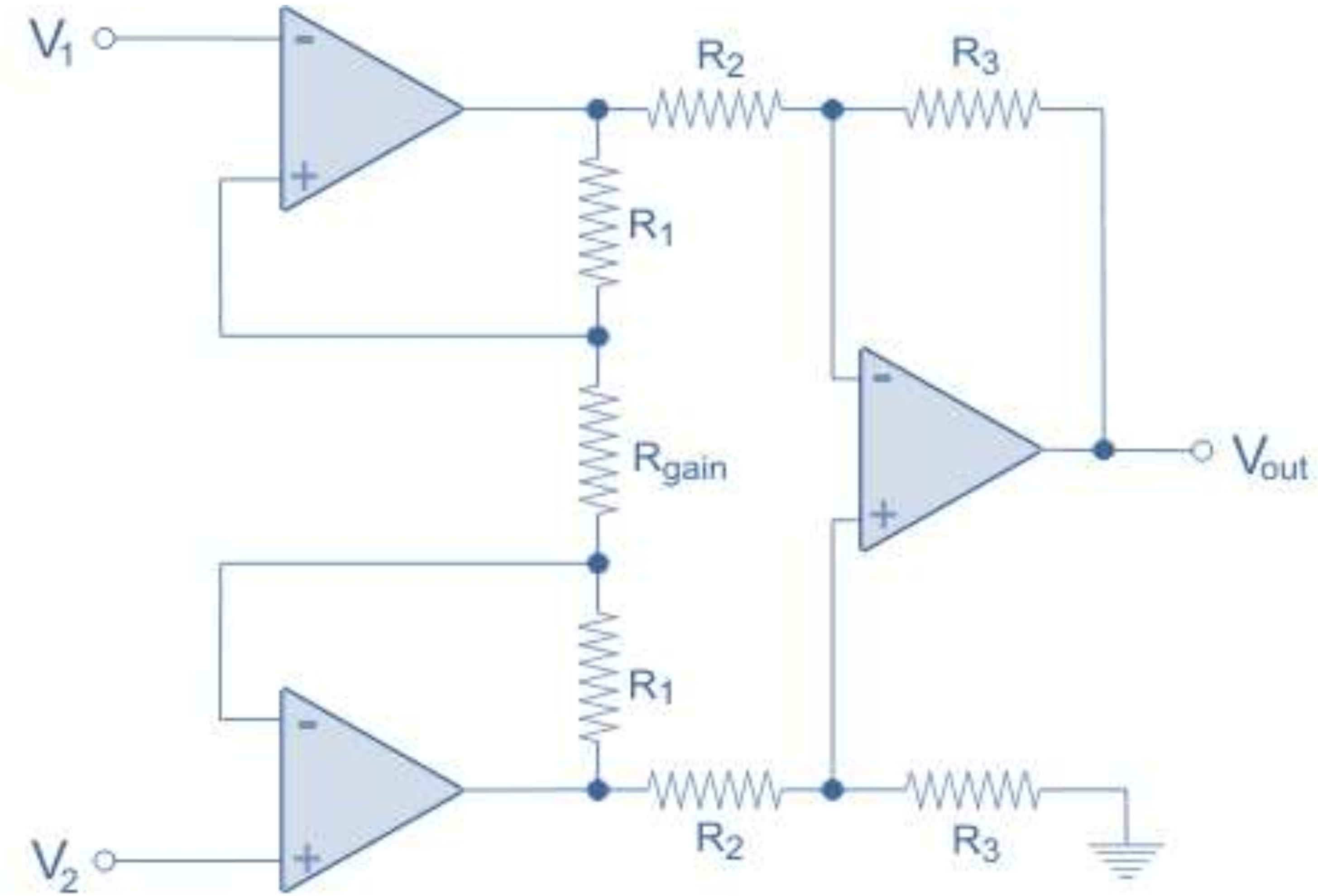
Types of Bio Amplifiers

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

Instrumentation Amplifier

- In biomedical applications, high gain and the high input impedance are attained with an instrumentation amplifier.
- a 3-amplifier setup forms the instrumentation amplifier circuit.
- The output from the transducer is given as input to the instrumentation amplifier.
- Before the signal goes to the next stage, a special amplifier is required with high CMRR, high input impedance and to avoid loading effects.
- This special amplifier is an instrumentation amplifier, which does all the required process.

Instrumentation Amplifier



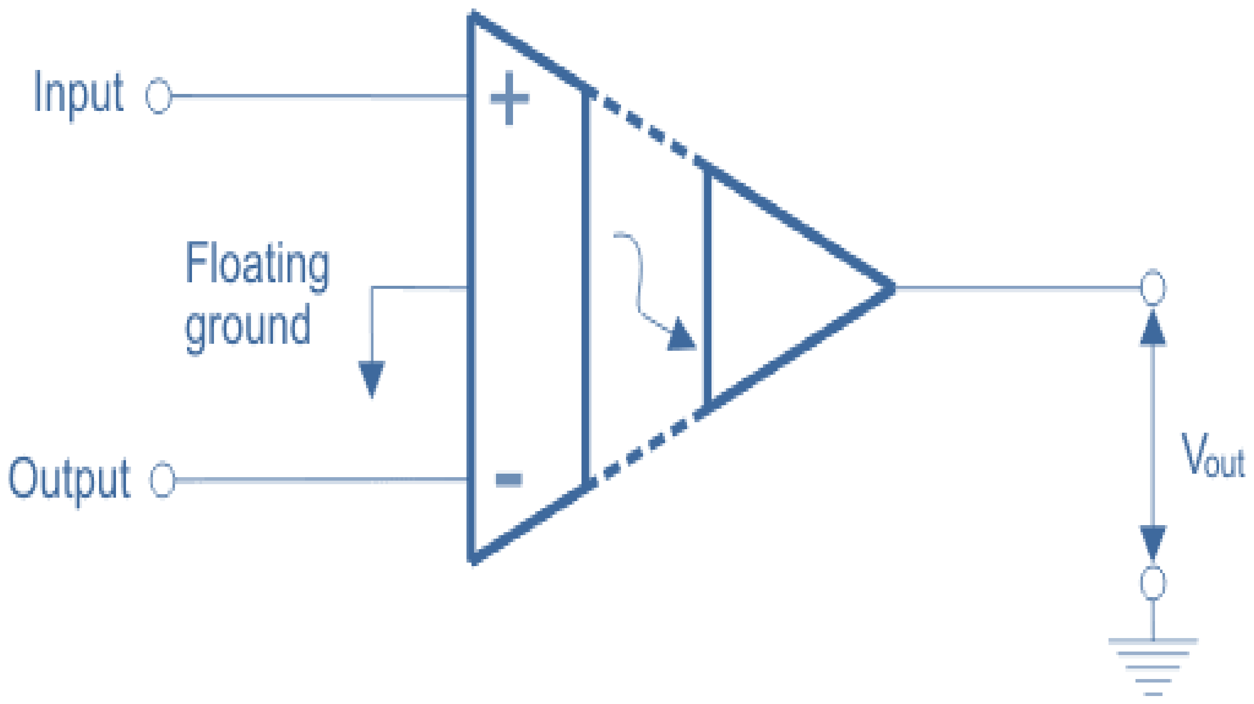
Instrumentation Amplifier

- To each input of the differential amplifier, the non-inverting amplifier is connected.
- In figure, the amplifier on the left side acts as non-inverting amplifiers.
- They combined together to form the input stage of the instrumentation amplifier.
- The third op-amp is the difference amplifier, and it is the output of the instrumentation amplifier.
- The output from the difference amplifier V_{out} is the difference between two input signals given at the input points.
- V_{O1} is the output from op-amp 1 and V_{O2} is the output from op-amp 2.

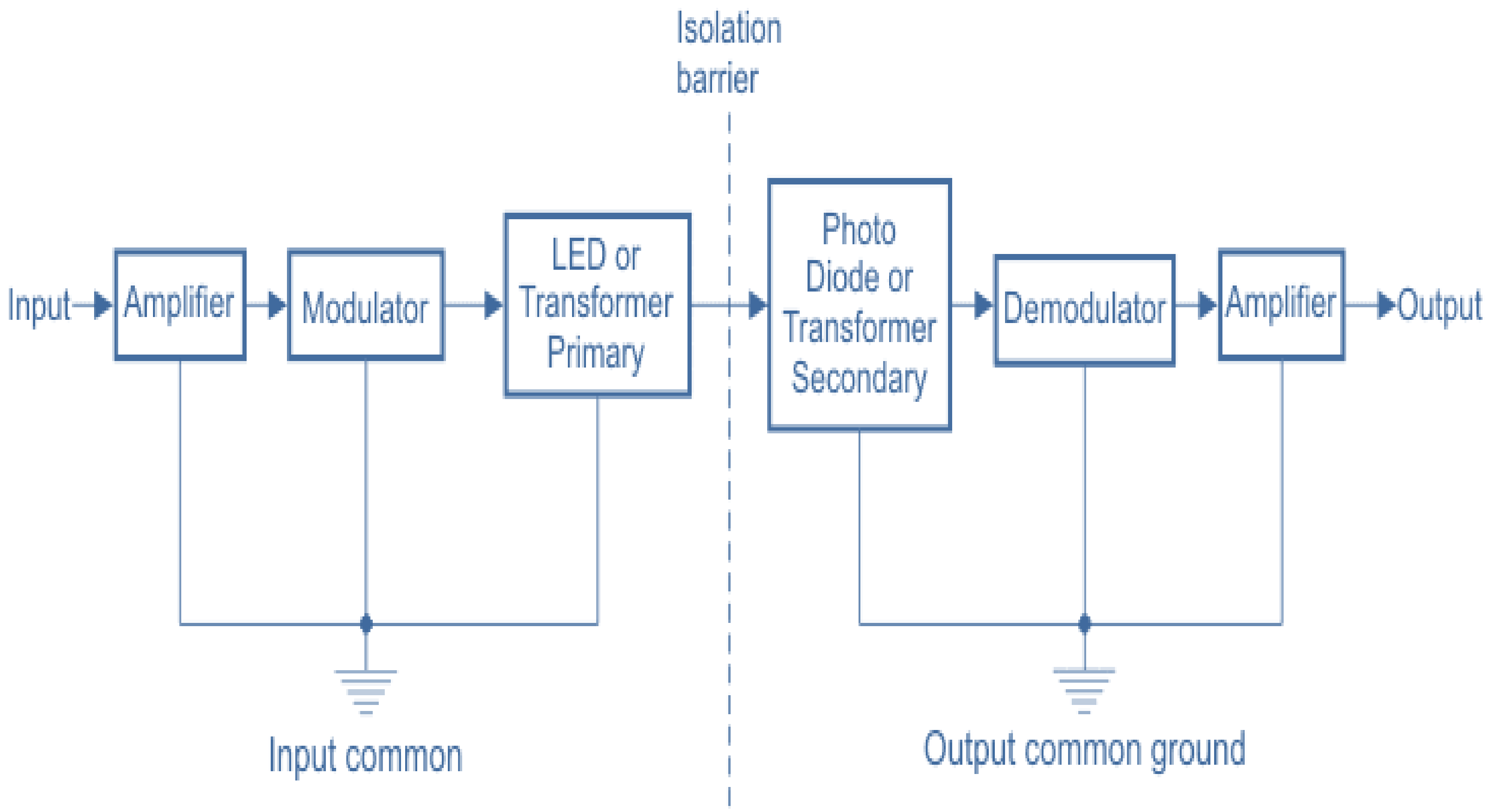
Isolation Amplifier

- Isolation amplifiers are Pre-amplifier isolation circuits.
- Isolation amplifier increases the input impedance of a patient monitoring system.
- It helps to isolate the patient from the device.
- Using isolation amplifier prevents accidental internal cardiac shock.
- It provides up to 1012 Ω insulation between the patient and the power line in hospitals.

Isolation Amplifier Symbol



Isolation Amplifier (Block Diagram)



Isolation Amplifier

- The electrical signals are obtained with electrodes.
- The signals received goes to the amplifier block, where signals amplification occurs.
- After amplification, the signal enters the modulation block.
- At next stage, secondary output enters the demodulation block.
- Finally, the amplified demodulated signal is obtained.

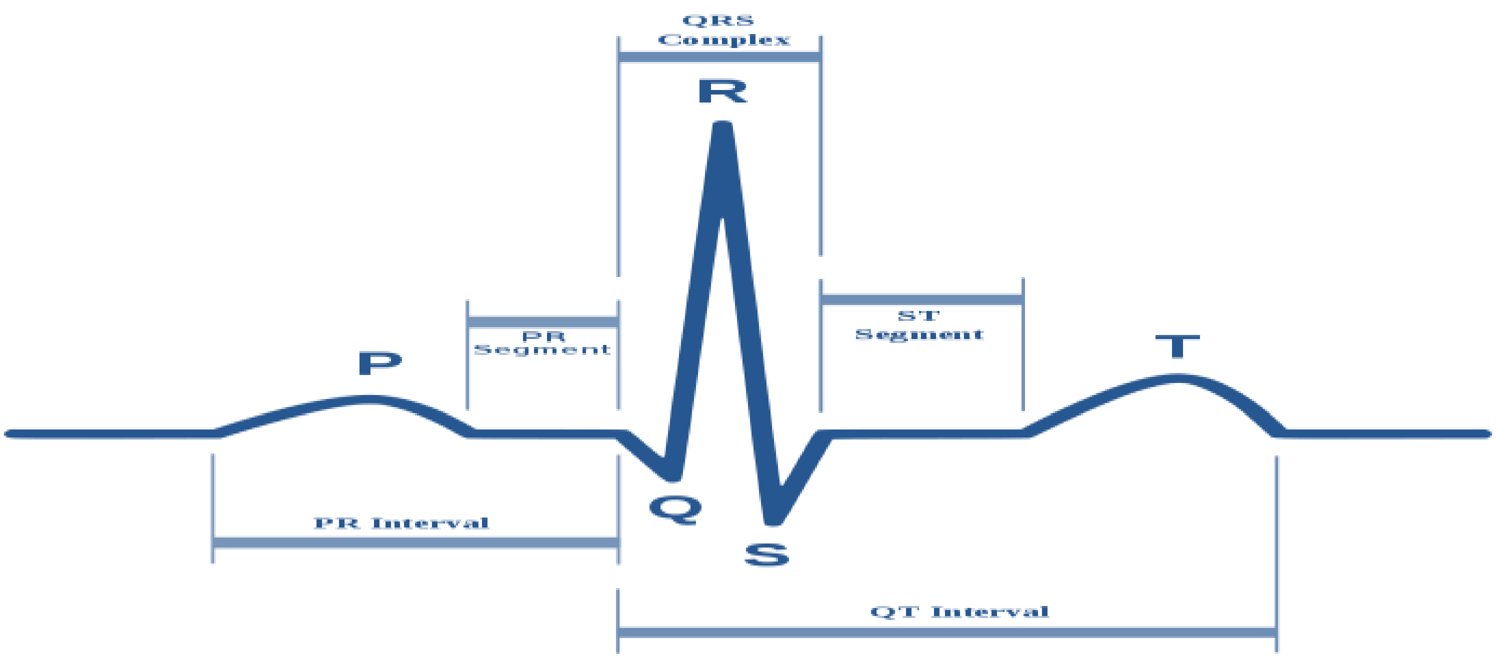
ELECTROCARDIOGRAM
ECG

ECG

- Electrocardiograph (ECG) is an instrument which records the electrical activity of the heart.
- ECG provides information about cardiac disorders such **as the presence of an inactive part** (infarction) or **an enlargement (cardiac hypertrophy)** of the heart muscle.
- Electrocardiographs are used in coronary care units for routine diagnostic applications in cardiology.

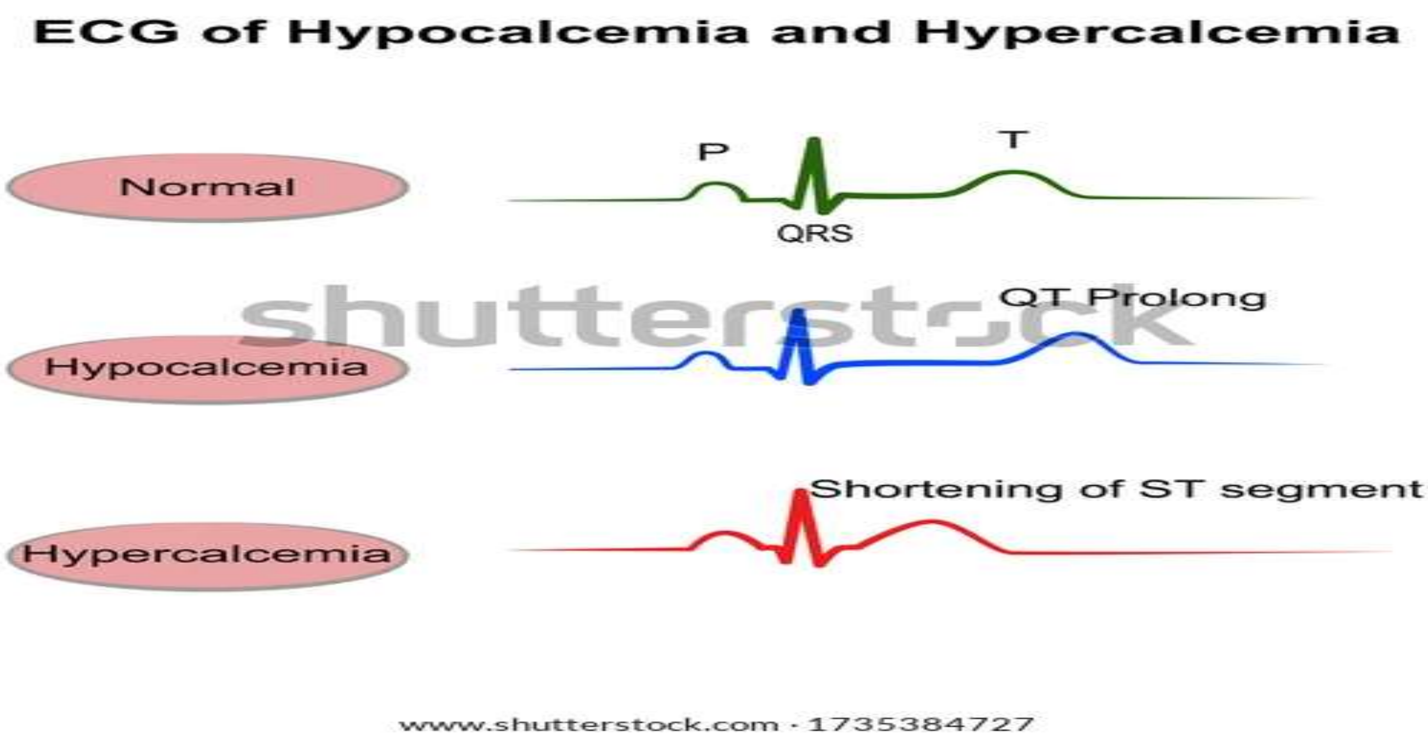
ECG Waveform

- The P wave represents the depolarization of the atria.
- The QRS complex, which represents the depolarization of the ventricles.
- T wave, which represents the repolarization of the ventricles.

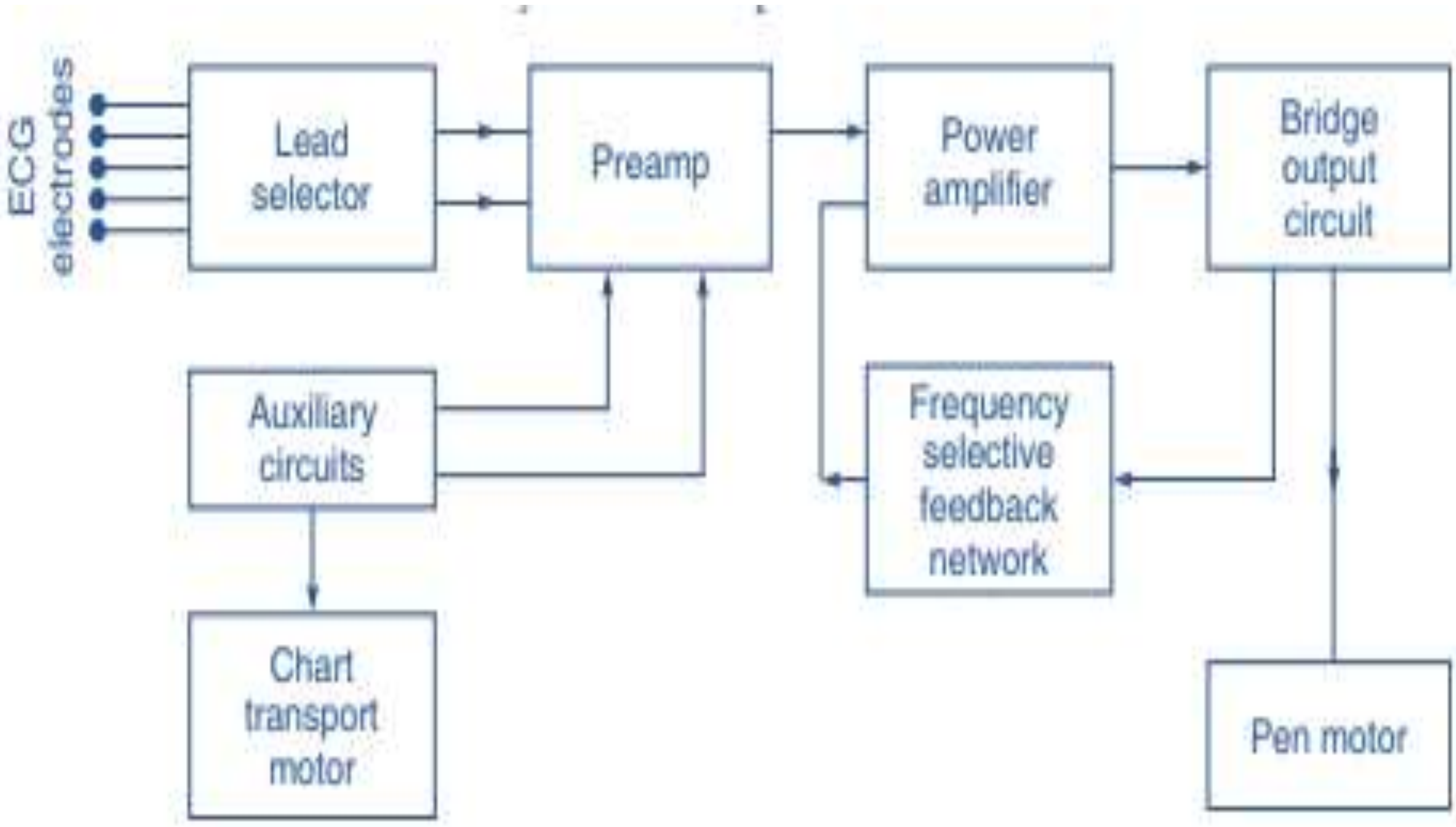


ECG With abnormalities

(Image Courtesy: www.shutterstock.com)



Block diagram of an ECG Machine



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

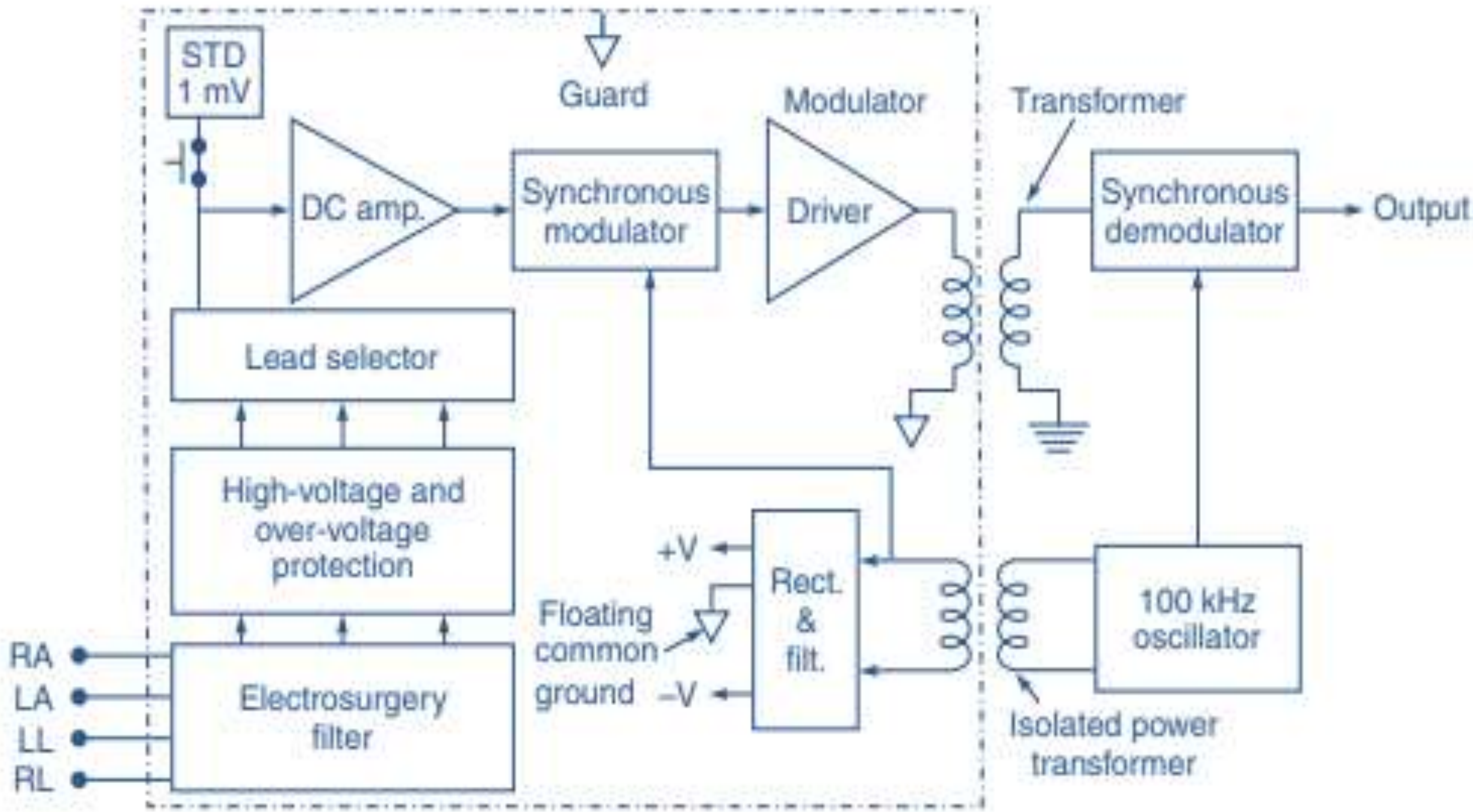
Block diagram of an ECG Machine..

- The potentials picked up by electrodes are taken to lead selector switch.
- In the lead selector, the electrodes are selected two by two according to the lead program.
- Using capacitive coupling, the signal is connected symmetrically to the long-tail pair differential **preamplifier**.
- The preamplifier is usually a three or four stage differential amplifier having a sufficiently large negative current feedback, from the end stage to the first stage, which gives a stabilizing effect.
- The amplified output signal is picked up single-ended and is given to the power amplifier.

Block diagram of an ECG Machine..

- The power amplifier is generally of the push-pull differential type.
- The base of one input transistor of this amplifier is driven by the preamplified unsymmetrical signal.
- The base of other transistor is driven by the feedback signal resulting from the pen position and connected via frequency selective network.
- The output of power amplifier is fed to the pen motor.
- Electrocardiograms are recorded on graph paper with horizontal and vertical lines at 1 mm intervals with a thicker line at 5 mm intervals.
- Time measurements and heart rate measurements are made horizontally on the electrocardiogram
- The paper recording speed is 25 mm/s.
- Amplitude measurements are made vertically in millivolts.
- The sensitivity of an electrocardiograph is typically set at 10 mm/mV.

Block diagram of an isolation preamplifier of Modern ECG Devices



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of an isolation preamplifier of Modern ECG Devices…

- Signals obtained from the right arm (RA), left arm (LA) and right leg (RL) are given to a low-pass filter.
- Filtering is performed in the input leads to reduce interferences caused by electrosurgery , RF emissions.
- The filter has a cut off frequency higher than 10 kHz.
- A multistage filter is used to attain a suitable reduction in high frequency signal.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of an isolation preamplifier of Modern ECG Devices…

- The filter circuit is followed by high voltage & over voltage protection circuits to withstand large voltages during defibrillation.
- The lead selector switch is used to derive the required lead configurations and give it to a dc-coupled amplifier.
- Isolation of the patient preamplifier obtained using low capacitance transformer whose primary winding is driven from a 100 kHz oscillator.
- The transformer secondary is used to obtain an isolated power supply of ±6 V for operating the devices in the isolated portion of the circuit and to drive the synchronous modulator at 100 kHz,which linearly modulates an ECG signal given to it.

Improvement in CMRR using right-leg drive

- To minimize common-mode signal between the body of the patient and the floating ground, a right leg drive circuit is used.
- The common-mode signals after amplification in a preamplifier are **inverted and fed back to the right leg electrode** to **reduce the common mode voltage** on the input with respect to the floating ground.

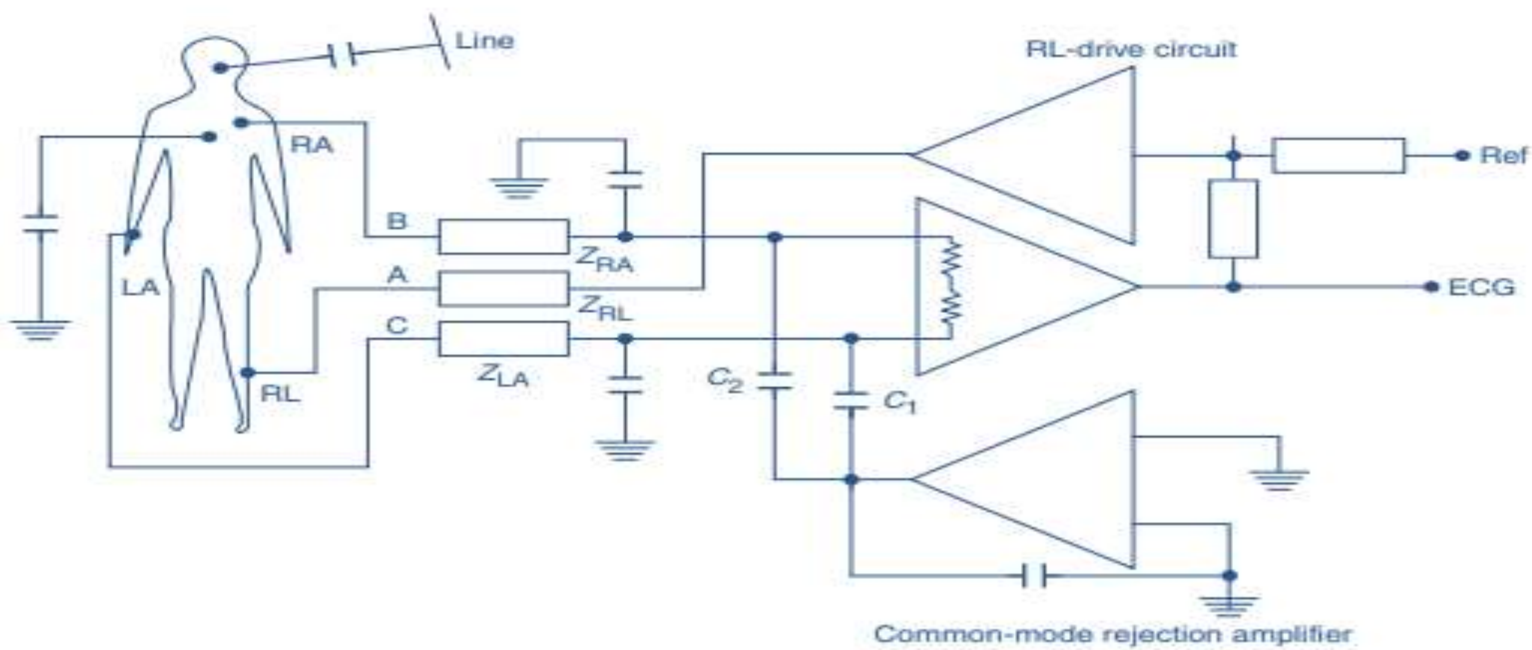


Image courtesy: Hewlett Packard, U.S.A

The ECG Leads

- Two electrodes placed at different areas of heart are connected to the galvanometer will pick up the electrical currents resulting from the potential difference between them.
- The resulting tracing of voltage difference at any two sites due to electrical activity of the heart is called a “**LEAD**”

Example:

- if under one electrode a wave of 1 mV &
- under the second electrode a wave of 0.2 mV occur at the same time.
- The two electrodes will record the difference between them (0.8 mV).

Bipolar Limb Leads (Einthoven leads)

- ECG is recorded by using two electrodes such that the final trace corresponds to the difference of electrical potentials existing between them.
- They are called standard leads & universally adopted.

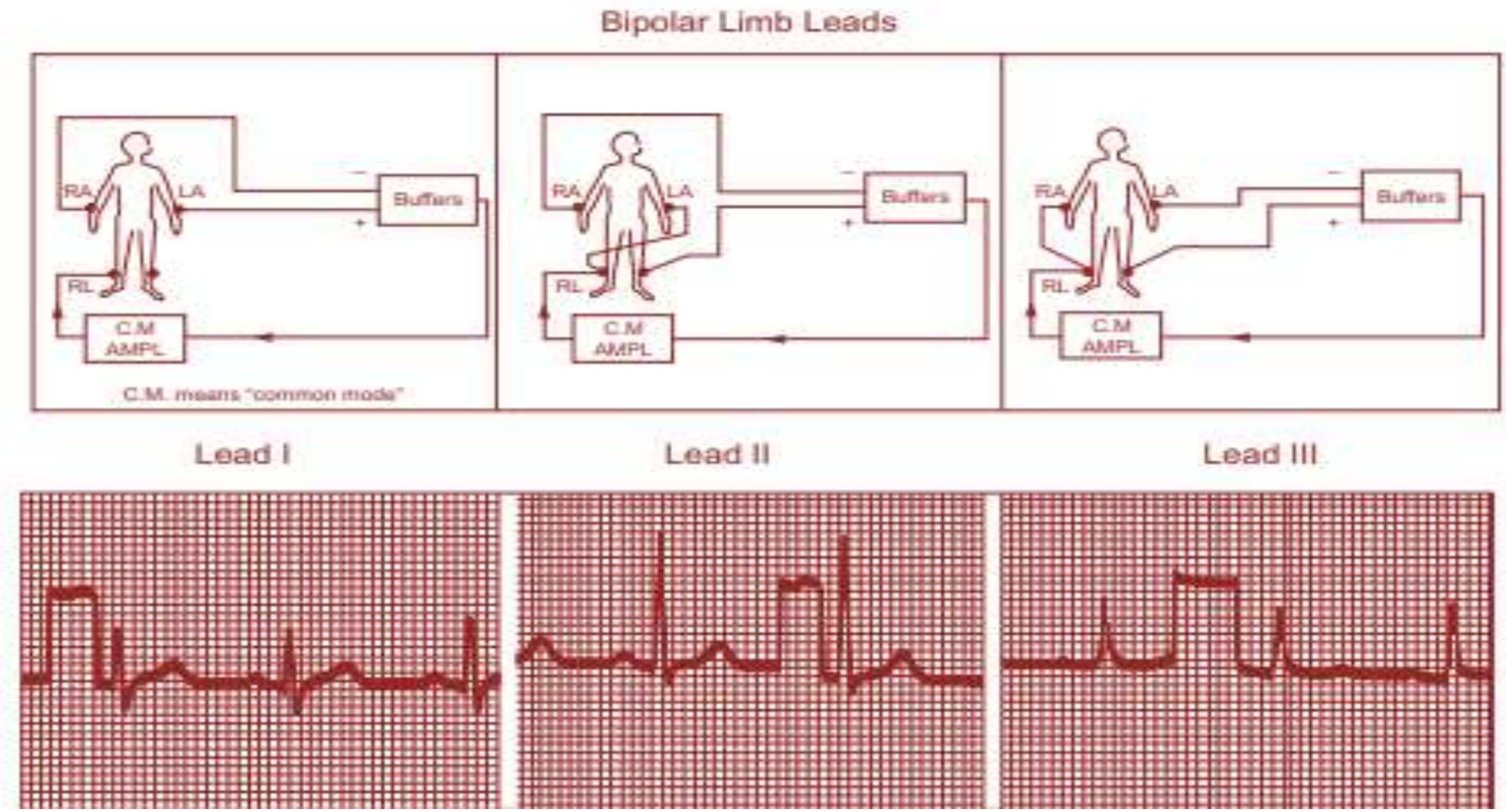


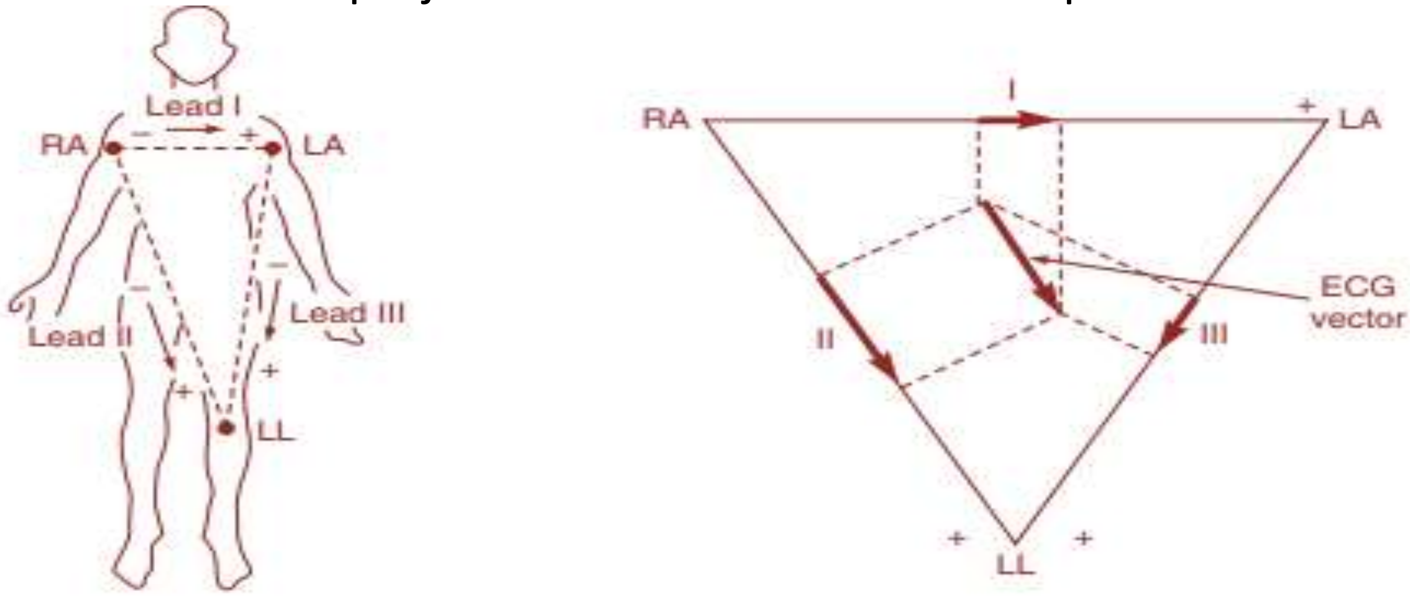
Image courtesy: Hewlett Packard, U.S.A

Bipolar Limb Leads (Einthoven leads)

- In lead I, the electrodes are placed on the right and the left arm (RA and LA).
- In lead II, the electrodes are placed on the right arm and the left leg.
- In lead III, electrodes are placed on the left arm and the left leg.
- In all lead connections, the difference of potential measured between two electrodes is always with reference to a third point on the body.
- This reference point is conventionally taken as the “right leg”.
- The records are using three electrodes at a time, the right leg connection being always presented.

Einthoven triangle for defining ECG leads

- According to **Einthoven:** to The electric field of the heart could be represented diagrammatically as a triangle(**Einthoven triangle**), because the heart located at the centre.
- The instantaneous voltage measured from any one of the three limb lead positions is approximately equal to the algebraic sum of the other two.
- The vector sum of the projections on all three lines is equal to zero



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Unipolar Leads

- The electrocardiogram is recorded between a **single exploratory electrode** and **the central terminal**, which has a potential corresponding to the centre of the body.
- Two types of unipolar leads are employed which are: (i) limb leads, and (ii) precordial leads.

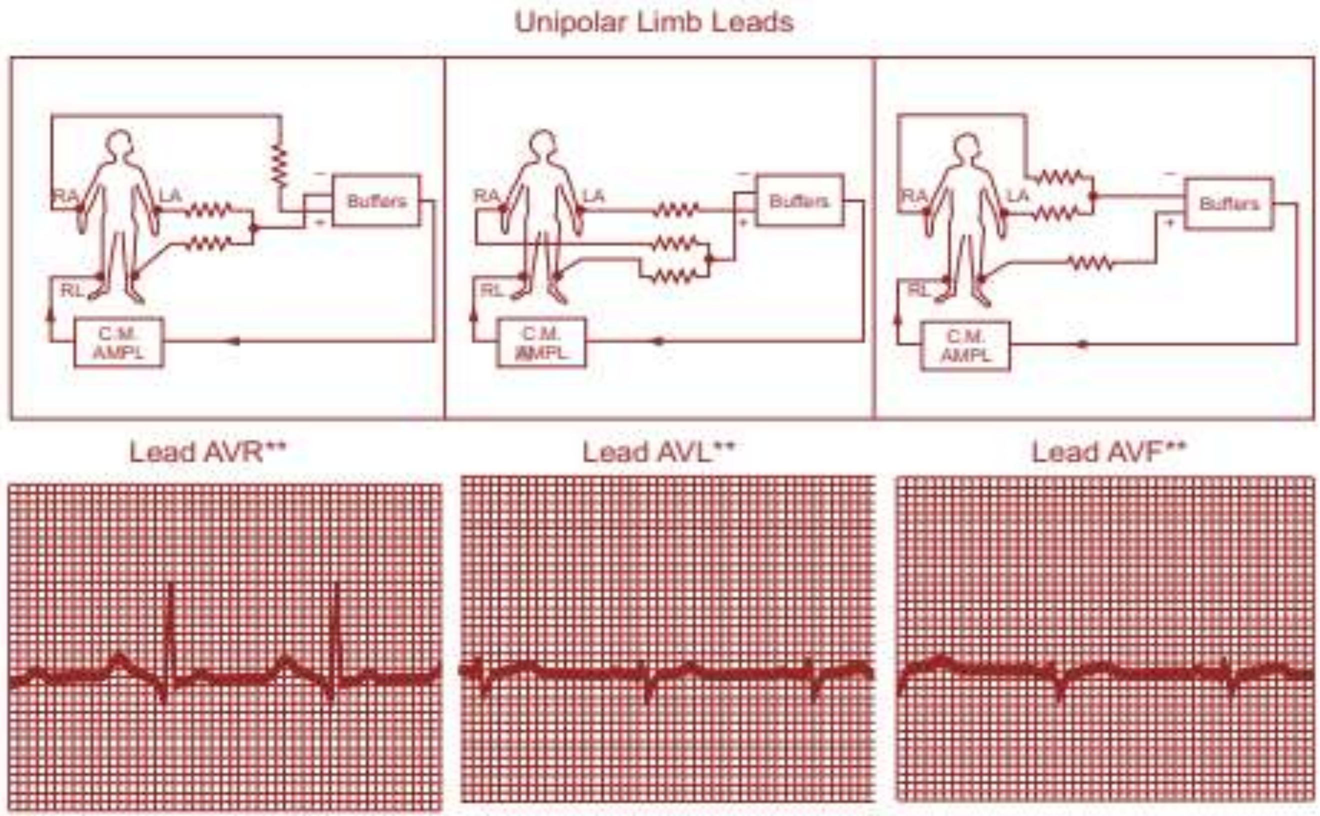
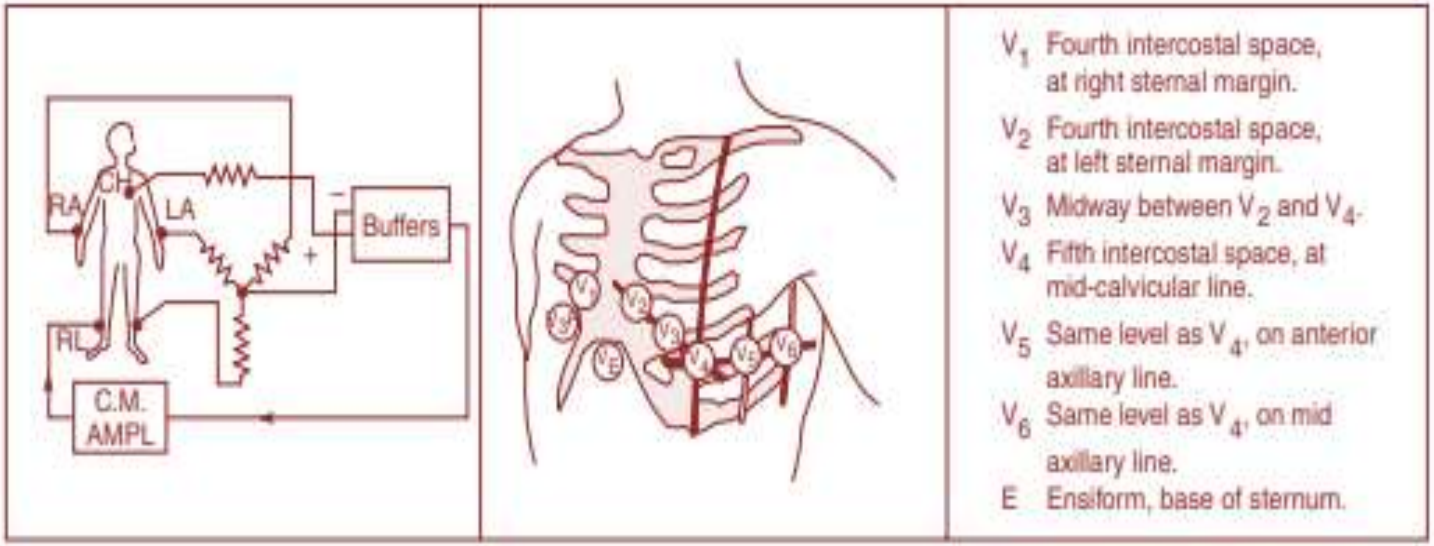


Image courtesy: Hewlett Packard, U.S.A

Precordial leads- Leads position

- The potential of the heart action on the chest recorded at six different positions.
- These leads are designated by the capital letter ‘V’ followed by a subscript numeral, which represents the position of the electrode on the pericardium.



Lead V ** CH positions CH positions

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Leads outcome

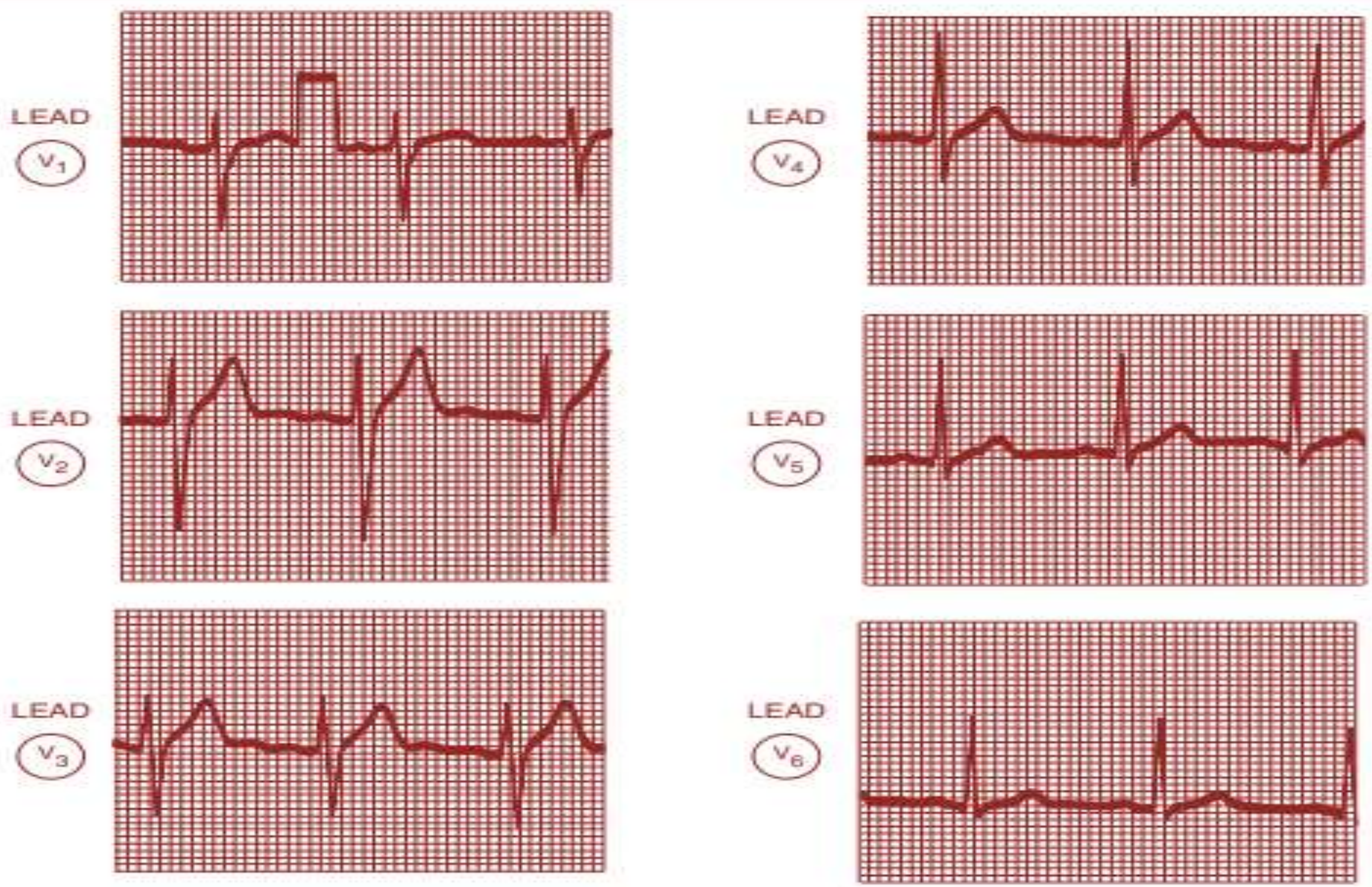
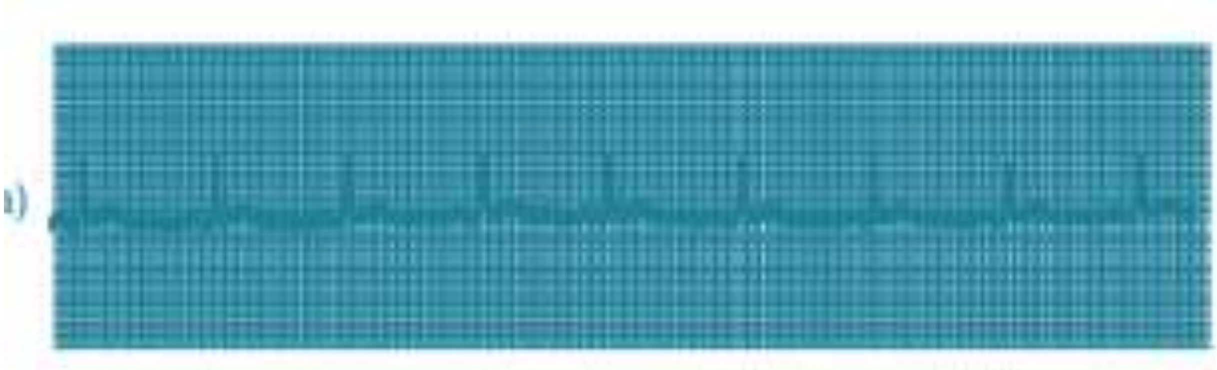


Image courtesy: Hewlett Packard, U.S.A

Effects of Artefacts on ECG Recordings

- **Interference from the Power Line**

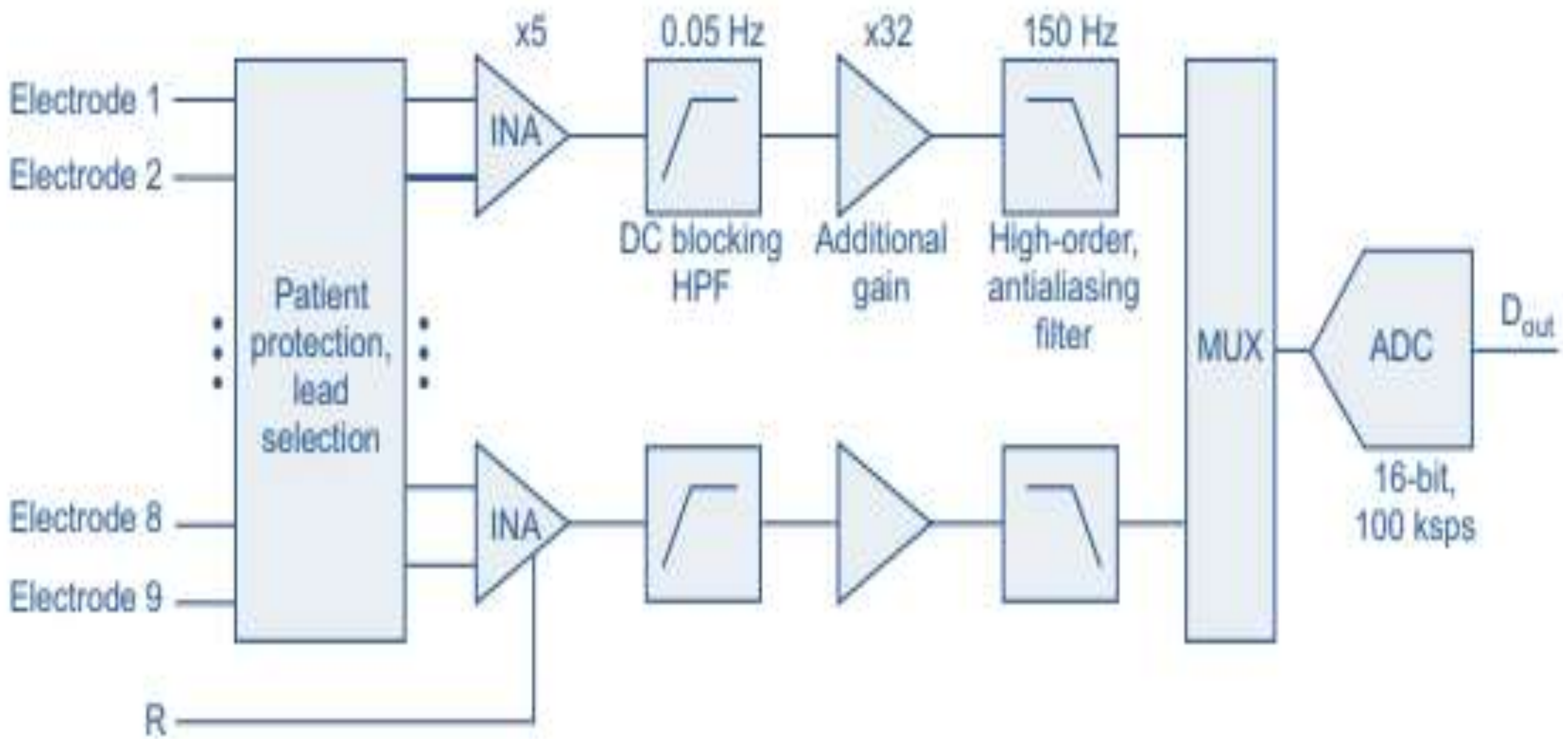


- **Shifting of the Baseline** (baseline shift can be eliminated by ensuring that the patient lies relaxed and the electrodes are properly attached)
- **Muscle Tremor** (older patients)

Major Challenges in Electrocardiograph Design

- **Safety**
- **Rejection of Common Mode Environmental Signals**
- **Dynamic Range**
- **Over Voltage Protection**
- **Electrical Noise**
- **Electromagnetic Capability**

Microprocessor-based ECG Machines

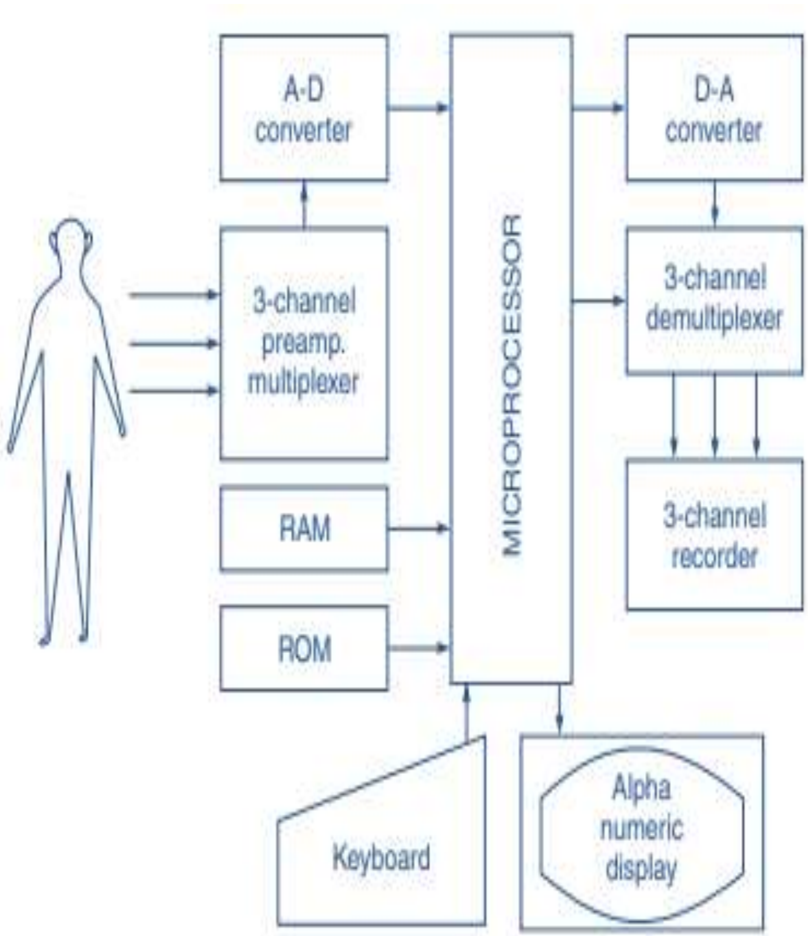


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Multi-channel ECG Machine

- It carry several amplifier channels & recording pens.
- It facilitates recording of several ECG leads simultaneously and thus considerably reduces the time required to complete a set of recordings.
- The waveforms are recorded simultaneously and they can be shown in their proper time relationship with respect to each other.
- Modern multi-channel ECG machines use microprocessor to capture the heart signals from a standard 12-lead configuration
- It sequencing the lead selector to capture four groups of three lead signals and switching groups every few seconds.

Block diagram of microprocessor based three channel ECG machine



- The operating program controlling the lead selection and other operations is stored in a ROM.
- The ECG signals selected by the microprocessor are amplified, filtered and sent to a three-channel multiplexer.
- The multiplexed analog signals are then given to an analog-to-digital converter.
- The microprocessor stores the digitized signals in a RAM.
- The contents of the RAM are sent to a digital-to-analog converter for reconstructing the analog signals.
- The analog signals are demultiplexed and passed to the video display or chart recorder.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

ELECTROENCEPHALOGRAM
ELECTROENCEPHALOGRAPH
EEG

EEG

- EEG is an instrument for **recording the electrical activity of the brain**, by suitably placing surface electrodes on the scalp.
- Monitoring the EEG is an effective method of diagnosing many neurological illnesses/diseases.
- Diseases such as epilepsy, tumour, cerebrovascular lesions, ischemia and problems associated with trauma.
- EEG is recorded by picking up the voltage difference between an active electrode on the scalp with respect to a reference electrode on the ear lobe /any other part of the body.
- EEG signals picked up by the surface electrodes are usually small as compared with the ECG signals.
- The brain waves, unlike the electrical activity of the heart, do not represent the same pattern over and over again.
- Hence, brain recordings are made over a much longer interval of time in order to be able to detect any kind of abnormalities.

EEG…

- Several types of **electrodes may be used to record EEG**.
- These include: **Peel and Stick electrodes**, **Silver plated cup electrodes and Needle electrodes**.
- EEG electrodes are smaller in size than ECG electrodes.
- They applied separately to the scalp or mounted in special head bands.
- If the electrodes are intended to be used under the skin of the scalp, needle electrodes are used (reducing movement artefacts)on the patient’s head.

EEG Waveforms Clinical Classification

- **Delta (0.5 to 4Hz)-** Deep sleep (frontocentral head regions)
- **Theta (4 to 7Hz)-** drowsiness as well as early stages of sleep- fronto-central head regions and slowly migrates backward replacing the alpha
- Alpha (8 to 12Hz)- Normal
- Beta (13 to 30Hz)- rhythm in normal adults and children.

Delta

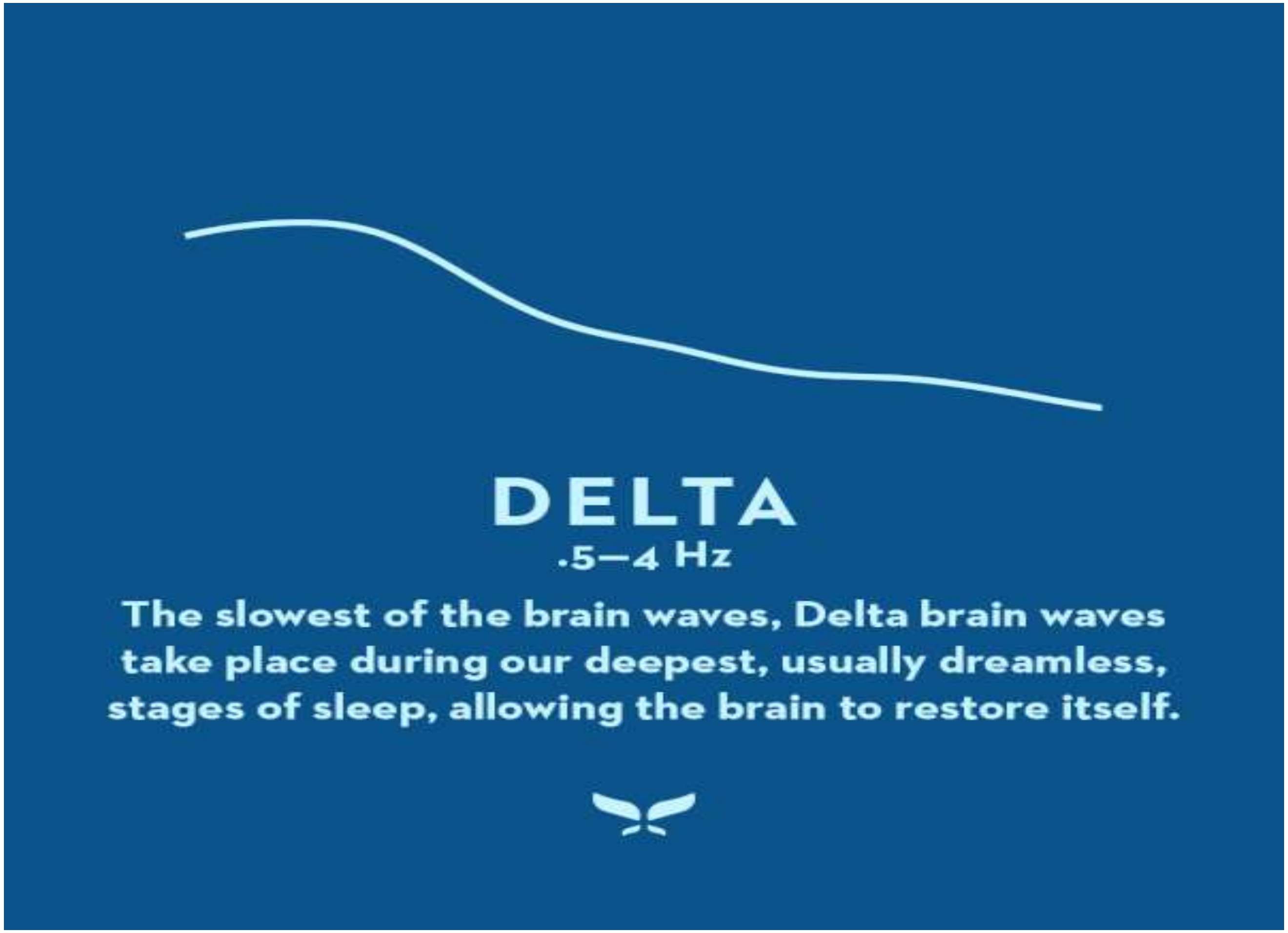


Image Courtesy: https://www.liveli.com/

Theta

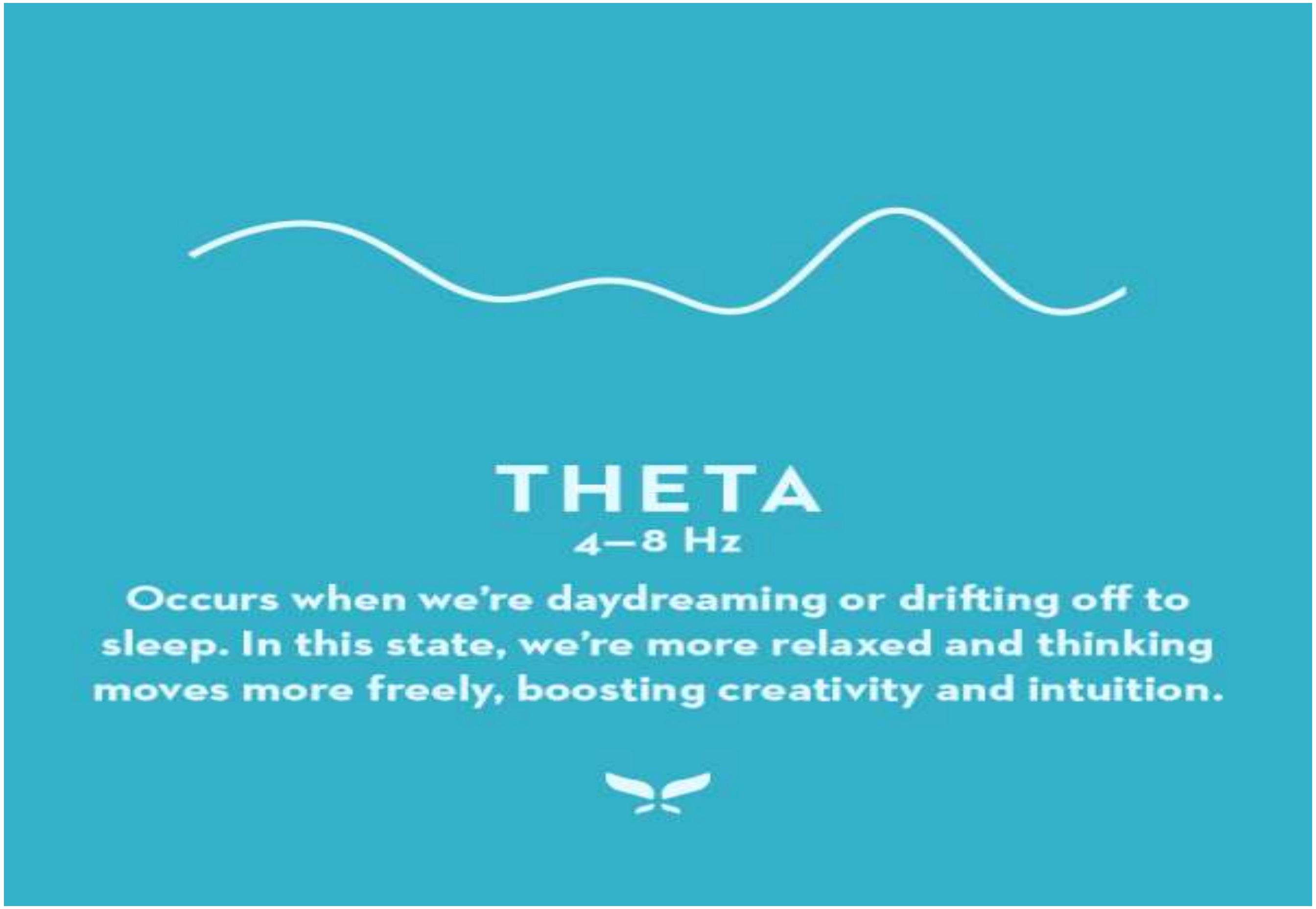


Image Courtesy: https://www.liveli.com/

Alpha

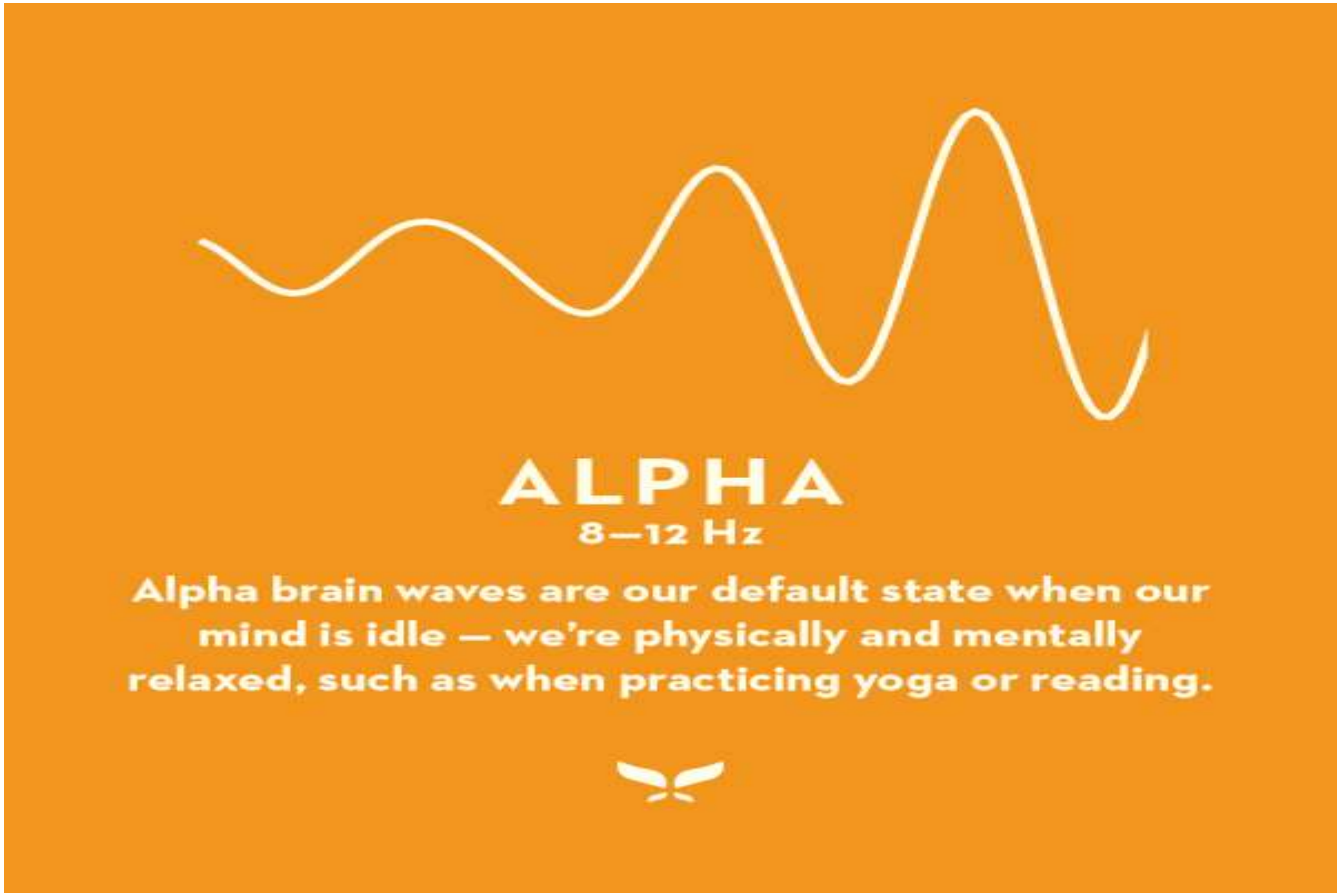


Image Courtesy: https://www.liveli.com/

Beta

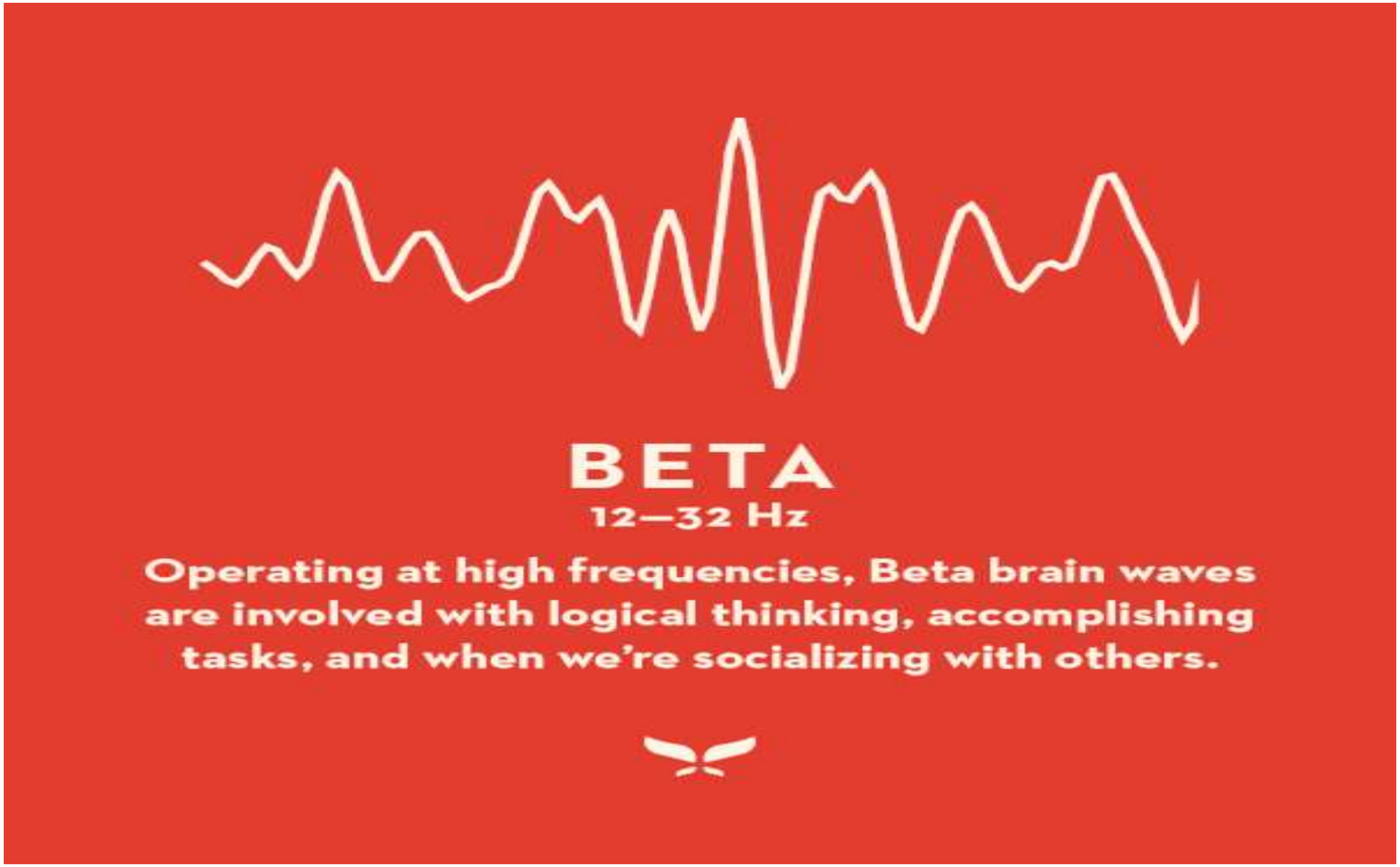


Image Courtesy: https://www.liveli.com/

Gamma

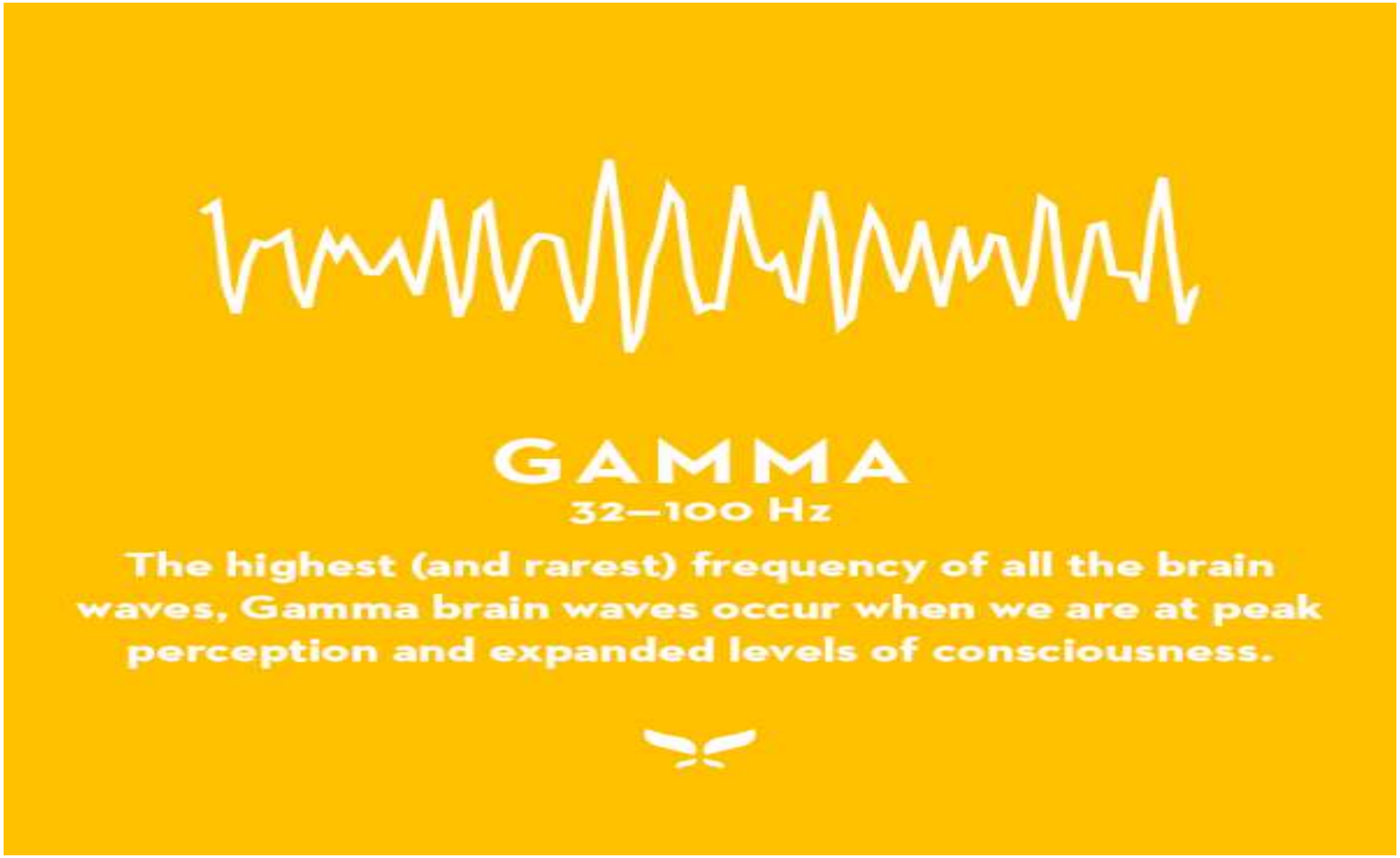
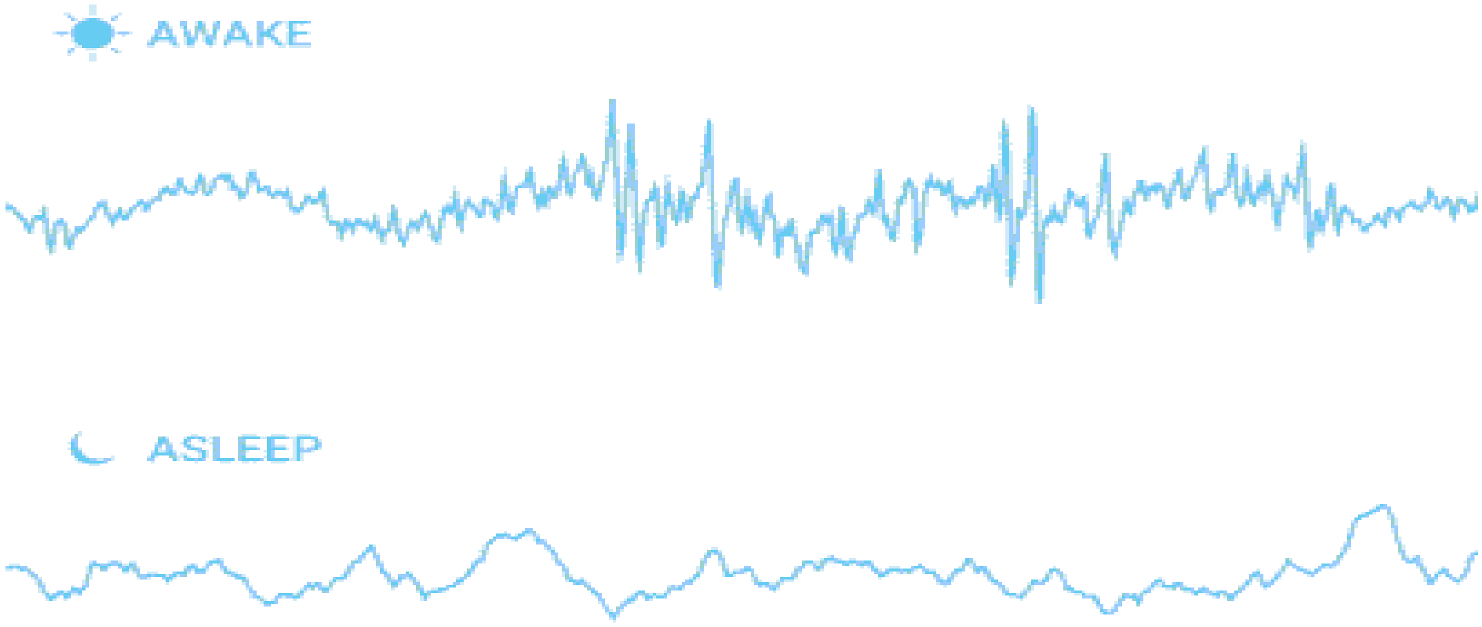


Image Courtesy: https://www.liveli.com/

EEG Signals



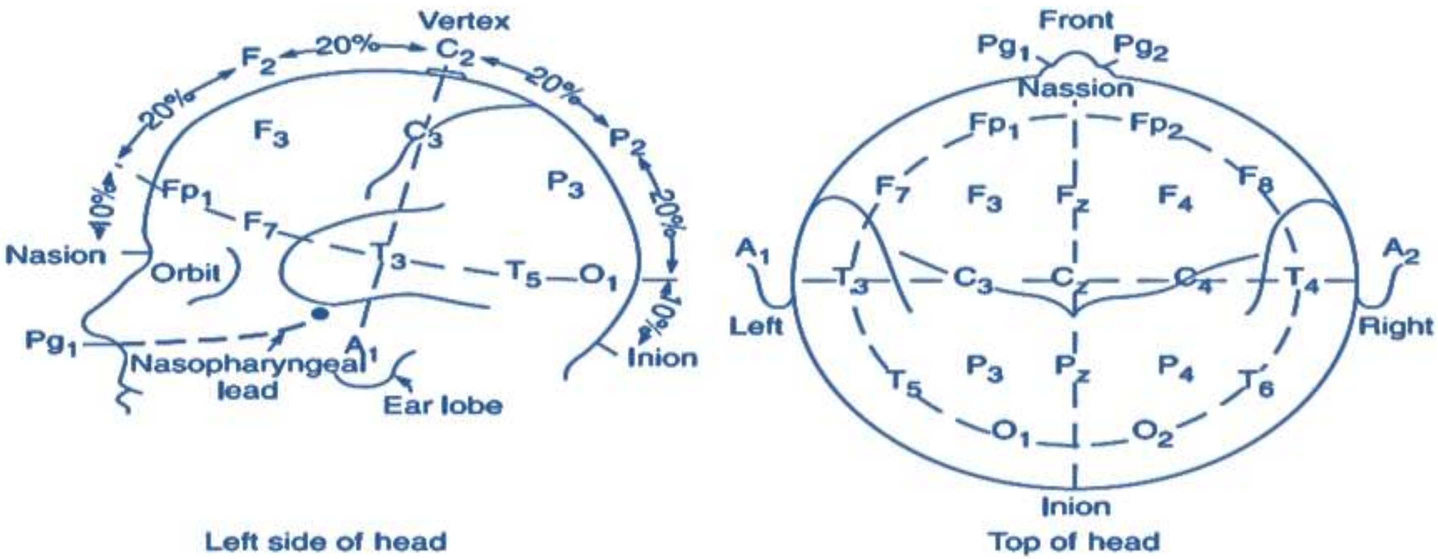
Applications

- Brain tumor
- Brain damage from head injury
- Brain dysfunction that can have a variety of causes (encephalopathy)
- Inflammation of the brain (encephalitis)
- Stroke
- Sleep disorders

10-20 System of placement of electrodes

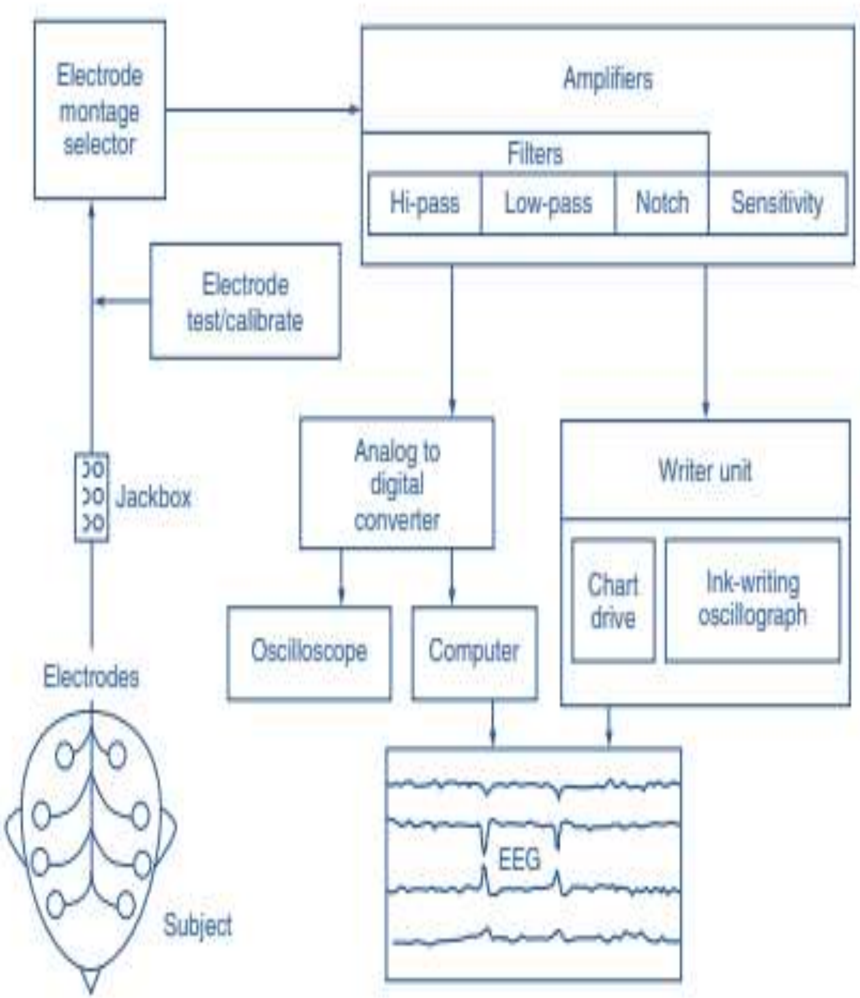
- EEG electrodes are arranged on the scalp according to the standard 10/20 system, adopted by the American EEG Society.
- The "10" and "20" refer to the 10% or 20% inter electrode distance.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation



- ➢ **Electrodes are identified according to their position on the head: Fp for frontal-polar, F for frontal, C for central, P for parietal, T for temporal and O for occipital.**
- ➢ **Odd numbers refer to electrodes on the left side of the head and even numbers represent those on the right**
- ➢ **Z denotes midline electrodes.**

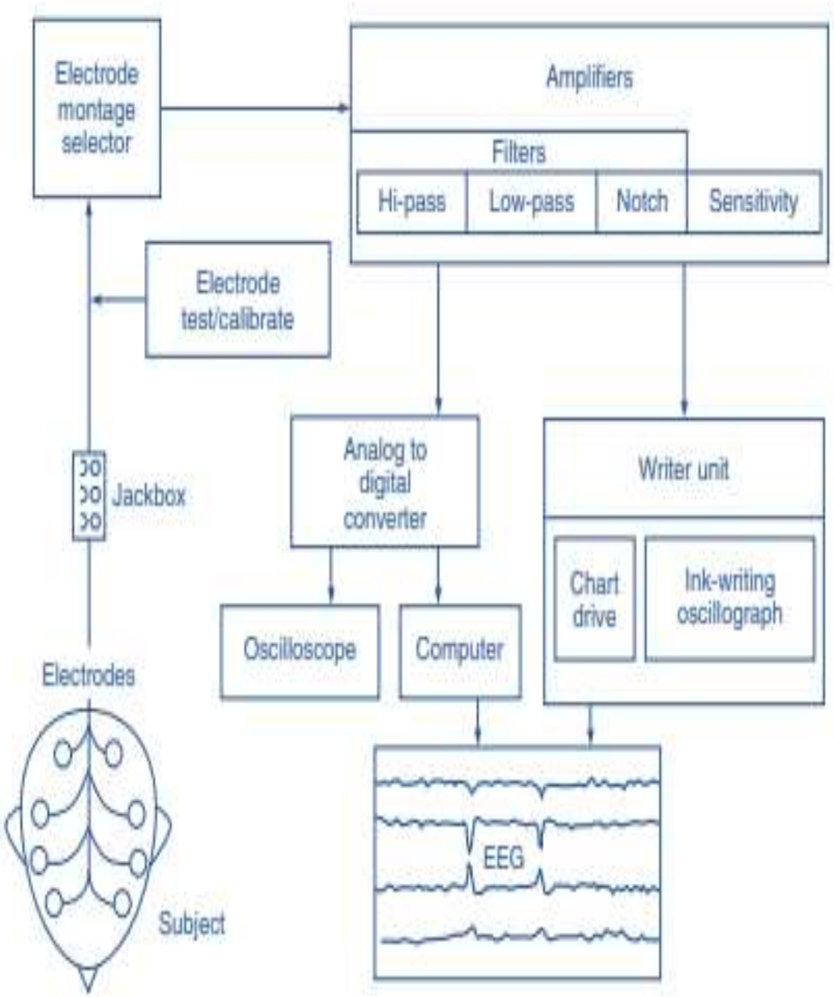
Block Diagram of EEG



- A pattern of electrodes on the head and the channels they are connected to is called a **montage**.
- The **reference electrode is generally placed on a non-active site such as the forehead/ earlobe**.
- **Electrode Montage Selector :** EEG signals are transmitted from the electrodes to the head box.
- The montage selector is a large panel containing switches that allow the user to select which electrode pair will have signals subtracted from each other to create a montage.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

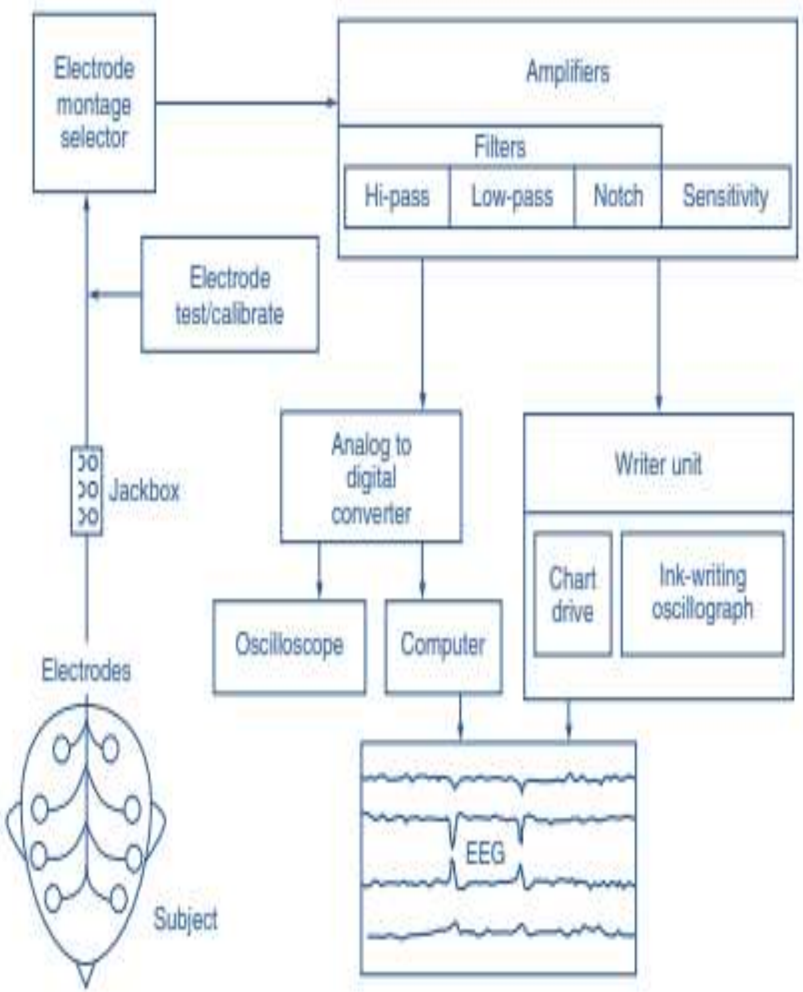
Block Diagram of EEG…



- The preamplifier must have high gain and low noise characteristics because the EEG potentials are small in amplitude.
- the amplifier must have very high common-mode rejection to minimise stray interference signals from power lines and other electrical equipment.
- Pre amplifier: The use of electrode amplifiers at the site also eliminates undesirable cross-talk effects of the individual electrode potentials.
- Sensitivity control: 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. This control is usually calibrated in decibels.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block Diagram of EEG…



- artefacts are generally removed using low-pass filters. This filter on an EEG machine has several selectable positions, which are usually labelled in terms of a time constant.
- The upper cut-off frequency can be controlled by the high frequency filter.
- Some EEG machines have a notch filter sharply tuned at 50 Hz so as to eliminate mains frequency interference.
- The writing part of an EEG machine in older versions was direct writing thermal recorder.
- The best types of pen motors used in EEG machines.
- Commercial EEG machines have up to 32 channels, although 8 or 16 channels are more common.
- Modern EEG machines are mostly PC based.
- The system can store up to 40 hours of EEG.
- The EEG is displayed on a colour monitor.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Recording of Evoked Potentials

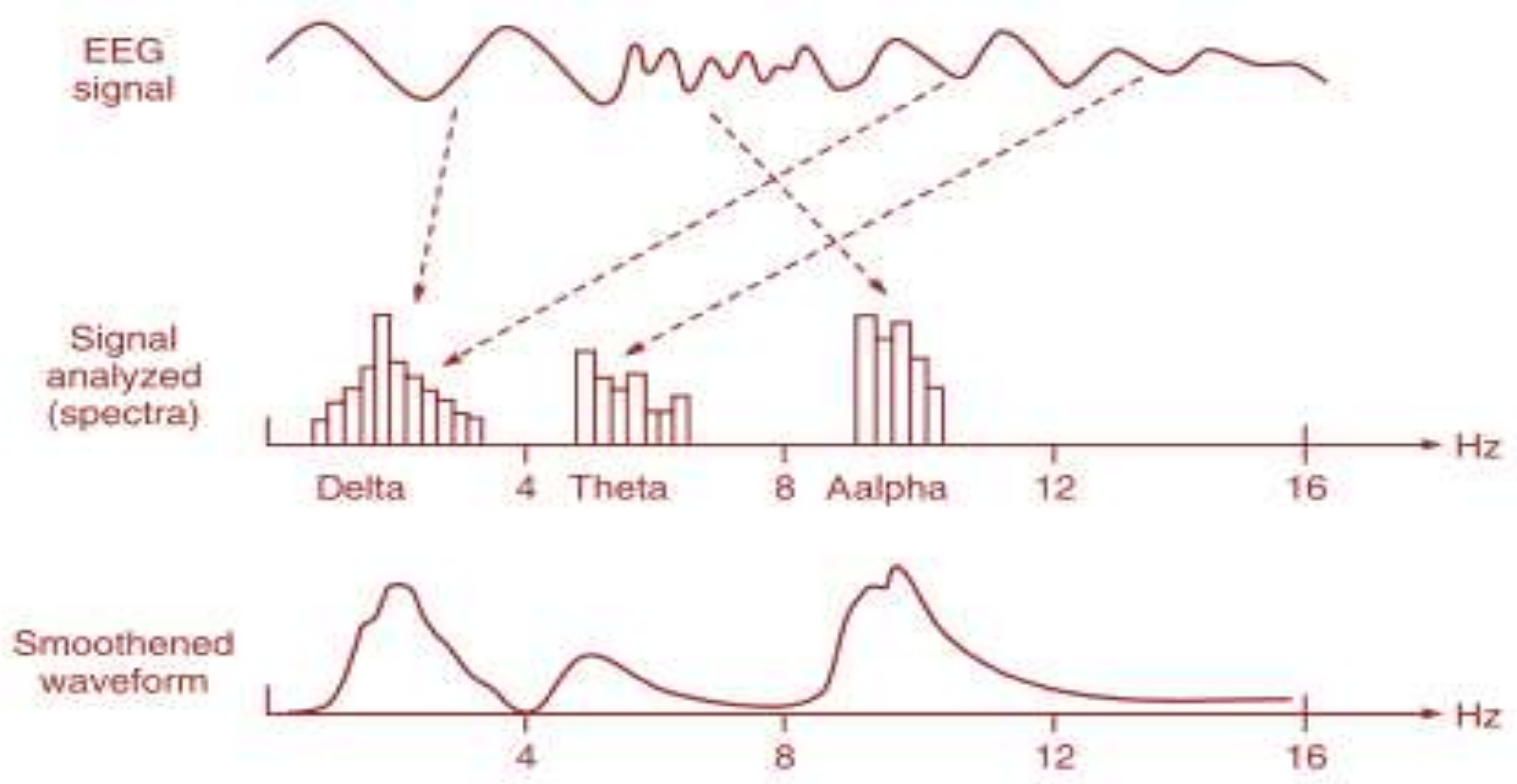
- If an external stimulus is applied to a sensory area of the brain, it responds by producing an electrical potential known as the ‘evoked potential’.
- Evoked potential, recorded at the surface of the brain, is the integrated response of the action of many cells.
- The amplitude of the evoked potential is of the order of 10 microvolts.
- The evoked potentials are generally superimposed with EEG.
- Therefore, it is necessary to remove the EEG by an averaging technique while making evoked potential measurements.

Computerized Analysis of EEG

- Assessment of the frequency and amplitude of the EEG is crucial for rapid and accurate interpretation.
- **Frequency Analysis:**
- It takes the raw EEG waves, mathematically analyzes them and breaks them into their component frequencies.
- The most popular method of doing this is called the Fast-Fourier Transform or FFT.
- Fast-Fourier Transformation of the digitized EEG waveform is a mathematical transformation of a complex waveform into simpler, more uniform waveforms (such as different sine waves of varying amplitudes).
- EEG signal is converted into a simplified waveform Spectrum.
- The spectral analysis transforms the analog EEG signal recorded on the time axis into a signal displayed on the frequency axis.

Computerized Analysis of EEG

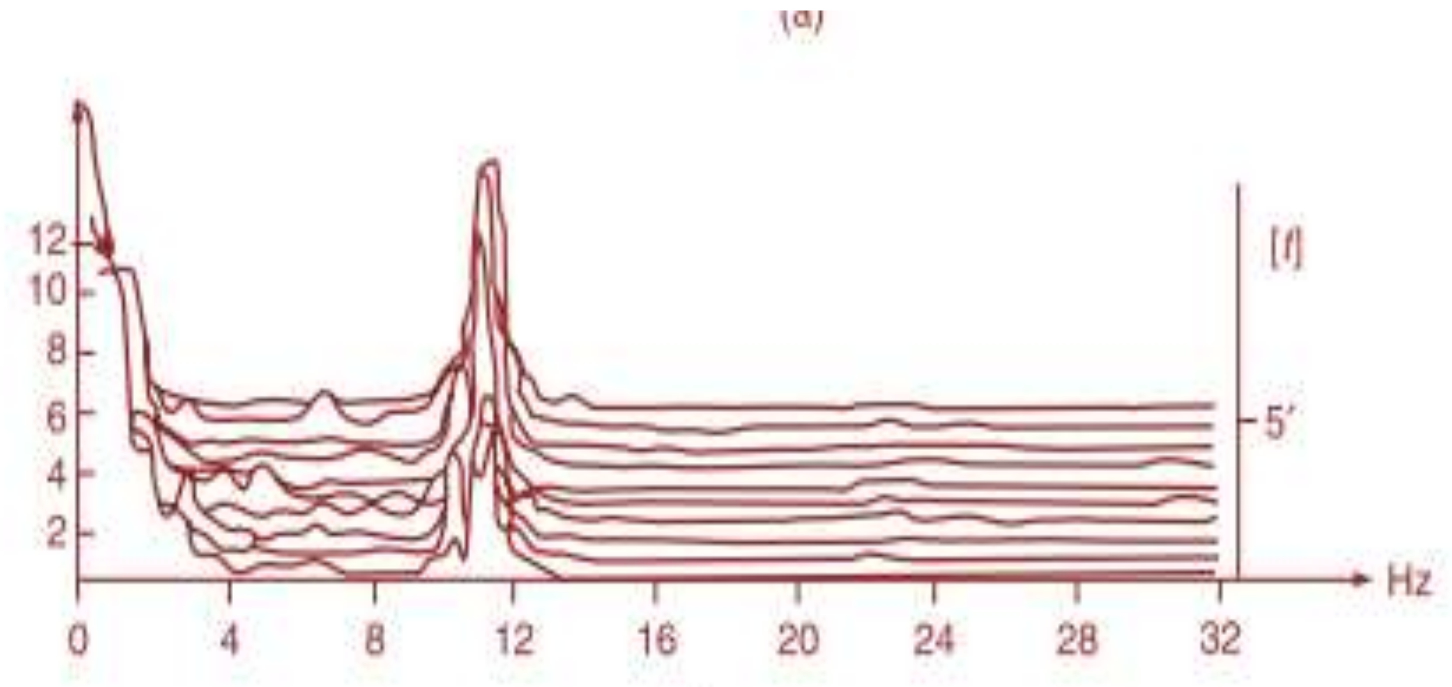
- Typical EEG waveform broken down into frequency components.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Computerized Analysis of EEG…

- Mathematical and display techniques used to generate the compressed spectral array format



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Computerized Analysis of EEG…

Amplitude Analysis:

- Changes in the **EEG amplitude can indicate clinical changes**.
- The **amplitude changes result in changes in the power of the resulting frequency spectrum**.
- Due to the microvolt amplitude of the EEG, power is either in nanowatts or picowatts.
- The **power spectrum is calculated by squaring the amplitudes of the individual frequency components**.
- The **powers of the individual frequency bands are also commonly** used and expressed as an **absolute or a percentage of the total power**.

Computerized Analysis of EEG…

Compressed Spectral Array (CSA):

- A series of **computer-smoothed spectral arrays are stacked vertically**, usually at **two second intervals**, with **the most recent EEG event at the bottom and the oldest at the top**.
- **Peaks appear at frequencies**, which contain more power or make **larger contributions to the total power spectrum**.
- it is **easy to find changes in frequency and amplitude** of each sample over a longer period of time.

Computerized Analysis of EEG…

Dot-density Modulated Spectral Array (DSA):

- Method for displaying the power spectra.
- This format displays a power spectrum as a line of variable intensities and/or densities
- Areas of greatest density represent frequencies, which make the greatest contribution to the EEG power spectrum.
- Advantage of the DSA format is that no data is hidden by the peaks as in the CSA display.
- DSA displays could be in the form of gray or colour-scaled densities.

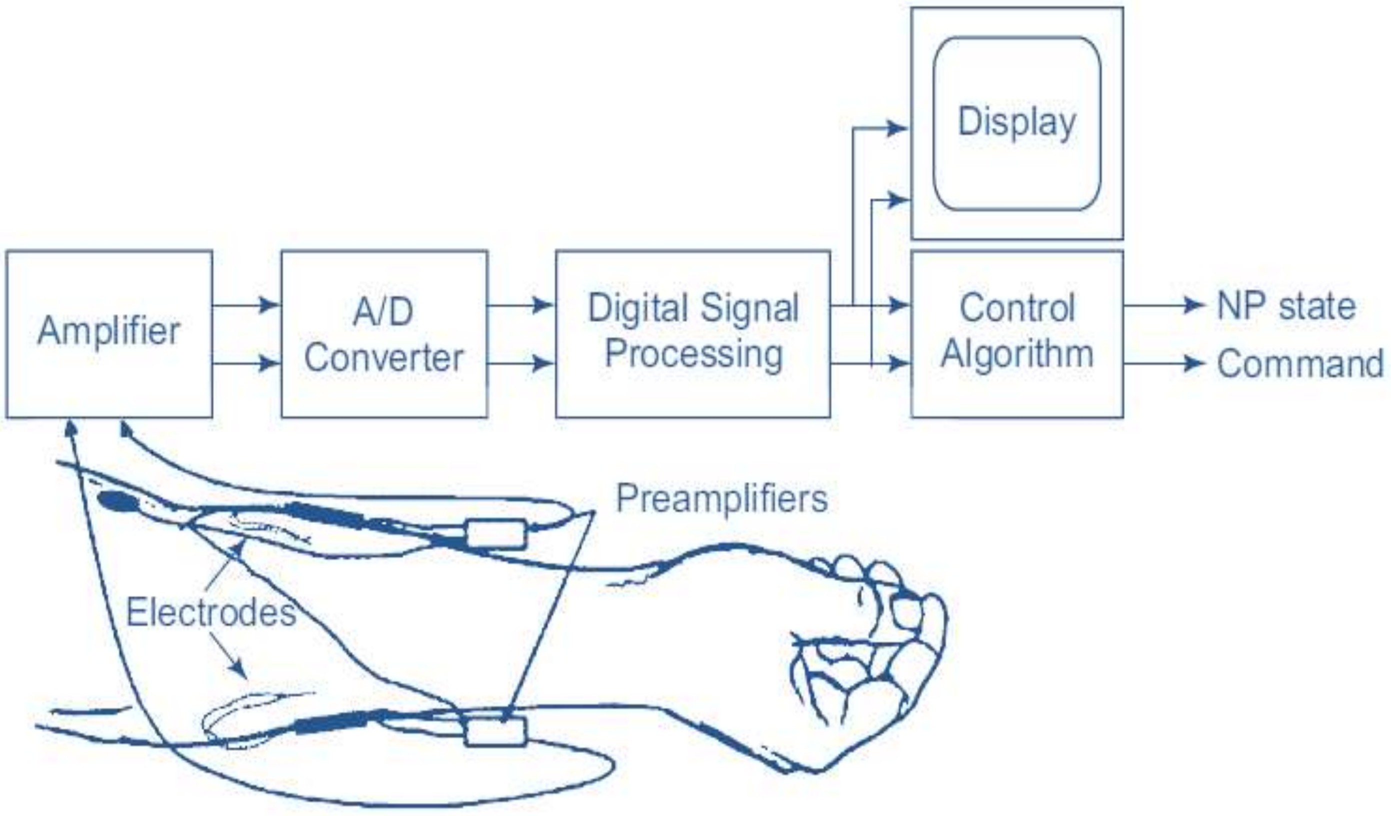
ELECTROMYOGRAM
&
ELECTROMYOGRPH

EMG

EMG

- EMG is an instrument used for recording the electrical activity of the muscles to determine whether the muscle is contracting or not.
- The instrument is useful for making a study of several aspects of neuromuscular function, neuromuscular condition, extent of nerve lesion, reflex responses, etc.
- EMG is recorded by using surface electrodes or more often by using needle electrodes, which are inserted directly into the muscle.
- The surface electrodes may be disposable, adhesive types or the ones which can be used repeatedly.
- A ground electrode is necessary for providing a common reference for measurement.
- These electrodes pick up the potentials produced by the contracting muscle fibres.
- The signal can then be amplified and displayed on the screen of a cathode ray tube.

EMG recording Block Diagram

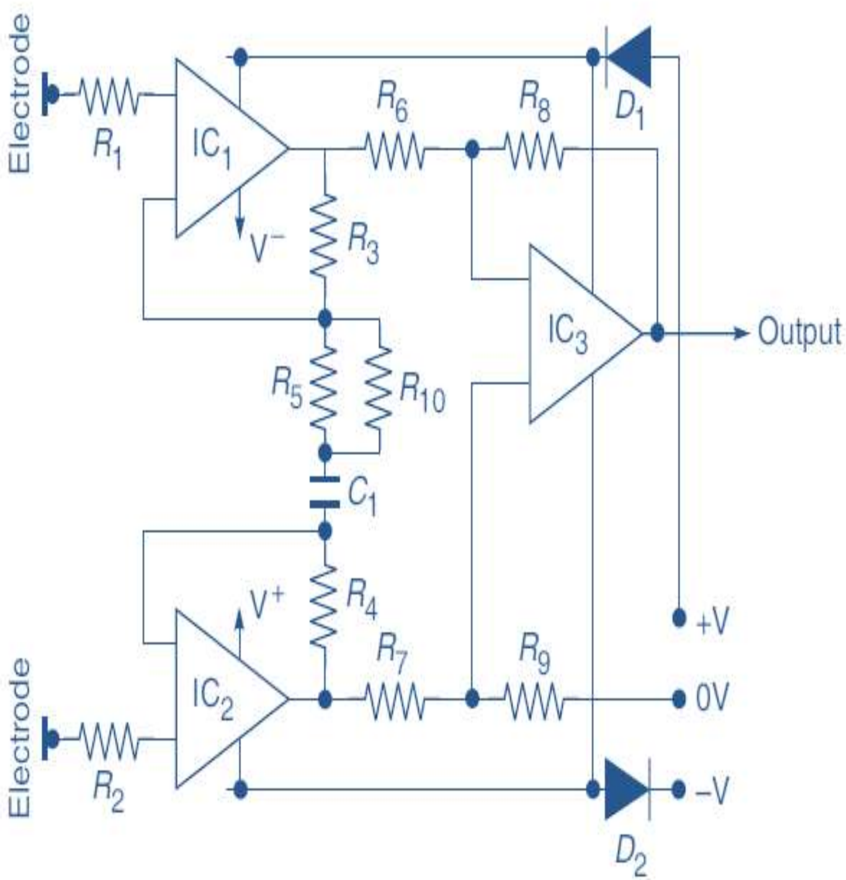


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

EMG recording Block Diagram..

- The myoelectric signals are amplified with the use of preamplifiers & a differential amplifier together having an effective passband of 10 to 1,000 Hz.
- The signals are sampled at 5 kHz with 16-bit analog-to-digital conversion, rectified, and smoothed with a running time window averager with a window length of 240 ms that is updated every 80 ms.
- The processed signals are normalized by the amplitudes of the maximum voluntary contractions and are displayed on a computer monitor.
- The waveforms can be stored to play and study of the EMG waveforms at a later.
- The waveform can also be printed as a hard copy.

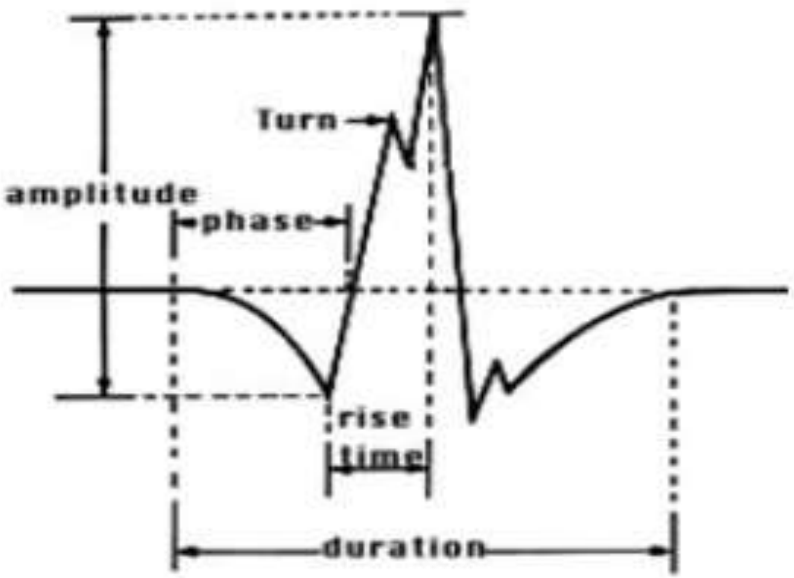
Preamplifier circuit for an EMG machine



- The amplifier design provides a flat frequency response between 10 Hz - 1 kHz, with CMRR of 100 dB.
- The two ICs in the input stage act as voltage followers, which present the desired high input impedance to the electrodes.
- They coupled via C1 and R5 to provide a high differential signal gain.
- Capacitor C1 determines the low frequency performance of the circuit.
- The second stage IC3 provides further differential signal gain, while rejecting common-mode signals.
- The overall gain of the amplifier is 1000.

Image Courtesy : Johnson et al., Med. & Biol. Eng. & Comput.

EMG Test Report



EMG Test Report (Electromyogram)

Image Courtesy : https://www.test-and-measurement-world.com/

Common Artefacts in EMG

- Power line interference (50–60Hz)
- **ECG artefacts** are a result of the electrical signals generated by the heart muscle and can also be picked up in EMG signals.
- A high-pass filter which may sometimes remove some of the signals of interest.
- Movement artefacts (patient moves)
- DC offset results from a difference in the electrical impedances between the skin and electrodes.
- Muscle crosstalk results from the electrical signals generated by muscles other than the desired.

PHONOCARDIOGRAM
&
PHONOCARDIOGRAPH

PCG

PCG

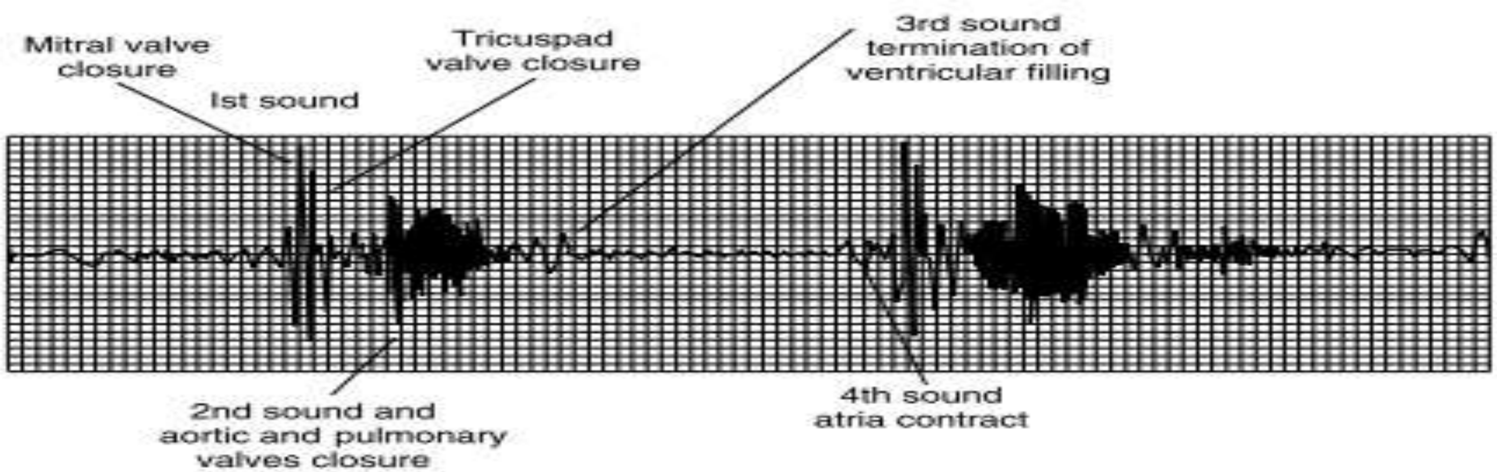
- Phonocardiograph is used for **recording the sounds** of **pumping action of the heart**.
- It provides an indication of the **heart rate** and its **rhythmicity**.
- It provides information related to the effectiveness of **blood pumping and valve action**.
- Sounds produced by **healthy hearts are remarkably identical** & abnormal sounds always correlate to specific physical abnormalities.
- The **major instrument** used for clinical detection of heart sounds is the **acoustical stethoscope**.
- Electronic stethoscope is advanced one , it consisting of a microphone, amplifier & head set.

PCG

- Electronic stethoscopes detect heart sounds (too low in intensity or too high in frequency) to be heard in a purely acoustal instrument.
- The phonocardiographs provide a **recording of the waveforms of heart sounds**.
- **Waveforms are diagnostically more important**.

Origin of Heart Sounds

- **Sounds** are produced by the **mechanical events occurring during heart cycle**.
- Sounds can be from the **movement of the heart wall, closure of walls , turbulence ,and leakage of blood flow.**



First sound:produced by closure of the valves between the upper and lower chambers of the heart. corresponds to R wave of the ECG- Longer duration- lower in frequency &greater in intensity- 30 to 100 Hz &time duration is 50 to 100 ms.

second sound: produced by the slight back flow of blood into the heart before the valves close. it occurs at the closure of aortic and the pulmonic valves.it is higher in pitch than the first, with frequencies above 100 Hz and the duration between 25 to 50 ms.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Origin of Heart Sounds..

- Third and fourth sounds but they are much lower in intensity and are normally inaudible.
- The third sound is produced by the inflow of blood to the ventricles and the fourth sound is produced by the contraction of the atria.
- These sounds are called diastolic sounds and are generally inaudible in the normal adult but are commonly heard among children.

Microphones for Phonocardiography

- Two types of microphones are commonly used for recording phonocardiograms.
- ➢ Contact microphone.
- ➢ Air coupled microphone.
- ➢ It can be Crystal type or dynamic type mic based on principle of operation.

Crystal Type Mic :

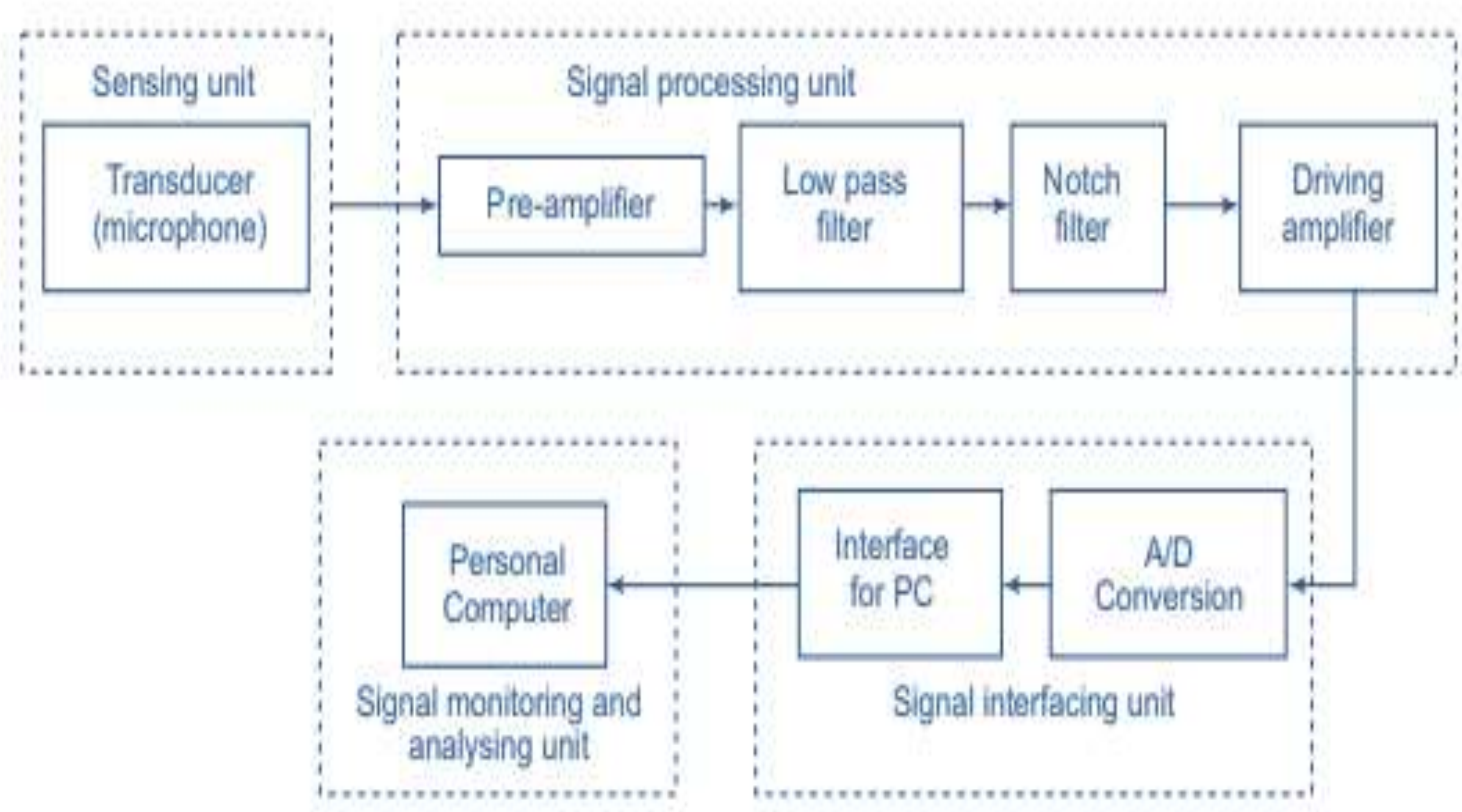
- ➢ It contains a wafer of piezo-electric material, which generates potentials when subjected to mechanical stresses due to heart sounds.
- ➢ They are smaller in size and more sensitive than the dynamic microphone.

Microphones for Phonocardiography

Dynamic type microphone:

- it consists of a moving coil having a fixed magnetic core inside it.
- The coil moves with the heart sounds and produces a voltage because of its interaction with the magnetic flux.
- The phonocardiogram depends on the design of the microphone, since it does not transform the acoustic oscillations into electrical potential uniformly for all frequencies.
- The heart sound recordings with a microphone are valid only for that particular type of microphone.

Block diagram of the phonocardiograph



(Image Courtesy: Singh and Anand, 2007)

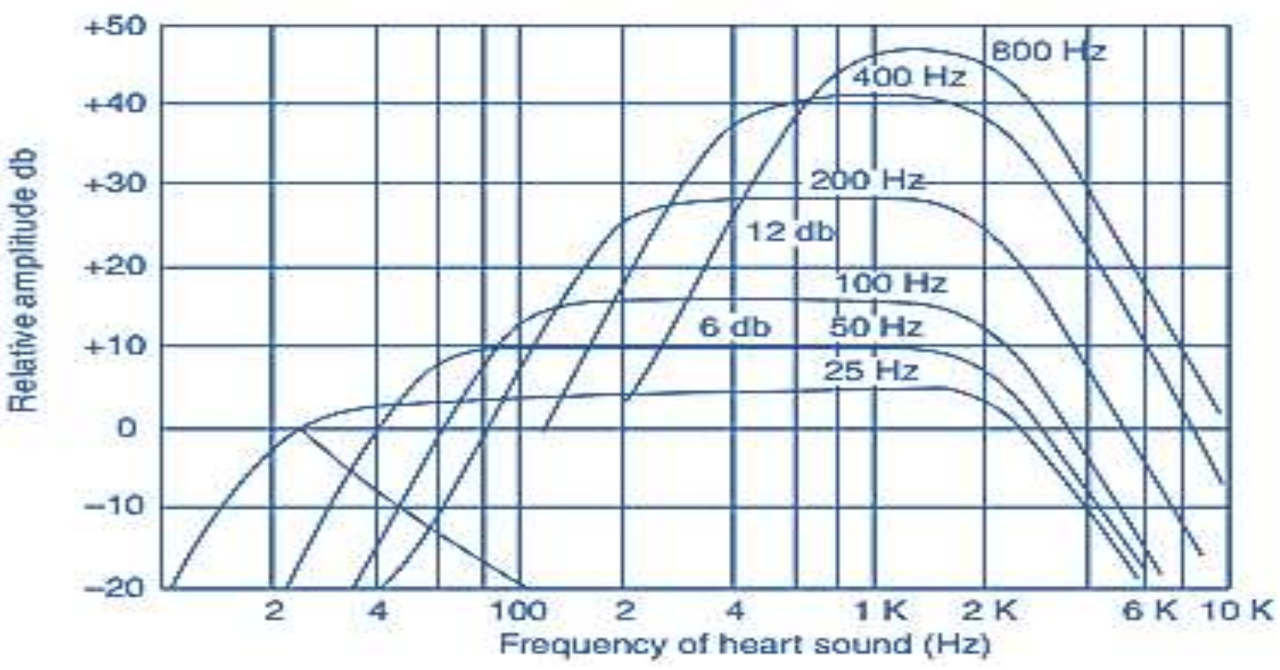
Block diagram of the phonocardiograph..

The equipment consists of four units:

- ➢ Sensing unit
  - carbon microphone, which with the supporting circuitry converts the heart sounds into proportional electric signals.
- ➢ Signal processing unit
  - Amplification and filtering circuit.
- ➢ Signal interfacing unit and signal monitoring
  - output of the signal processing unit is given to the digital interface unit which converts the analog signal into a proportional digital signal.
  - The digital signal is then connected to the PC for display on the PC monitor in real time.
- ➢ Analysing unit
  - Analyse time and frequency domains with the help of software algorithms (Example:Singh and Anand (2007).

Characteristics of amplifiers in phonocardiography

Image Courtesy: Hewlett Packard, U.S.A



Writing Methods for Phonocardiography

- Direct writing recorders based on galvanometric principle are not suitable.
- Generally done by digital recorders such as the electrostatic recorder or the thermal array recorder.
- Many phonocardiograms also have a provision for recording the patient's electrocardiogram on the same chart.
- Simultaneous recording of the **phonocardiogram and the electrocardiogram displays** both the **sounds and the electrical activity of the heart in their proper time relationship**.

Writing Methods for Phonocardiography

- The phonocardiogram is more informative than an electrocardiogram for monitoring heart valve actions.
- Fans, air-conditioners & other noise producing gadgets working nearby create vibrations within the same frequency range as the heart sounds and murmurs and will result in artefacts on the recording.
- We need a quiet area for recording phonocardiography.
- The walls and ceiling of the room should be acoustic-tiled and the recording system placed on some cushioning material, to minimize external and internal noise.

Electrooculography (EOG)

EOG

- EOG is a technique for measuring the **resting and action potential** of retina.
- Electrodes are placed either above and below the eye or to the left and right of the eye.
- **The eye acts as a dipole**
  - **The anterior pole is positive**
  - **The posterior pole is negative**

EOG..

- The EOG is the **electrical signal produced by the potential difference between the retina and the cornea of the eye**.
- This **difference is due to the large presence of electrically active nerves in the retina** compared to the front of the eye.
- Eye movement will respectively generates voltage up to **16µV and 14µV** per **1° in horizontal and vertical way**.

Electrodes used

Ag-AgCl Electrode:

- It is a type of reference electrode.
- The electrode is a silver wire that is coated with a thin layer of silver chloride.
- They are inexpensive to manufacture, are simple construction and have stable potential.

Metal disk electrode:

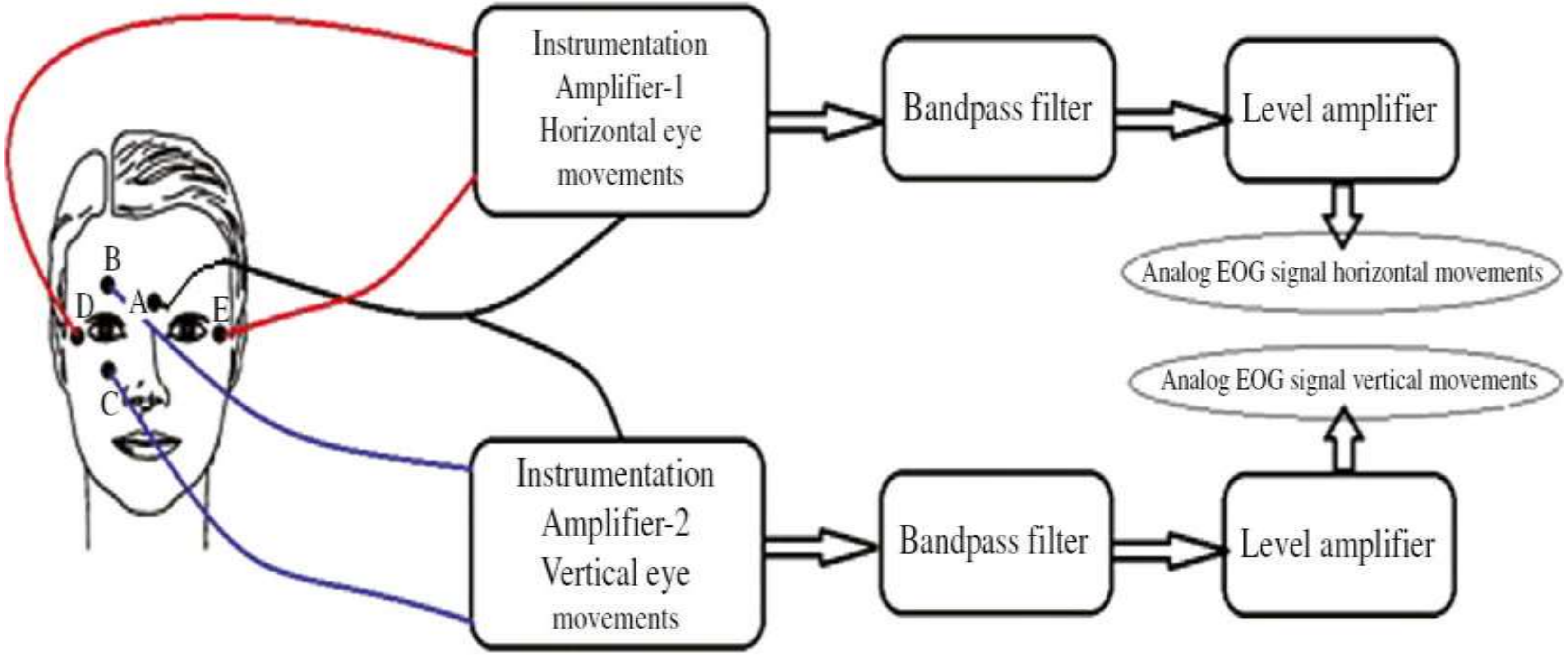
- They are generally made of high purity tin, silver, gold or even surgical steel
- Application area is near the eye region
- Diameter range is 4-10mm

Electrode placement

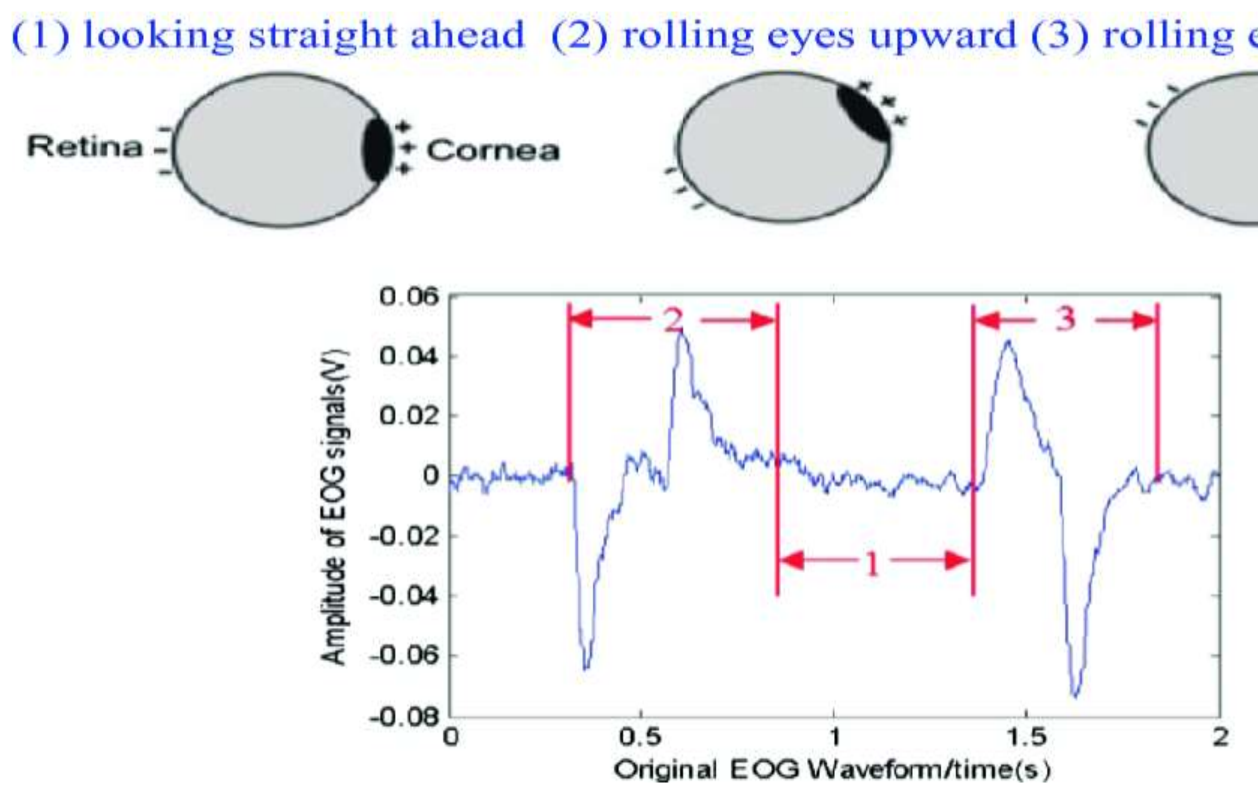
- Two electrodes are placed on the **outer side of the eye**.
- Another pair **above and below the eye**
- A **reference electrode**

EOG Data Collection

Reference: Fatma Latifoğlu et al. ," Diagnosis of attention-deficit hyperactivity disorder using EOG signals: a new approach", De Gruyter , 2020.



EOG & Eye movement..



Eda R., Tantawi M., shedeed H., Tolba M.F. (2020) Analyzing Electrooculography (EOG) for Eye Movement Detection. In: Hassanien A., Azar A., Gaber T., Bhatnagar R., F. Tolba M. (eds) The International Conference on Advanced Machine Learning Technologies and Applications (AMLTA2019). AMLTA 2019. Advances in Intelligent Systems and Computing, vol 921. Springer, Cham. https://doi.org/10.1007/978-3-030-14118-9_18

EOG Signals

- **HEOG Signals:** Obtained from horizontal eye movements

Eye movement: from center to left: +ve voltage spike from center to right:-ve voltage spike

- **VEOG Signals:** Obtained from vertical eye movements

Eye movement: from center to top: +ve voltage spike from center to bottom: -ve voltage spike

- **Blink Signals:** Obtained due to blinking of eyes

  Voluntary Blink Signals

  Involuntary Blink Signals

LEAD SYSTEMS AND RECORDING METHODS

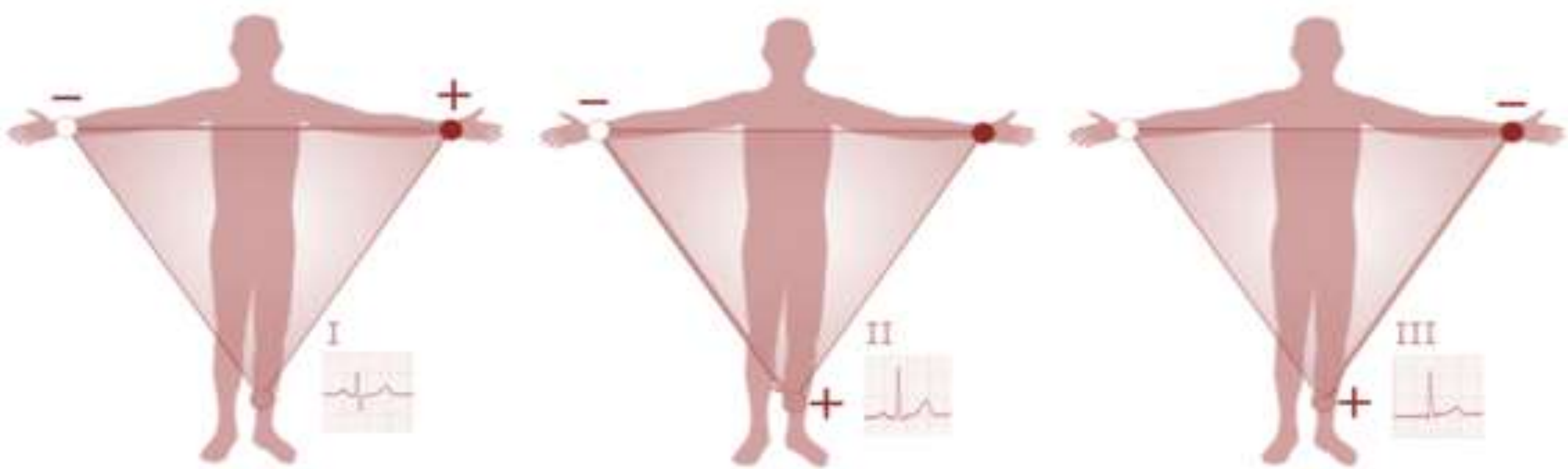
Electrodes and leads

- Electrodes are the **conductive pads attached to the body surface**.
- pair of electrodes can measure the electrical potential difference between the two corresponding locations of attachment.
- **Pair of electrodes forms *a* lead**.
- Leads can also be formed between a physical electrode and a *virtual electrode,* known as **Wilson's central terminal** (**WCT**).
- Potential of WCT is defined as the average potential measured by three limb electrodes that are attached to the right arm, the left arm, and the left foot, respectively.
- **Leads are classified into three types:**

1. **Limb**
2. **Augmented limb**
3. **Precordial or chest**

Limb leads

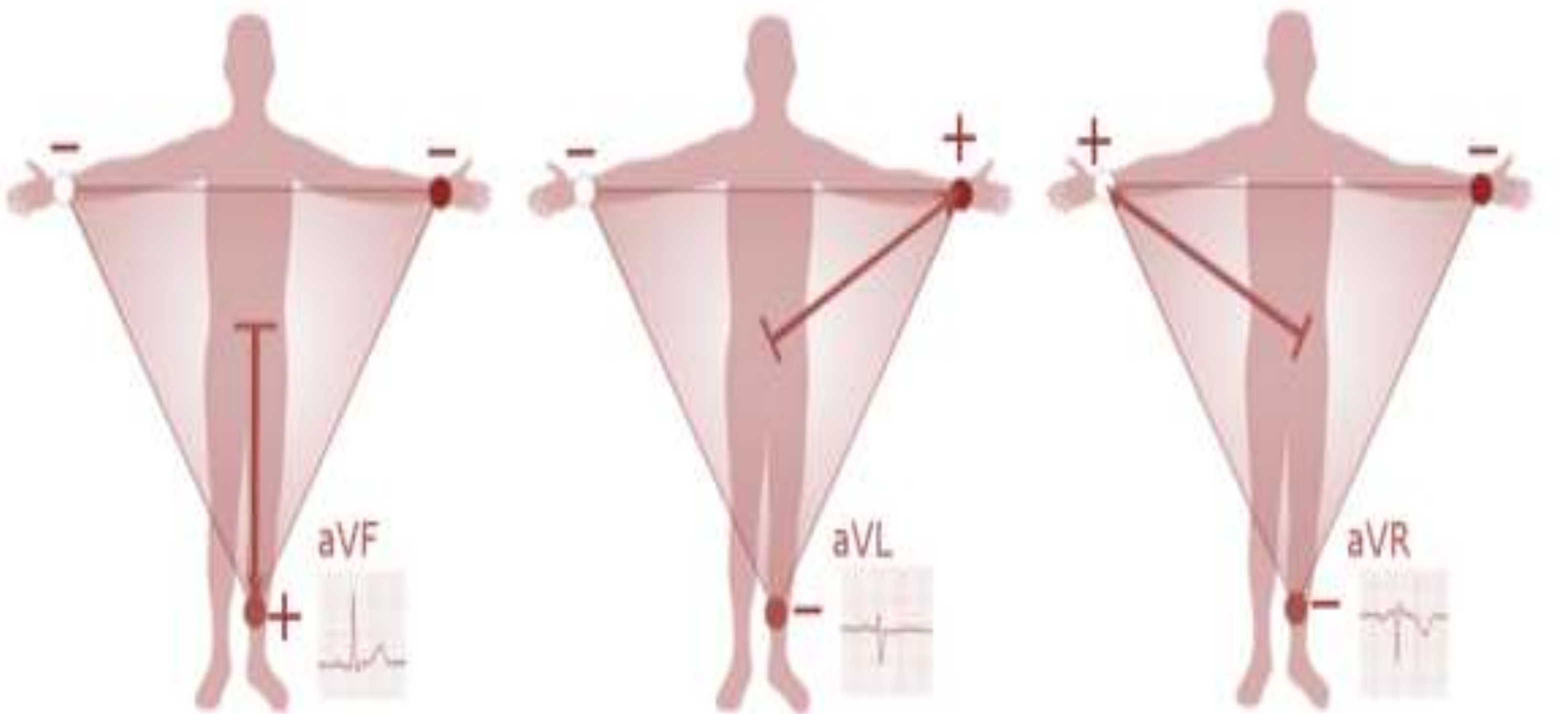
- **Leads I, II and III are called the limb leads**.
- The electrodes that form these signals are located on the limbs – one on each arm and one on the left leg.



- **Lead I is the voltage between the (positive) left arm (LA) electrode and right arm (RA) electrode:** $I = LA - RA$
- **Lead II is the voltage between the (positive) left leg (LL) electrode and the right arm (RA) electrode:** $II = LL - RA$
- **Lead III is the voltage between the (positive) left leg (LL) electrode and the left arm (LA) electrode:** $III = LL - LA$

Augmented limb leads

- Leads **aVR, aVL, and aVF are the *augmented limb leads*.**
- They are derived from the same three electrodes as leads I, II, and III, but they use Goldberger's central terminal as their negative pole.



Augmented limb leads…

- **Lead *augmented vector right* (aVR**) has the positive electrode on the right arm. The negative pole is a combination of the left arm electrode and the left leg electrode:

$$aVR = RA - \frac{1}{2}(LA + LL) = \frac{3}{2}(RA - V_W)$$

- **Lead *augmented vector left* (aVL)** has the positive electrode on the left arm. The negative pole is a combination of the right arm electrode and the left leg electrode:

$$aVL = LA - \frac{1}{2}(RA + LL) = \frac{3}{2}(LA - V_W)$$

- **Lead *augmented vector foot* (aVF)** has the positive electrode on the left leg. The negative pole is a combination of the right arm electrode and the left arm electrode:

$$aVF = LL - \frac{1}{2}(RA + LA) = \frac{3}{2}(LL - V_W)$$

Precordial leads

- The precordial leads lie in the transverse (horizontal) plane, perpendicular to the other six leads.
- The six precordial electrodes act as the positive poles for the six corresponding precordial leads: (V_1, V_2, V_3, V_4, V_5, and V_6).
- **Wilson's central terminal is used as the negative pole**.

Various Lead Systems

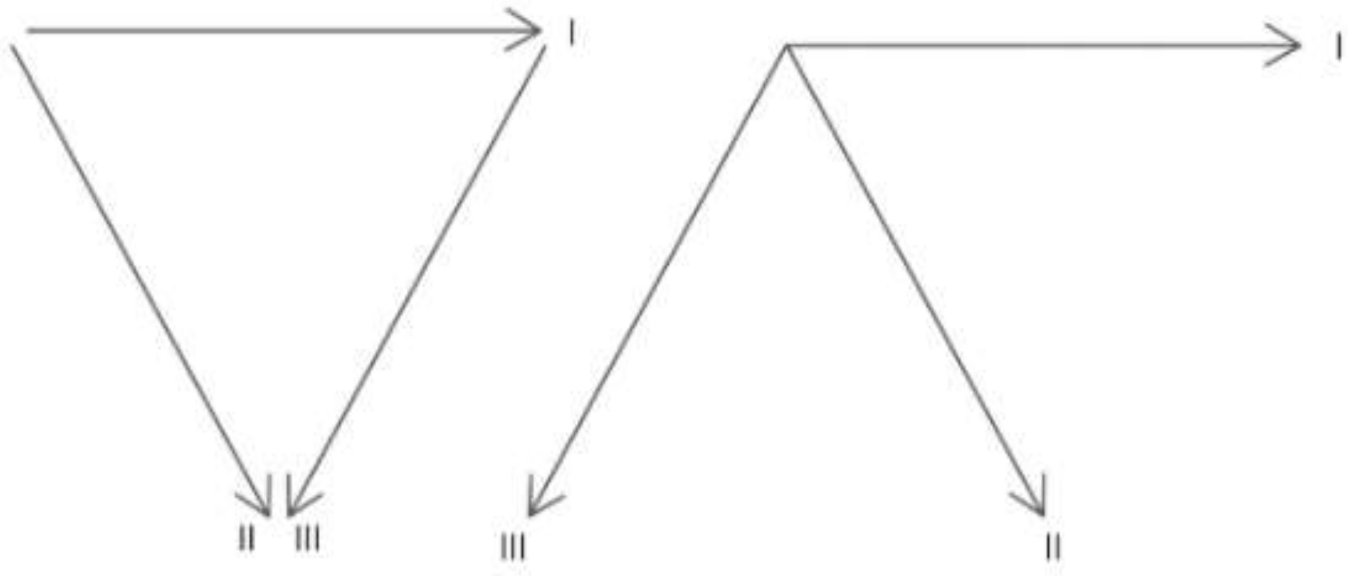
- Various lead systems have been developed and improved.

- **Einthoven’s Lead System**
- **Goldberger’s Lead System**
- **Wilson’s Lead System**
- **Frank’s Lead System**
- **EASI Lead System**
- **360°Lead System**

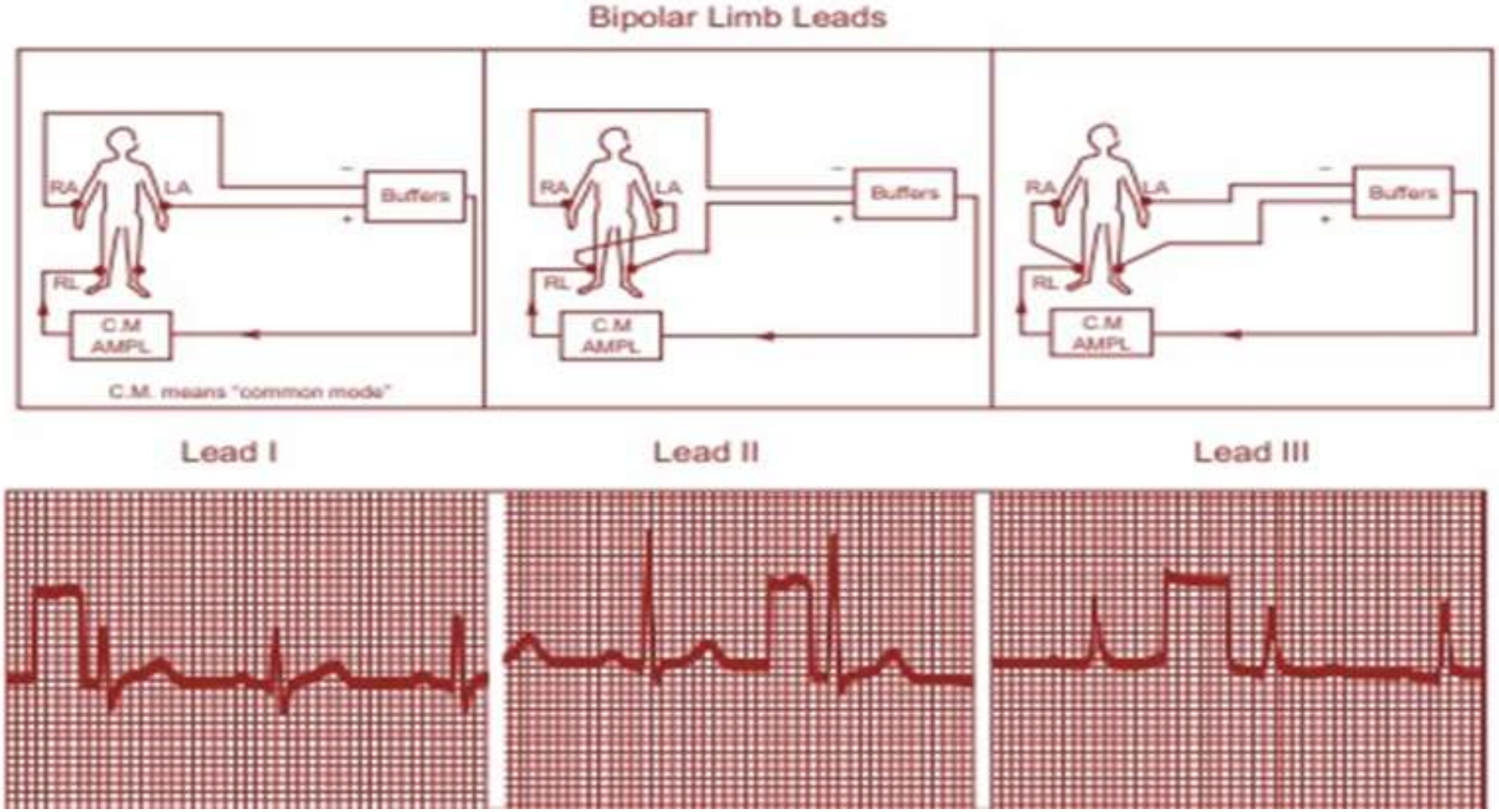
Einthoven's Lead System

- Einthoven recorded the first ECG in the world in 1903.
- The first ECG visible with the help of a string galvanometer.
- Einthoven measured the tension between **the right and left arm (lead I), the right arm and left leg (lead II), and the left arm and left leg (lead III)**.

Einthoven's Triangle



Einthoven's Triangle Based ECG

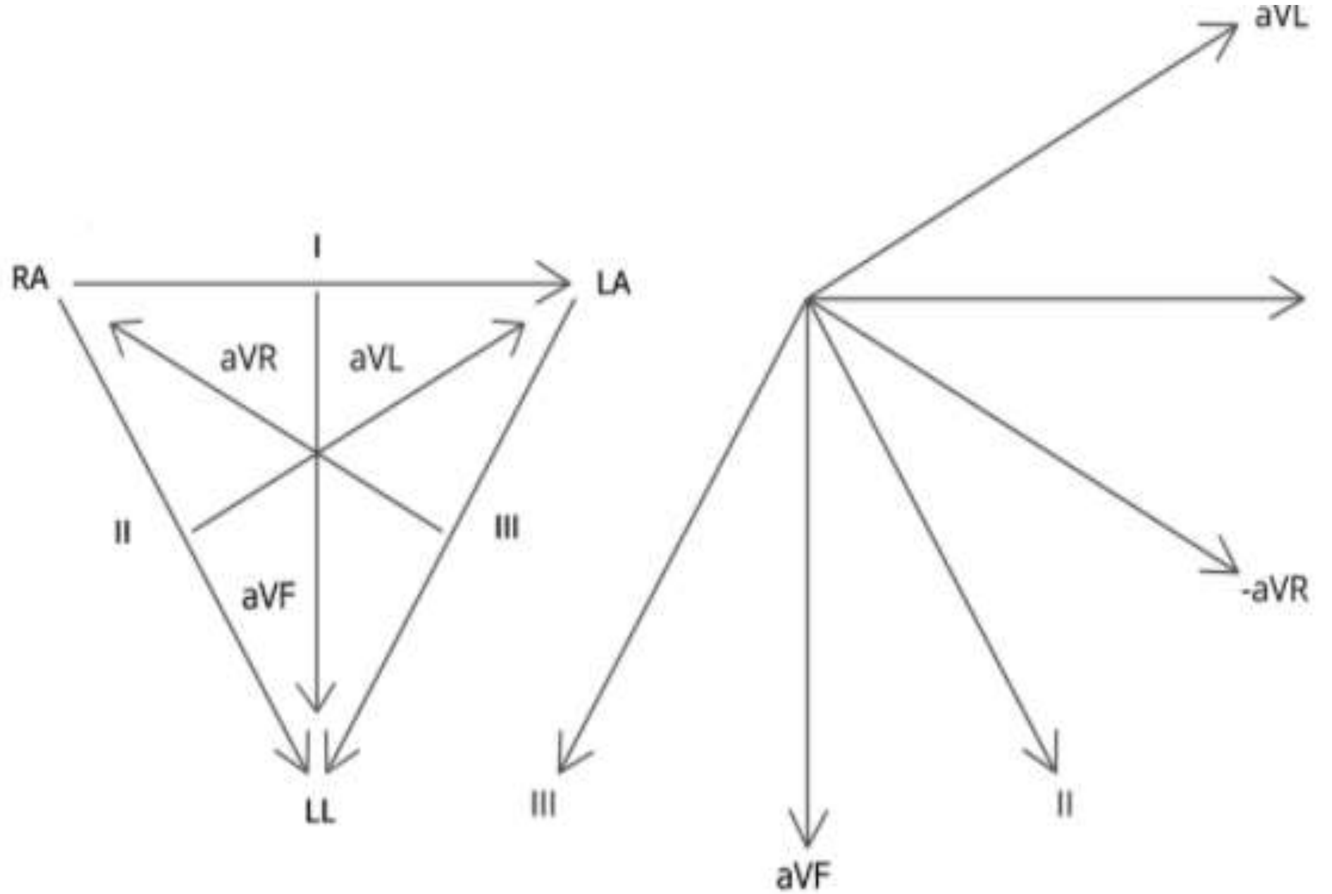


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Goldberger's Lead System

- The angle between leads I and II, II and III and II and I is 120°.
- To improve diagnosis result, cut the angles in half, with the help of a resistor network.
- This corresponds to an analog calculation of the following rules:
  - -aVR = (I + II) / 2
  - aVL = (I - III) / 2
  - aVF = (II + III) / 2

Goldberger's Lead System



Wilson's Lead System

- Electrodes are attached directly to the chest wall and measuring them against a virtual reference point, located in the middle of the heart.
- This reference point was called the CT (Common Terminal), and was generated from a resistor network.
- The Wilson leads are known as V1-V6, and portray the chest wall and the left side of the heart.
- Together with the leads from Einthoven and Goldberg, the 12-lead ECG was created.
- This lead system created the 12-lead ECG that is known today as the gold standard for ECGs.

Frank's Lead System

- Frank described the heart as a rotating dipole within space.
- In principle, a rotating dipole is like a battery with a positive and negative pole spinning in space.
- The electrodes on the body X, Y and Z were placed in a row, thereby making a Cartesian coordinate system.

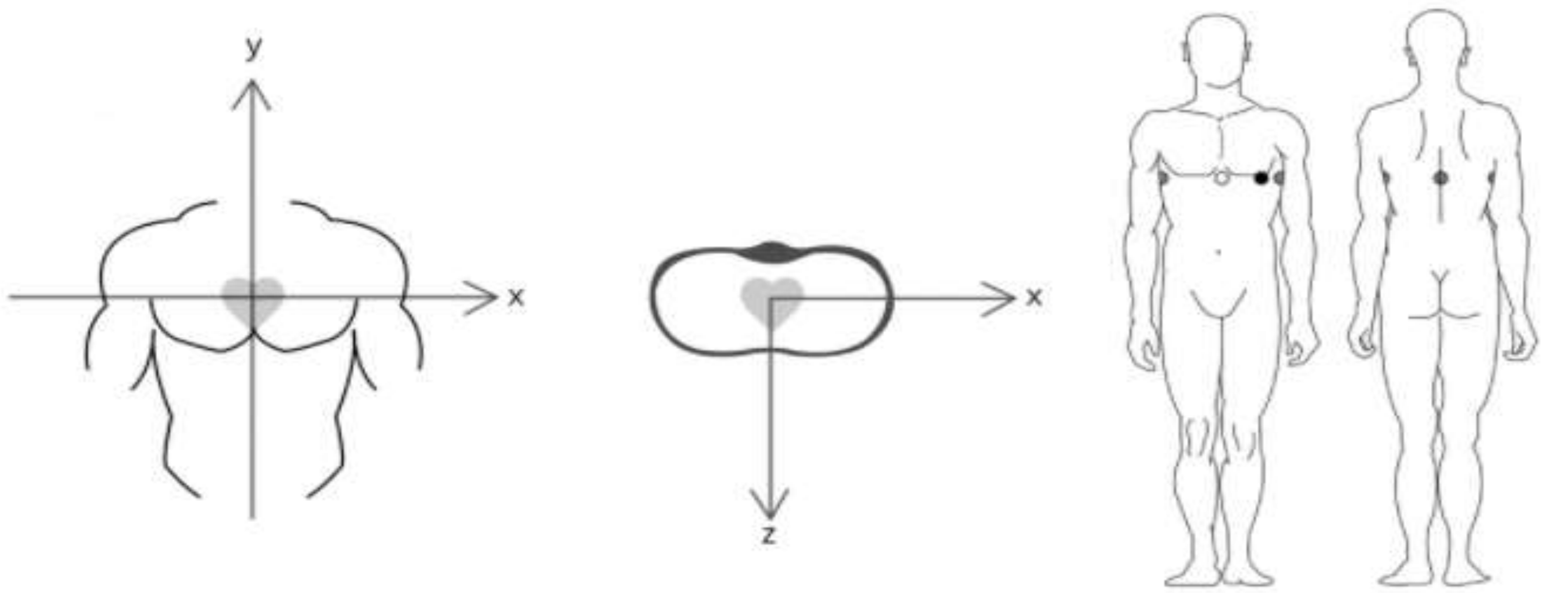


Image courtesy: https://www.cardiosecur.com/

Frank’s Lead System..

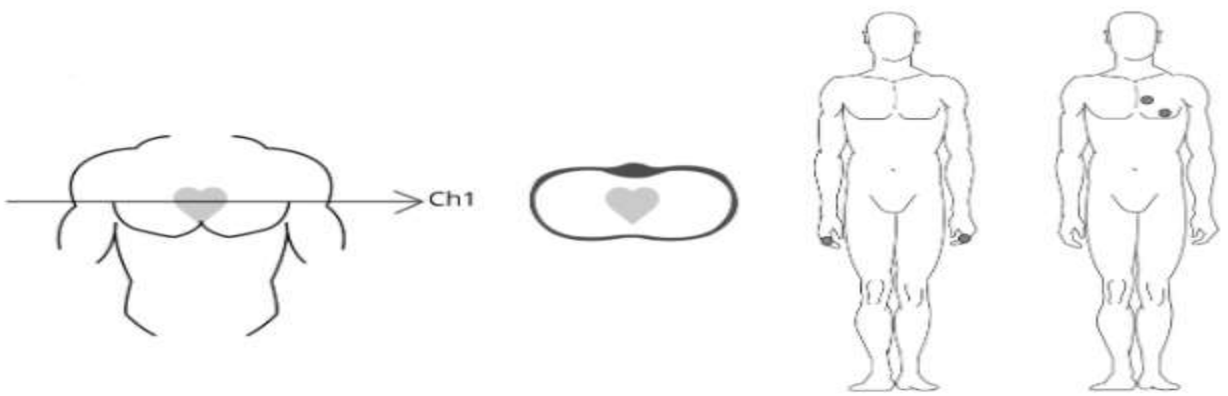
- This results in a representation in the form of a so-called vector loop.
- This corresponds to a 3D representation of the rotating heart’s dipole in space.

EASI Lead System

- Dower made Frank’s electrode system even simpler, as **he reduced the number of electrodes to five**.
- He was furthermore **able to calculate the classic 12 leads from the vector loop**.
- Dower made it possible for **classically-trained physicians to be able to read and understand the measurements from a vector ECG**.

1-lead ECG

- 1-lead ECG systems are very common today.
- These systems may be used to record either a very long recording up to 14 days (like iRhythm) or a recording of merely a few seconds (like Alivecor).
- The medical relevance of one lead ECGs is very limited.



Disorders such as atrial fibrillation or extra ventricular beats will not be recorded.

Image courtesy: https://www.cardiosecur.com/

3-lead ECG

- 3-lead ECGs are used most often for recording a 24-hour reading.
- A 24-hour reading is a frequently used tool for the diagnosis of heart problems.

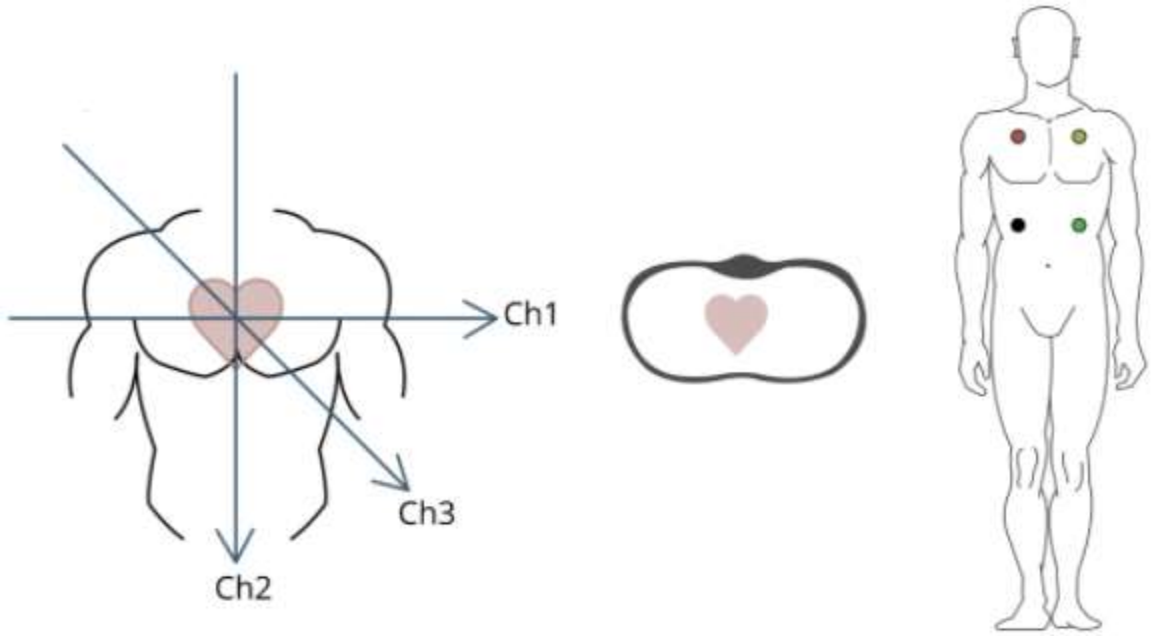
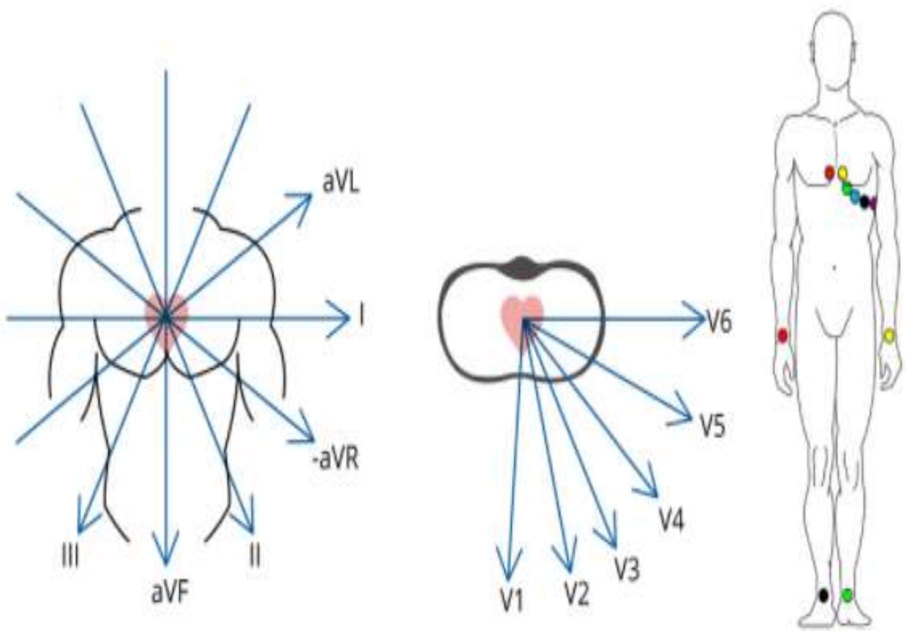


Image courtesy: https://www.cardiosecur.com/

12-lead ECG

- A 12-lead ECG combines the lead systems from Einthoven, Goldberger and Wilson, thereby providing information about vertical and horizontal axes.
- The 12-lead ECG is the gold standard for ECG diagnosis and is used for both resting and stress ECGs.



Extremities: I, II, III, aVR, aVL, aVF

Chest wall: V1, V2, V3, V4, V5, V6

Measured Leads: I, II, III, V1, V2, V3, V4, V5, V6

Calculated Leads: aVR, aVL, aVF

Image courtesy: https://www.cardiosecur.com/

Vector ECG

- The vector ECG views the heart as a rotating dipole.
- This can be described via the three mutually perpendicular axes of a Cartesian coordinate system.
- The rotating dipole in space is represented in the form of a vector loop.

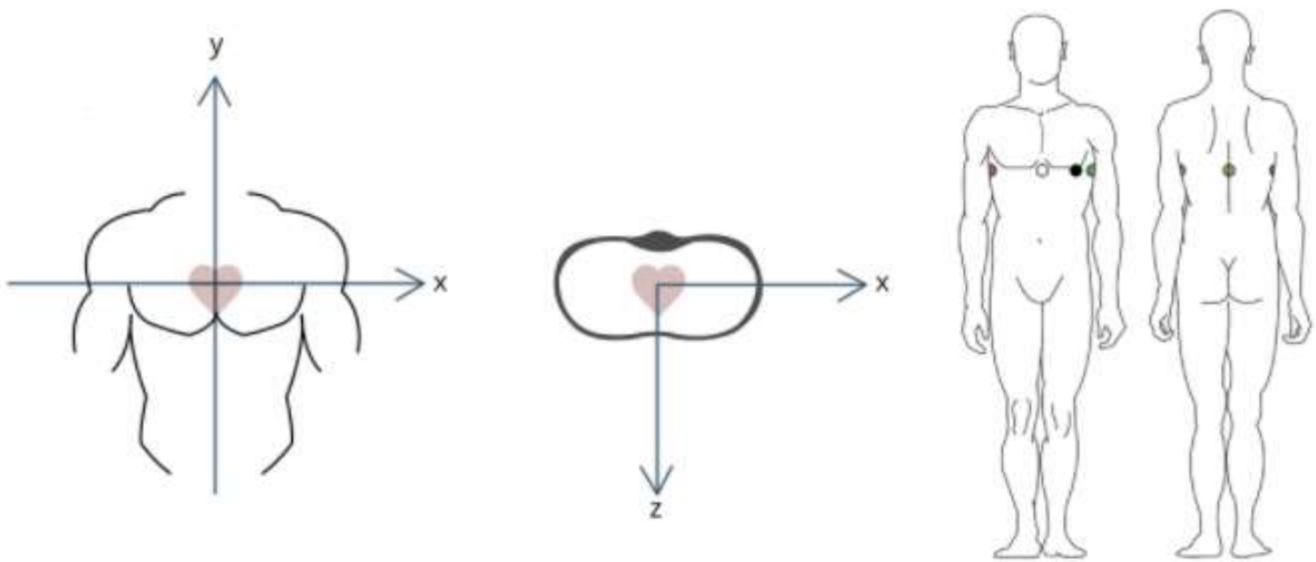


Image courtesy: https://www.cardiosecur.com/

EASI Lead System of Today

- The EASI lead system is based upon the vector loop of a vector ECG, with the classic 12 ECG leads being calculated from this vector loop.

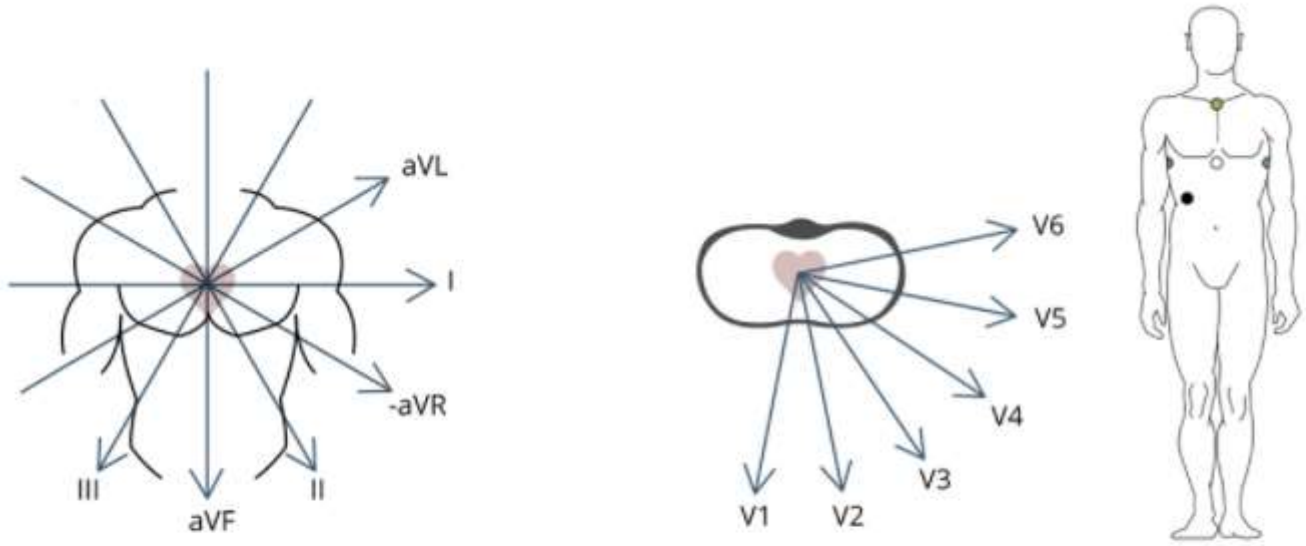


Image courtesy: https://www.cardiosecur.com/

360° Lead System

- The 360° lead system is based, as with the EASI ECG, on the vector loop of a vector ECG.
- In addition to the classic 12 ECG leads, the leads of the right and posterior heart can be calculated, making it an all-encompassing 22-lead ECG.
- It is the only ECG system that enables physicians to be 100% compliant with the cardiology guidelines without reattaching electrodes, which require anterior and posterior analysis of the heart.

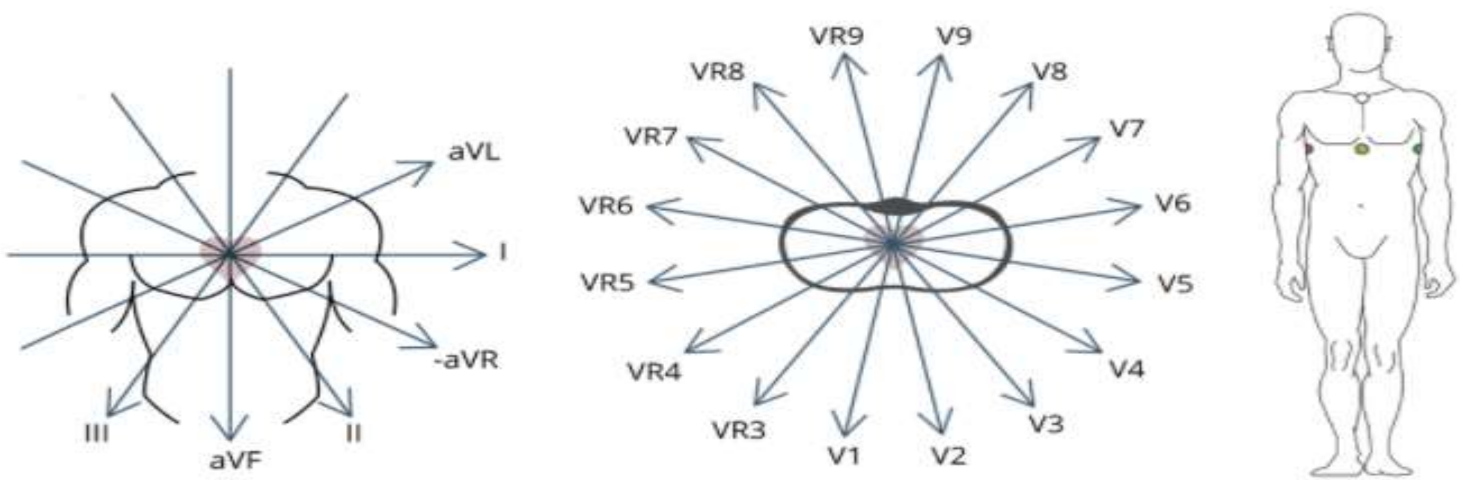
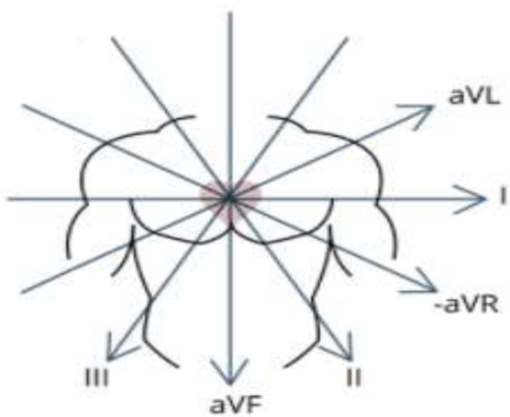


Image courtesy: https://www.cardiosecur.com/

360° Lead System

Leads:

- Extremities: I, II, III, aVR, aVL, aVF
- Chest Wall: V1, V2, V3, V4, V5, V6
- Measured Leads: R, M, L (not shown)
- Calculated Leads: I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5, V6, V7, V8, V9, VR3, VR4, VR5, VR6, VR7, VR8, VR9



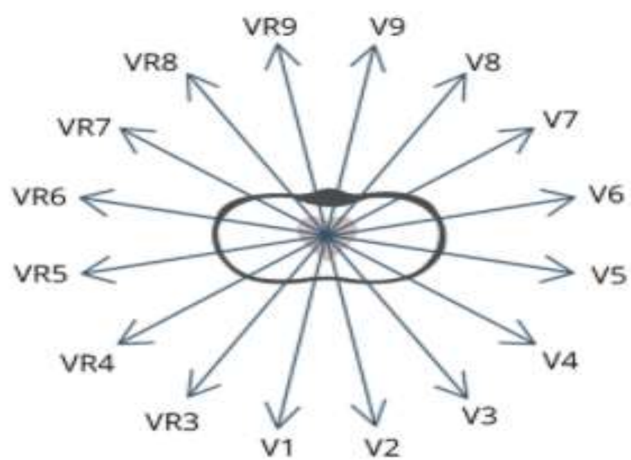


Image courtesy: https://www.cardiosecur.com/

Recording of an ECG

- Overall direction of depolarization and repolarization produces positive or negative deflection on each lead's trace.
- For example, depolarizing from right to left would produce a positive deflection in lead I because the two vectors point in the same direction.
- In contrast, that same depolarization would produce minimal deflection in V_1 and V_2 because the vectors are perpendicular, and this phenomenon is called isoelectric.

Recording of an ECG

- Depolarization of the heart *towards* the positive electrode produces a positive deflection.
- Depolarization of the heart *away* from the positive electrode produces a negative deflection.
- Repolarization of the heart *towards* the positive electrode produces a negative deflection.
- Repolarization of the heart *away* from the positive electrode produces a positive deflection.

Recording of an ECG

- The **recording** of an **ECG** on standard paper allows the time taken for the various phases of electrical depolarisation to be measured, usually in milliseconds.
- **The first electrical signal on a normal ECG originates from the atria** and is known as the **P wave.** P wave represents atrial depolarization.
- There is **a short, physiological delay** as the **atrioventricular (AV) node** slows the electrical depolarisation before it **proceeds to the ventricles**. This delay is responsible for the **PR interval.**
- PR interval (measured from the beginning of the P wave to the first deflection of the QRS complex). **Normal range 120 – 200 ms (3 – 5 small squares on ECG paper)**. QRS complex represents ventricular depolarization.
- T wave represents ventricular repolarization. U wave represents papillary muscle repolarization.Depolarisation of the ventricles results in usually the largest part of the ECG signal (because of the greater muscle mass in the ventricles) and this is known as the **QRS complex**.

Recording of an ECG

- **QRS duration** (measured from first deflection of QRS complex to end of QRS complex at isoelectric line). **Normal range up to 120 ms (3 small squares on ECG paper).**
- In the case of the ventricles, there is also an electrical signal reflecting repolarisation of the myocardium. This is shown as the **ST segment** and the **T wave.**
- **QT interval** (measured from first deflection of QRS complex to end of T wave at isoelectric line). **Normal range up to 440 ms** (varies with heart rate and may be slightly longer in females)

Sample standard ECG paper

Standard ECG recording settings:

Paper speed – 25mm/sec

Voltage gain – 10mm/mV

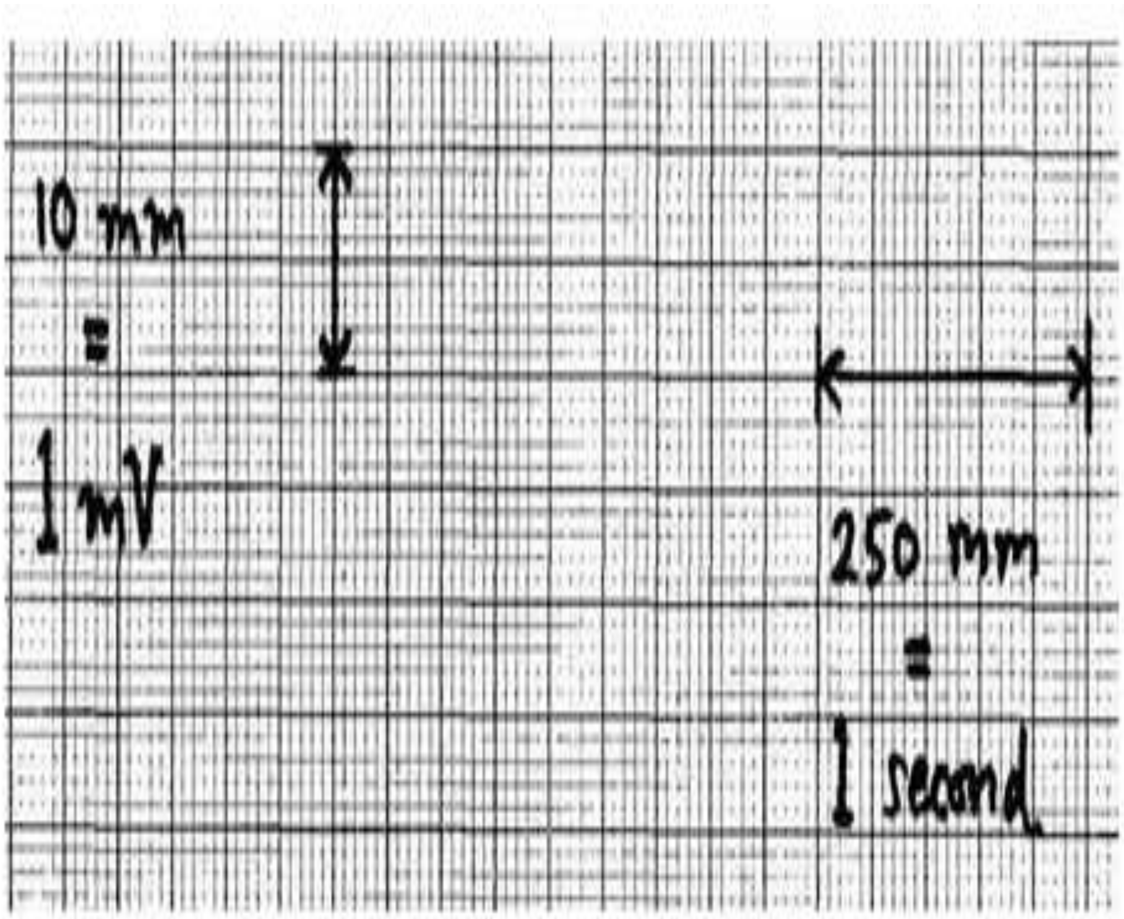


Image Courtesy: Dr Dallas Price

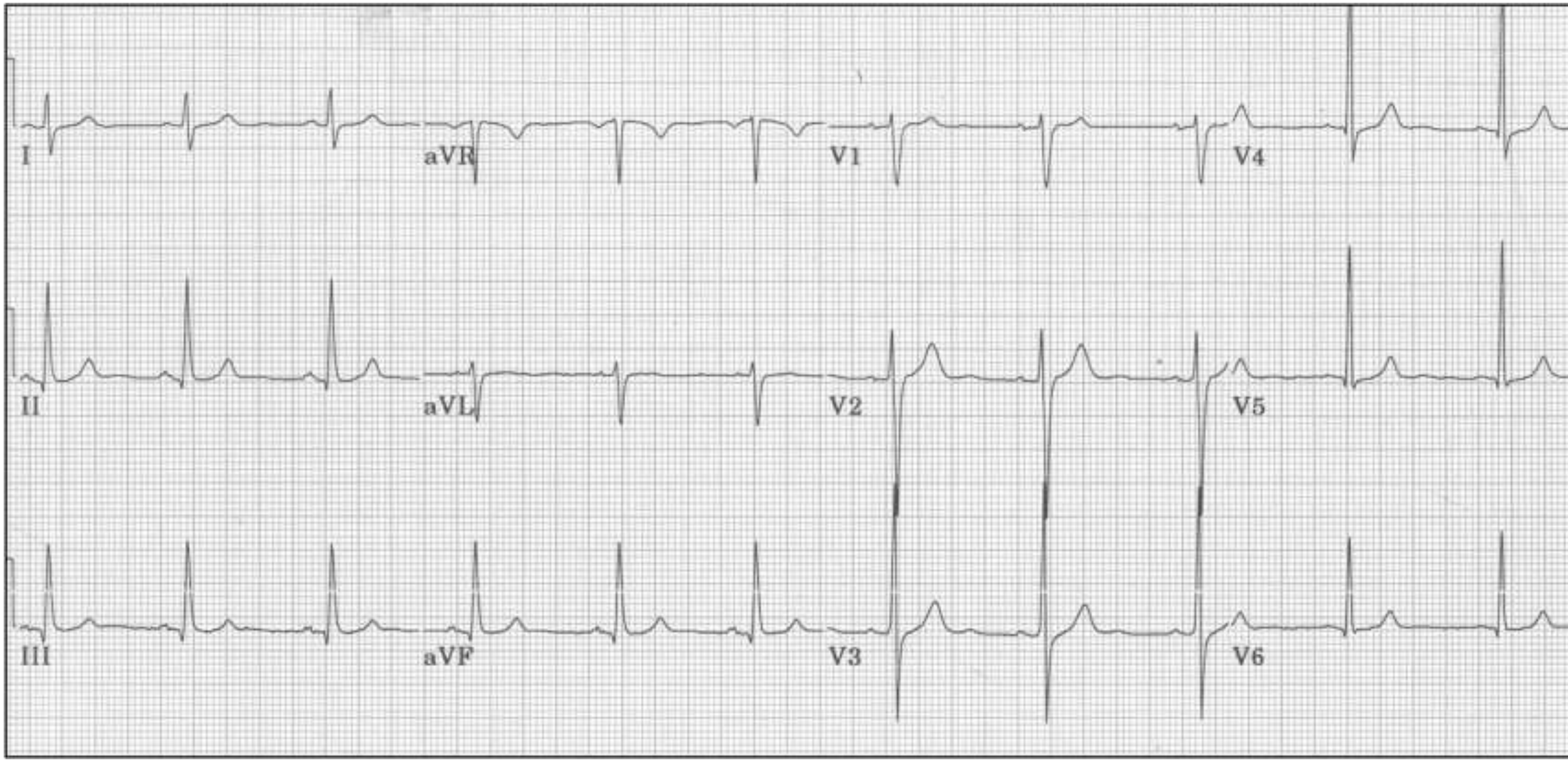
Heart rate estimation from the ECG

- Standard ECG paper allows an approximate estimation of the heart rate (HR) from an ECG recording.
- Each second of time is represented by 250 mm (5 large squares) along the horizontal axis.
- If the number of large squares between each QRS complex is:
  - 5 - the HR is 60 beats per minute.
  - 3 - the HR is 100 per minute.
  - 2 - the HR is 150 per minute.

TYPICAL WAVEFORMS AND SIGNAL CHARACTERISTICS

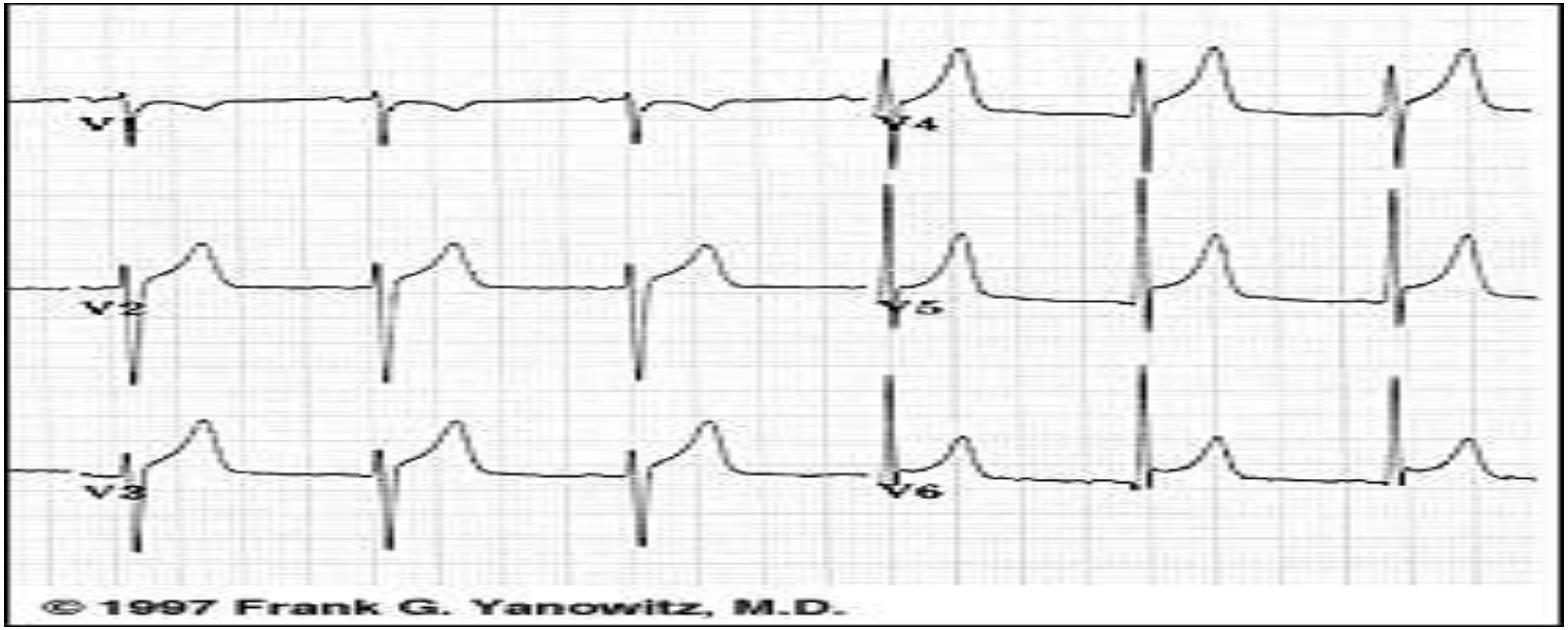
ECG waveforms and signal characteristics

Characteristics of the Normal ECG



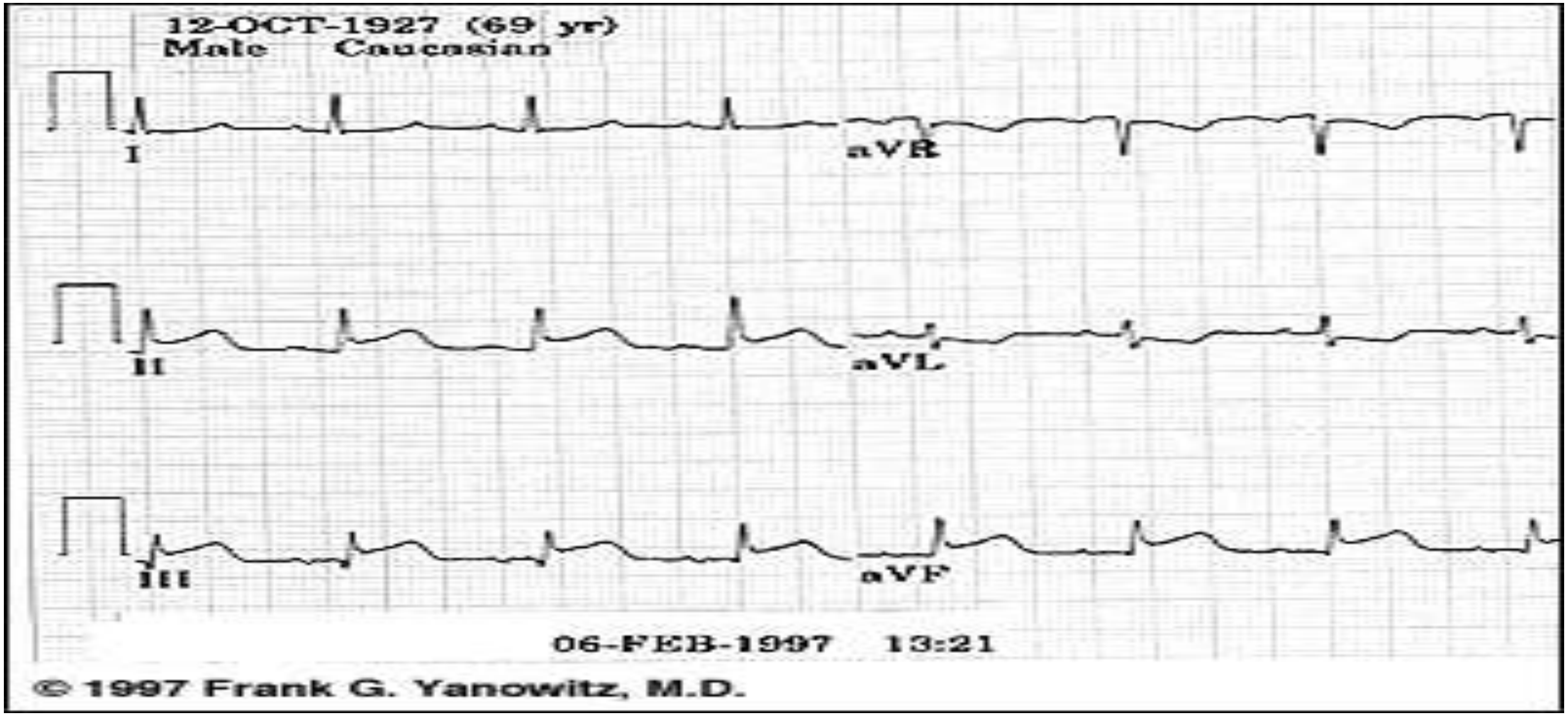
Concave upward

- Normal ST segment elevation: this occurs in leads with large S waves (e.g., V1-3), and the normal configuration is **concave upward**.
- ST segment elevation with concave upward appearance may also be seen in other leads; this is often called **early repolarization**, although it's a term with little physiologic meaning (see example of "early repolarization" in leads V4-6):



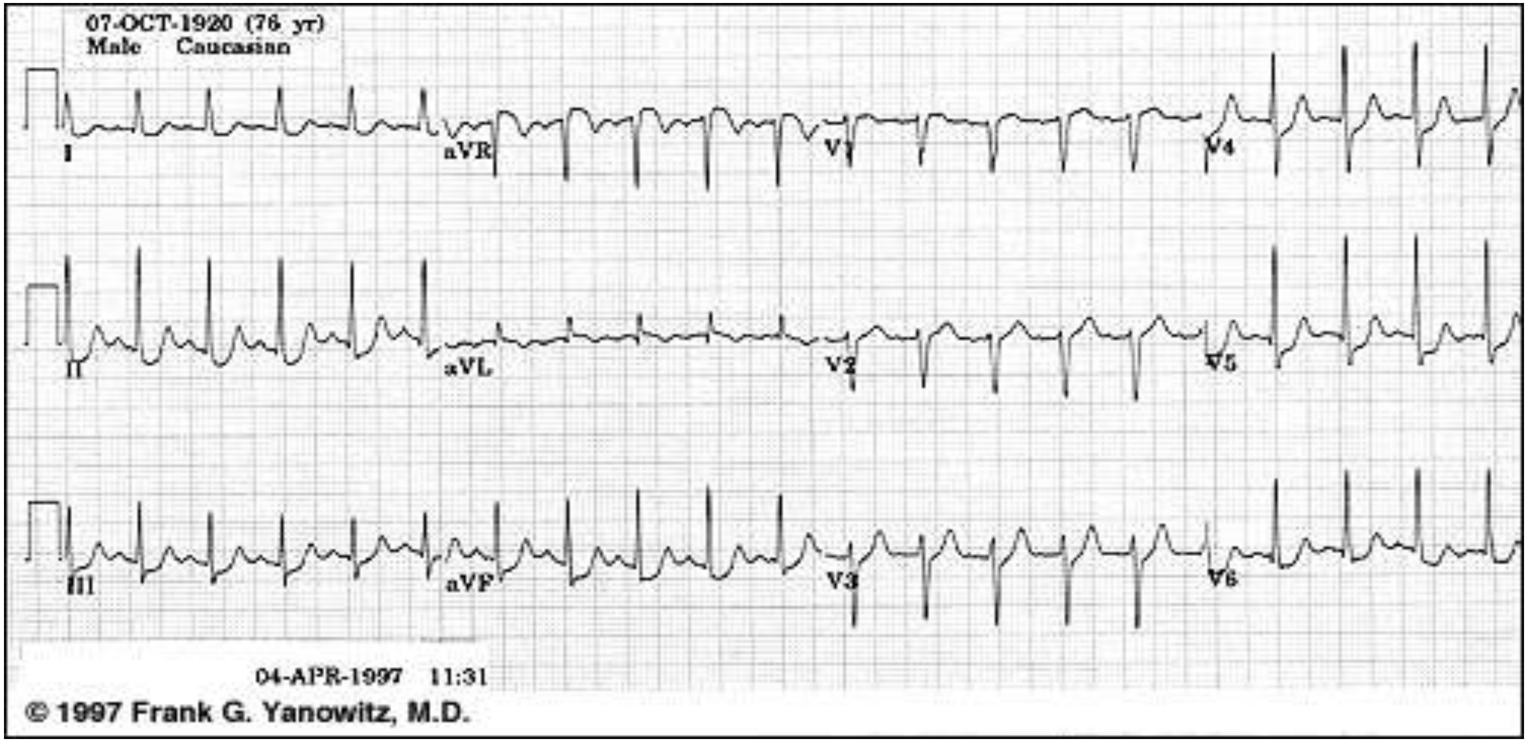
Convex or straight upward

- **Convex or straight upward** ST segment elevation (e.g., leads II, III, aVF) is abnormal and suggests transmural injury or infarction:

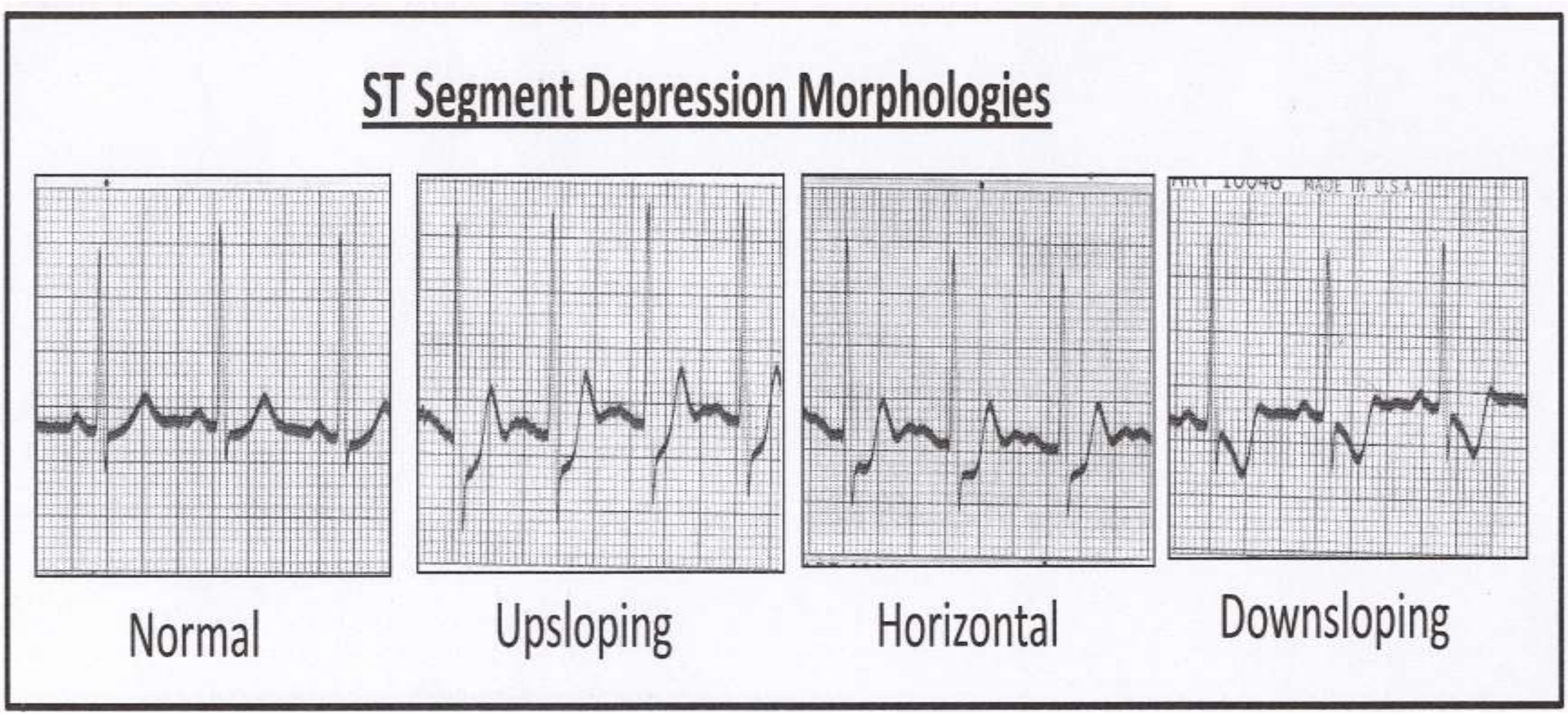


ST segment depression

- ST segment depression is always an abnormal finding, although often nonspecific

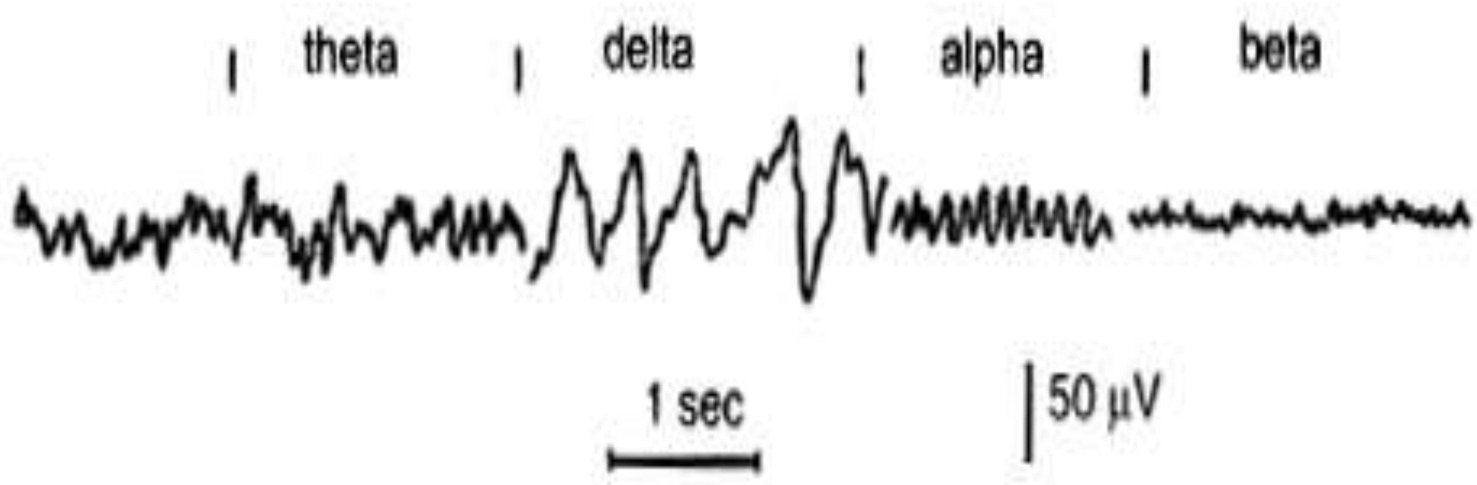


ST segment depression

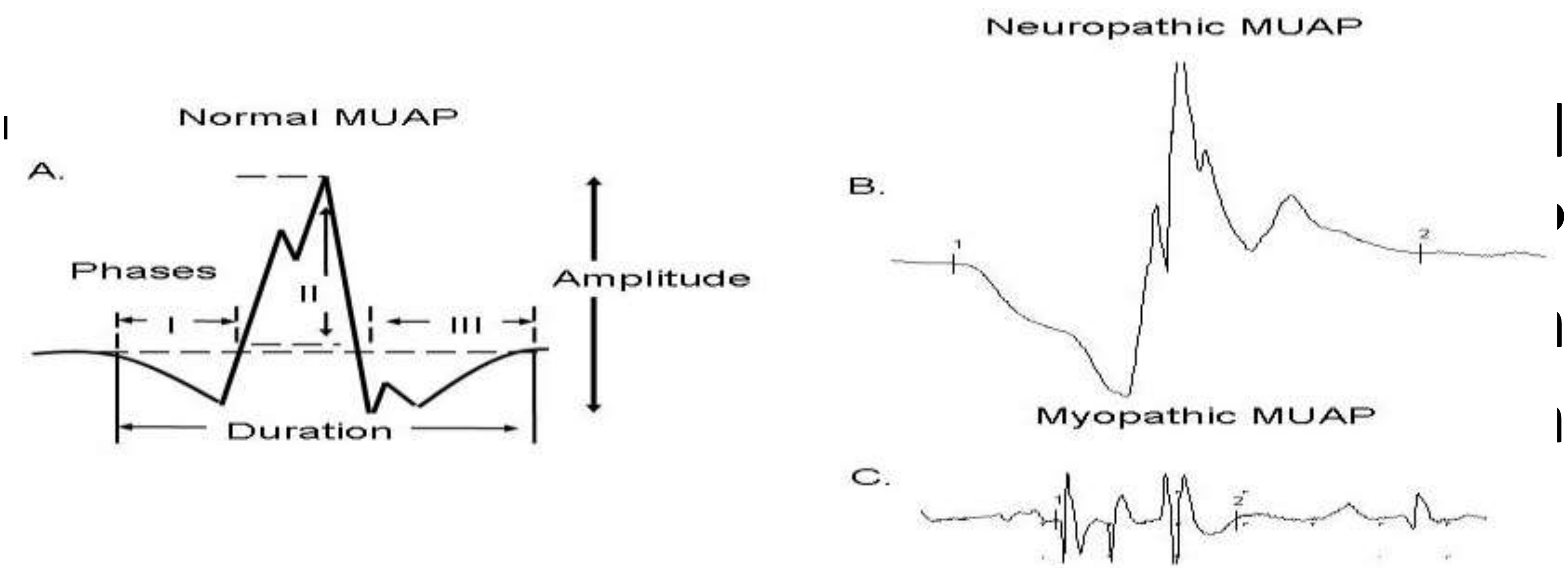


Other Wave forms & Signal Characteristics

- EEG



EMG



- **Myopathic and neuromuscular junctions (NMJ) disorders, the resulted motor unit action potential (MUAP)s are of short duration, small amplitude and also polyphasic.**

END OF UNIT II

Biomedical Instrumentation (U18PCEC603)

UNIT III

ASSIST DEVICES AND BIO-TELEMETRY

Topics

- Cardiac pacemakers
- DC Defibrillator
- Telemetry principles & frequency selection
- Biotelemetry
- Radio-pill
- Tele-stimulation & Tele-medicine.

CARDIAC PACEMAKERS

Cardiac pacemakers

- A device capable of generating artificial pacing impulses and delivering them to heart is known as pacemaker system or pacemaker.
- A pacemaker is a small, battery-operated device.
- This device senses when the heart is beating irregularly or too slowly.
- It sends a signal to your heart that makes the heart beat at the correct pace.
- Pacemakers weigh as little (28 grams)
- Pacemakers have 2 parts:

➢ The **generator contains the battery** and the information to control the heartbeat.

➢ The **electrodes(leads) that connect the heart to the generator & carry the electrical messages to the heart**.

➢ A pacemaker is implanted under the skin.

Types of Pacemakers

- The classification of pacemakers is based on the mode of application of the stimulating pulses to the heart.
- **Types: (i) External pacemakers (ii) Internal pacemakers**
- **External pacemakers** are used when the heart **block** as an emergency and when it is expected to be present for a **short time**.
- **Internal pacemakers** are used in cases requiring **long-term pacing** because of **permanent damage which affect the self- triggering of the heart**.
- The internal pacemaker implanted in the body.
- The patient is able to move freely & internal pacemaker is not tied to any external apparatus.

EXTERNAL PACEMAKERS

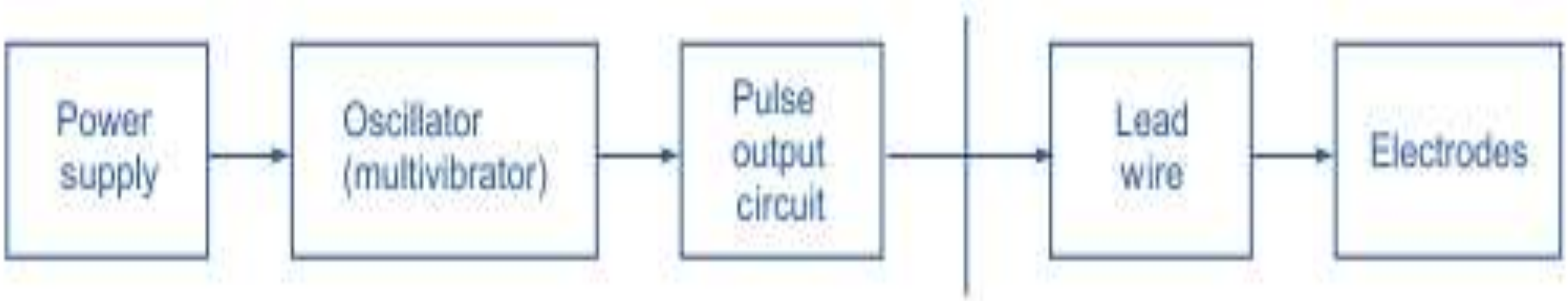
- External pacemakers are used for patients recovering from cardiac surgery to correct temporary conduction disturbances resulting from the surgery.
- When normal conduction returns and the use of pacemakers is discontinued.
- The pacing impulse is applied through metal electrodes placed on the surface of the body.
- Electrode jelly is used for better contact and to avoid burning of the skin.
- External pacemaker may apply up to 80-mA pulses through 50-cm^2 electrode on the chest.
- This is painful &it is used only in an emergency or a temporary situation.

EXTERNAL PACEMAKERS..

- The pulses may be delivered:
- ➢ Continuously
- ➢ On demand R-wave synchronous pacing:
- ➢ Normally the pacemaker is inoperative but it is activated when the heart rate falls below the normal or pre-set value.
- ➢ The beat to beat examination of the time interval between two R-waves is done. When this interval exceeds the pre-set value, the pacemaker comes into operation.

BLOCK DIAGRAM OF EXTERNAL PACEMAKERS

- The electronic circuit of a pacemaker consists of two parts, namely the impulse-generating (oscillator) circuit and the output circuit.
- The impulse-forming circuit determines the frequency and duration of the impulses.
- This is usually a multi-vibrator circuit with adjustable rate and fixed pulse width.
- The output circuit determines the shape and amplitude of the impulse.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

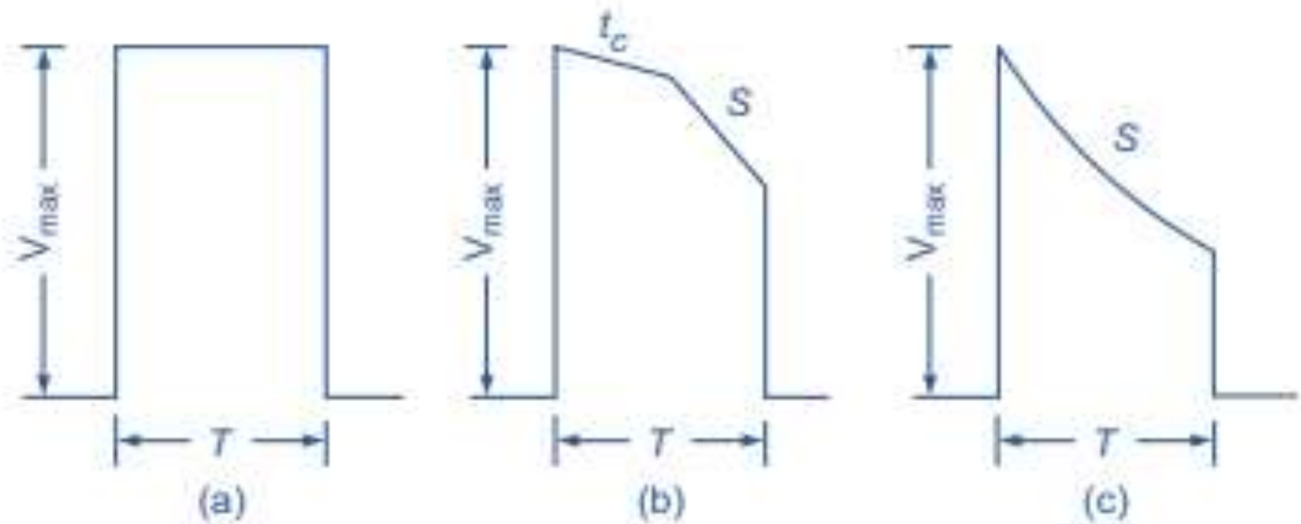
Different types of pacemakers as seen on oscilloscope

- There are three types of pacemakers based on the type of output waveform

  (a) constant current type pacemaker

  (b) current limited voltage pacemaker

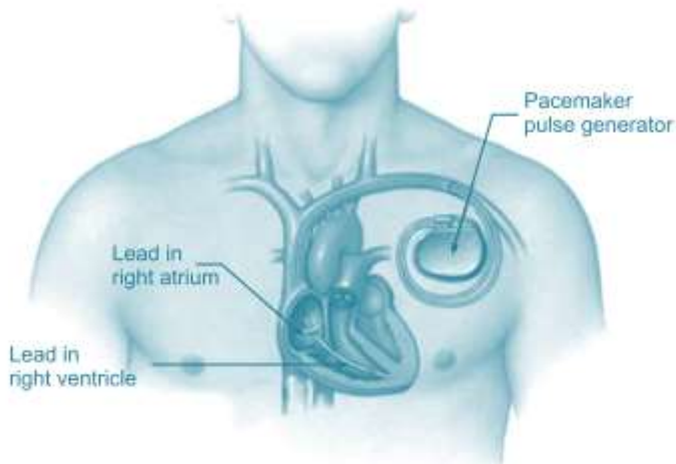
  (c) voltage pacemaker



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

IMPLANTABLE PACEMAKERS

- The implantable pacemaker is designed to be entirely implanted beneath the skin.
- Its output leads are connected directly to the heart muscle.



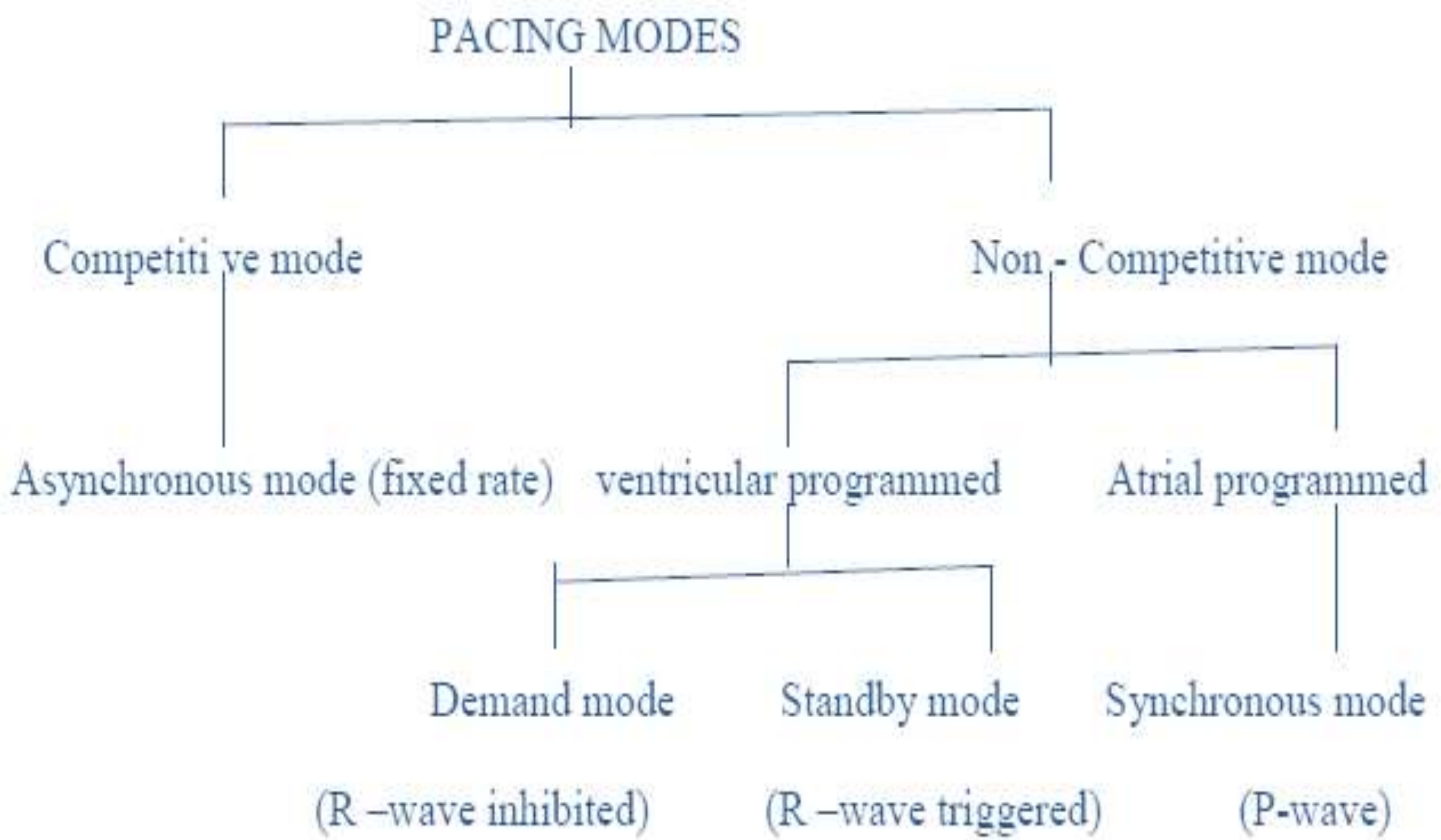
- The pacemaker is a miniaturized pulse generator and is powered by small batteries.
- The circuit is so designed that the batteries supply sufficient power for a long period.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Basic requirements

- The components used in the circuit should be highly reliable
- The power source should be in a position to supply sufficient power to the circuit over prolonged periods of time
- The circuit should be covered with a biological inert material so that the implant is not rejected by the body.
- The unit should be covered in a way that body fluids do not find a way inside the circuit (to avoid short ckt)

PACING MODES



Types of Implantable Pacemakers

Single-Chamber Pacemakers

- only one wire is placed into a chamber of the heart.
- Sometimes it is the upper chamber, or atrium.
- Other times it is the lower chamber, or ventricle.

Dual-Chamber Pacemakers

- wires are placed in two chambers of the heart.
- One lead paces the atrium and one paces the ventricle.
- This type of pacemaker can coordinate function between the atria and ventricles.

Rate-Responsive Pacemakers

- Have sensors that automatically adjust to changes in a person's physical activity.

Types of Pacemakers..

Fixed Rate Pacemaker:

- This type of pacemaker is intended for patients having permanent heart blocks. The rate is pre-set, at 70 bpm.

R wave Triggered Pacemaker:

- The ventricular synchronized demand type (R wave triggered) pacemaker is for patients who are in heart block with occasional sinus rhythm. The pacemaker detects ventricular activity (R wave of ECG) and stimulates the ventricles after a very short delay time of some milliseconds.

Types of Pacemakers..

Ventricular Inhibited or R Wave Blocked Pacemaker:

- The ventricular inhibited type (R wave blocked) pacemaker is meant for patients who generally have sinus rhythm with occasional heart block. The circuitry detects spontaneous R wave potentials at the electrodes and the pacemaker provides a stimulus to the heart after pre-set asystole.

Atrial Triggered Pacemaker:

- This is a R wave triggered or atrial triggered pacemaker. The pacemaker detects the atrial de-polarization and starts the pulse forming circuits after a delay so that the impulse to the ventricles is delivered after a suitable PR interval.

Types of Pacemakers..

Dual Chamber Pacemakers:

- These devices are capable of treating the majority of those patients who suffer from diseases of the sino-atrial node by providing atrial stimulation whenever needed.
- In these devices, both the atria and the ventricles are sensed and stimulated as needed while maintaining proper synchronization of the upper and lower chambers.

Pacemaker Code

I	II	III	IV	V
Chamber(s) paced	Chamber(s) sensed	Response to sensing	Programmability, rate modulation	Antitachyarrhythmia function(s)
0 = None	0 = None	0 = None	0 = None	0 = None
A = Atrium	A = Atrium	T = Triggered	P = Simple Programmable	P =Pacing (antitachyarrhythmia)
V = Ventricle	V = Ventricle	I = Inhibited	M = Multiprogrammable	
D =Dual (A+V)	D = Dual (A+V)	D= Dual (T+I)	C = Communicating	S = Shock
S= Single	S= Single (A or V)	(A or V)	R = Rate modulation	D = Dual (P+S)

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

VENTRICULAR ASYNCHRONOUS PACEMAKER (FIXED RATE PACEMAKER)

- It can be implemented in atrium or ventricle.
- Suitable for patients who are suffered by total AV block, atrial arrhythmia.
- It consists of square wave generator and monostable multivibrator circuit.
- The period square Wave generator is given as T.

$$T = -2(RC)\ln\left(\frac{R3}{2R2+R3}\right)$$

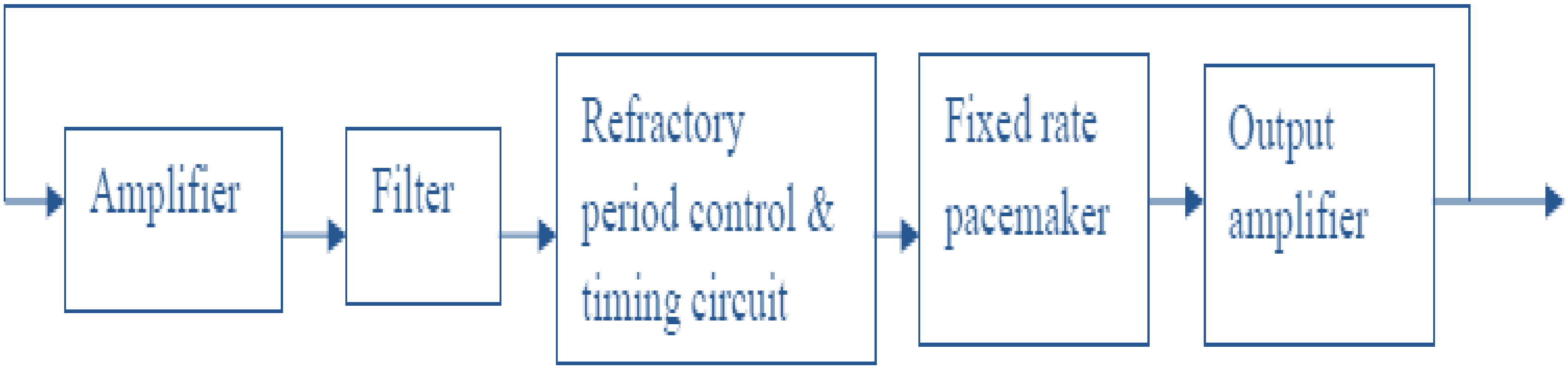
- Pulse duration is given by

$$T_d = 5C_c\left(\frac{R5R6}{R5+R6}\right)$$

VENTRICULAR SYNCHRONOUS PACEMAKER (STANDBY PACEMAKER)

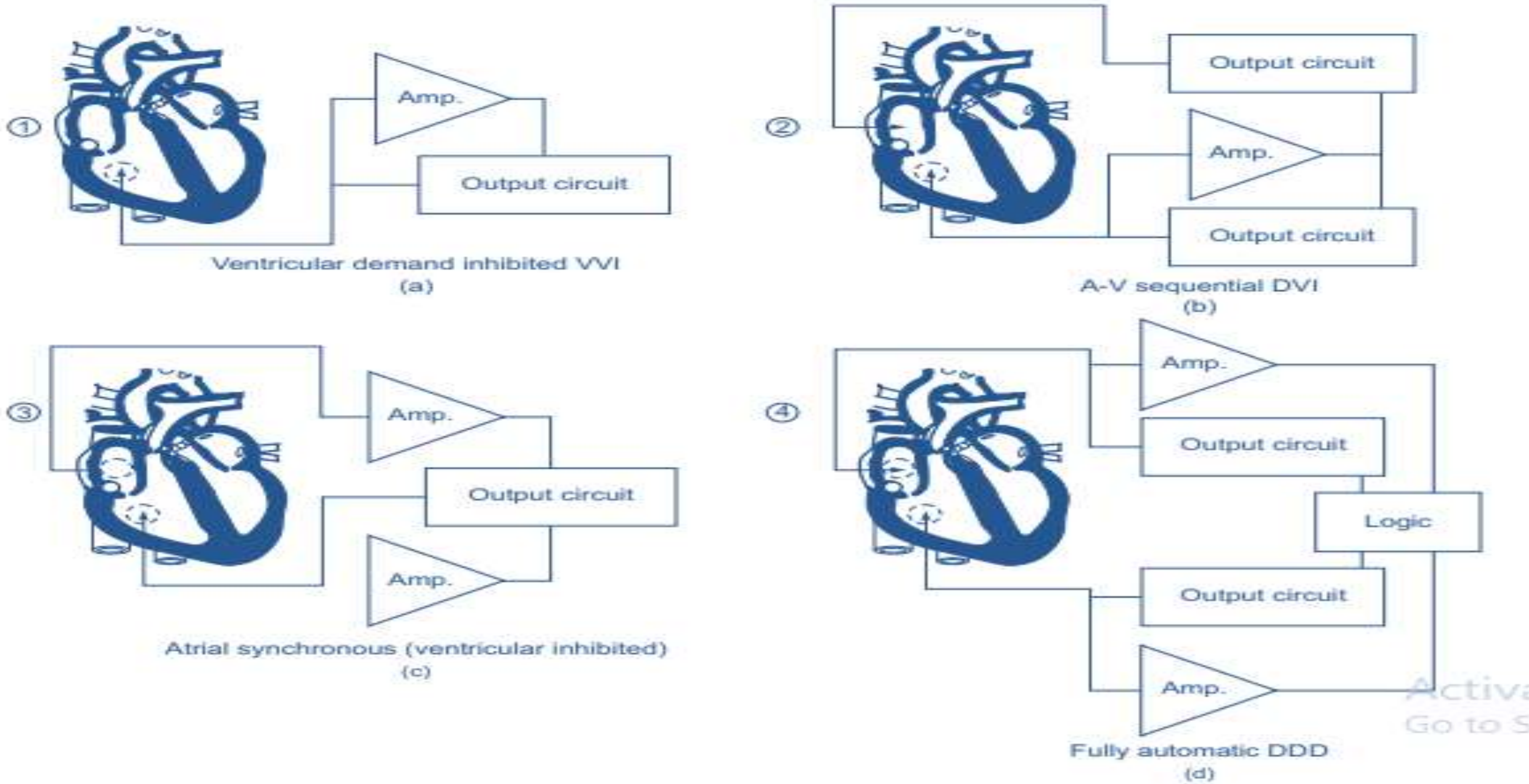
- Suitable for the patients who are suffered by short period of AV block.
- Electrode placed in the right ventricle of heart. This electrode is used to sense the R-wave.
- If ventricular contractions are absent, then the pacemaker provides the impulses.
- This type of pacemaker does not compete with the normal heart activity.

VENTRICULAR SYNCHRONOUS PACEMAKER (STANDBY PACEMAKER)..



- Electrode is used to detect the heart rate and it is given to the amplifier and filter circuit. Because heart rate amplitude is very low.
- Amplifier is used to amplify the cardiac signal.
- Filter is used to remove unwanted noise signal.
- Signal is given to refractory period control and timing circuit.
- R-wave is below the certain level, at that time only, this pacemaker will deliver the pulses.

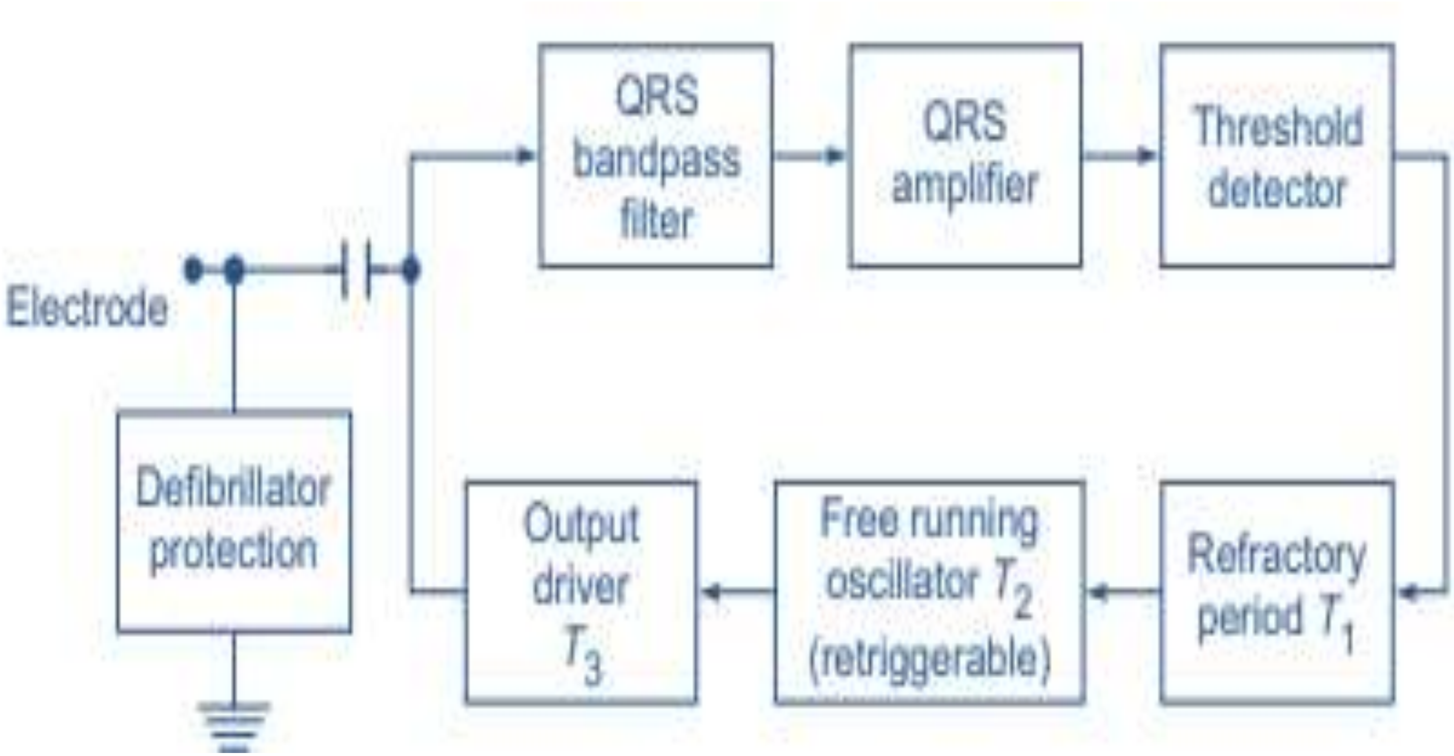
Various pacing modalities in demand pacemakers



(a) ventricular demand inhibited :(b) A-V sequential (c) atrial synchronous (ventricular inhibited), (d) fully automatic

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Ventricular Synchronous Demand Pacemaker



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Ventricular Synchronous Demand Pacemaker..

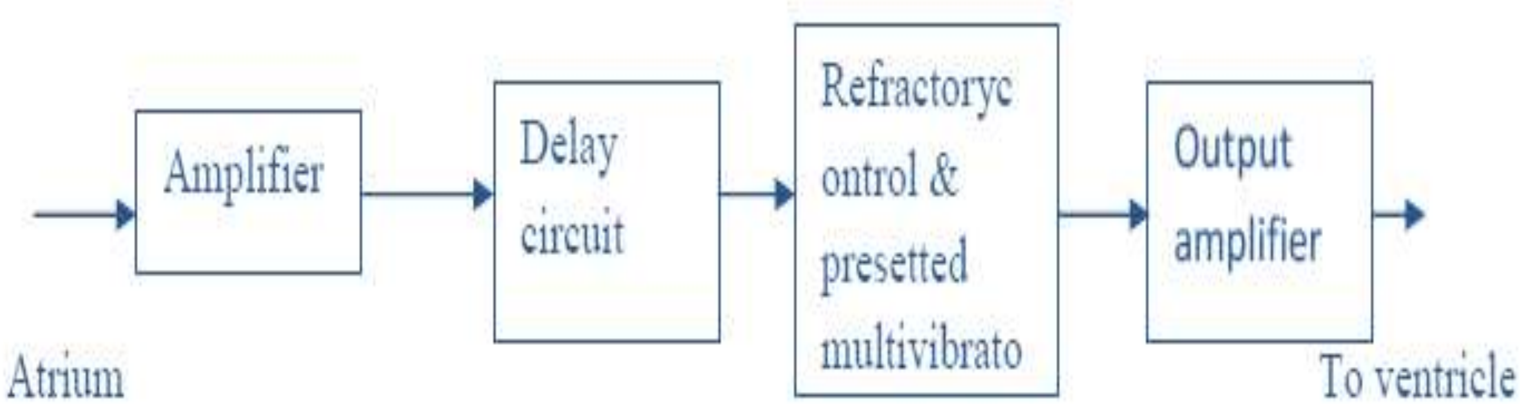
- The pulse generator has two functions pacing and sensing.
- Sensing is accomplished by picking up the ECG signal.
- In the case of dual-chamber pacing, the P wave is also sensed.
- Once the ECG signal enters the sensing circuit, it is passed through a QRS bandpass filter.
- This filter is designed to pass signal components in the frequency range of 5-100 Hz, with a centre frequency of 30 Hz.

Ventricular Synchronous Demand Pacemaker..

- This is followed by an amplifier and threshold detector which is designed to operate with a detection sensitivity of 1–2 mV.
- A refractory period (T1) is necessarily incorporated to limit the pulse delivery rate, particularly in the presence of electromagnetic interference.
- It is meant to prevent multiple re-triggering of the a stable multivibrator following a sensed or paced contraction.
- The free-running multivibrator provides a fixed rate mode with an interval of T2 via the output driver circuit.

ATRIAL SYNCHRONOUS PACEMAKER

- P wave is sensed and picked by the electrode fixed on the atrium. It is given to the amplifier circuit.
- Amplifier circuit is used to amplify the P-waveform.
- Circuit is used to give the delay 0.12 second.

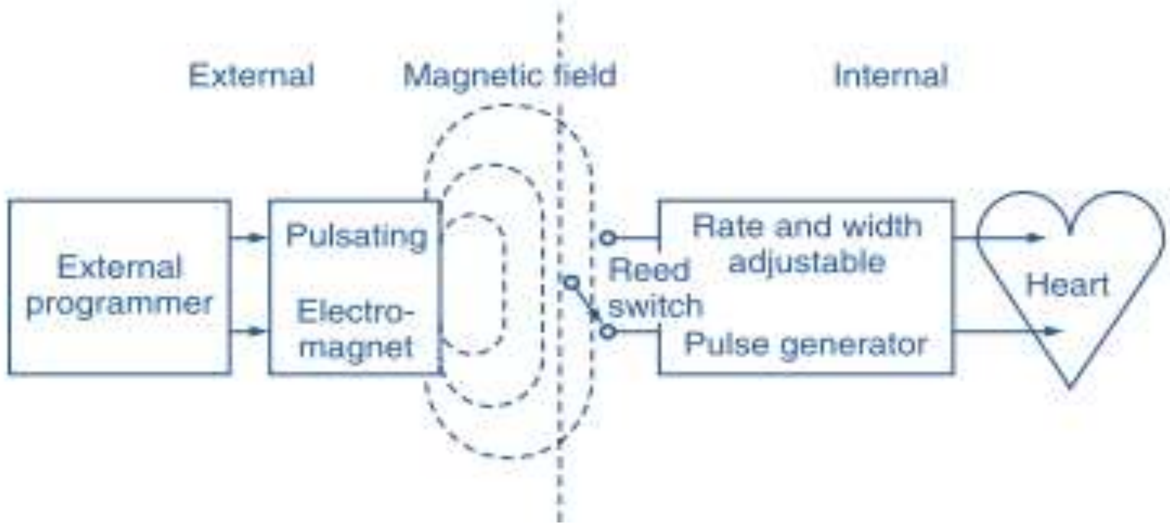


ATRIAL SYNCHRONOUS PACEMAKER..

- The output of the delay circuit given to refractory control and preset multivibrator block.
- If the P wave amplitude is not in normal value, then fixed rate pacemaker will turn ON.
- When P-wave amplitude is normal, then fixed rate pacemaker is OFF.
- If fixed rate pacemaker is ON, then the output is given to amplifier.
- The amplified signal is given to ventricle through electrode.
- Refractory control circuit provide some time delay, because pacemaker pulse is too large.

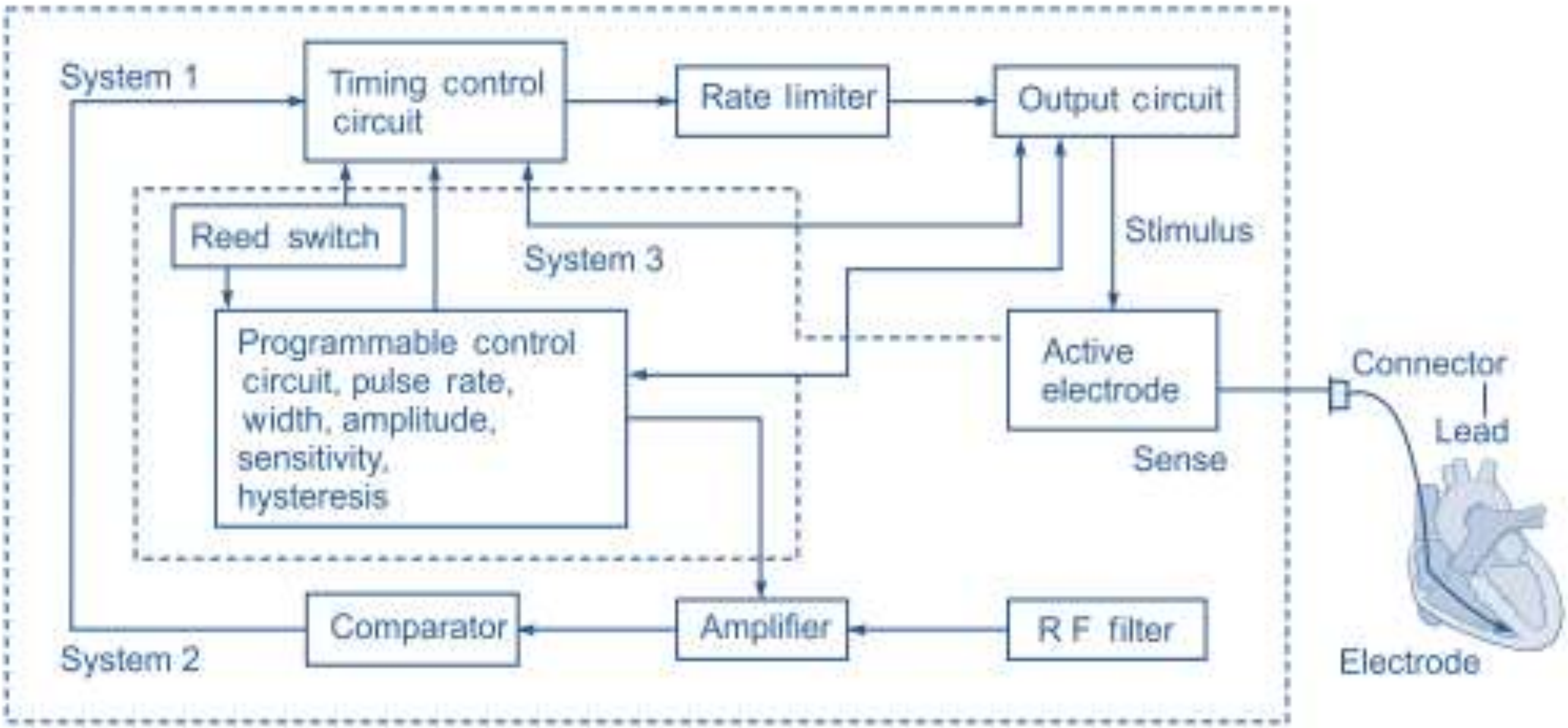
Programmable Pacemaker

- A programmable pacemaker consists of two parts: the external unit which generates programmed stimuli which is transferred to an internal unit by one of the several communication techniques.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of a multi programmable pacemaker



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block diagram of a multi programmable pacemaker…

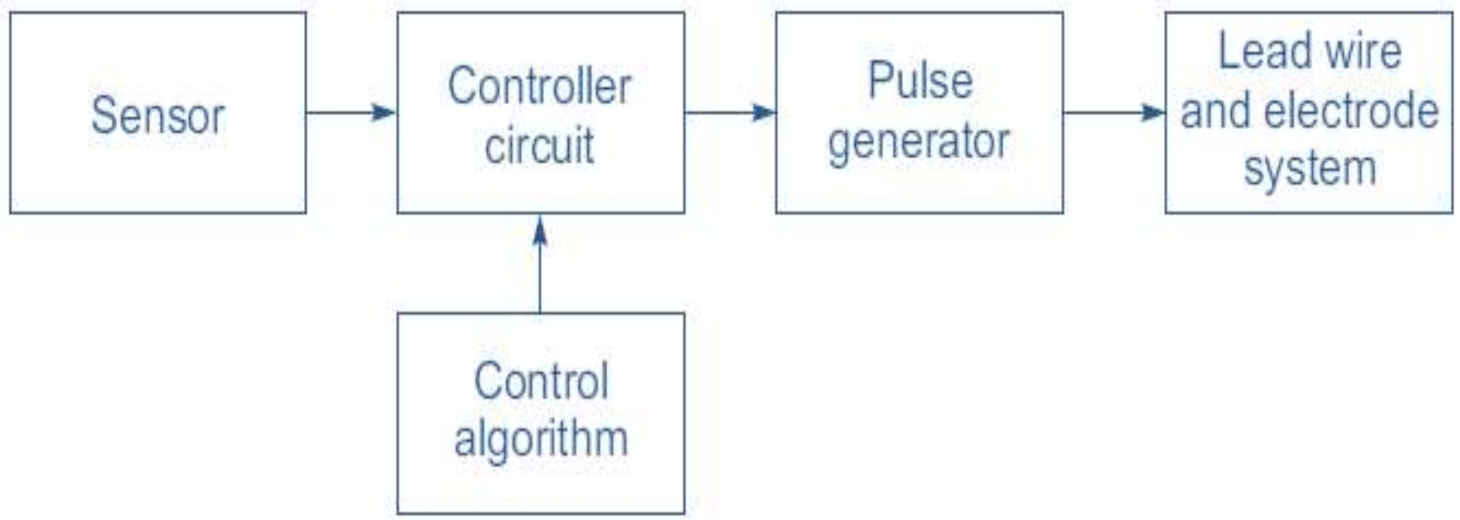
- It comprised of the three systems.
- System I controls the main timing functions of the pulse generator and carries the rate limiter, the pulse output circuit and the stimulating function of the electrode.
- Operating as directed by the programmable control circuit, this system generates output pulses at the programmed rate, width and amplitudes unless over-ridden by System 2.
- System 2 carries the sensing and signal discriminating function of the circuit.
- Comprising the sensing function of the electrode, an RF filter, a signal amplifier and comparator, this system identifies signals of cardiac origin and, where appropriate, sends an inhibit signal to System 1.
- System 3 carries the programmable control circuit, the data validate circuit, the reed switch and the master timing crystal. This system effects program recognition, storage, and execution as well as control of the battery and various test sequences.

Rate-responsive Pacemakers

- In some patients, due to the diseased condition of the sinus node, the heart's natural pacemaker is not able to increase its rate in response to metabolic demands.
- Although the synchronous pacemakers can meet some of the physiological demand for variation in heart rate, these devices cannot replicate the functions of the heart or meet the demands of the body during stressful activities such as exercise.

Rate-responsive Pacemakers..

- A sensor is used to convert a physiological variable in the patient to an electrical signal that serves as an input to the controller circuit, which can determine whether any artificial pacing is required or not.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Power Sources for Implantable Pacemakers

Lithium Cells:

- The long-life **lithium-iodine battery** powered pacemaker represents a significant advance in pacemaker technology.
- The lithium battery is solid-state and consists of an anode of metallic lithium (Li) and a cathode of molecular iodine (I_2) bonded in complex form to an organic carrier.
- The solid electrolyte consists of crystalline lithium-iodide (LiI).

$$2Li + I_2 = 2\,LiI + e$$

Power Sources for Implantable Pacemakers..

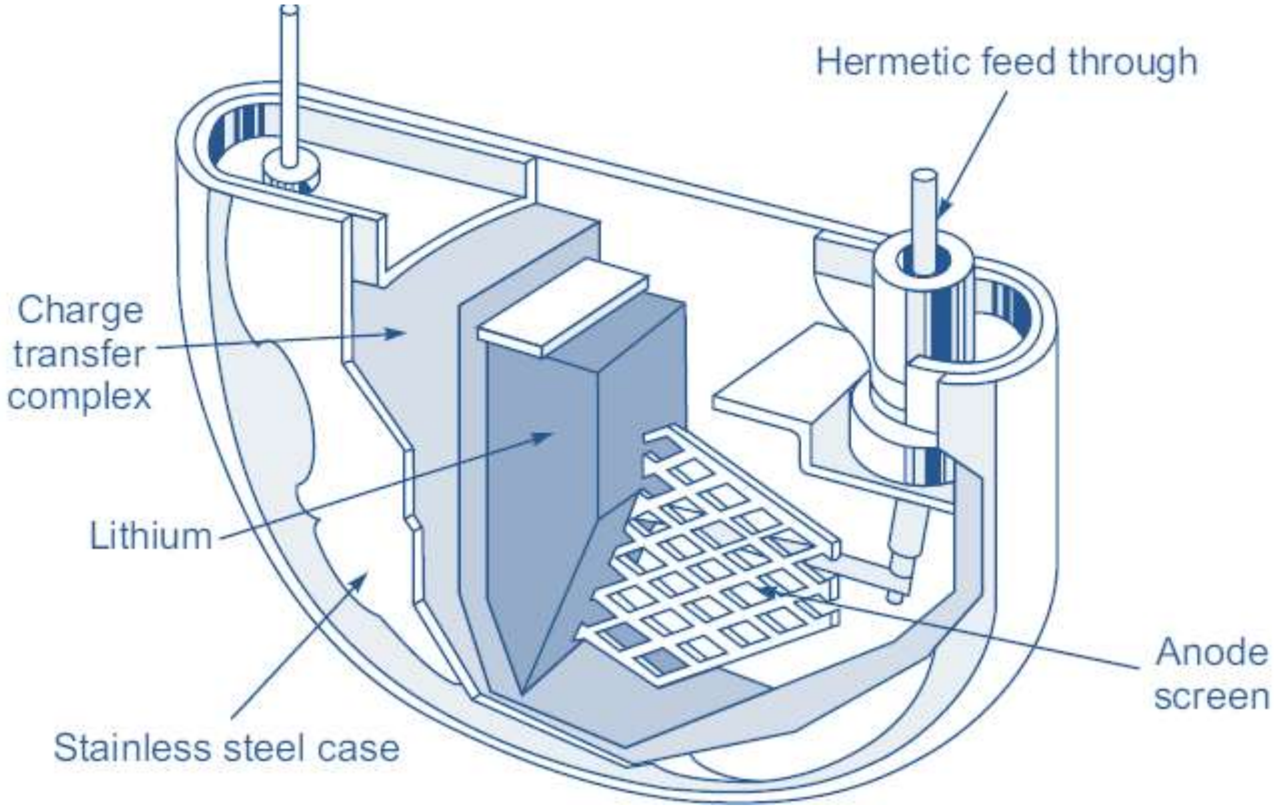


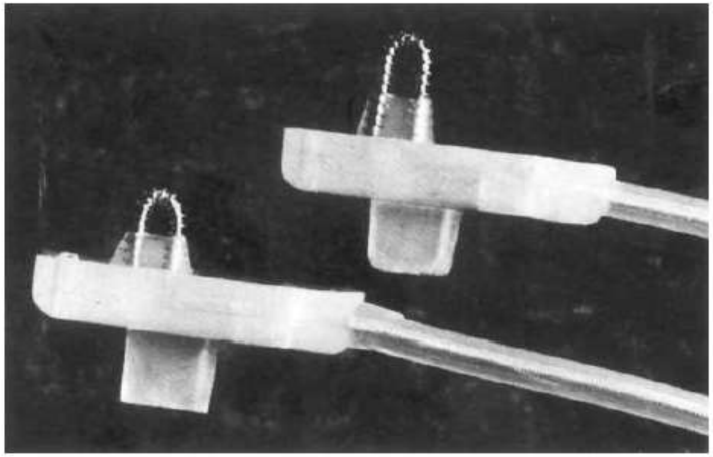
Image Courtesy: Wilson Greatbatch, U.S.A.

Power Sources for Implantable Pacemakers…

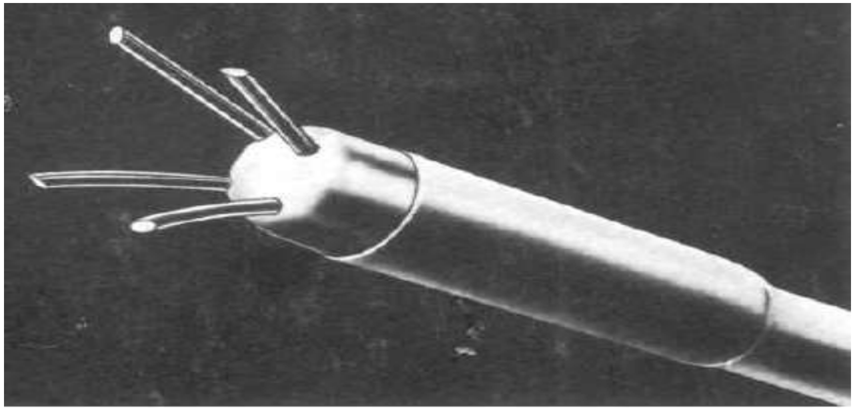
- An anode current is pressed between two layers of lithium, forming the anode assembly.
- The battery develops a voltage of 2.8 volts, which is stepped up to 5 V in the circuitry.
- No gas is evolved from the simple cell reaction.
- The lithium cell can be hermetically sealed in a welded stainless steel enclosure.
- The lithium iodide battery shows a continuous, but gradual drop in voltage over a period of years, due to the slow increase in the internal resistance.
- Once the output voltage has fallen to 3.3 V, producing a 6 bpm decline in pulse rate, replacement of the pulse generator is indicated.
- Pacemakers can last anywhere from 5 to 10 years or more - on the average about seven years.

Type of Leads and Electrodes

- Sutureless Leads



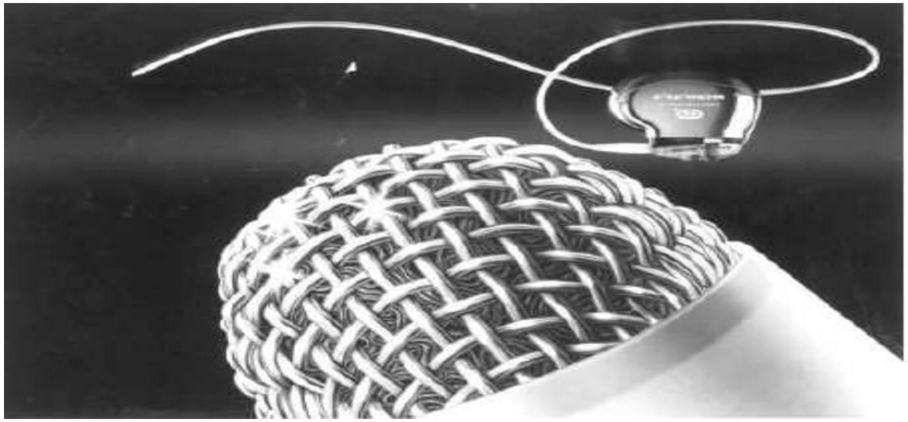
- **A special unipolar intracardial type electrode**



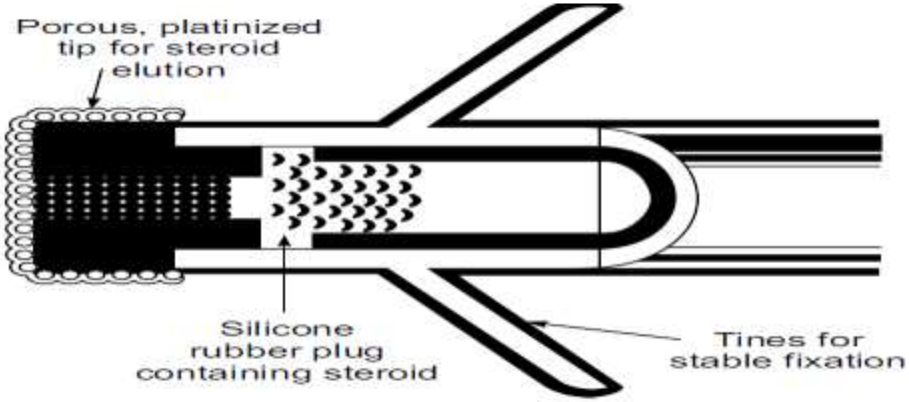
(Image Courtesy: Cardiac Pacemakers Inc., U.S.A.)

Type of Leads and Electrodes..

- Porous tip lead



- Steroid elution electrode



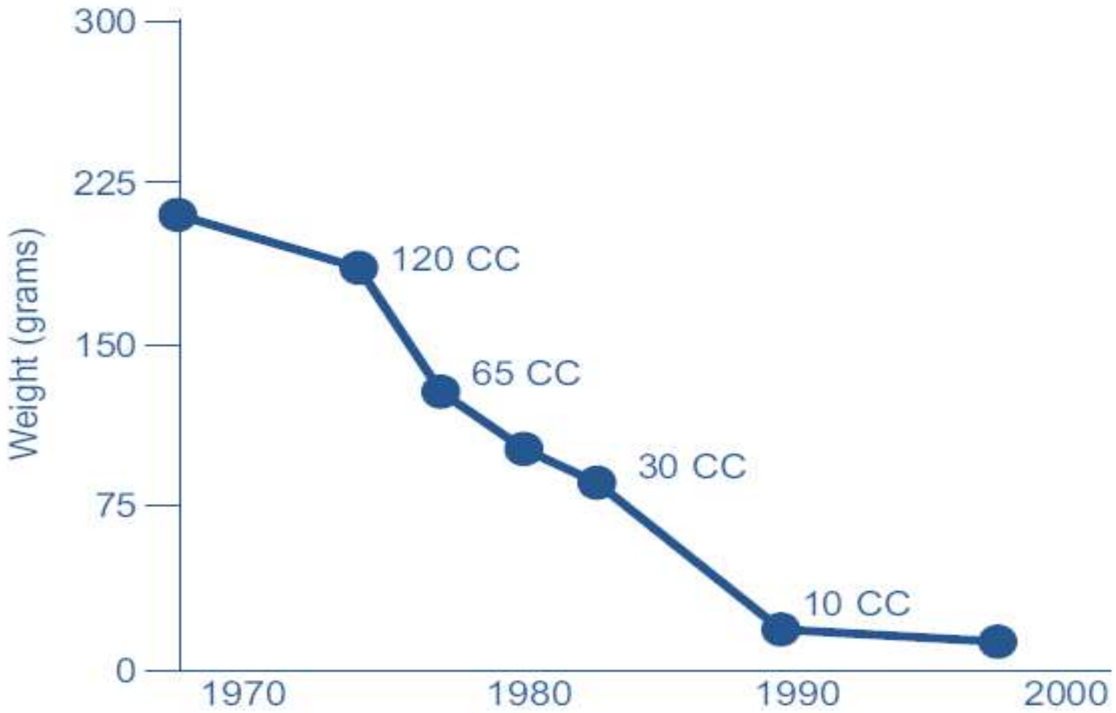
(Image Courtesy: Cardiac Pacemakers Inc., U.S.A.)

Problem with Leads and Electrodes

- Technical problems
  - broken conductors
  - broken insulation
  - poor interface with pulse generator
- Non-technical problems
  - displacement
  - exit block → (increase in threshold for satisfactory pacing above pacemaker output)
  - surgical
    - extrusion
    - infection
    - penetration

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

RECENT DEVELOPMENTS IN IMPLANTABLE PACEMAKERS



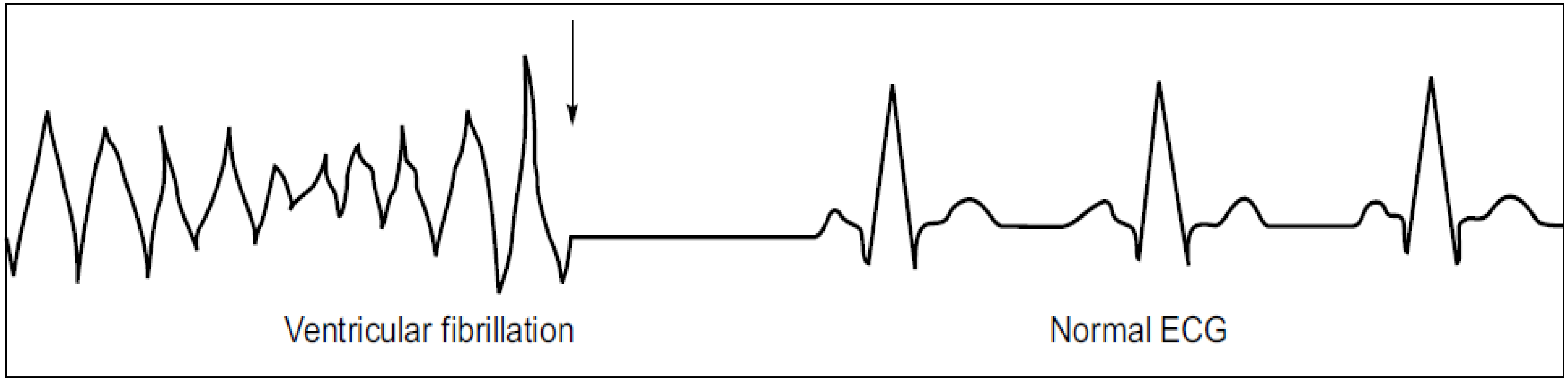
The diagram shows dramatic decrease in weight and volume which has begun to plateau at around 25 g and 10 cc of volume.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

DC DEFIBRILLATOR

DC DEFIBRILLATOR

- **Defibrillators** are devices that restore a normal heartbeat by sending an electric pulse or shock to the heart.
- Restoration of normal rhythm in fibrillating heart as achieved by direct current shock across the chest wall.



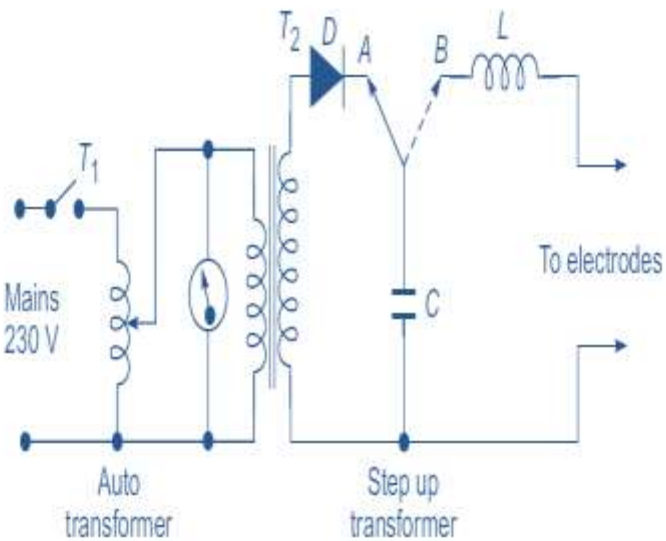
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

DC DEFIBRILLATOR..

- The shock can be delivered to the heart by means of electrodes placed on the chest of the patient (external defibrillation) or the electrodes may be held directly against the heart when the chest is open (internal defibrillation).
- Higher voltages are required for external defibrillation than for internal defibrillation.
- Implantable defibrillates are also available for patients who are at high risk of ventricular fibrillation.

DC DEFIBRILLATOR..

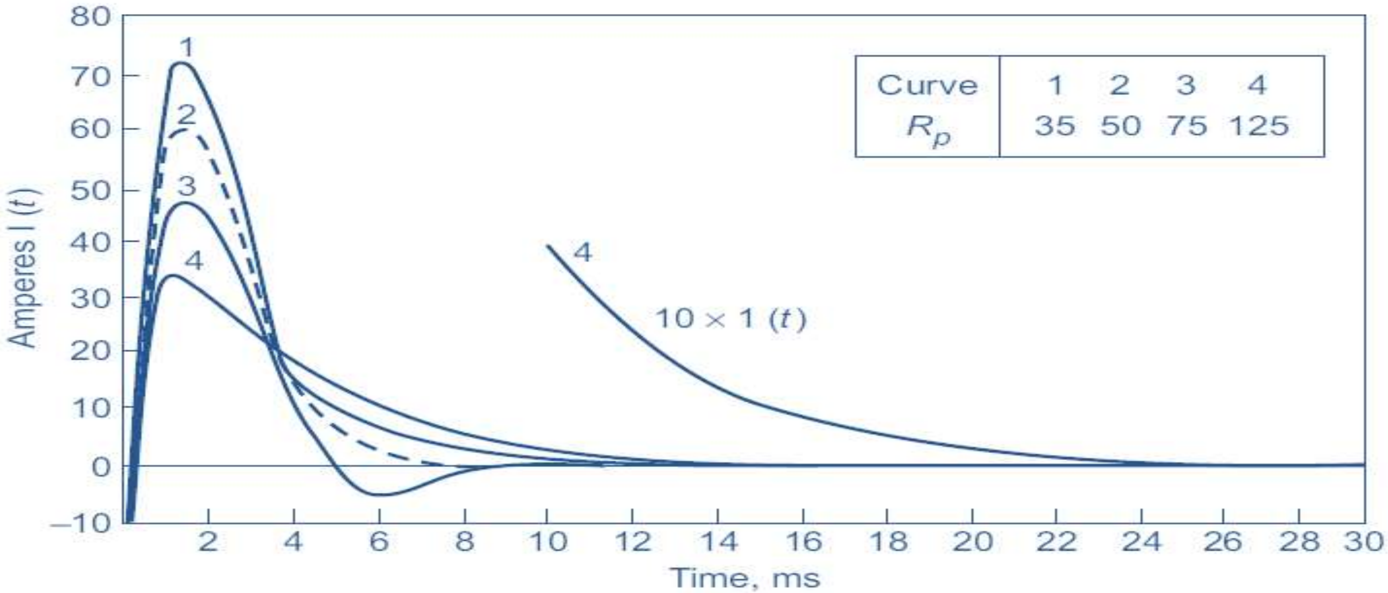
- DC defibrillation is capable of correcting both the **atrial fibrillation and ventricular fibrillation**.
- In this dc defibrillation method , a **capacitors charged to a high dc voltage and then rapidly discharged through electrodes across the chest of patient**.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

- A variable auto-transformer T1 forms the primary of a high voltage transformer T2.
- The output voltage of the transformer is rectified by a diode rectifier and is connected to a vacuum type high voltage change-over switch.
- In position A, the switch is connected to one end of an oil-filled 16 micro-farad capacitor.
- Inthis position, the capacitor charges to a voltage set by the positioning of the auto-transformer.
- When the shock is to be delivered to the patient, a foot switch or a push button mounted on the handle of the electrode is operated.
- The high voltage switch changes over to position 'B' and the capacitor is discharged across the heart through the electrodes.

Current waveform I(t) versus patient impedance Rp for a typical damped sine wave defibrillator. (C = 32 mF, L = 35 mH, RC = 67W)



- *Curve 1* shows a typical discharge pulse of defibrillator which called **Lown waveform.**
- I rises rapidly to app. 20 A
- Then I decays to 0 with 5 ms
- A negative pulse is produced for 1 to 2 ms
- The pulse width defined as the time that elapses between the start of the impulse and the moment that the current intensity passes the zero line for the first time and changes direction (5 ms or 2.5 ms)

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

DEFIBRILLATOR ELECTRODES

- The electrodes for **external defibrillation are usually metal discs** about 3-5 cm in diameter and are attached to highly insulated handles.
- Most of the **conventional electrode systems are circular, a little concave with sharp rims and an insulated back-side**.
- For internal defibrillation when the chest is open, **large spoon-shaped electrodes are used**.
- For internal use smaller **paddles are used on infants** and children.
- For external use, pair of electrodes are firmly pressed against the patients chest.

DEFIBRILLATOR ELECTRODES..

- Two electrodes are
  - Anterior-anterior
  - Anterior-posterior
- Anterior-anterior paddles are applied to the chest.
- Anterior-posterior paddles are applied to both the patients chest wall and back so that energy is delivered through the heart.

Need of Insulation Handle &Thumb Switch

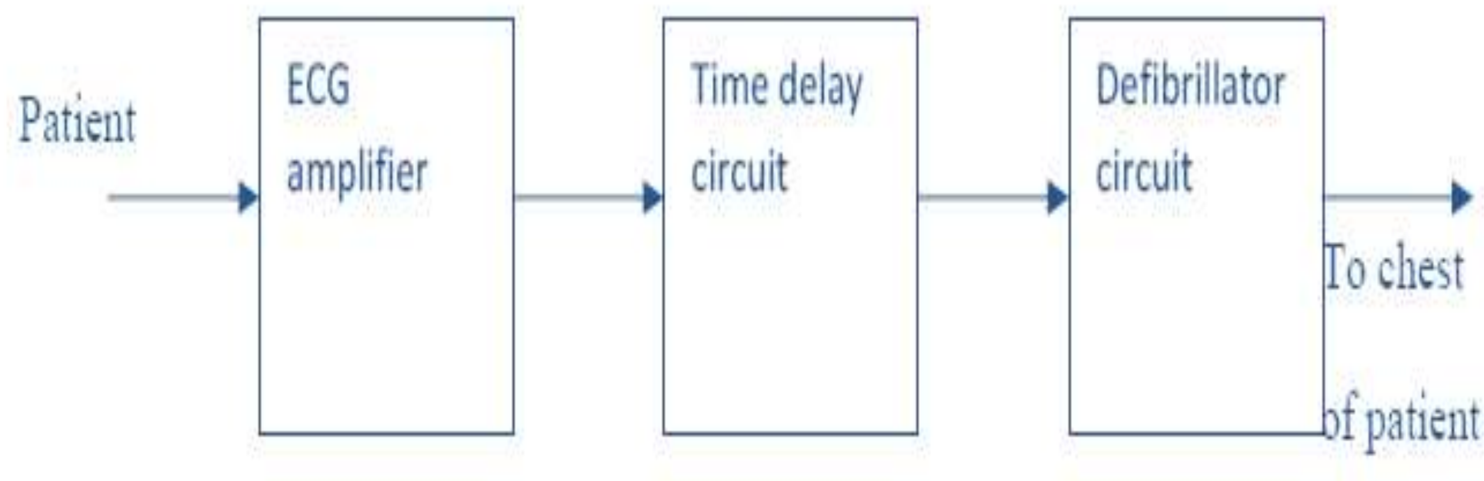
Need of Insulation Handle

- To prevent the person applying the electrodes from accidential electric shock.
- specially insulated handles are provided in the paddles.
- When paddles are properly positioned , this prevents the patient from receiving a shock.
- In earlier equipment a foot switch is used instead of thumb switch.

Need of Thumb Switch

- There is a possibility of someone accidentally stepping on the foot switch in the excitement of an emergency before the paddles are placed.
- Hence thumb switches are mostly preferred.

DC DEFIBRILLATOR WITH SYNCHRONIZER



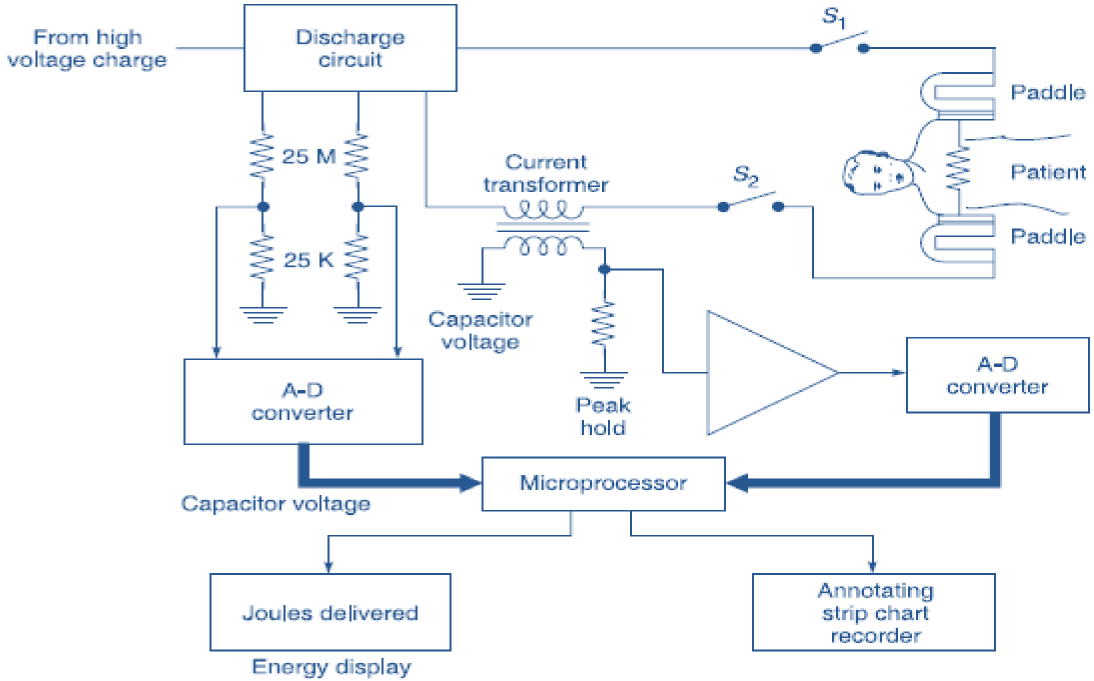
DC DEFIBRILLATOR WITH SYNCHRONIZER..

- Synchronized the working of the heart with the pacemaker.
- Synchronized DC defibrillator allows the electric shock at the right point on the ECG of the patient.
- Electric shock is delivered approximately 20 to 30 ms after the peak of R wave of patients ECG.
- ECG waveform is traced from the patient.
- R-wave in the output of ECG amplifier triggers the time delay circuit .
- It gives the delay of 30 ms approximately. After that, defibrillator circuit is switched ON.

DC DEFIBRILLATOR WITH SYNCHRONIZER..

- The capacitor discharges the electric shock to the patient’s heart.
- The moment at which electric shock occurs is noted by producing the marker pulse on monitoring display.
- This type of circuit is preferred in cardiac emergencies.
- The sudden cardiac arrest can be treated using a defibrillator and 80 percent of the patients will be cured from the cardiac arrest if the is given within one minute of the attack.

Block diagram of the discharge control and recording circuitry of a microprocessor based defibrillator monitor

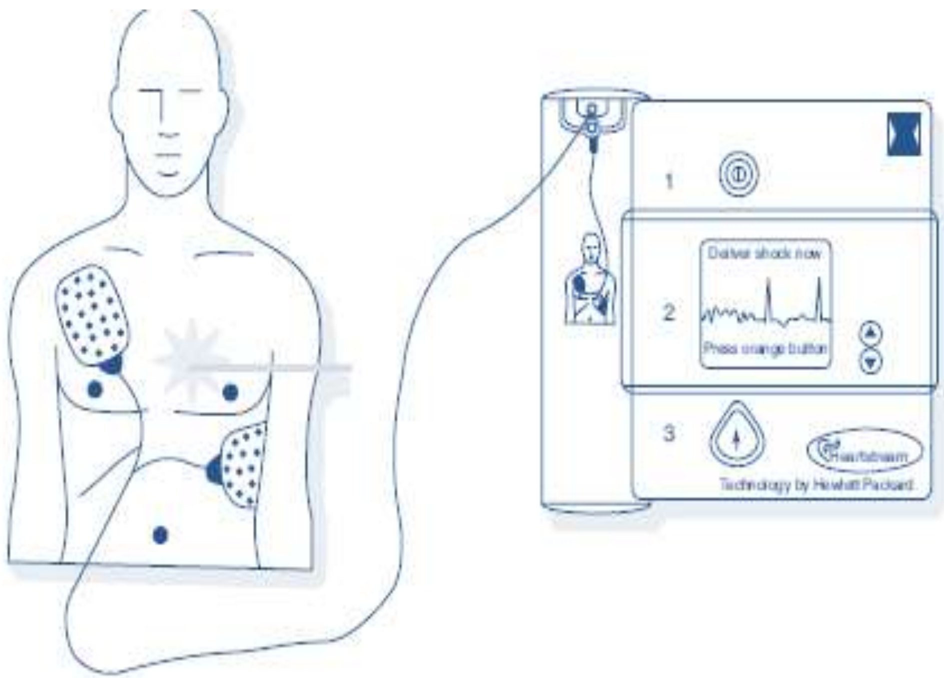


- The microprocessor determines the corresponding value of stored energy taking into consideration the defibrillator internal resistance and the patient impedance.
- The corresponding storage capacitor voltage V (Estored = 0.5CV2) is sensed and regulated by the microprocessor.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

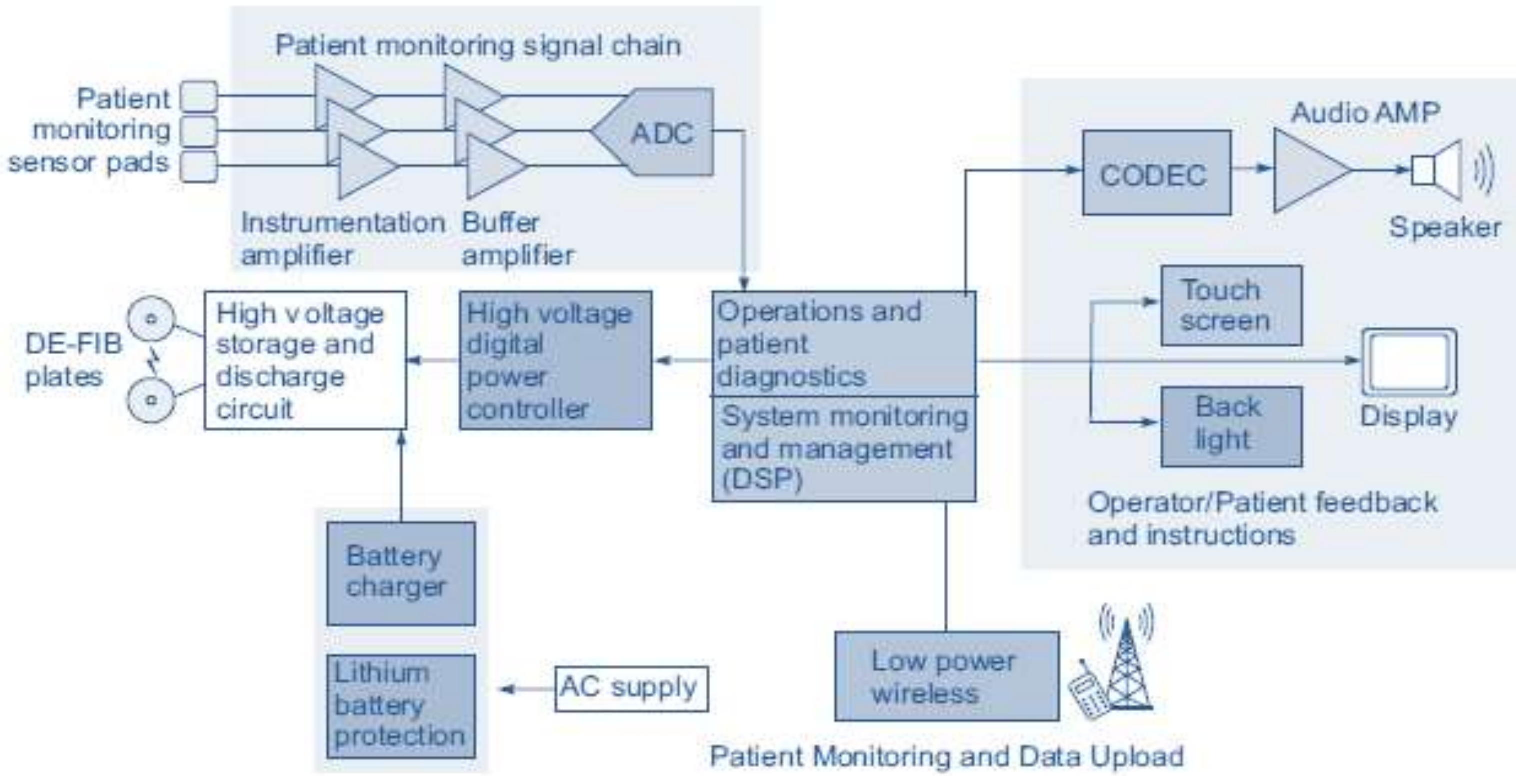
AUTOMATIC EXTERNAL DEFIBRILLATOR

Image Courtesy: Agilent Technologies



- It require self-adhesive electrodes instead of hand-held paddles for the two following reasons:
- The ECG signal acquired from self-adhesive electrodes usually contains less noise and has higher quality ⇒ allows faster and more accurate analysis of the ECG ⇒ better shock decisions.
- Hands off‖ defibrillation is a safer procedure for the operator, especially if the operator has little or no training.

Block diagram of electronics circuit of Automated External Defibrillator (Image Courtesy: M/s Texas Instruments)

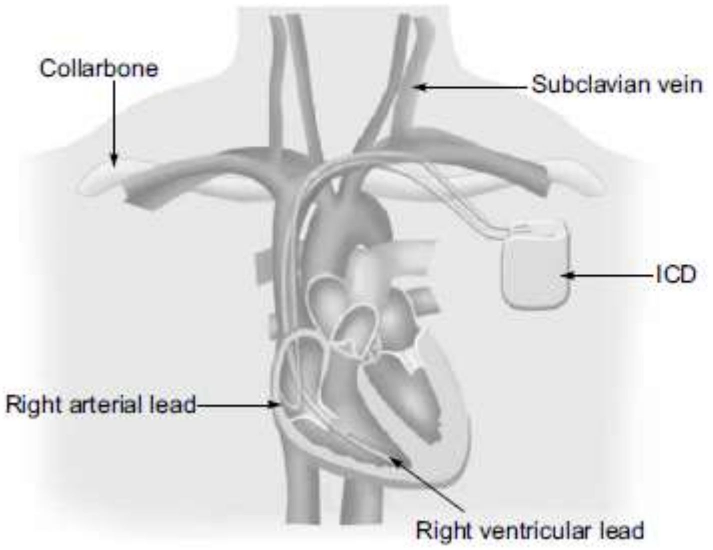


Block diagram of electronics circuit of Automated External Defibrillator..

- It is a highly sophisticated microprocessor-based device that monitors, assesses and automatically treats patients with life-threatening heart rhythms.
- It captures ECG signals from the electrodes, runs an ECG analysis algorithm to identify shockable rhythms, and then advises the operator about whether defibrillation is necessary.
- A basic defibrillator contains the usual components such as a high-voltage power supply, storage capacitor, inductor, and patient electrodes.
- It develops an electrical charge in the capacitor to a desired voltage, creating the potential for current flow.
- The higher the voltage, the more current can potentially flow.
- The AED outputs audio instructions and visual prompts to guide the operator through the defibrillation procedure.
- In a typical defibrillation sequence, the AED provides voice prompts to instruct the user to attach the patient electrodes and starts acquiring ECG data.
- If the AED analyzes the patient's ECG and detects a shockable rhythm, the capacitor is charged according to energy stored in the capacitor.

IMPLANTABLE DEFIBRILLATOR

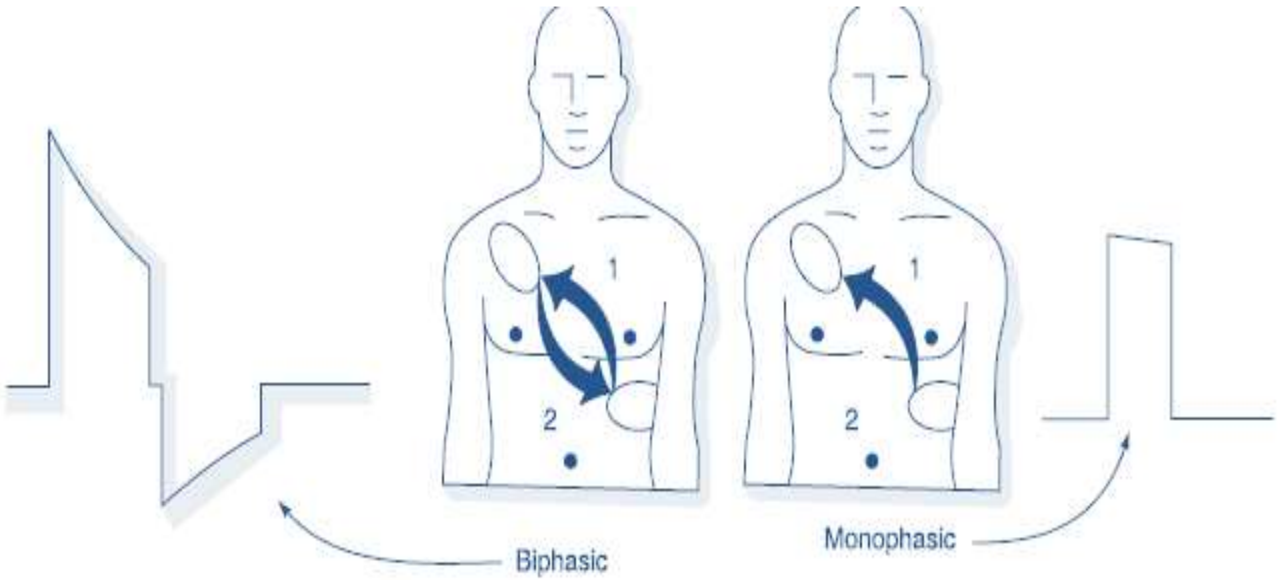
- Automatic implantable defibrillators (AID) is recommended for patients who are at high risk for ventricular fibrillation.
- An implantable defibrillator is continuously monitors a patient's heart rhythm.
- If the device detects fibrillation, the capacitors with in the device are charged



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Monophasic and biphasic waveform

Monophasic and biphasic waveform

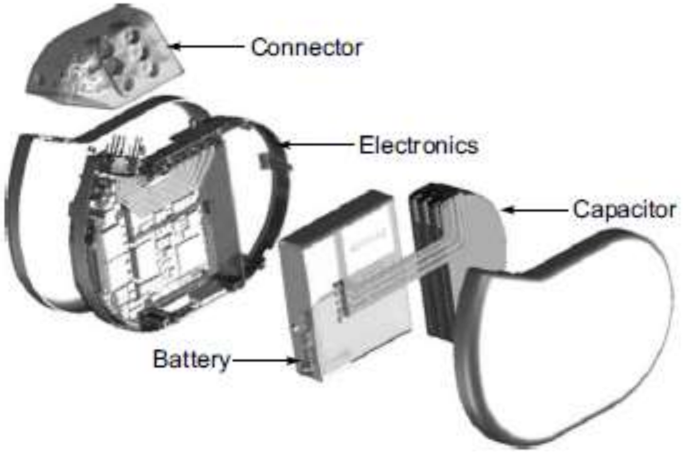


- Biphasic waveforms are more efficient and probably safer than monophasic waveforms and produce successful defibrillation at lower energies

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

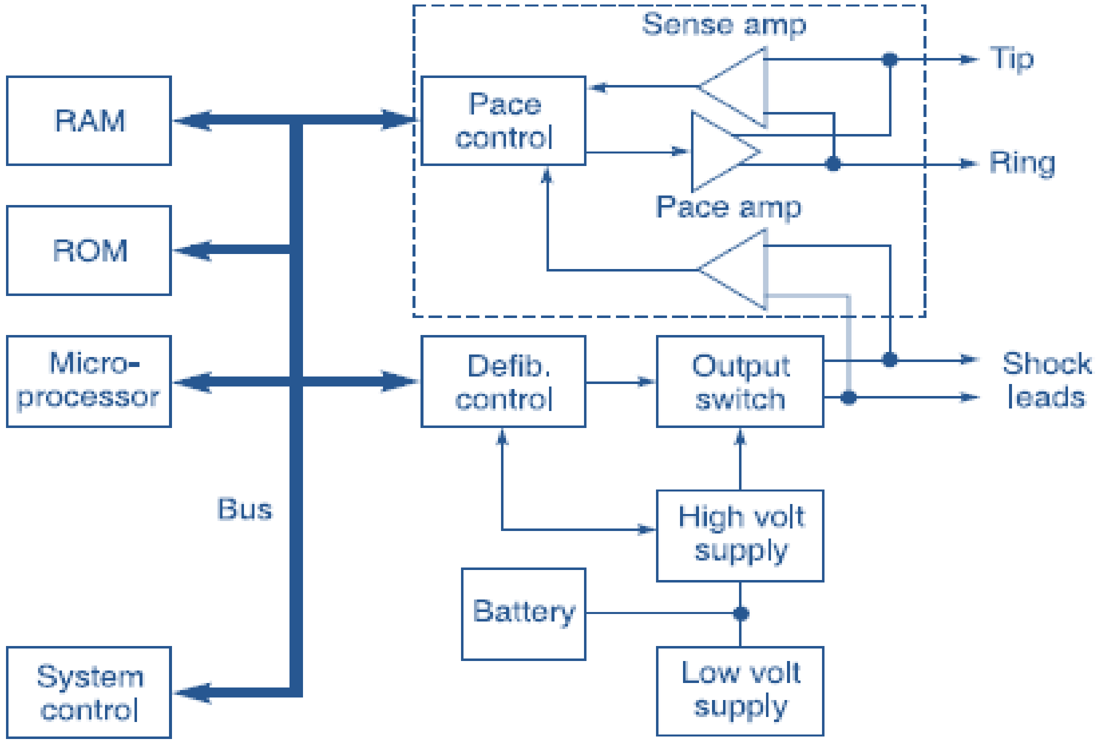
Basic components of an implantable defibrillator.

- It contains a battery, a capacitor to store and deliver charges, a microprocessor and integrated circuits for electrogram sensing, data capture, storage and control of therapy delivery.
- a header to connect the endocardial leads used for sensing, pacing and defibrillation.
- All these components together are called a pulse generator and are encased in a titanium can.



Courtesy: M/s Biotronik

Implantable defibrillator system architecture



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

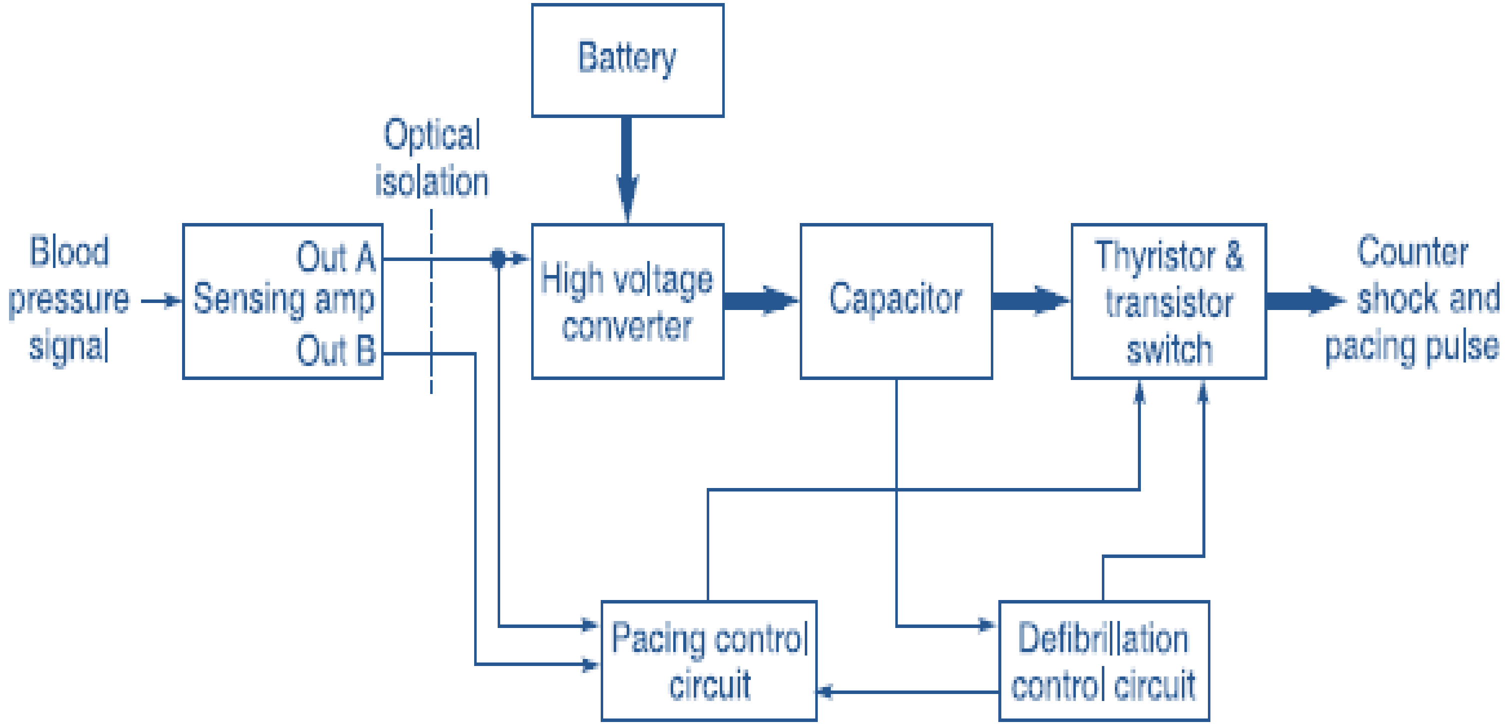
Implantable defibrillator system architecture..

- It has a microprocessor which controls overall system functions.
- An 8-bit device is sufficient for most systems.
- ROM provides non-volatile memory for system start-up tasks and some program space.
- RAM is required for storage of operating parameters, and storage of electrocardiogram data.
- The system control part includes support circuitry for the microprocessor like a telemetry interface, typically implemented with a UART-like (universal asynchronous receiver/ transmitter) interface and general purpose timers.

Implantable defibrillator system architecture..

- The power supply to the circuit comes from lithium Silver Vanadium oxide (Li SVO) batteries.
- Digital circuits operate from 3 V or lower supplies whereas analog circuits typically require precision nanoampere current source inputs.
- Separate voltage supplies are generated for pacing (approximately 5 V) and control of the charging circuit (10–15 V).
- The sense amplifier must also be immune to both physiological and external sources of interference.

PACER-CARDIOVERTER-DEFIBRILLATOR



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

PACER-CARDIOVERTER-DEFIBRILLATOR…

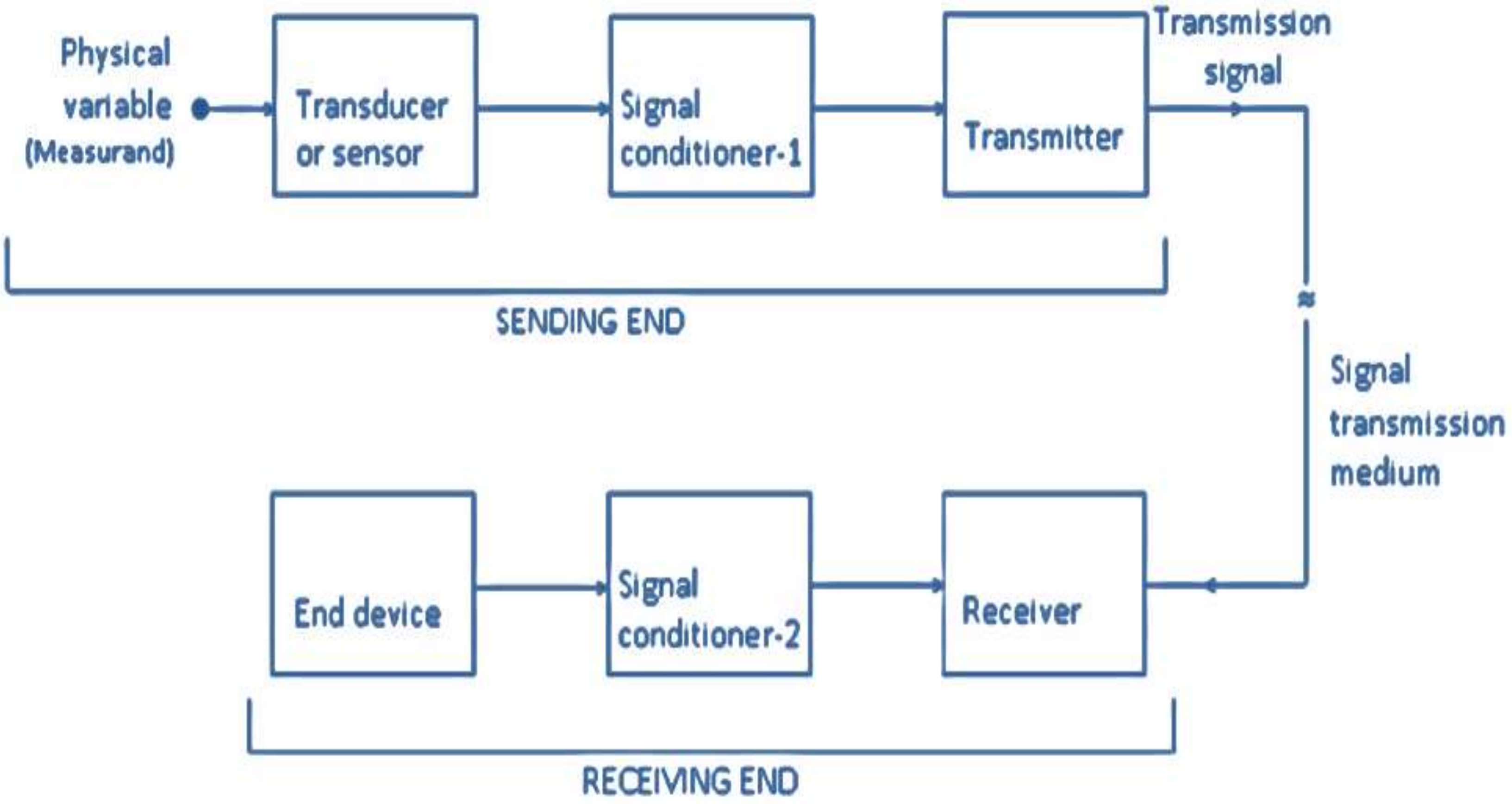
- sensing circuit, high voltage converter, switching circuit, defibrillation control circuit, and pacing control circuit.
- The heartbeat signal is detected by a catheter-type heartbeat sensor, is amplified for heartbeat monitoring.
- The absence of a heartbeat for 3.5 s causes the fibrillation detecting circuit to deliver the turn-on signal which then switches on the high voltage converter.
- At a predetermined voltage level ,the thyristor switch allows the capacitor to discharge its current through the right ventricular electrode.
- After defibrillation, high-output demand pacing is activated by using the residual energy in the output-capacitor.
- The pacing rate and pulse width are controlled by the pacing control circuit, and the heartbeat signal is used for demand function.

TELEMETRY PRINCIPLES

Telemetry principles

- Telemetry defined as measurement at a distance.
- Telemetry is a technology that allows remote measurement and reporting of information. The word is derived from Greek roots tele = remote, and metron = measure.
- Telemetry is the process by which the measured quantities such as temperature, level, pressure, flow, displacement, velocity, acceleration etc.
- Transmitted to a convenient remote location, in a form, suitable for displaying, recording, actuating a process.

BLOCK DIAGRAM OF A TYPICAL TELEMETRY SYSTEM



Telemetry system classification

A) Basis of the signal transmission medium used

Wire Telemetry:

- It uses a pair of copper wires (or conductors) as the signal transmission medium or link between the sending and receiving ends.

Radio Telemetry or Wireless Telemetry:

It uses a radio link between the transmitting and receiving ends.

- ***Short-Range Radio Telemetry:*** When *radio link* is used for the reason that the sensor Output cannot be taken through wires whereas the distance involved is so *short* that even conventional methods of measurement could have been used, then this type of radio telemetry is called short range radio telemetry.

Telemetry system classification..

- ***Satellite-Radio Telemetry:*** When satellite radio communication is used for linking Widely spaced transmitter and receiver of a radio telemetry system, it is referred to as satellite-radio telemetry.
- **Optical-Fibre Telemetry or Fibre-Optic Telemetry**
- It uses optical fibre as the signal transmission medium or link between the transmitting and receiving ends.

B) Telemetry Classification Based on Modulation Method

DC Telemetry Systems

- These telemetry systems use no modulation. The information signal which varies very slowly and is considered as a DC signal is transmitted as such.

There are two telemetry systems in this category:

1. Direct voltage telemetry system
2. Direct current telemetry system

Telemetry system classification..

AC Telemetry Systems

- These telemetry systems use an AC carrier, which is modulated using one of the AC modulation techniques.

There are two telemetry systems in this category:

1. Amplitude modulation (AM) telemetry system
2. Frequency modulation (FM) telemetry system

Pulse Telemetry System

- These telemetry systems use a pulse carrier, which is modulated using one of the pulse modulation techniques.

  There are five telemetry systems in this category:

  1. Pulse amplitude modulation (PAM) telemetry system

Telemetry system classification..

2. Pulse width modulation (PWM) telemetry system
3. Pulse phase modulation (PPM) telemetry system
4. Pulse frequency modulation (PFM) telemetry system
5. Pulse code modulation (PCM) telemetry system

C) Telemetry Classification Based on Type of Information Signal

- Telemetry methods and systems are very often also classified on the basis of the type of the Information signal, which can be either analog or digital. Accordingly the telemetry system is called analog or digital telemetry system.

Telemetry system classification..

Analog Telemetry Systems

1. Direct voltage telemetry system
2. Direct current telemetry system
3. Amplitude modulation (AM) telemetry system
4. Frequency modulation (FM) telemetry system
5. Pulse amplitude modulation (PAM) telemetry system
6. Pulse width modulation (PWM) telemetry system
7. Pulse phase modulation (PPM) telemetry system
8. Pulse frequency modulation (PFM) telemetry system

Telemetry system classification..

D) Single- and Multi-Channel Telemetry Systems

(a) Time Division Muliplexing (TDM):

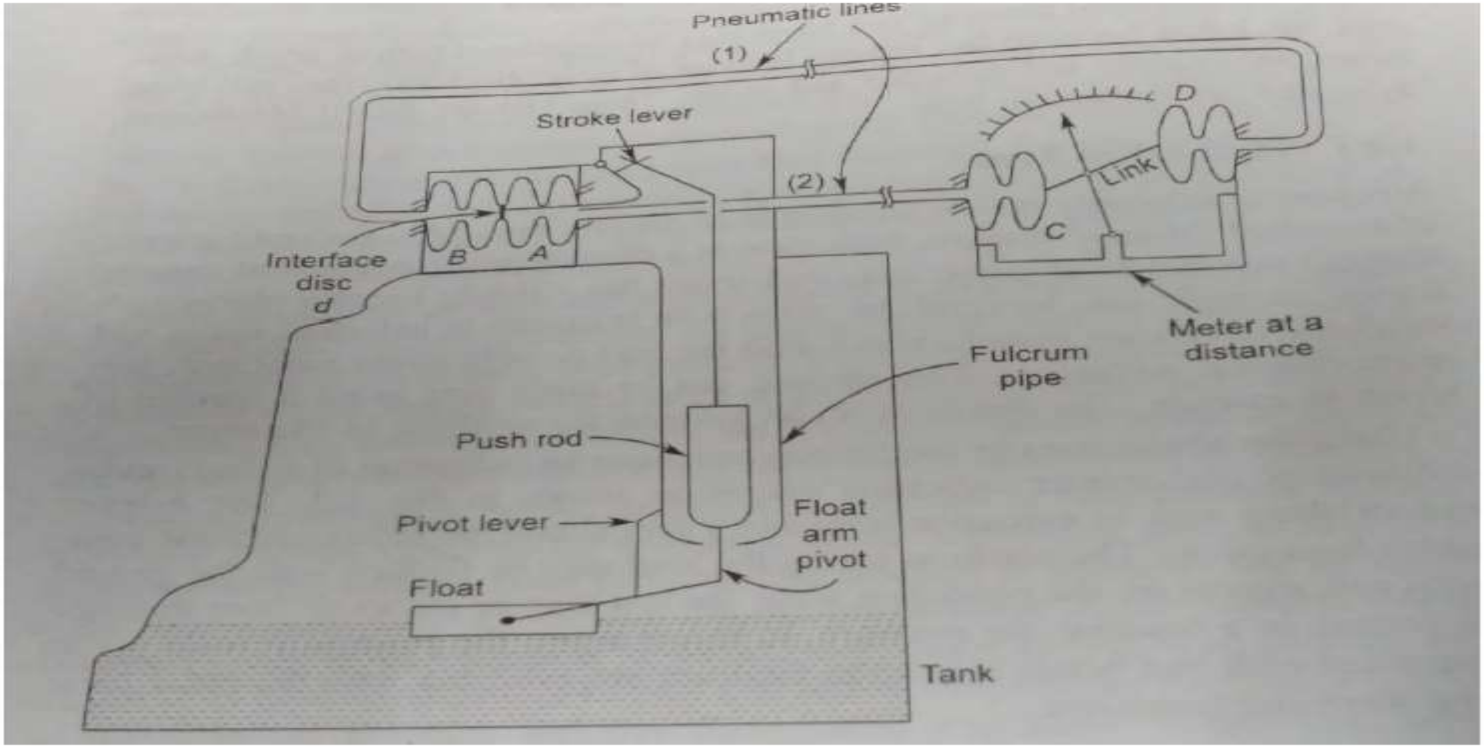
- It can be used with all types of signal transmission links.

(b) Frequency Division Multiplexing (FDM):

- It can be used with copper wire links and radio links only.

PNEUMATIC TELEMETRY

- In a pneumatic telemetry system, compressed air is used to communicate the values of measured quantity from one location to the other location.



PNEUMATIC TELEMETRY..

- There are four bellows elements A and B transmitting with stroke lever & the interface disc d.
- C & D form the receiving & display block along link.
- The two blocks are connected by pneumatic lines.
- with the float rising or falling ,the push rod moves up pressing bellows element B or expanding it so pressure increase in line 1 or 2 expanding element D or C at the receiving end.

PNEUMATIC TELEMETRY..

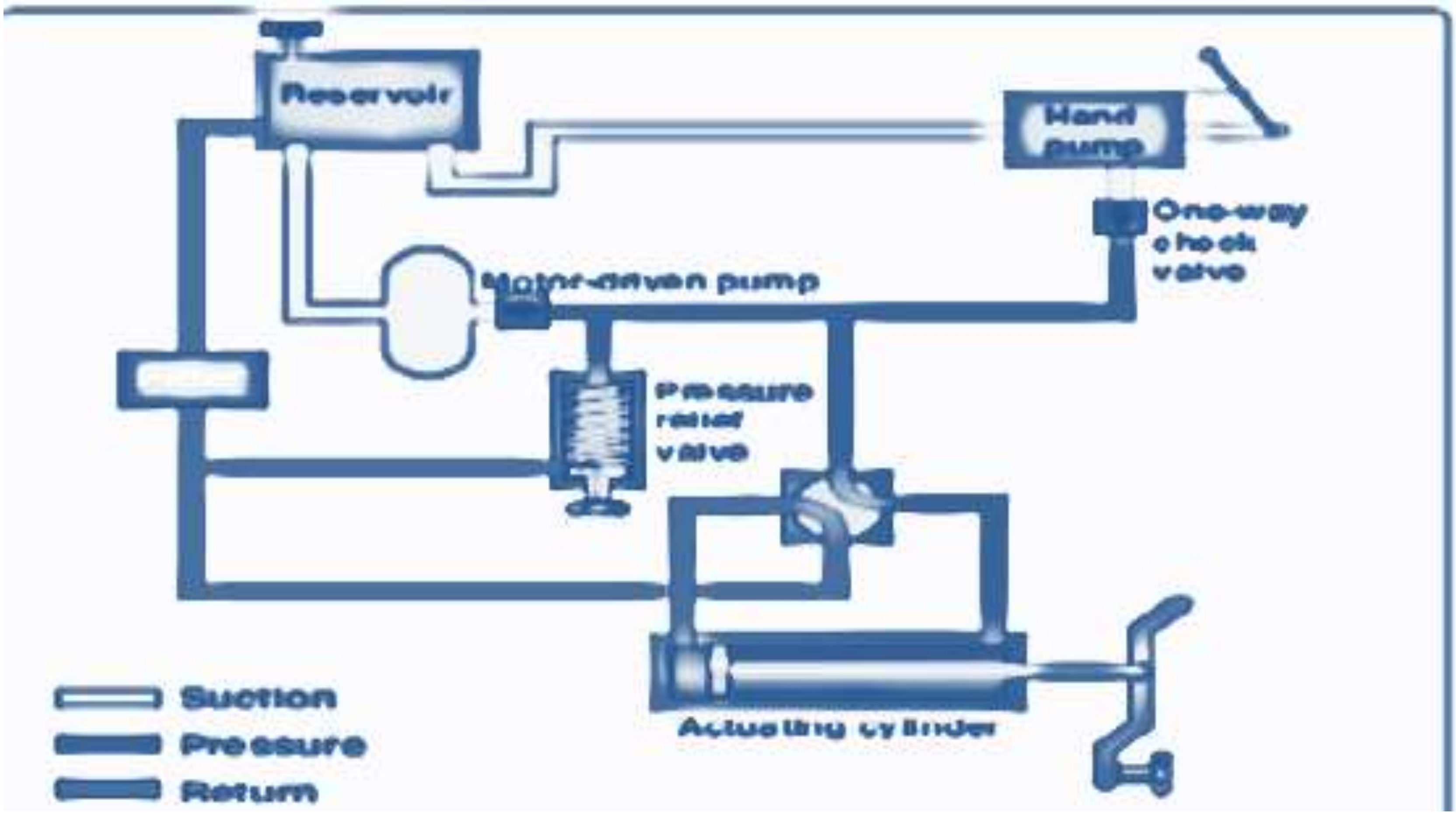
ADVANTAGES

- They are safe and explosion proof.
- They are unaffected by electric power failures.
- Pneumatic actuators and control valves are directly operated through pneumatic signals without requiring any conversion.
- Improved dynamic response and facilities for calibration and checking.

DISADVANTAGES

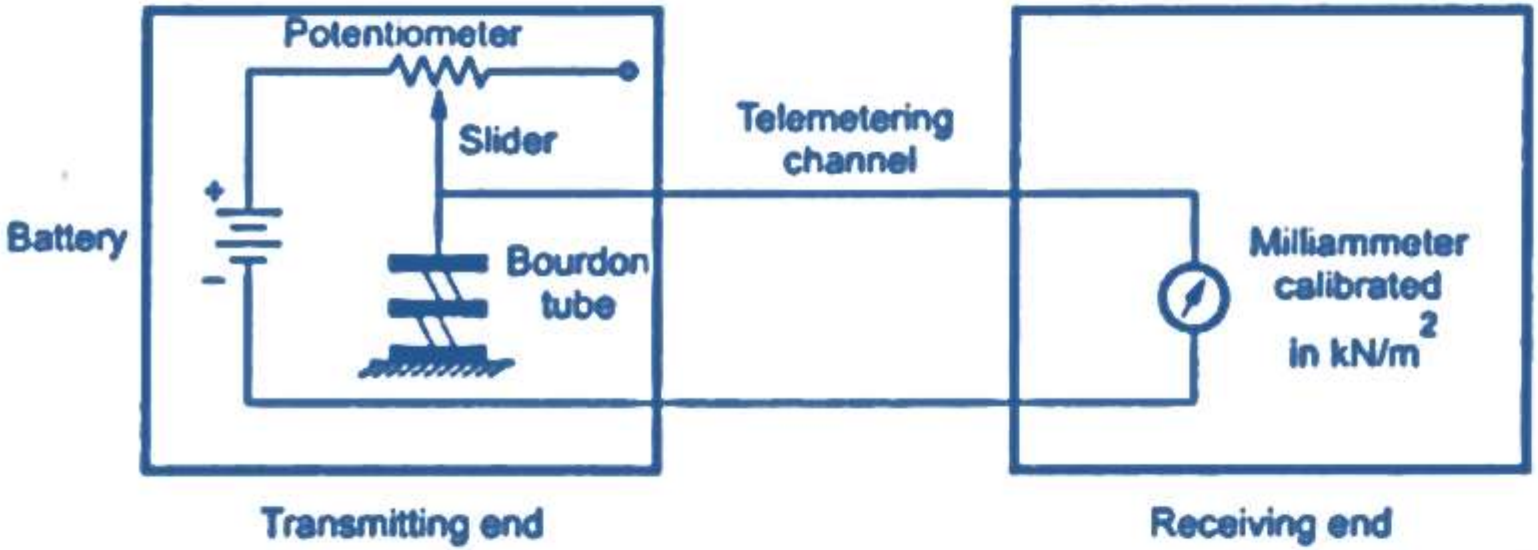
- They are slow to respond.
- System is not suitable for larger distances.

HYDRAULIC TELEMETRY



ELECTRICAL TELEMETRY

- **CURRENT TELEMETRY SYSTEM**



ELECTRICAL TELEMETRY…

CURRENT TELEMETRY SYSTEM

ADVANTAGES

The current system can develop higher voltages than most voltage systems.

- Simple D.C. milliammeters can be used.
- Several receivers can be operated simultaneously.
- The energy level is high.

DISADVANTAGE

- This system is not suitable for larger distance.

PULSE TELEMETRY

- In this type of telemetry, the measurand is transmitted in terms of time rather than magnitude of an electrical quantity.
- The information may be conveyed through radio frequency links to the remote control room.
- Pulse telemetry is classified into two categories:

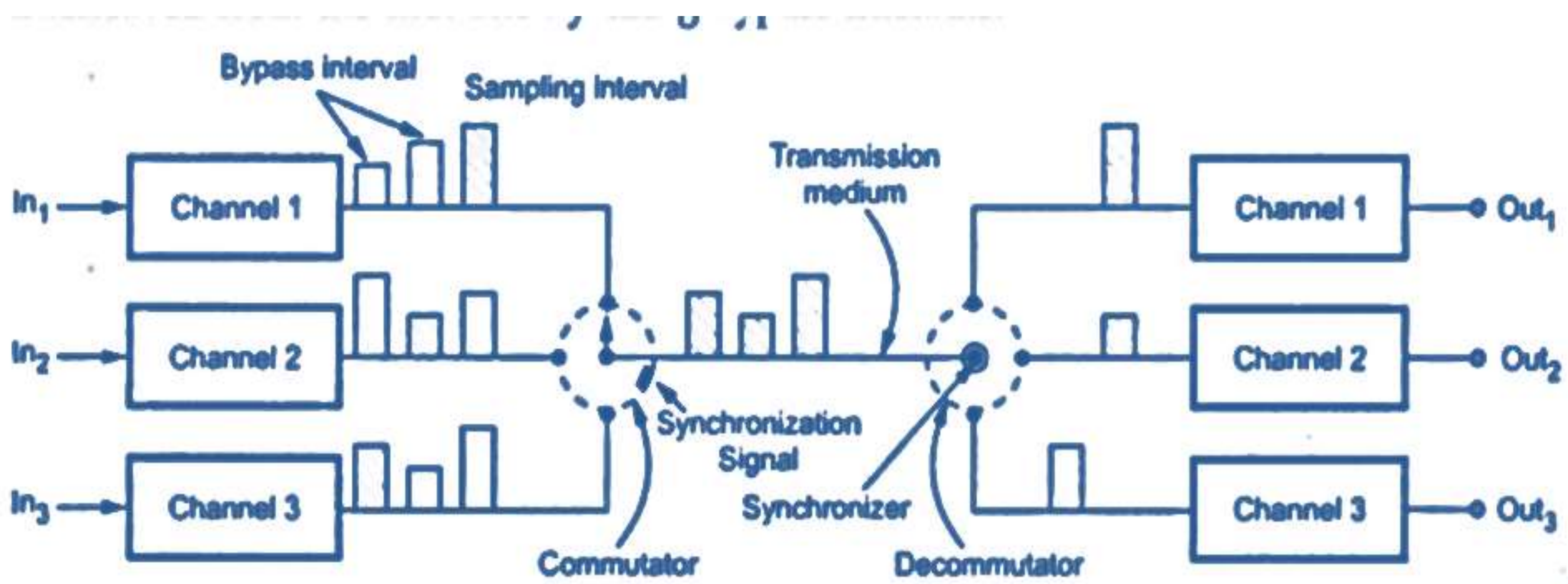
1) Analog pulse telemetry
2) Digital pulse telemetry

ANALOG PULSE TELEMETRY

- In an analog pulse telemetry, the signal which is transmitted to a remote location is converted into the number of pulses which are D.C. or A.C. voltages of constant amplitude and small width.
- **Analog pulse telemetry is classified into three categories:**

1) Pulse amplitude modulation (PAM)
2) Pulse width modulation (PWM)
3) Pulse position modulation (PPM)

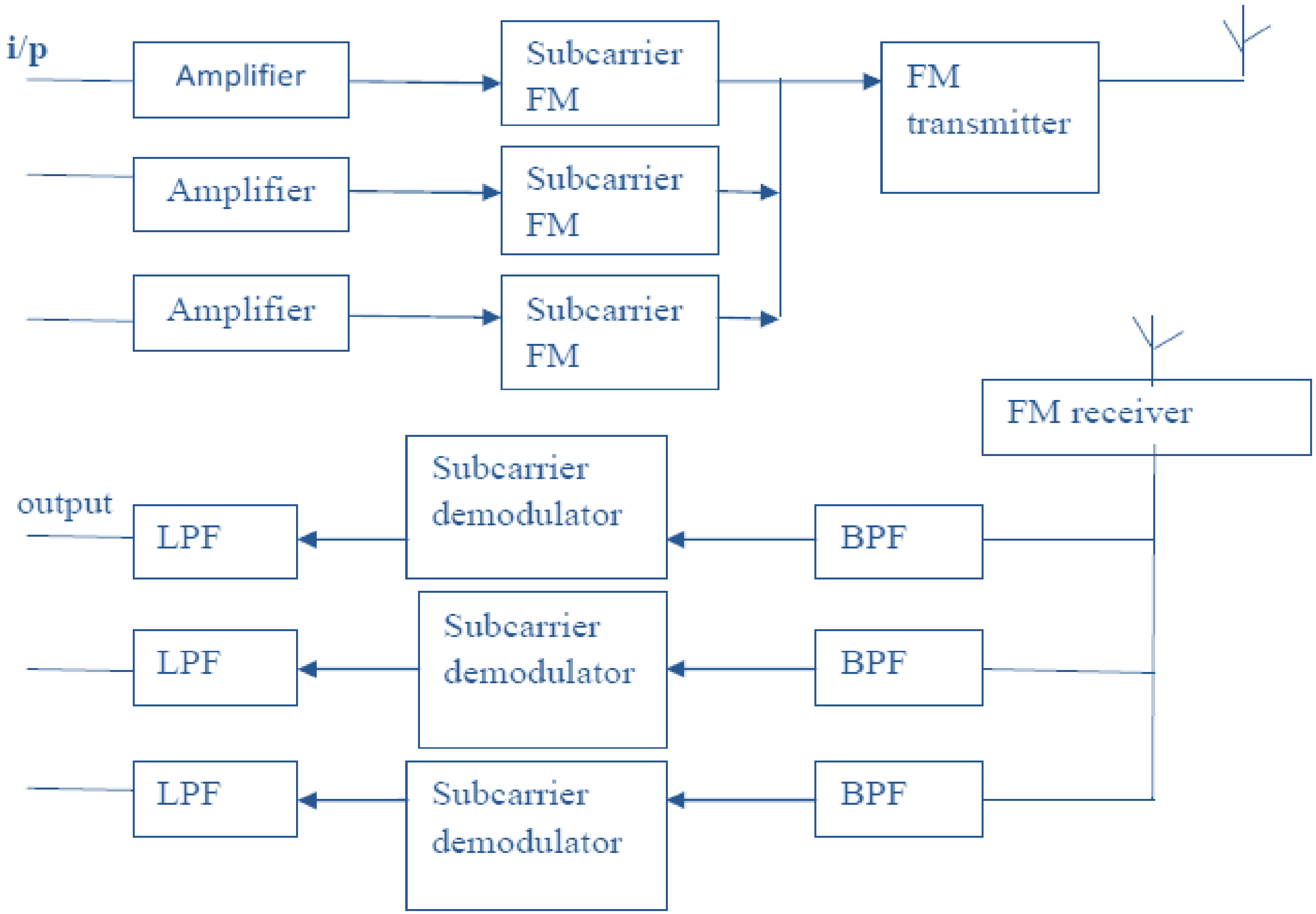
TDM Telemetry system



TDM Telemetry system..

- Most biomedical signals have low frequency bandwidth requirement, we can use time division multiple system by time sharing scheme.
- Transmission channel is connected to each signal channel input for a short time to sample and transmit that signal.
- Transmitter is switched to the next input signal channel in a definite sequence.
- All the channels have been scanned once, a cycle is completed and the next cycle will start.
- Scanning follows a order from signal 1 to signal 3.
- At the receiver the process is reversed. The sequentially arranged, signal pulses are given to the individual channels by using gate signal generator.

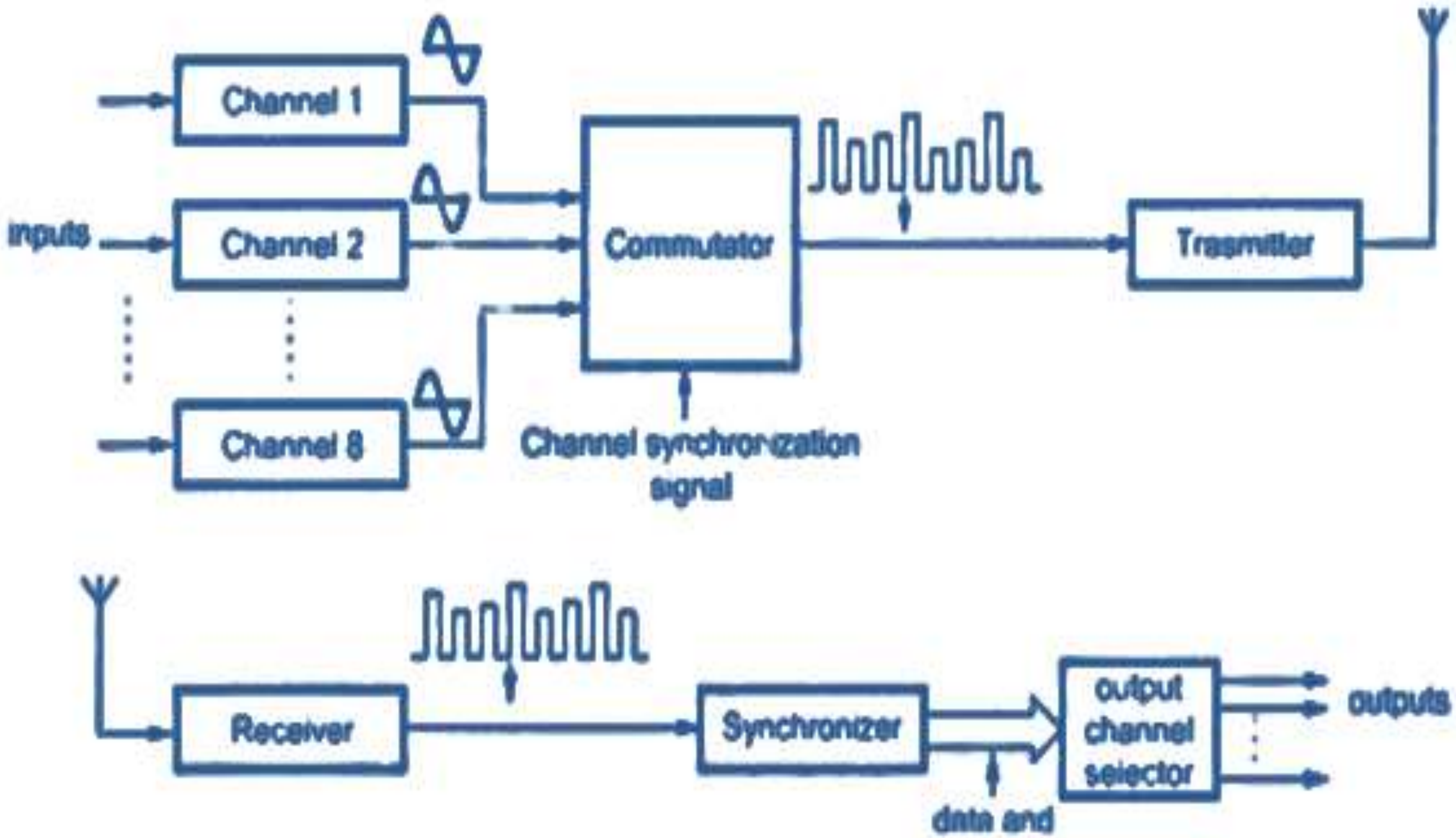
FDM Telemetry system..



FDM Telemetry system

- Each signal is frequency modulated on a sub carrier frequency.
- Modulated sub carrier frequencies are combined to modulate the RF carrier.
- At receiver the modulated sub carrier can be separated by the proper band pass filter.
- Then the each signals are demodulated by using specified frequency.
- Frequency of the sub carrier has to be carefully selected to avoid interference.
- The low pass filter are used to extract the signals without any noise.
- Finally the output unit displays the original signal.

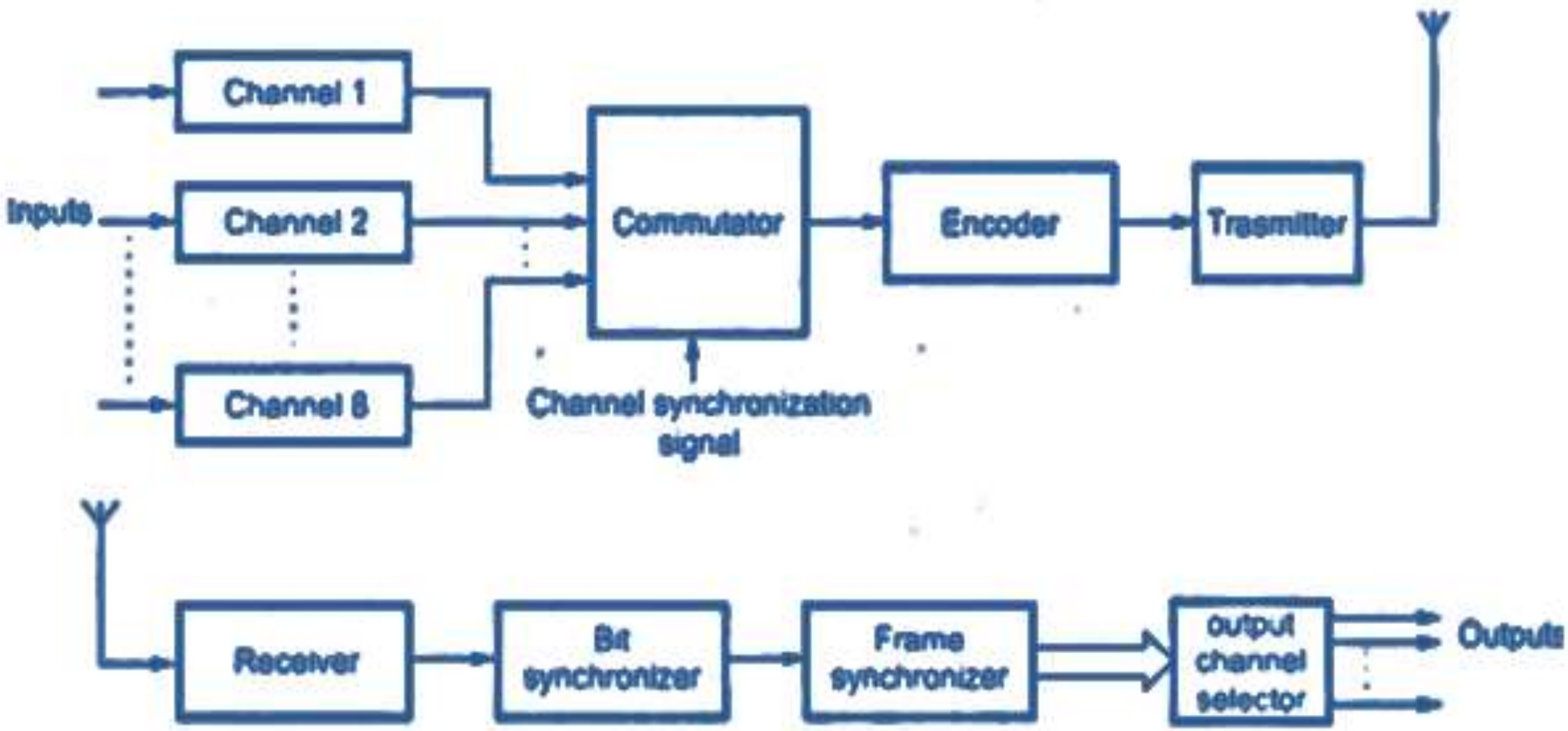
PAM Telemetry system



DIGITAL PULSE TELEMETRY

- In digital pulse telemetry system, the data to be measured is quantized and transmitted serially as data words in pulse code.
- Due to this reason, the process is also called pulse code modulation (PCM).
- The analog signal is sampled at regular intervals and then each sample value is converted into coded form.

PCM Telemetry system



FREQUENCY SPECTRUM FOR TELEMETRY APPLICATIONS

NAME	FREQUENCIES	APPLICATIONS
Very low frequency (VLF)	Below 30 kHz	Radio location equipment
Low frequency (LF)	30 kHz to 300 kHz	Wartime radio navigation
Medium frequency (MF)	300 kHz to 3 MHz	Includes AM radio broadcast band
High frequency (HF)	3 MHz to 30 MHz	Radio
Very high frequency (VHF)	30 MHz to 300 MHz	Includes FM broadcast band and television VHF channels
Ultra high frequency (UHF)	300 MHz to 3 GHz	Includes television UHF channels
Super high frequency (SHF)	3 GHz to 30 GHz	Satellite communications
Extremely high frequency (EHF)	30 GHz to 300 GHz	Satellite communications

Comparison

Criteria	Electrical system	Hydraulic system	Pneumatic system
Energy Production	Hydro, nuclear	Pump, Electrically Driven	Compressor, Electrically Driven
Availability Of Medium	Generally Available Everywhere	Obtaining And Disposing Of Oil Is Costly	Air is freely available
Energy Storage	In Batteries and cells to a small extent; Expensive and maintenance difficult	Limited storage capability in accumulator, Gas is needed as an auxiliary medium	Large amount can stored in receiver tank without amount of extent.
Energy Transmission	Large distance, even beyond 1000km	Up to 100 m	Up to 1000 m
Cost of Energy	Smallest	High	Highest
Controllability	Limited means of control, High cost	Speed control is very good especially in slow speed range	Speed control is easy, but uniform speed is not possible
Linear force	Lower forces , Poor efficiency, problem of overloading , high energy consumption during no-load and large physical size	Large forces due to high pressure, good controllability, and possibility of large stoke	Force limited up to (50000 N)due to low pressure and cylinder, high speed operation(up to 1.5 m/s) , high acceleration, stroke up to 10 m possible
Rotary force	Using electric motors, highest efficiency, limited speed	Using hydraulic motors, good efficiency, easily controllable when moving slow, high performance due to high pressure	Using air motors, very high speed, up to 50000 rpm, simple, reversible

Comparison....

Adjustment of force	Very complicated	Simple due to pressure regulating valve	Simple due to pressure regulating valve
Consumption at standstill	Standstill with load and no specific precaution leads to destruction	Maximum energy consumption at full force	No energy consumption at standstill
Overloading	Not loadable at standstill	Loadable until standstill	Loadable until standstill
Temperature influence	Insensitive to variations in temperature	sensitive to variations in temperature	Relatively insensitive to variations in temperature
Leakage	Lethal accident risk at high voltage	Lose of energy and environment fouling	Loss of energy
Handling	Specialized knowledge required	More intricate	Good result obtainable
Noise	Loud actuating noise of contactors and relays	Pump noise at high pressure	Unpleasant exhaust noise can be reduced by installing silencers.

BIOMEDICAL TELEMETRY

BIOTELEMETRY INTRODUCTION

- Biotelemetry is the use of telemetry methods in order to remotely observe, document, and measure certain physiological functions in human beings or other living organisms.
- Measurements which have been done in biotelemetry can be determined in two categories:
- **Bioelectrical variables**, such as **electrocardiogram (ECG), electromyogram (EMG) and electroencephalogram (EEG).**
- **Physiological variables** that require transducers, such as blood pressure, gastrointestinal pressure, blood flow and temperature.

Wireless Telemetry

- Wireless telemetry permits examination of the physiological data of man / animal under normal conditions and in natural surroundings without any discomfort or obstruction to the person or animal under investigation.
- Using wireless telemetry, physiological signals can be obtained from swimmers, riders, athletes, pilots or manual labourers.
- Telemetric surveillance is most convenient during transportation within the hospital area & continuous monitoring of patients sent to other wards or clinics for check-up or therapy.

Wireless Telemetry..

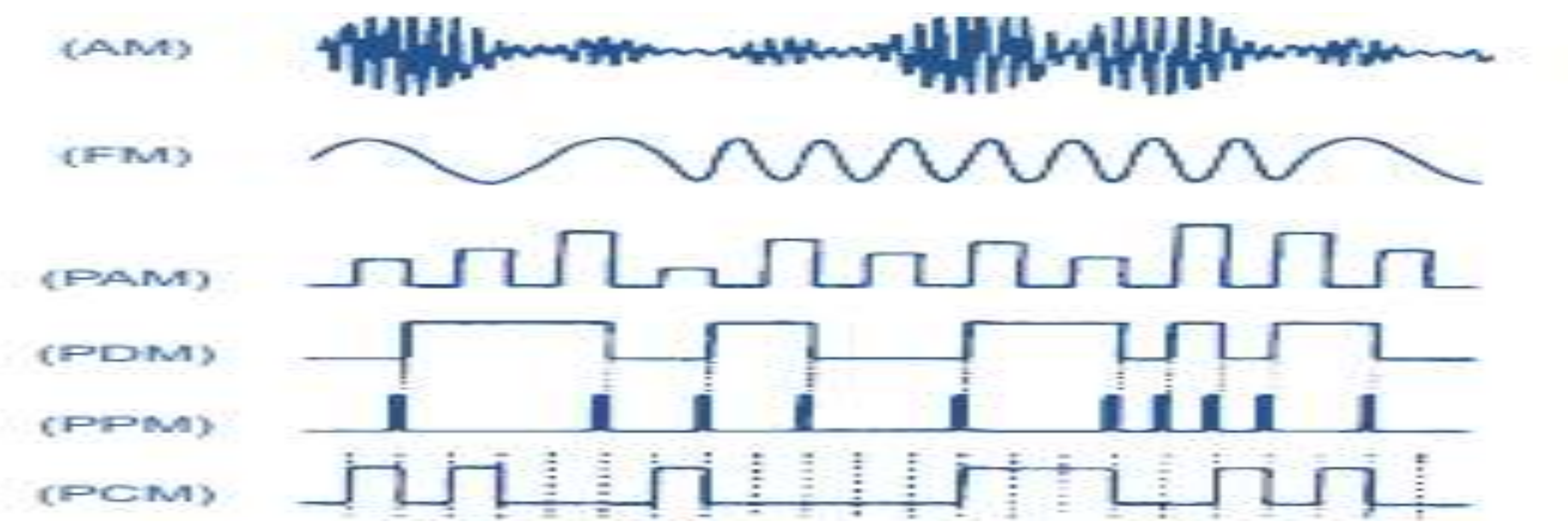
- Most biotelemetry systems are wireless.
- They consist of several components, including sensors, transmitters, a radio antenna, and a receiver.
- Subjects typically wear the transmitters on the outside of their bodies.
- Signals are then sent from the transmitters to a receiver in the biotelemetry lab to be reviewed & analyzed.
- A display unit in the lab allows the staff to see vital sign information from several different patients at one time.

Wireless Telemetry..

- cardiovascular patients benefit from the use of wireless bio telemetric systems.
- These devices offer cardiac patients the ability to stay mobile while being observed.
- The systems used for these patients usually depend on radio-frequency communications to monitor heart rates, blood flow, and blood pressure.

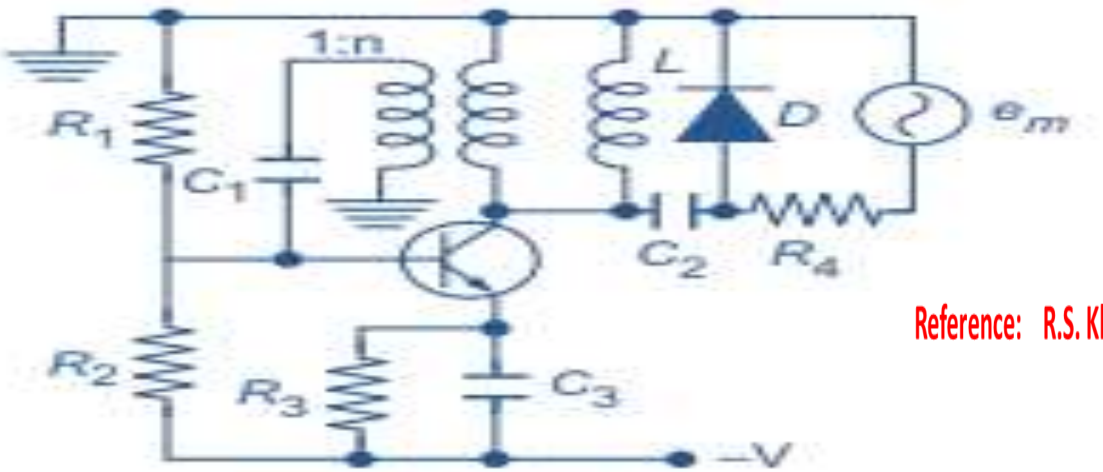
Modulation Systems

- The physiological signal alone cannot be transmitted with reasonable efficiency as a radio wave because of its low frequency.
- Therefore a high-frequency carrier wave is usually used as a transmitting vehicle.
- The signal information is forced upon the carrier by modulation, that is, by a signal-dependent (and thus time-variant) characteristic parameter such as amplitude, frequency, or phase.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

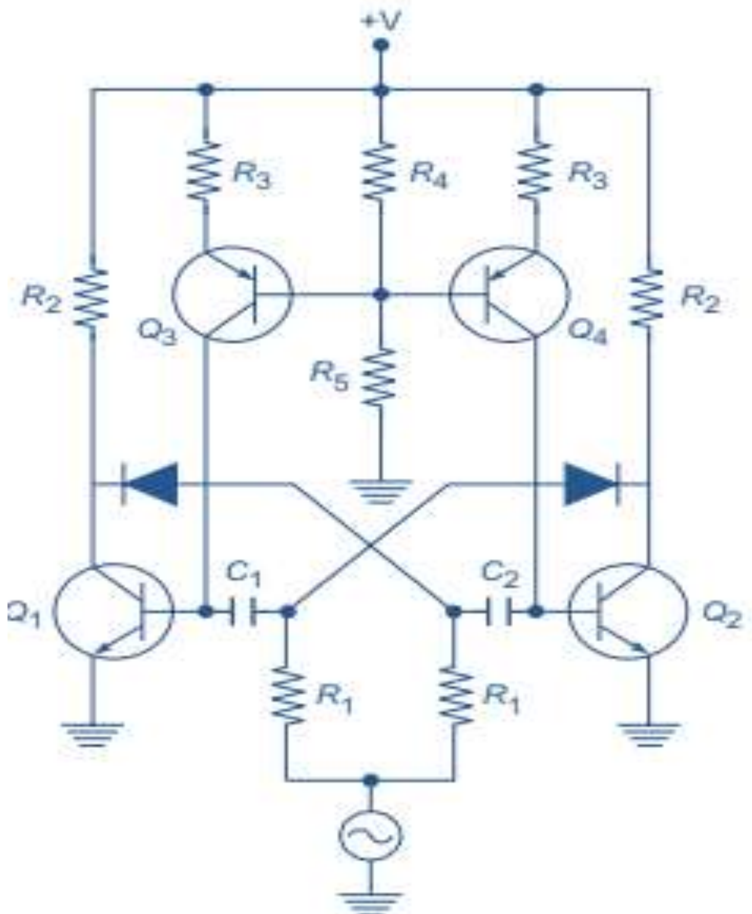
Circuit diagram of a frequency modulator



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

- FM signal is produced by **controlling the frequency of an oscillator by the amplitude of the modulating voltage.**
- **Frequency of oscillation** for oscillators **depends** on a **value of capacitance**.
- If the modulation signal can be applied in such a way that it changes the value of capacitance, then the frequency of oscillation will change in accordance with the amplitude of the modulating signal.
- The diode used is a varactor diode operating in the reverse-biased mode and, therefore, presents a depletion layer capacitance to the tank circuit.

Pulse width modulator



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

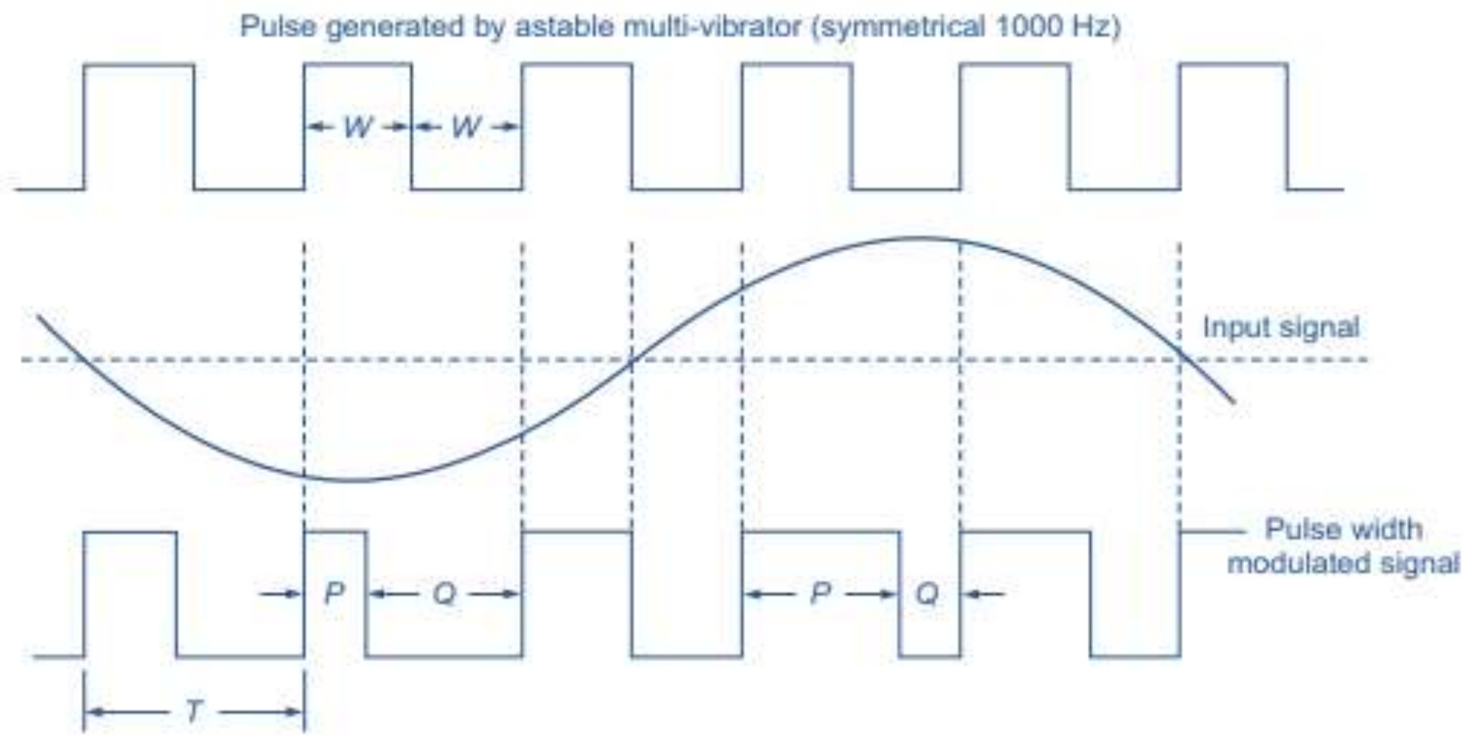
- Transistors Q1 and Q2 form a free-running multi-vibrator.
- Transistors Q3 and Q4 provide constant current sources for charging the timing capacitors C_l and C_2 and driving transistors Q1 and Q2.
- When Q1 is 'off' and Q2 is 'on', capacitor C2 charges through R1 to the amplitude of the modulating voltage e_m.
- When Q1 turns 'on' switching the circuit to the other stage, the base voltage of Q2 drops from approximately zero to $-e_m$.
- Transistor Q2 will remain 'off' until the base voltage charges to zero volt.
- Since the charging current is constant at I, the time required to charge C2 and restore the circuit to the initial stage is

$$T_2 = \frac{C_2}{I}.e_m$$

- Similarly

$$T_1 = \frac{C_1}{I}.e_m$$

Variation of pulse width with amplitude of the input signal



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

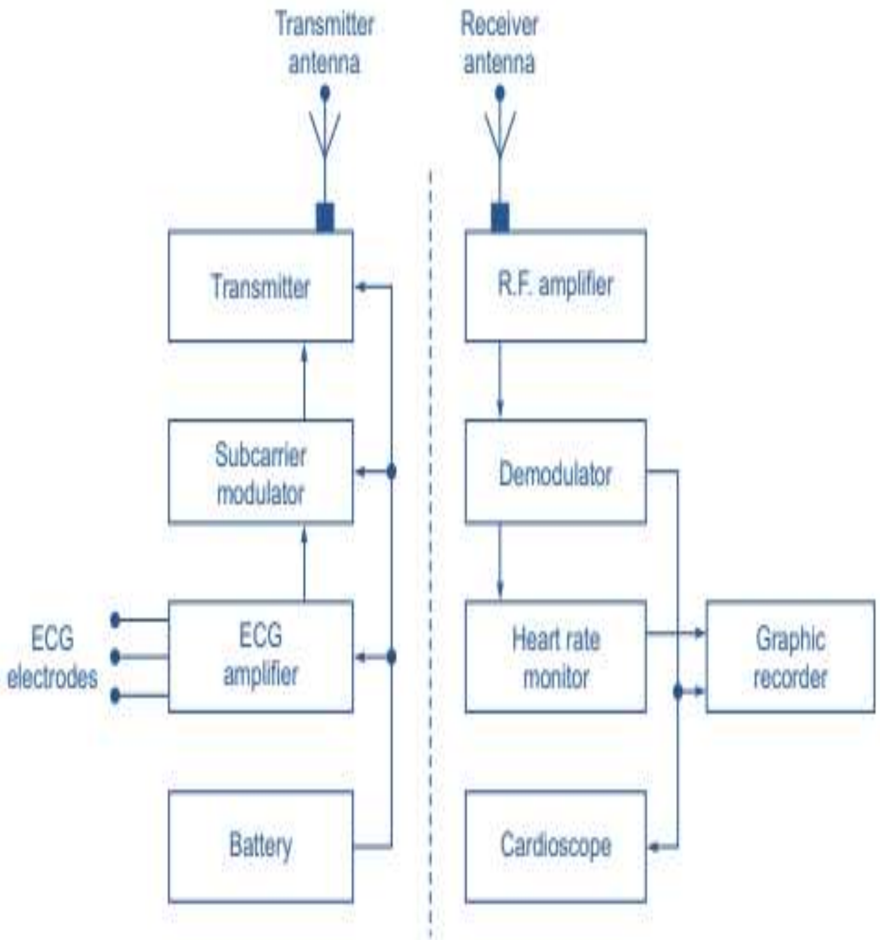
Choice of Radio Carrier Frequency

- The radio frequencies normally used for medical telemetry purposes are of the order of 37, 102, 153, 159, 220 and 450 MHz.
- Refer Frequency Band.

SINGLE CHANNEL TELEMETRY SYSTEMS

- In a majority of the situations requiring monitoring of the patients by wireless telemetry, the parameter which is most commonly studied is the electrocardiogram.
- The display of the ECG and cardiac rate gives sufficient information on the loading of the cardiovascular system of the active subjects.
- A single channel telemetry system suitable for the transmission of an electrocardiogram.

ECG Telemetry System

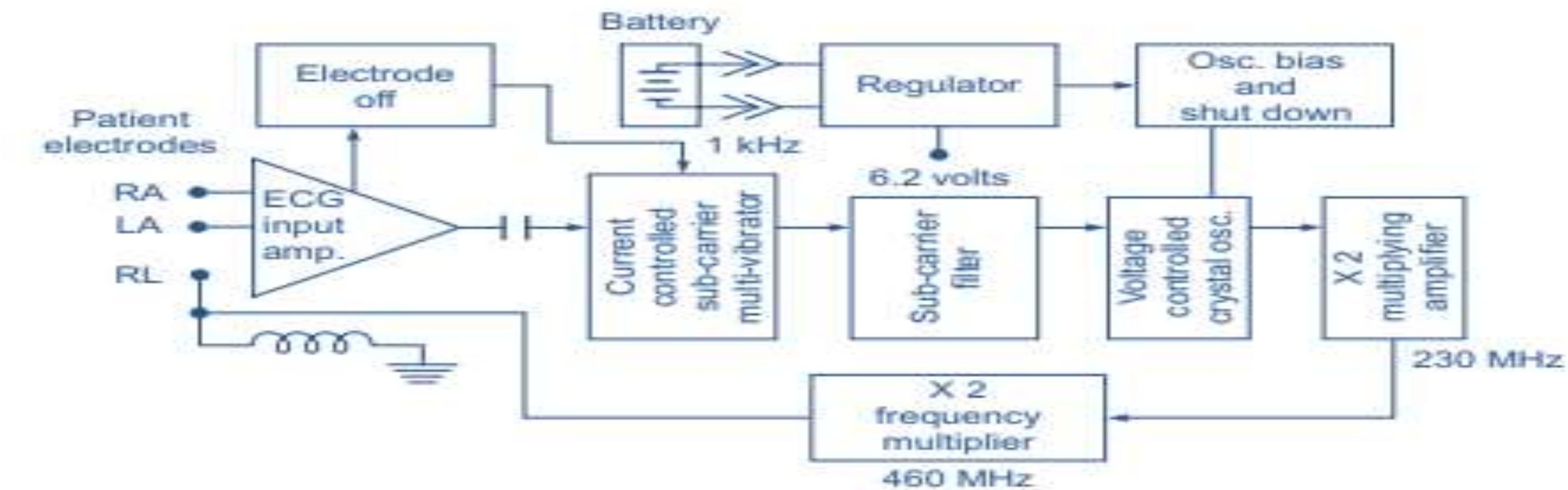


- The Telemetry Transmitter which consists of an ECG amplifier, a sub-carrier oscillator and a UHF transmitter along with dry cell batteries.
- Telemetry Receiver consists of a high frequency unit and a demodulator, to which an electrocardiograph can be connected to record, a cardioscope to display and a memory device 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.

Distortion-free transmission of ECG

- The subject should be able to carry on normal activities 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.

Block diagram of ECG telemetry transmitter



- 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.

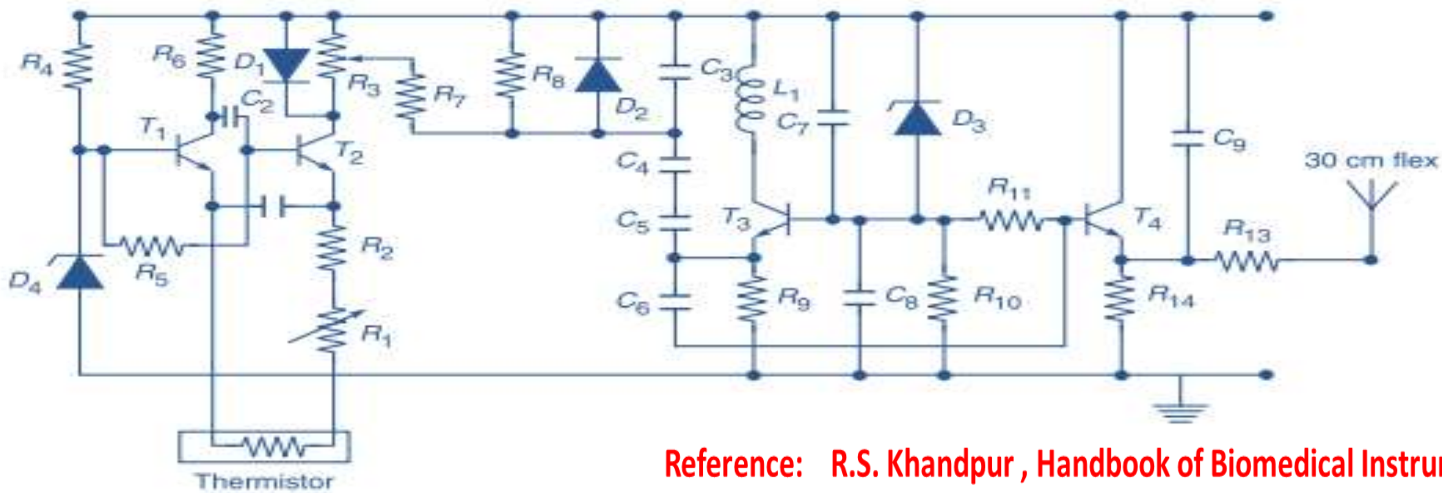
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

ECG telemetry receiver

- The receiver uses an omnidirectional 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.
- RF amplifier, which provides a low noise figure, RF filtering and image-frequency rejection.
- Automatic Frequency Control (**AFC**) , AGC are used in many ECG receiver.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Temperature Telemetry System



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

- Temperature is sensed by a thermistor having a resistance of 100 W (at 20°C) placed in the emitter of transistor T1.
- Transistors T1 and T2 form a multi-vibrator circuit timed by the thermistor, R1 + R2 and C1.
- R1 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.
- This is fed to the variable capacitance diode D2 via potentiometer R3. D2 is placed in the tuned circuit of a RF oscillator constituted by T3.
- Transistor T3 forms a conventional 102 MHz oscillator circuit, whose frequency is stabilized against supply voltage variations by the Zener diode D3 between its base and the collector supply potential.
- T4 is an untuned buffer stage between the oscillator and the aerial.

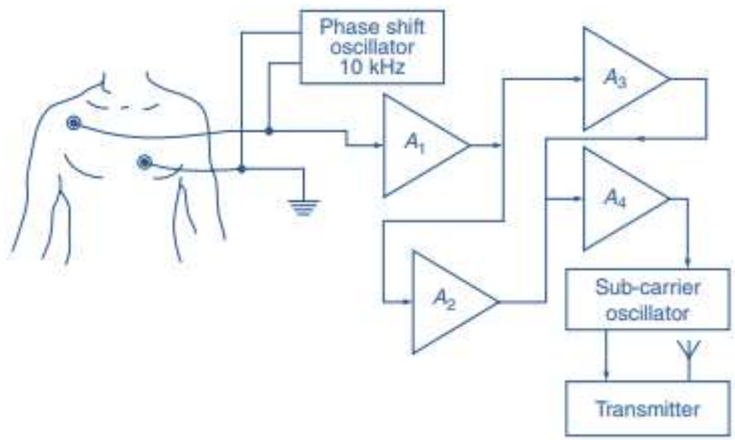
Temperature Telemetry System…

- 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.
- The circuit is designed to operate on 5.4 V, 350 mAh battery which gives a continuous operation for 100 hours.

MULTI-CHANNEL WIRELESS TELEMETRY SYSTEMS

- Multi-channel telemetry is particularly useful in **athletic training programs**.
- It **simultaneously surveying several physiological parameters of the person**.
- With appropriate electrodes/transducers and preamplifiers, the multi-channel systems permit the transmission of the ECG and heart rate, respiration rate, temperature, intravascular and intra-cardiac blood pressure parameters simultaneously.
- In multi-channel telemetry, the number of sub-carriers used is same as the number of signals to be transmitted.
- Multi-channel radio telemetry, various channels information are combined into a single signal.
- This technique is called multiplexing.
- There are two basic methods of multiplexing.
- **Frequency–division multiplexing & Time–division multiplexing**

Telemetry of ECG and Respiration



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

- Respiration is detected by the impedance pneumographic principle by using pair of electrodes used for the ECG.
- A 10 kHz sinusoidal constant current is injected through electrodes E1 and E2 attached across the subject's thoracic cavity.
- The carrier signal is generated by a phase shift oscillator.
- The varying thoracic impedance associated with respiration produces an AC voltage whose amplitude varies with a change in impedance.
- The amplitude varying carrier is amplified by an amplifier A1.
- An amplifier filter A3 recovers the respiration signal by using rectifiers and a double pole filter. T
- he ECG signal, detected by electrodes E1 and E2 is amplified in A1 along with the respiratory signal.

Telemetry of ECG and Respiration…

- It is passed through a low-pass Butterworth filter stage A2 which passes the ECG signal but blocks respiratory signal.
- The amplified ECG signal is then summed up with the pre-processed respiration signal in A4.
- The output of A4 is a composite signal which is supplied to an astable multi-vibrator which acts as a voltage-controlled sub-carrier oscillator.
- The output of the sub-carrier oscillator is then fed to an RF oscillator for transmission.
- Signals can be transmitted over distances up to 15 m for about four weeks before replacing the battery.

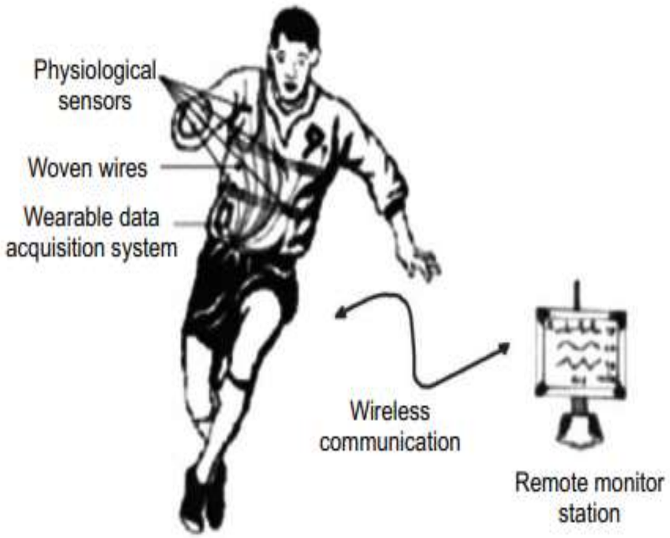
MULTI-PATIENT TELEMETRY

- The main advantage of a multi-patient single parameter telemetry system is that patients making satisfactory recovery can vacate the instrument beds in the ICU/CCU units.
- Data from different patients is received at central station.
- The station have the facility of non-fade display of received waveforms, an ECG recorder which gets activated when the patient goes into alarm, loose lead/loss of signal alarm.
- The heart rate of each patient is derived and displayed simultaneously with a digital display.
- Multi-patient telemetry is usually done using crystal controlled circuits, which provide frequency stability.

MULTI-PATIENT TELEMETRY…

- The multi-patient telemetry systems, having utility mostly with cardiac patients, should have transmitters provided with defibrillator protection to 5000 V, 400 Watt sec. pulse.
- ECG waveforms should not be seriously affected in the presence of pacemaker pulses of 2.5 ms in width and at rates up to 150 bpm.

Wearable physiological monitoring system



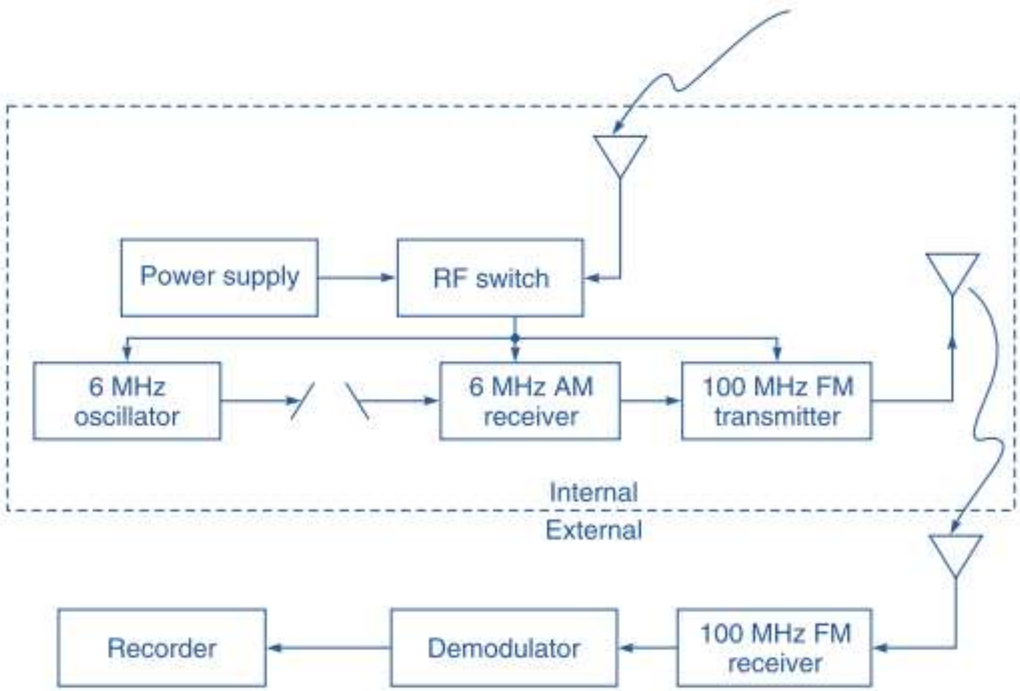
Reference: R.S. Khandpur, Handbook of Biomedical Instrumentation

- The system consists of an array of sensors embedded into the fabric of the wearer to continuously monitor the physiological parameters and transmit wireless to a remote monitoring station.
- The physiological sensors make use of miniaturized electronics to condition, process, digitize and wireless transmission integrated into the single module.
- Number of sensors integrated into the fabric form a network (Personal Area Network) and interacts with the human system to acquire and transmit the physiological data to a wearable data acquisition system.
- The wearable data acquisition hardware collects the data from various sensors and transmits the processed data to the remote monitoring station.
- A number of wearable physiological monitoring systems have been developed to monitor the health status of the individual wearer.

IMPLANTABLE TELEMEETRY SYSTEMS

- Implantable telemetry has been used exclusively in animal research.

Block diagram of an implantable blood flowmeter based on ultrasonic Doppler shift principle



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

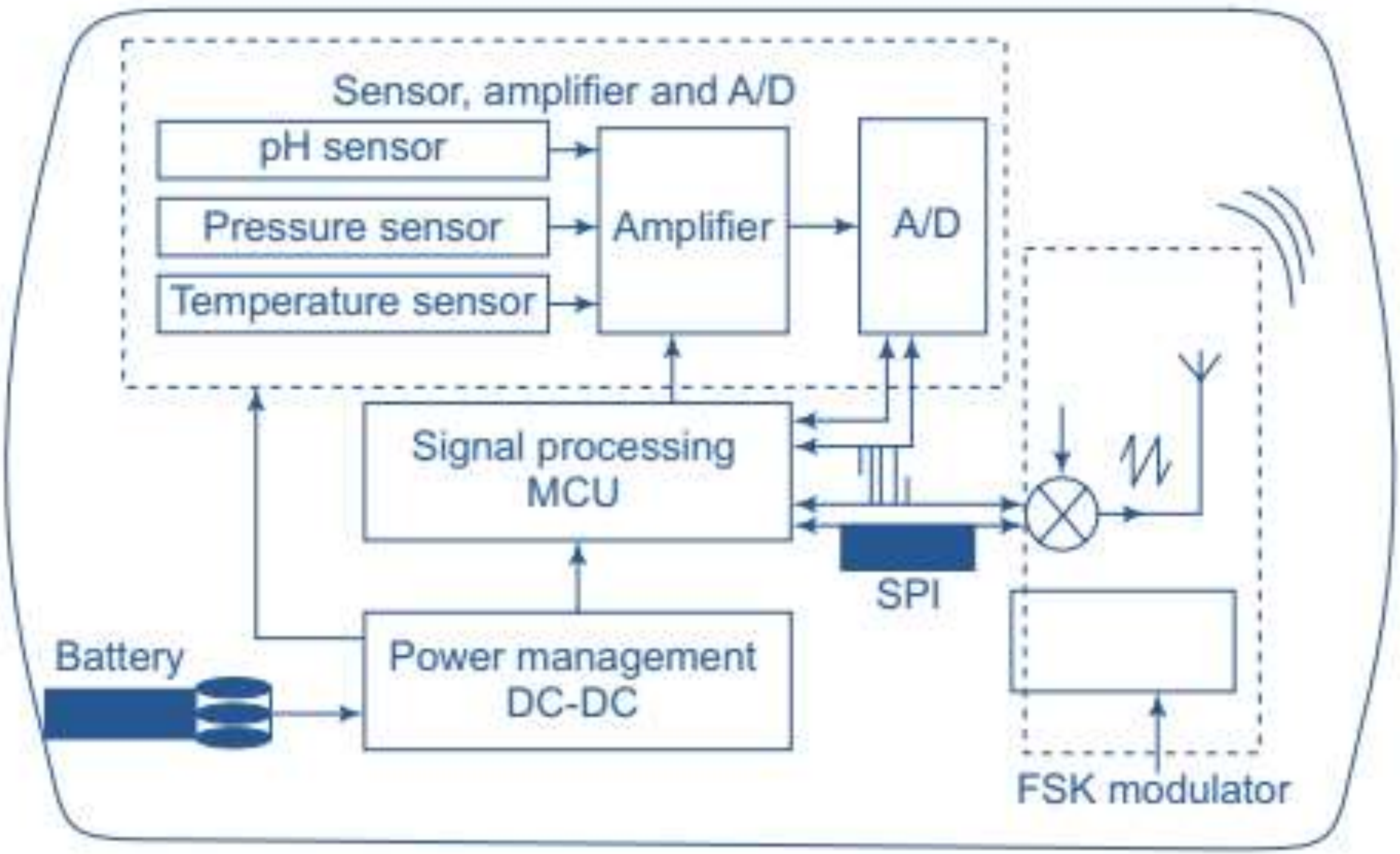
IMPLANTABLE TELEMEETRY SYSTEMS..

- Blood velocity information is converted to an electrical signal by means of two ultrasonic transducers which are mounted in a rigid cuff surrounding the vessel.
- High frequency power for the flow transducer is generated by the 6 MHz oscillator.
- The 6 MHz AM receiver converts the incoming ultrasonic signal to an audio frequency signal by synchronous detection.
- Data recovery is accomplished by an internal 100 MHz, FM transmitter and an external commercial FM receiver.
- A demodulator, external to the body, converts the Doppler shift frequency to a flow estimate.
- The demodulator measures the zero-crossing rate of the Doppler signal which is proportional to the blood velocity.

Implantable Multi-sensor Radio-telemetry

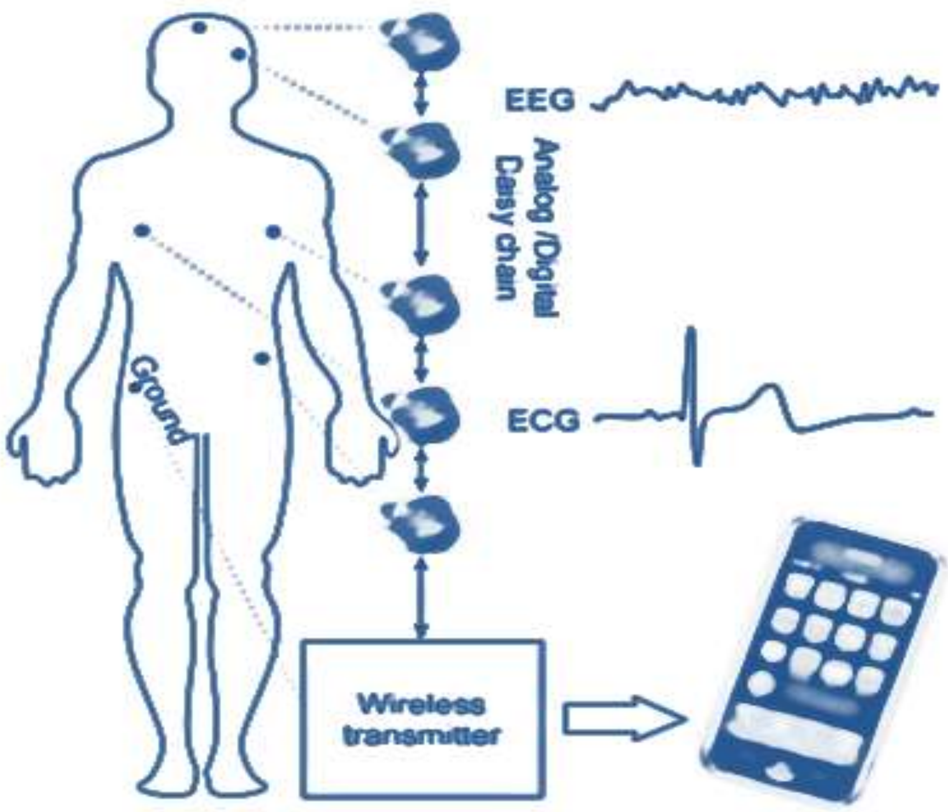
- The radiotelemetry capsule can monitor the pH, pressure and temperature of the entire intestinal tract and send the data to the data logger outside the body through a wireless communication link.
- The capsule containing the radio transceiver is swallowed and gets naturally transported from mouth to the anus.
- The capsule is not absorbed in the body and eventually exits the patient through the colon.
- The main elements of the radiotelemetry capsule comprise three sensors, signal-conditioning circuits, transceiver, micro controller unit (MCU), a pair of silver oxide cells and a magnetic switch.

Internal diagram of the Radio-telemetry Capsule



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

BIOTELEMETRY APPLICATION ON WIMAX NETWORKS



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

BIOTELEMETRY APPLICATION ON WIMAX NETWORKS..

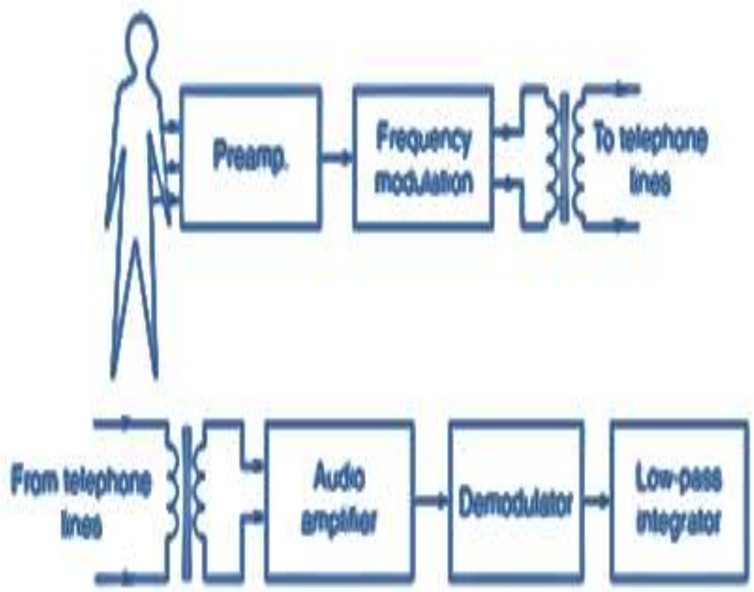
- The system uses a set of simple capacitive electrodes fabricated on standard printed circuit board that can operate through fabric or other installation.
- The system contains usual signal processing modules such as ultra high impedance preamplifier, a differential amplifier and an analog to digital converter.
- Signals are digitized directly on top of the electrode and transmitted in serial .
- A microprocessor bridges the serial data from the electrode’s ADC to a standard commercial Bluetooth module.
- A wireless base unit transmits EEG/ECG telemetry to a computer for storage and processing.

Telephone Telemetry System

- It is a method of sending physiological signals over telephone lines for remote processing.
- ECG and other signals sending over the telephone lines.
- A patient can communicate with the doctor from his home.
- most of the bioelectric signals and other physiological signals such as ECG, respiration, temperature & blood pressure consist of frequency components, which are much below the audio band width permitted by telephone-line systems.

Telephone Telemetry System

Single Channel Telephone Telemetry

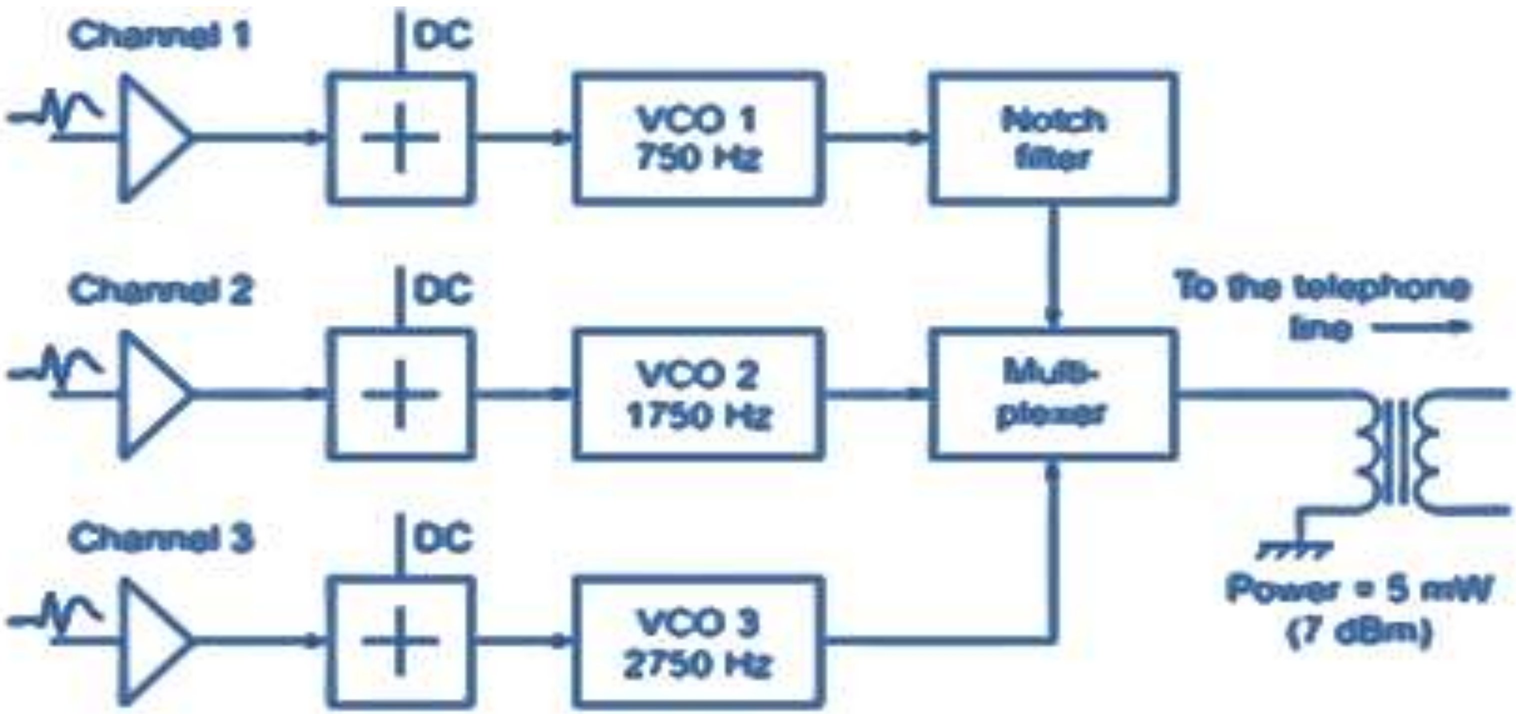


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

- For frequency modulation, a modulator is used with a centre frequency of 1500 Hz.
- The demodulator consists of an audio amplifier, a carrier rejection filter and a low-pass integrator output circuit to recover the input signal.
- The transmitting as well as receiving ends, coupling or isolation transformers are used to match the standard telephone line impedance.
- This technique makes use of a wired electrical connection of the amplified signal to the telephone transmission system.
- This is largely due to the technical difficulties involved with carbon microphones normally used as transmitters in telephone handsets.

Telephone Telemetry System

Multi-channel Patient Monitoring Telephone Telemetry System



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Multi-channel Patient Monitoring Telephone Telemetry System..

- Single and multi-channel systems employed as remote diagnostic aids for cardiac patients recovering at home and for pacemaker performance follow up.
- Increasing need for multi-channel parameter monitoring, for simultaneous transmission of ECG, blood pressure, respiration and also temperature.
- A frequency modulation system using 750 Hz, 1750 Hz and 2750 Hz was employed.
- The physiological signals after amplification to a nominal 1 volt peak-to-peak amplitude are input to an adder circuit.

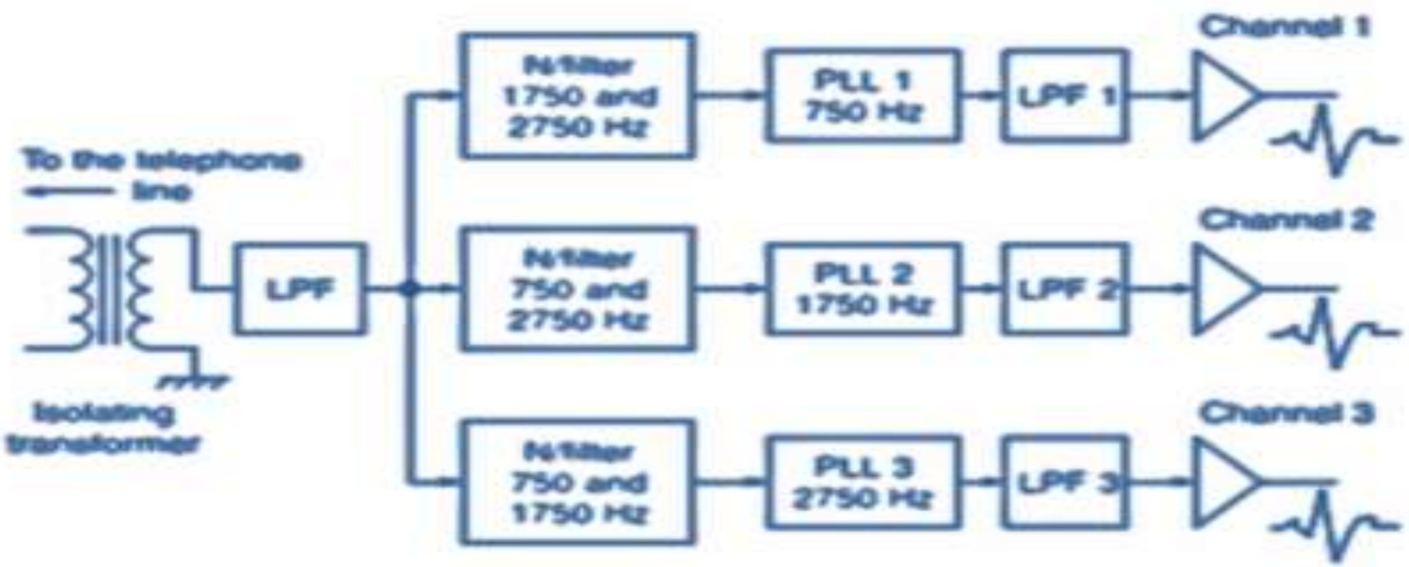
Multi-channel Patient Monitoring Telephone Telemetry System..

- This adds an appropriate dc level to the signals prior to their connection to the corresponding channel of the voltage controlled oscillator (VCO).
- After multiplexing the signals generated by the VCO, a low-pass filter cutting off at 3500 Hz is used to prevent out of band signals entering the line.
- A 1:1 isolating transformer is required to link the system with the telephone line.
- The transmitter uses the frequency division multiplexing (FDM) technique to accommodate the 3-channels of data within the 3100 Hz available bandwidths of the telephone lines.

Multi-channel Patient Monitoring Telephone Telemetry System..

- The three physiological signals frequency modulate three different VCOs.
- The VCO centre frequencies are 750, 1750 and 2750 Hz.
- This frequency spacing ensures that the spectral components of one channel do not directly overlap signals on either of the other modulated channels.
- The VCO used can generate three output waveforms: square, triangular and sine wave.
- The sine wave is preferred for use in a multi-channel system where cross-talk is to be minimized.
- The bandwidth occupied by each channel was calculated as 600 Hz, leaving 400 Hz as the guard band between the channels to prevent inter-channel cross-talk.

Three-channel telephone receiver



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Three-channel telephone receiver..

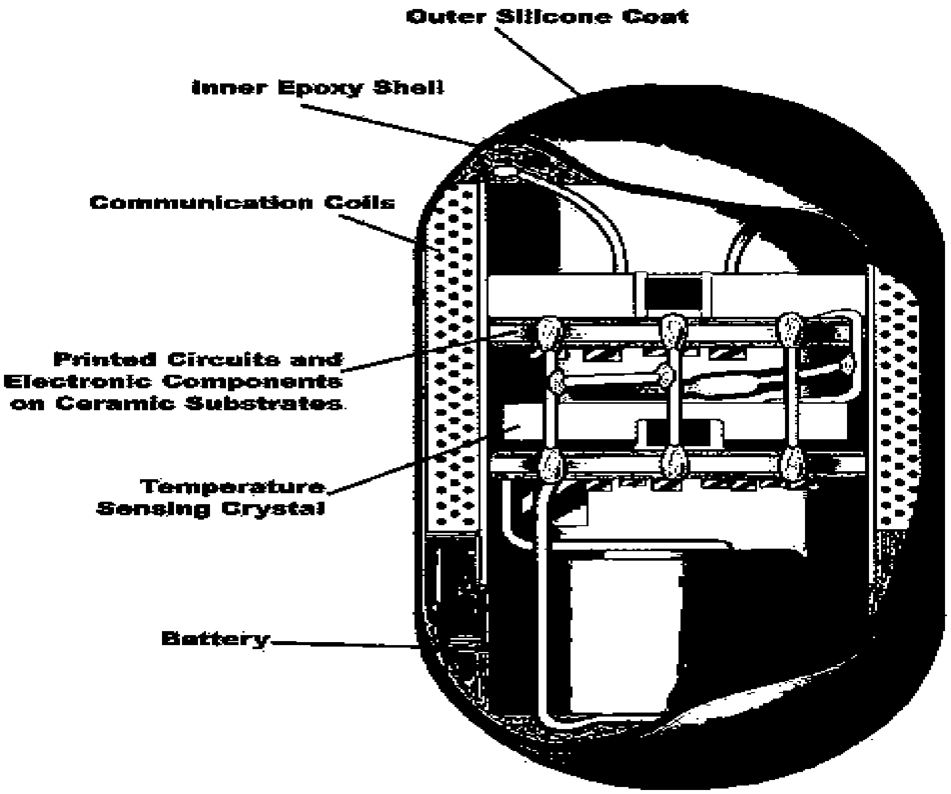
- The multiplexed signals are filtered after being terminated by the isolating transformer.
- A second order low-pass filter with a roll-off frequency set at 3 kHz to prevent high frequency line noise is used.
- The main component of each receiver channel is a phase-locked loop (PLL) used as a frequency demodulator.
- The PLLs are set to lock at frequencies of 750, 1750 and 2750 Hz for the first, second and third channels respectively.
- The NE 565, was selected as the PLL.
- After low-pass filtering the multiplexed signals, filters are used as band-reject notch filters, followed by PLL detectors in each channel.
- Finally, low-pass filtering of each output channel is needed to remove carrier ripple noise.
- The system was used over a 40 kms distance on normal telephone line.

RADIO PILLS

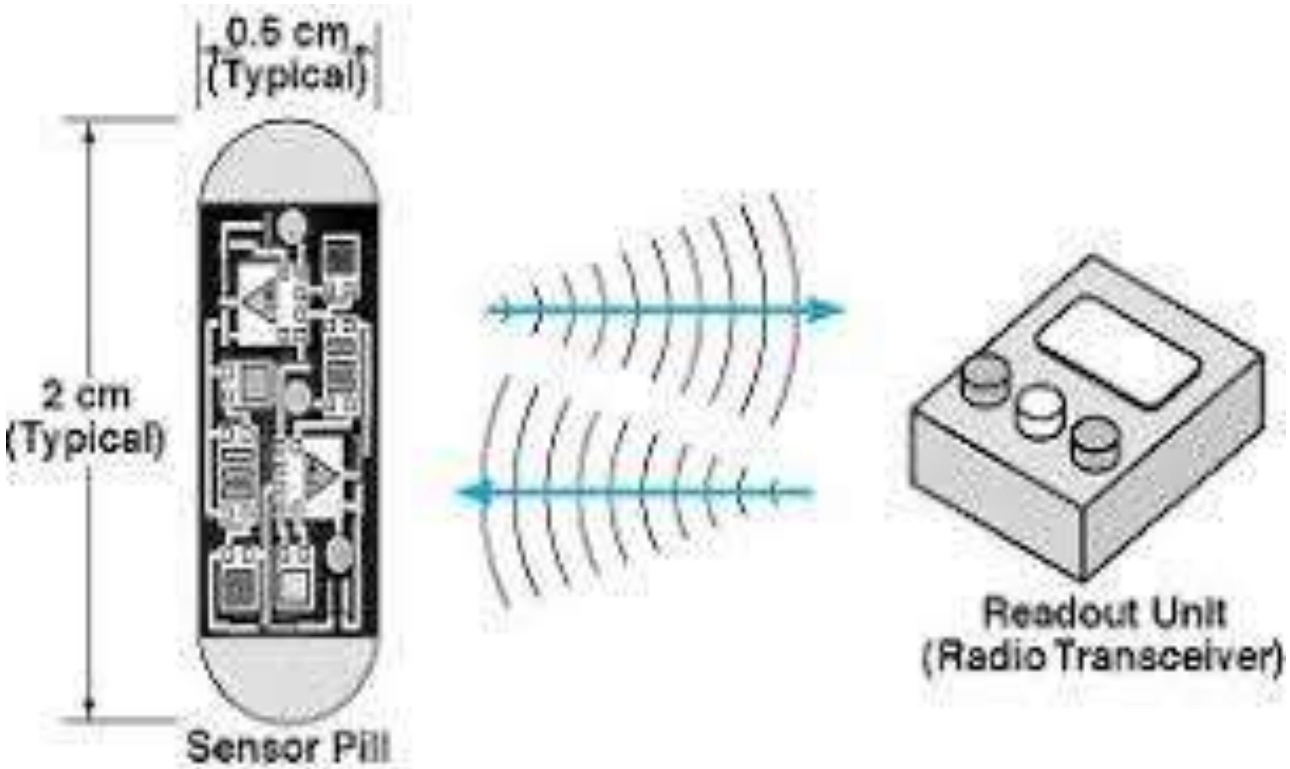
Radio Pills

- A capsule containing a miniature **radio** transmitter that can be swallowed by a patient.
- During its passage through the digestive tract it transmits information.
- The '**radio pill**' is the name given to a device developed in 1957 by Bertil Jacobson, professor of medical electronics at the Karolinska Hospital, Stockholm.
- He produced a very accurate **radio**-telemetry capsule, transmitting at 400 KHz, to measure pressure waves in the small intestine and in patients with diarrhea.

Radio Pills..


Outer Silicone Coat
Inner Epoxy Shell
Communication Coils
Printed Circuits and Electronic Components on Ceramic Substrates
Temperature Sensing Crystal
Battery

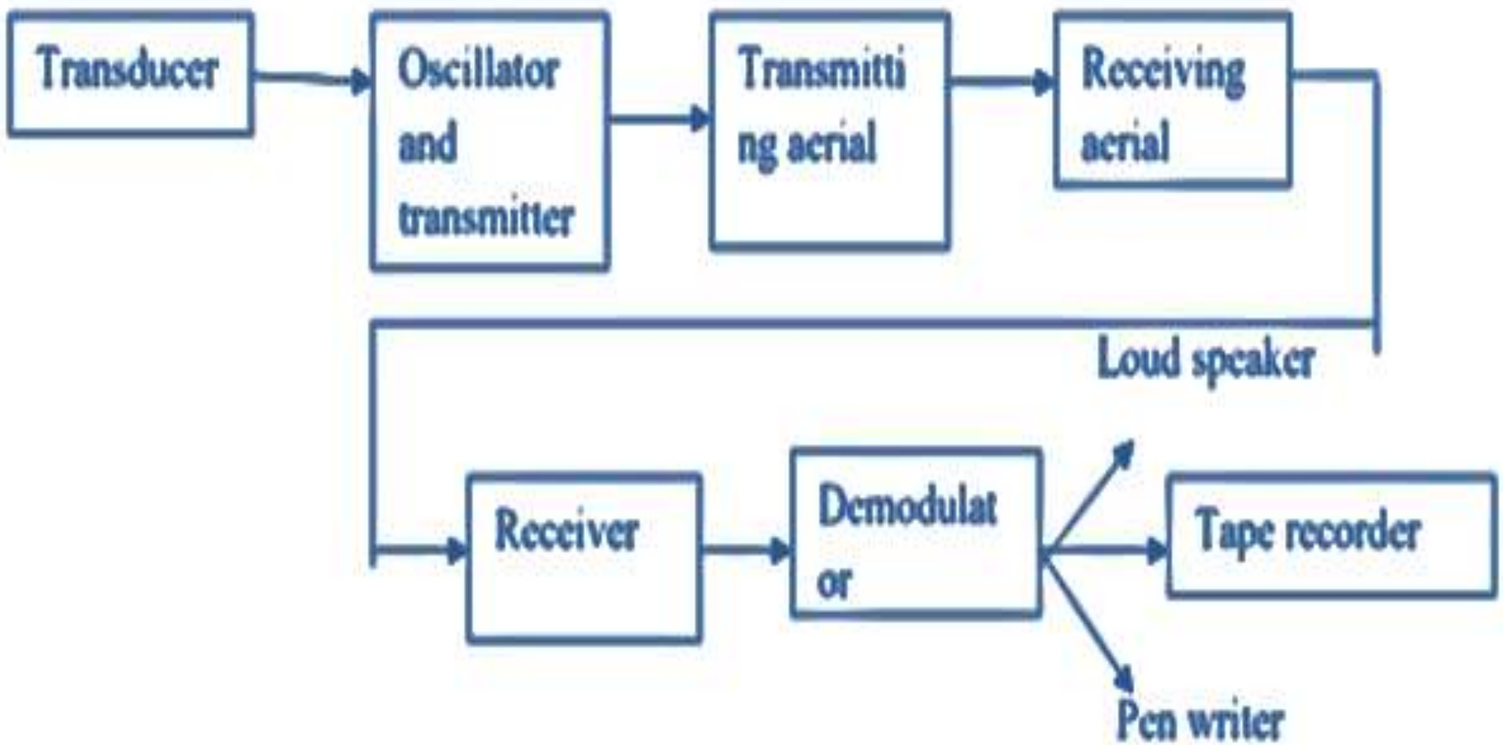
Radio Pills..


0.5 cm
(Typical)
2 cm
(Typical)
Sensor Pill
Readout Unit
(Radio Transceiver)

Radio Pills..

- **Practical Application**

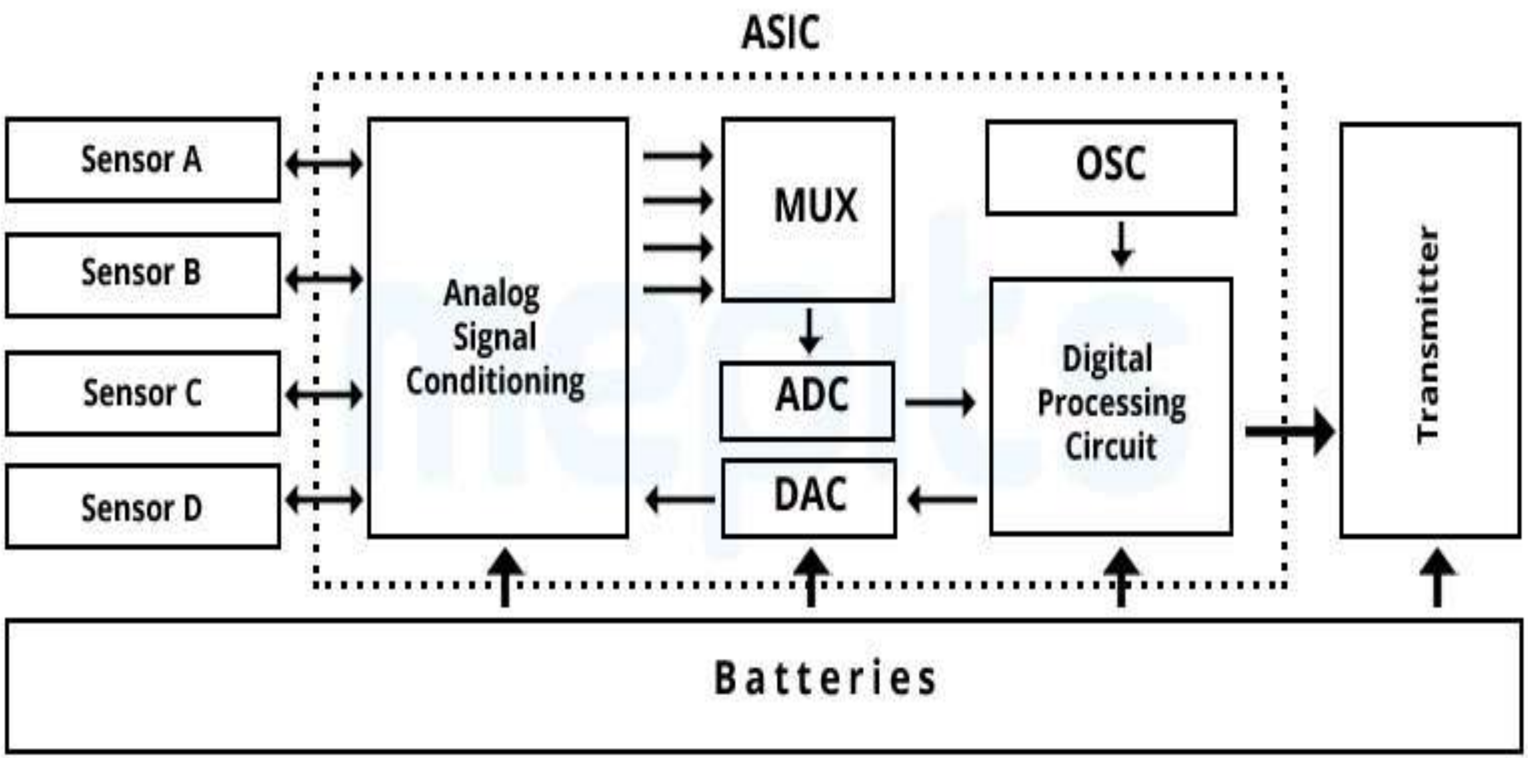
Block diagram of Radio Pills



Block diagram of Radio Pills..

- It contains transducer sensitive to pH, temperature and pressure.
- It is used for telemetering continuous information about one or various variables from lumen of the gut.
- Temperature sensitive pills are designed by the medical research council’s bioengineering lab.

Modern Radio Pill Architecture



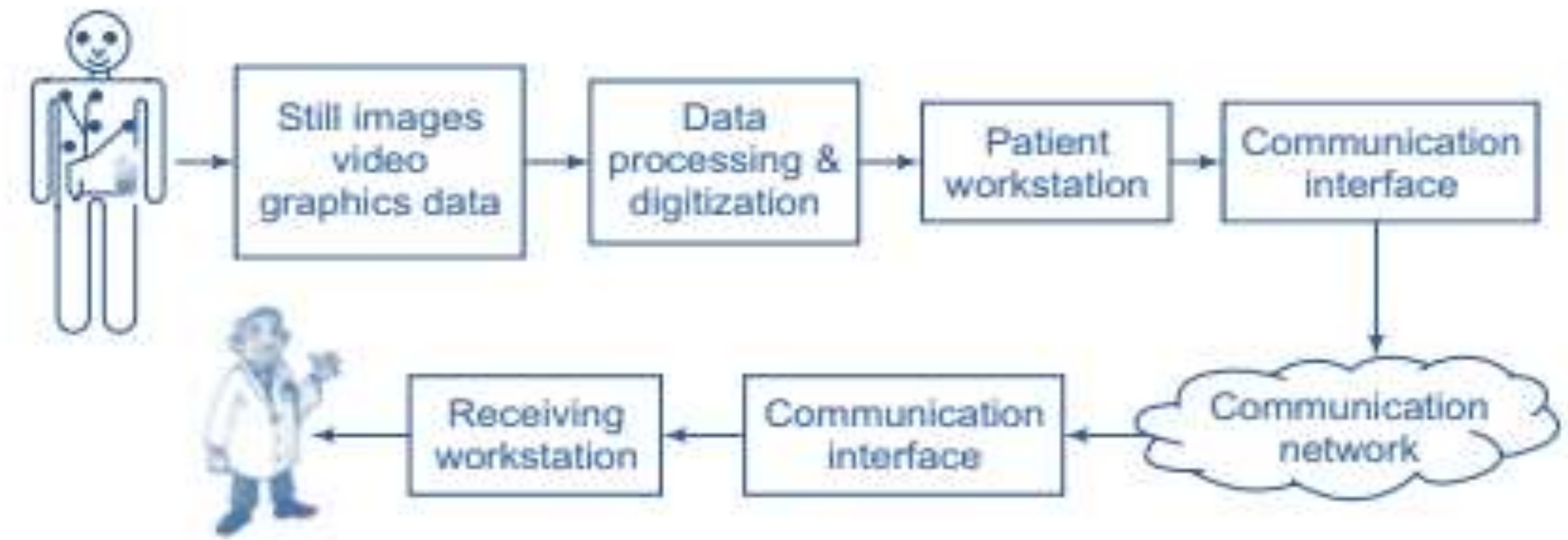
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

TELEMEDICINE TECHNOLOGY

Telemedicine Technology

- Telemedicine is the application of telecommunications & computer technology to deliver healthcare from one location to another.
- The **objective** : **move the information instead of the patient**.
- **WHO definition :** The **delivery of healthcare services**, where **distance is a critical factor**, by all **healthcare professionals using information and communication technologies** for the **exchange of valid information for diagnosis**, treatment and prevention of disease and injuries, **research and evaluation,** and for the continuing education of healthcare providers, all in the interests of advancing the health of individuals and their communities.

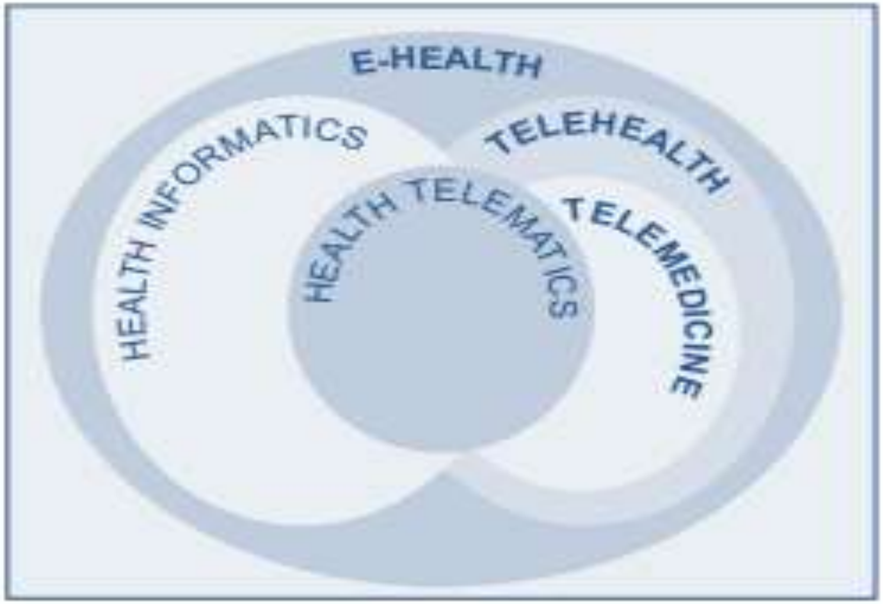
Basic concept of a telemedicine system



- The telemedicine technology includes hardware, software, medical equipment and communications link.
- The technology infrastructure is a telecommunication network with input and output devices at each connected location.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Concept of e-health



- It is an umbrella term encompassing various telemedicine and telehealth activities, together with health informatics (electronic health data) and public health telematics.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Concept of e-health..

Telehealth:

- **T**elehealth is a broader term which includes all services, from health promotion to palliative care.
- It allows for these services to fall under an umbrella term, particularly the preventive component of healthcare.

eHealth:

- It refers to all forms of electronic healthcare delivered over the internet.
- It includes a wide variety of the clinical activities that have traditionally characterized telehealth, but delivered through the internet.

Concept of e-health..

mHealth:

- Mobile health is a component of eHealth & it is defined as medical and public health practice supported by mobile devices, like mobile phones, personal digital assistants (PDAs), & other wireless devices.

uHealth:

- uHealth or ubiquitous healthcare relates to eHealth applications which can provide healthcare to people anywhere at any time using mobile technologies.

Concept of e-health..

Telecare:

- It is somewhat different term, related equally to the domain of social care, as well as to the healthcare.
- It commonly covers a spectrum of ICT (Information and communication technology)-based applications and services using remote data transfer and control.
- It aimed at facilitating independent living of the elderly and vulnerable individuals, ranging from household appliances to health data monitoring.

Health Telematics:

- Health Telematics broadly include 4 areas: telemedicine, tele-education for health, telematics for health research, and telematics for health services management.
- **WHO statement :** It is “a composite term for health-related activities, services and systems, carried out over a distance by means of information and communications technologies, for the purposes of global health promotion, disease control, and healthcare, as well as education, management, and research for health

ESSENTIAL PARAMETERS FOR TELEMEDICINE

Data:

- Disease history, status of physiological parameters like blood pressure, pulse, respiration rate, temperature.

Audio:

- Such as Heart sounds, sounds from respiratory movements.

Still images:

- X-ray, CT, MRI images (radiology), skin images (dermatology), images of tissue and cellular specimens (pathology)

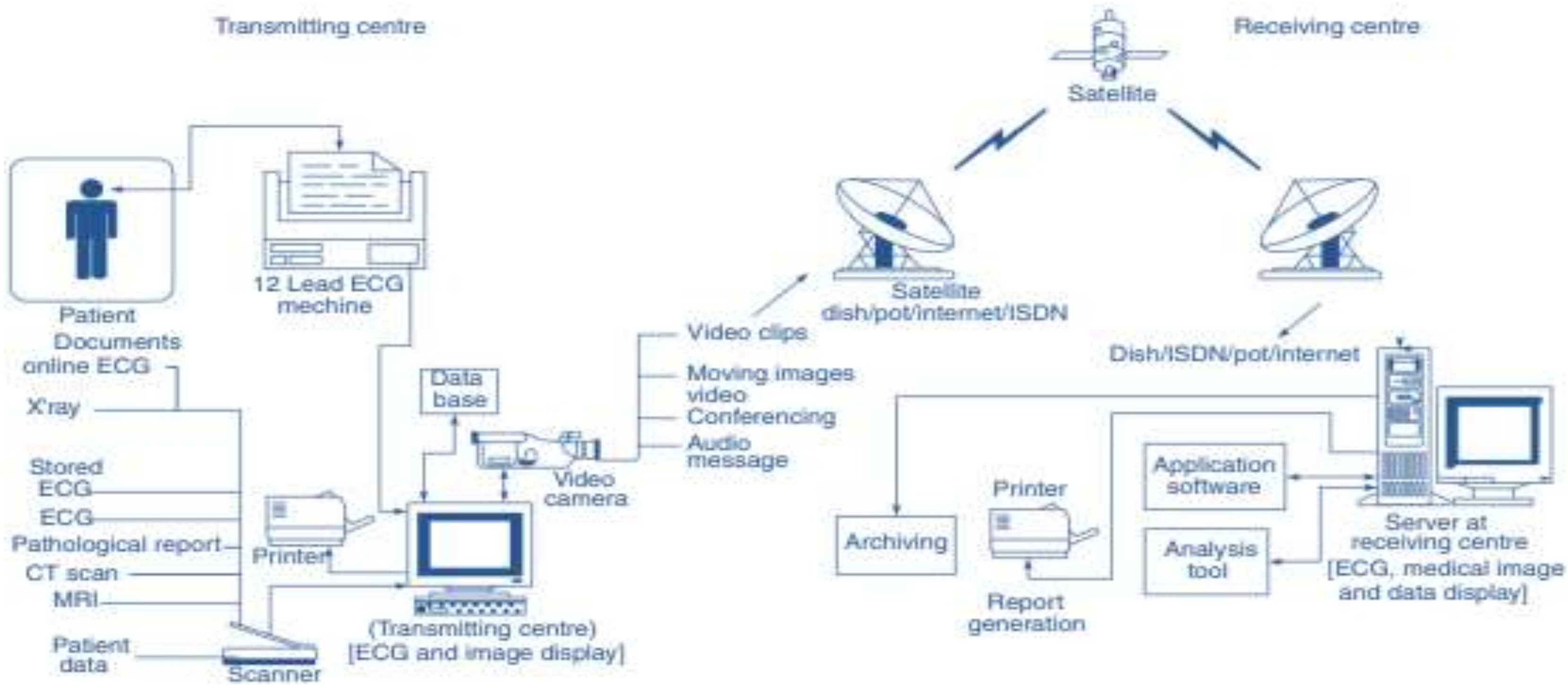
Video:

- Video of the patient, echocardiography, videoconferencing.

ESSENTIAL PARAMETERS FOR TELEMEDICINE..

- Patient Data : Name ,Age, Sex
- Patient History: Family History
- Clinical information: Diagnostic information
- Data & Reports: Such as MRI, CT Scan ,ECG.

Principle and various sub-systems used in a telemedicine setup



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

DELIVERY MODES IN TELEMEDICINE

Store and Forward Telemedicine:

- It involves collecting patient data, images and other clinical information (store) and then forwarding it from one location to another location.
- This is typically used for non-emergent situations, mostly for second opinion on a medical problem.
- The 'store-and-forward' technique primarily involves file transfer which may include:
  - Patient record
  - Radiology (X-ray, CT, MRI images)
  - Still image applications (pathology, dermatology etc.)
  - Graphics such as ECG, EEG and EMG recordings
  - Investigation results in the form of data (Laboratory Information)
  - Real images/video

DELIVERY MODES IN TELEMEDICINE..

Real Time Data Telemedicine:

- Physiological data and images can be transmitted in real time across a standard telephone or digital network, radio, cellular or satellite phones.
- Example: the transmission of ECG to support the diagnostics of acute myocardial infarction and delivery of pre-hospital care.

Hybrid Systems:

- Hybrid systems combine capabilities of real time and store-and-forward telemedicine.
- Combining stored still or motion video with real-time videoconferencing is an example of a hybrid telemedicine system.

TELEMEDICINE SYSTEM

- A typical telemedicine program consists of a two-way communications link between a medical centre and several satellite stations.
- Telemedicine may also involve two way interactive video consultations by transmitting digital images such as X-rays, CT and MRI Images to other sites.
- Thus, telemedicine systems can range from simple telephone networks to sophisticated videoconferencing systems.

TELEMEDICINE SYSTEM…

- The transmission of various types of data and images from different situations and locations takes place via satellite to specialty hospitals.

Image Courtesy: Trixie Ricablanca

TELEMEDICINE SYSTEM…

Medical Devices:

A telemedicine system may have the following medical devices at a telemetry transmitting station:

- Telecardiology: PC based Digital ECG machine Electronic Stethoscope
- Teleradiology: Medical film scanners – Laser or CCD based scanners Digital radiographic equipment
- Telepathology: Video microscopy system – Microscope, CCD Camera Single chip camera (one CCD) Three chip camera (3 CCDs, one for each of RGB for better image quality)
- Teledermatology: Dermascope with digital camera
- Miscellaneous: Document Camera – CCD based camera that forms the image of the document placed over its flat bed

TELEMEDICINE SYSTEM…

Medical Devices & Computers interfacing:

- Digital or parallel I/O, in which the two voltage levels are used to represent logical 0 and 1 .
- RS 232 C Serial Interface.
- IEEE-488 standard interface defines the 16-line bus, linking the device and computer

TELEMEDICINE SYSTEM…

Workstation for Telemedicine:

- Workstations usually offer higher performance than is normally seen on a personal computer, especially with respect to graphics, processing power, memory capacity and multitasking ability.
- In terms of computing power, workstations lie between personal computers and minicomputers, although the line is fuzzy on both ends.

Network Computing:

- The heart of the telemedicine system is the network computing.
- It relates to the computing devices which drive functionality, permit the storage of data (local or on a central server) and facilitate the transfer of a desired data from the medical device to the communication platform for distribution to other professionals.

TELEMEDICINE SYSTEM…

Videoconferencing Equipment:

- Videoconferencing system is an important component of telemedicine system .
- It enables a general physician and a specialist to see and talk to each other, exchange notes, discuss a case, transmit video and still images, and examine a patient.

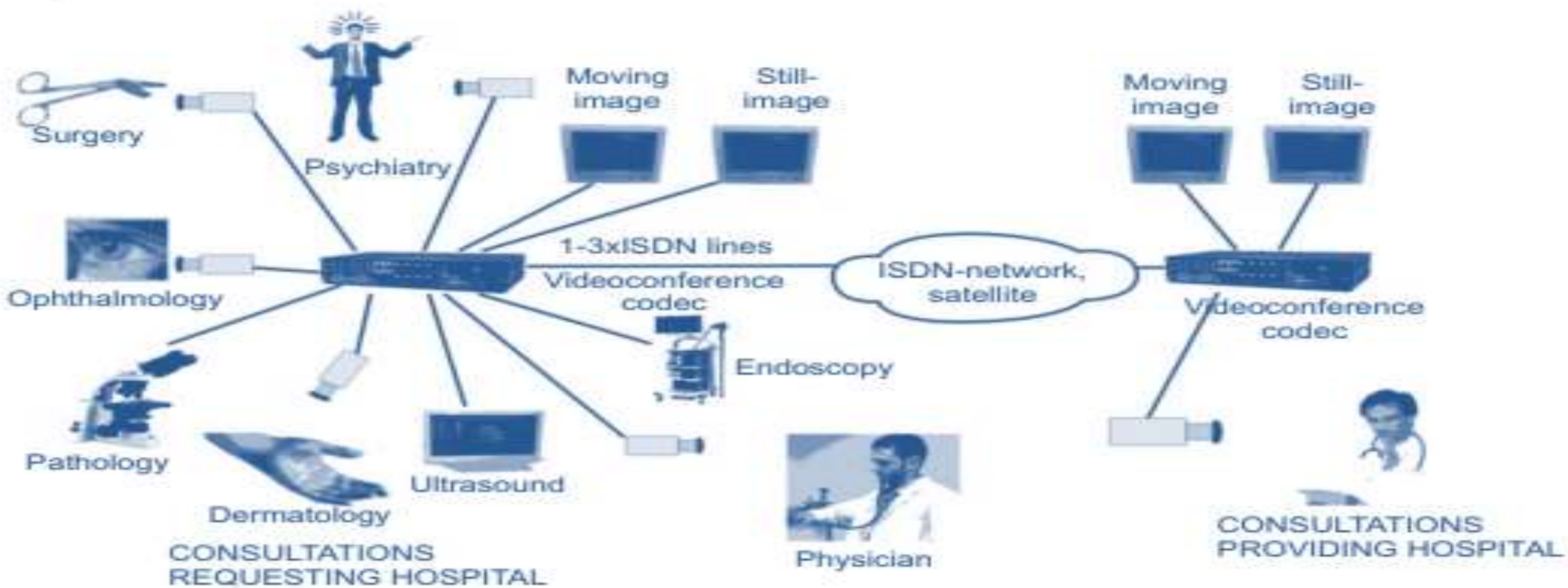


Image Courtesy: ITU-D

TELEMEDICINE SYSTEM…

Videoconferencing Equipment….

The equipment requirements of a videoconference are:

- ✓ Video input devices: Webcam or video camera
- ✓ Video output devices: Computer Monitor, television or
- ✓ Audio input devices: Projection microphones
- ✓ Audio output devices: Speakers associated usually with the display device
- ✓ Data transfer: Analog or digital telephone network, LAN or Internet

Any videoconferencing terminal has the following basic components:

- ✓ camera (to capture local video),
- ✓ video display (to display remote video),
- ✓ microphone (to capture local audio)
- ✓ speakers (to play remote audio)

TELEMEDICINE SYSTEM…

Videoconferencing Equipment….

Multipoint videoconferencing for teleconsultation

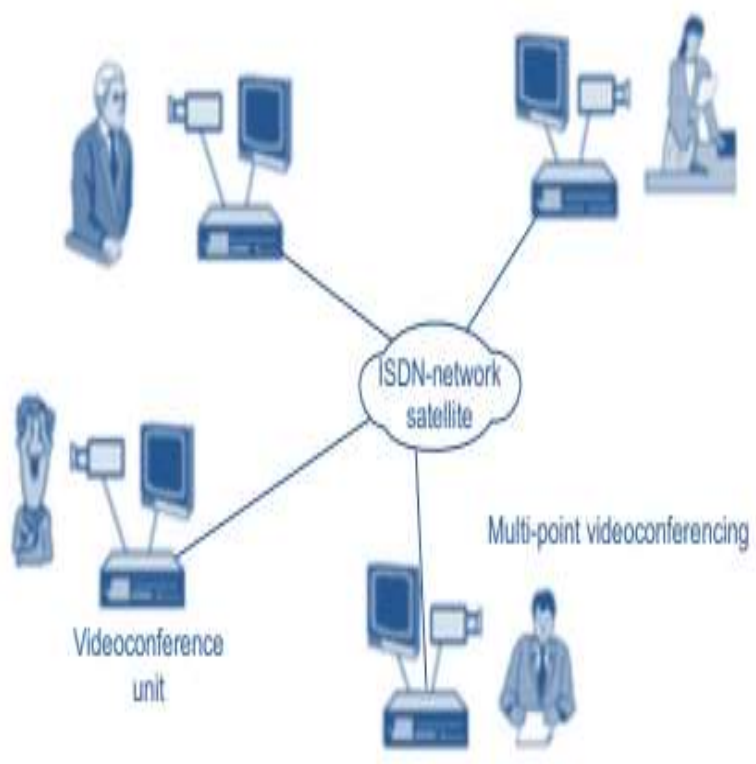


Image Courtesy: ITU-D

- Multipoint videoconferencing enables doctors from different medical facilities or countries to share teaching materials with more impact, relevance and immediacy.
- This facility is uniquely dependent on high-performance and low round-trip latency among all the components in the system to ensure the best interactivity among all participants.

TELEMEDICINE SYSTEM…

Communication Systems:

- Telecommunication is a major component of a telemedicine system.
- Different telemedicine technologies require different capacities or bandwidth of telecommunication infrastructure.
- It ranging from regular telephone line bandwidth to expensive broadband infrastructure (for real-time full motion interactive video).

Example :POTS (Plain Old Telephone Service):

- – Using a modem (modulator/demodulator) with the analog telephone system POTS digital signals at data rates upto about 30 kbps can be transmitted.
- – This service is adequate for data file transfers of still images.

TELEMEDICINE SYSTEM…

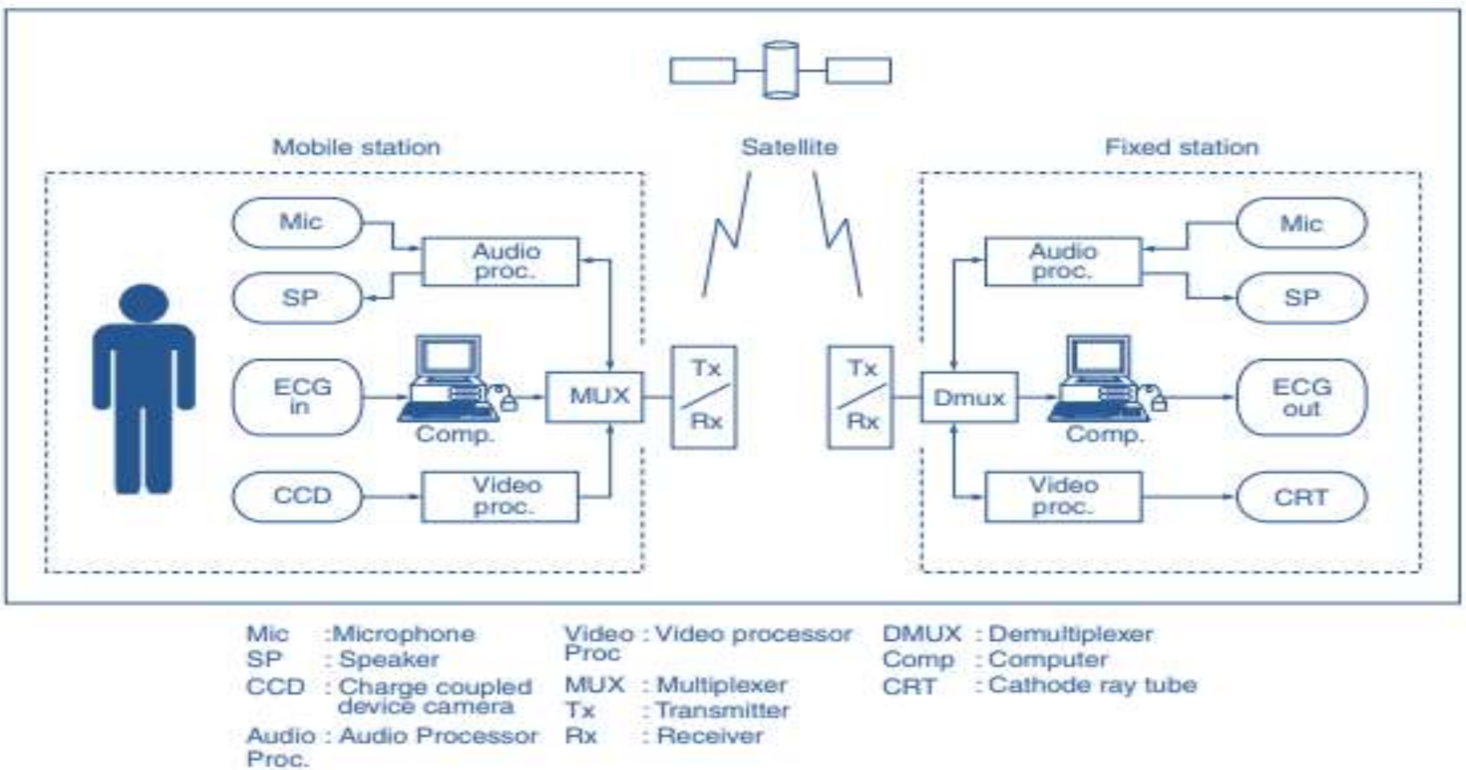
Communication Systems…

- It can handle only analog signals.
- Modems translate the computer’s digital information into an analog signal which is transported over the phone lines.
- When the signal arrives at its destination, it is demodulated—converted back into digital form for the receiving computer.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

TELEMEDICINE SYSTEM…

Telemedicine Using Mobile Communication



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

TELEMEDICINE SYSTEM…

Telemedicine Using Mobile Communication…

- A patient in a mobile station such as an ambulance where color images, audio signals and physiological signals such as ECG and blood pressure are obtained using conventional sensors/ transducers.
- These images and signals are multiplexed and transmitted to a fixed station via a satellite communication network.
- In the fixed station, the signals received are demultiplexed and presented to a medical specialist.
- Instructions from the specialist are then transmitted back to the mobile station through the same satellite communication link.
- In mobile communication, the capacity of transmission link is generally limited.
- Therefore, for sending video, audio and physiological signals, some form of data compression is used.

TELEMEDICINE SYSTEM…

Telemedicine Using Mobile Communication…

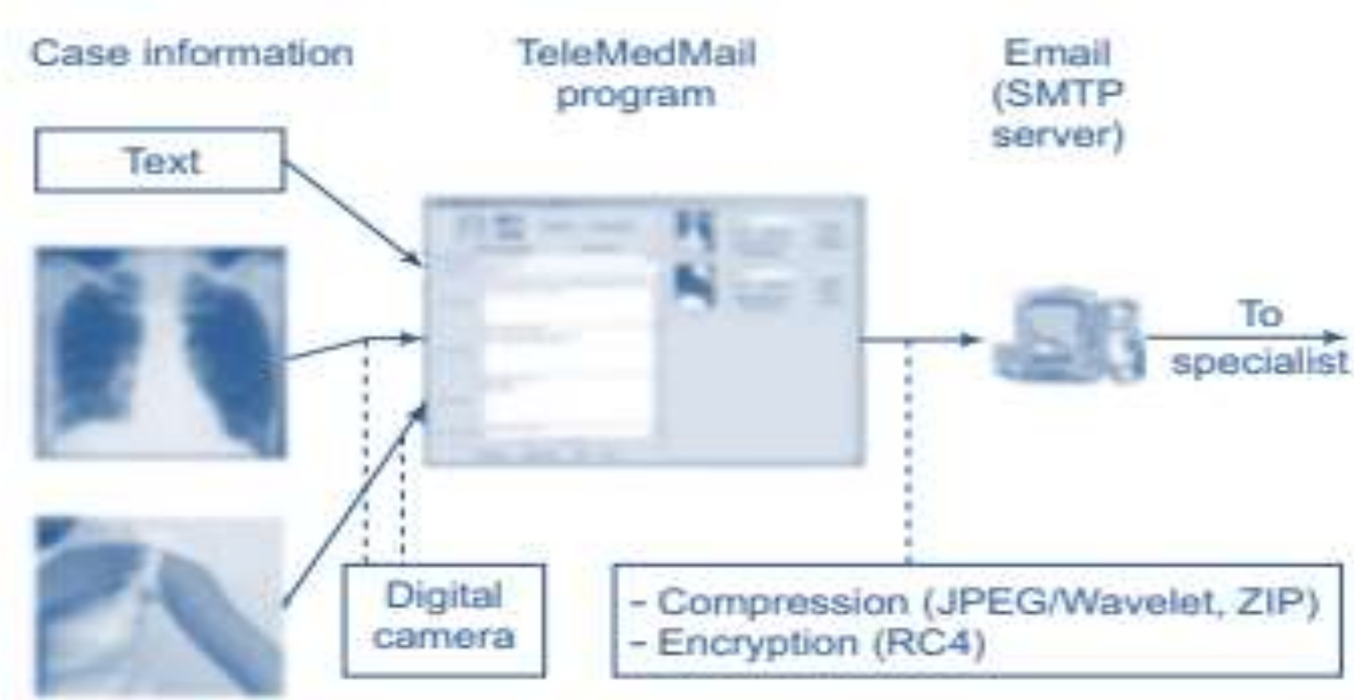
Parameters and Data Compression Ratios

Data	*Sampling*	*Compression Ratio*	*Bit Rate*
Video	256 × 256 pixels/plane 8-bit RGB/pixels 1 plane/20 sec	10:1	8 kbit/sec
Audio	8 bit/sample 6000 sample/sec	4.8:1	10 kbit/sec
ECG	3 channel 8 bit/sample 200 sample/sec	8:1	600 bit/sec (3 channel)
Blood Pressure	1 sample/min 16 bit/sample	1:1	0.3 bit/sec

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

TELEMEDICINE SYSTEM…

- **e-mail based telemedicine system**



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

CLINICAL DATA INTERCHANGE/EXCHANGE STANDARDS

- Standards for information technology used in healthcare, particularly in telemedicine, are developed by a variety of Standards Development Organisations.
- The major healthcare IT related standards are:
  - **Health Level Seven (HL7)**
  - **Digital Imaging Communication in Medicine (DICOM)**

CLINICAL DATA INTERCHANGE/EXCHANGE STANDARDS

Health Level Seven (HL7):

- The standard developed for information exchange between medical applications is HL7.
- The HL7 protocol (standard for exchanging information between computer programs.) was developed by the **Health Level 7 Organization which is based in Ann Arbor, MI, USA.**
- HL7 essentially is a protocol for electronic data exchange, defining transmission transactions for patient registration, insurance, billing, orders and results of laboratory and physiological tests, imaging studies, observations, nurse's notes, diet and pharmacy orders and inventory/ supply orders.
- HL7 stands for Health Level Seven.
- The term "Level 7" refers to the top layer (Level 7, the application level) of the Open System Interconnection (OSI) model of the International Organization for Standardization (ISO) for the healthcare environment.

CLINICAL DATA INTERCHANGE/EXCHANGE STANDARDS

Health Level Seven (HL7):

- HL7 being a protocol for data exchange, defines the format and the content of the messages that applications must use when exchanging data with one another in various circumstances.
- It defines a communication between two independent applications, rather than between closely coupled, client-server type applications.
- The scope of interest for HL7 is the message exchange between the applications, rather than the specific role of each application in the healthcare delivery process.

CLINICAL DATA INTERCHANGE/EXCHANGE STANDARDS

Digital Imaging and Communication in Medicine (DICOM):

- DICOM or “Digital Imaging Communication in Medicine” is a standard that is a framework for medical imaging communication.
- It is based on the Open System Interconnect (OSI) reference model, which defines a 7-layer protocol.
- DICOM provides standardized formats for images, a common information model, application service definitions, and protocols for communication.
- **DICOM was developed by the ACR (American College of Radiology) and NEMA (National Electrical Manufacturers Association).**

TRANSMISSION OF STILL IMAGES

- Still images are generated in telemedicine in the fields of radiology, pathology, dermatology, ultrasound, endoscopy, ophthalmology etc.
- The images are captured by still cameras or video microscopes etc.

High resolution still image transfer from PC to PC using digital cameras

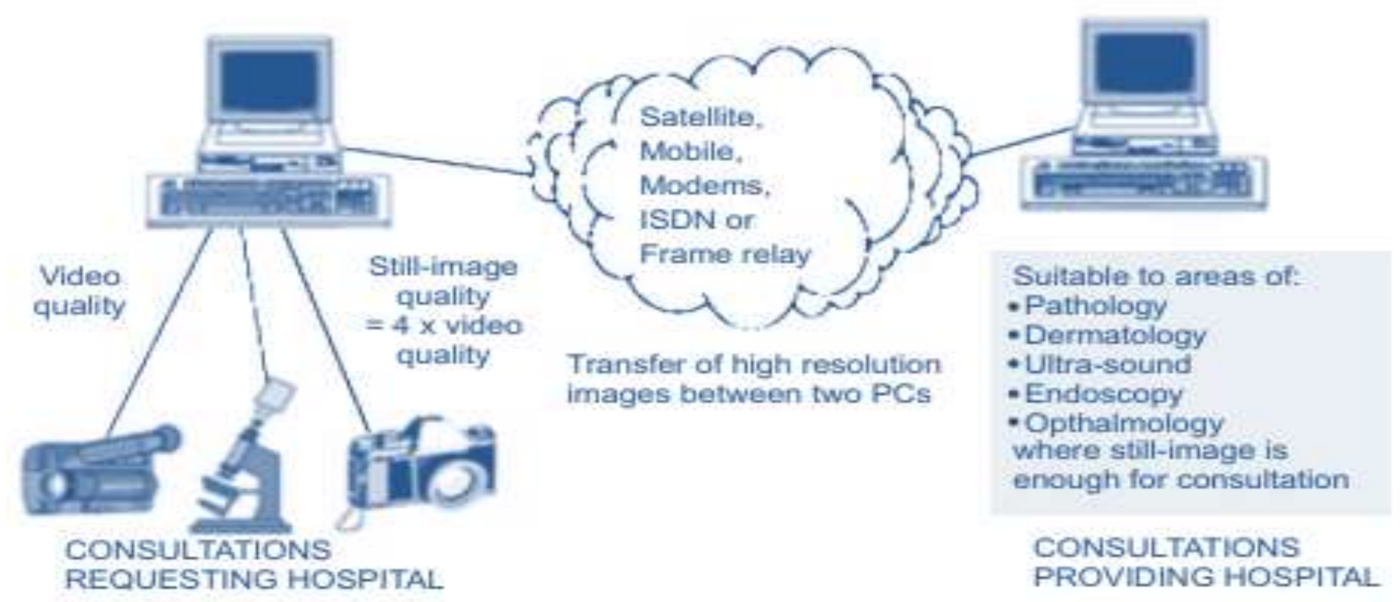


Image Courtesy: ITU Document 2/155(Rev.2)-E 7 September 1997

TRANSMISSION OF STILL IMAGES..

Modality	*Image size (pixels)*	*Dynamic range (bits)*	*Average number of images per exam*	*Average storage requirement per exam (M Bytes)*
Computed tomography	512 × 512	12	30	15.0
Magnetic resonance imaging	256 × 256	12	50	6.5
Digital subtraction angiography	1,000 × 1,000	8	20	20.0
Digital fluorography	1,000 × 1,000	8	15	15.0
Ultrasound imaging	512 × 512	6	36	9.0
Nuclear medicine	128 × 128	8	26	0.4
Computed radiography	2,000 × 2,000	10	4	32.0
Digitized film	4,000 × 4,000	12	4	128.0

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

TRANSMISSION OF STILL IMAGES..

Need for Data Compression

- The aim of data compression is to squeeze data so that it requires less disk space for storage and less bandwidth on a data transmission channel.

Types of Data Compression

(i) Lossless Compression:

- Lossless compression is a compression technique in which data is compressed without any loss of data in the compression process.

Example:

- A GIF (Graphical Image Format) file is a typical example of lossless data compression.
- The file size of an image may be reduced without degrading visual quality, provided the image fits into 256 colours, as against over 16 million representable in 24-bit image.
- GIF formats 256 colour limitation makes it unsuitable for transmission of photographs.
- GIF is normally used for diagrams, buttons etc. that have a small number of colours.

TRANSMISSION OF STILL IMAGES..

Types of Data Compression..

(ii) Lossy Compression:

- Lossy compression works on the data do not have to be stored perfectly and that some loss of information is acceptable.

Example:

- JPEG (Joint Photographic Experts Group) standard.
- JPEG is mostly used for still image transmission of world wide web.
- JPEG can generally give much higher compression ratios than other file formats while retaining good image quality.
- Compression ratios in the range of 10:1 to 20:1 are common with JPEG.
- JPEG is most often used to compress 24-bit colour or 8-bit grey scale images, and is thus preferred for digital photographs.

TRANSMISSION OF VIDEO

- Video images of the patient are often required for adequate patient assessment in a telemedicine system.
- Video is captured one frame at a time typically in a 640 X 480 pixel format, with an intensity scale typically consisting of eight bits for monochrome and 24 bits for colour (8-bit each for red, green and blue).
- For high-resolution cameras; a 1024 X 726 pixel format at 8,10 or 12 bits per pixel can be achieved with a capture time, which depends in part on the time needed to integrate a sufficient number of photons from dark areas of the image.
- Digital data produced by a video image are at a rate of over 100 Mbps (Megabits per second).
- communication and storage limitations and costs necessitate that some form of compression be used to reduce this data rate.
- MPEG (Moving Picture Experts Group) is the compression method for video .

TRANSMISSION OF DIGITAL AUDIO

- Audio channels are usually provided for diagnostic instruments such as an electronic stethoscope / Doppler ultrasound.
- To reproduce heart and lung sounds accurately, an electronic stethoscope must have a uniform frequency response from 20 Hz to 2 kHz, while Doppler ultrasound requires a uniform frequency response from 100 Hz to 10 kHz.
- Audio used for conversation and medical diagnosis in a telemedicine system must be digitized and compressed before it can be combined with digital video and other information.
- Typical audio compression algorithms, operate at data rates from 16 kbps to 64 kbps.
- Medical diagnostic applications which require fidelity at higher audio frequencies will require higher data rates; 120 kbps is is adequate for the normal physiologic hearing signals.

TRANSMISSION OF DIGITAL AUDIO..

Frequency Response and Digital Bandwidth Requirements for Different Audio Formats

Format	Frequency Response	Bandwidth Required
ITU* G711	50-3.4 kHz	64 kbps
ITU G722	50-7 kHz	64 kbps
ITU G728	50-3.4 kHz	16 kbps

ITU - International Telecommunication Union

- MPEG-1 Audio Compression is the method of compression

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

CYBER MEDICINE

- It is applying internet and global networking technologies to medicine and public health for medical education, training, learning and research.
- providing healthcare service through global networking to educate and communicate in ways that promote medical practice, commerce, scholarship and empowerment .

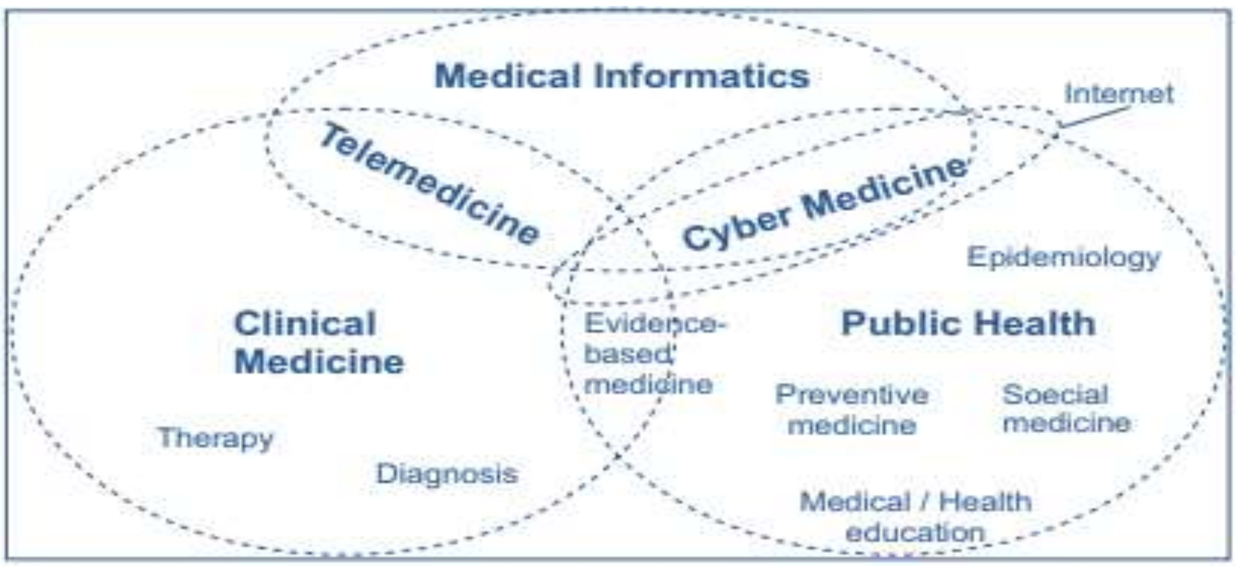


Image Courtesy : Eysenbach and Diepgen, 1999

Types of Cyber Medicine

Information Oriented Sites:

The websites that give medical information about some sickness or drugs.

The Consultation Sites:

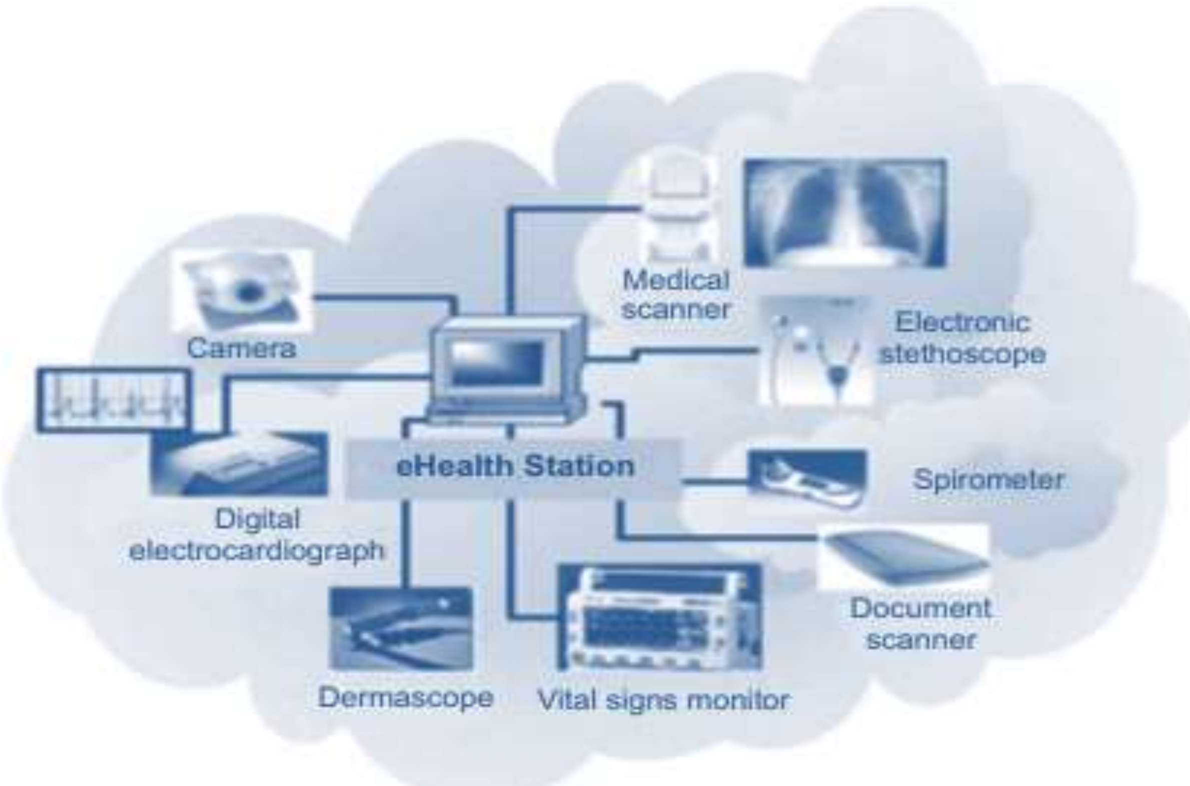
This type of cyber medicine provides a direct communication between the cyber doctors and their patients.

The e-Pharmacy Sites:

The e-pharmacy sites are actually drug shops.

APPLICATIONS OF TELEMEDICINE..

Telemedicine transmission station set up

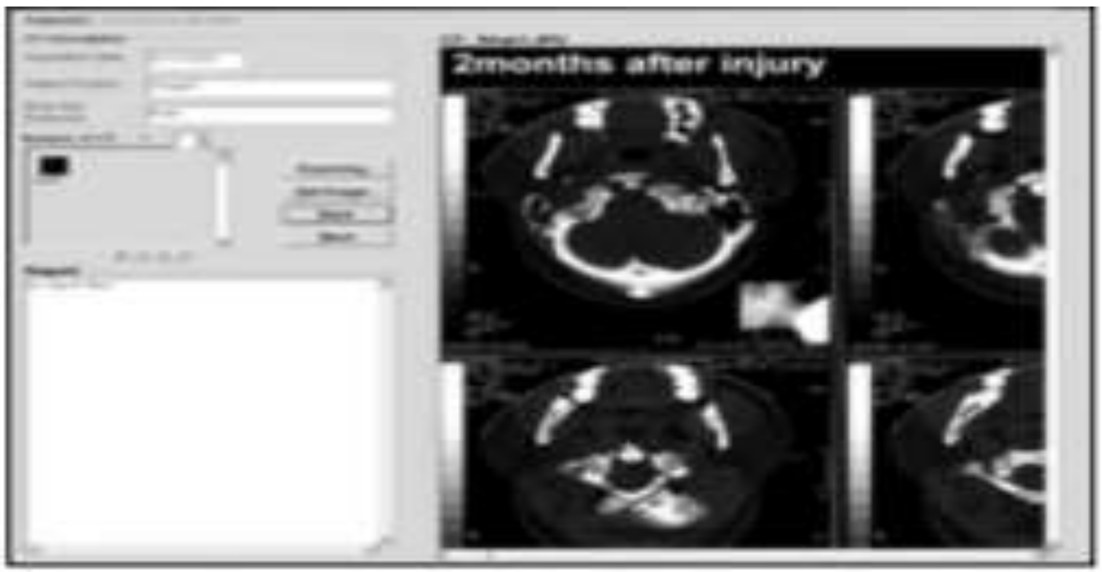


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

APPLICATIONS OF TELEMEDICINE..

Teleradiology

Teleradiology is the electronic transmission of radiological images from one location to another for the purposes of interpretation and/or consultation.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

APPLICATIONS OF TELEMEDICINE..

Telepathology

- Pathology is the science of diseases in tissues and organs, and the pathologist provides a diagnosis based on microscopical examinations of cell and tissue sections.
- Hence, telepathology is the same service, but carried out remotely by means of transferred microscopic images of tissue samples.
- The pathologist sees images of tissue on a monitor rather than viewing the tissue specimen directly under a microscope.

APPLICATIONS OF TELEMEDICINE..

Telepathology….

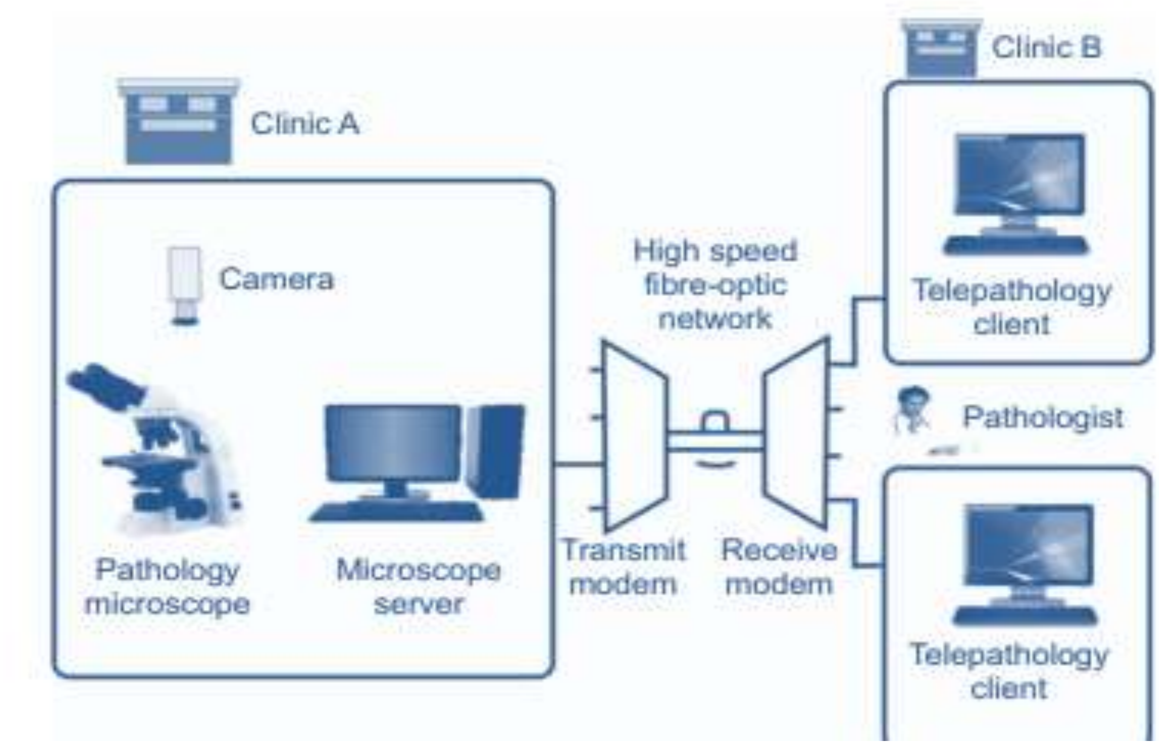


Image Courtesy: National Instruments

APPLICATIONS OF TELEMEDICINE..

Telecardiology

- It is the transmission of cardiac data to a remote location from the patient site.
- Telecardiology has been in use for a long time. Telephones have been used for auscultating heart and breath sounds for over 70 years.

Transferring electrocardiogram from home or ambulance via satellite, telephone network or GSM network

(Image Courtesy: ITU Document 2/155(Rev.2)-E 7 September 1997)

APPLICATIONS OF TELEMEDICINE..

Telecardiology

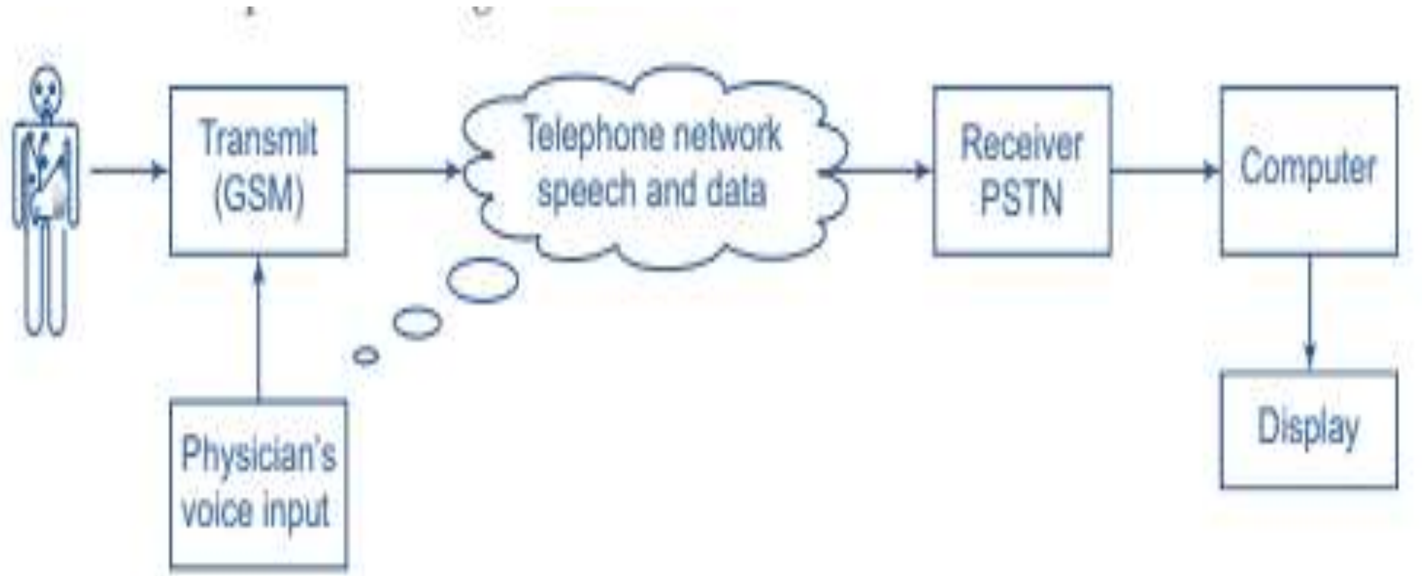


Image Courtesy: Scanlon, 2000

APPLICATIONS OF TELEMEDICINE..

Telesurgery

- Telesurgery is basically surgery at a distance.
- It is the provision of surgical care over a distance, with direct, real-time visualization of the operative field.
- This application is still years away from becoming widespread because of its complexity and relatively high cost.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

An urological surgical operation (telesurgery) being performed using three-armed ZEUS robot

APPLICATIONS OF TELEMEDICINE..

Telemedicine in Home Care

- Telemedicine technology is enabling to make home as the hub of healthcare and shifting it from a central, hospital based system to a patient – centered system.

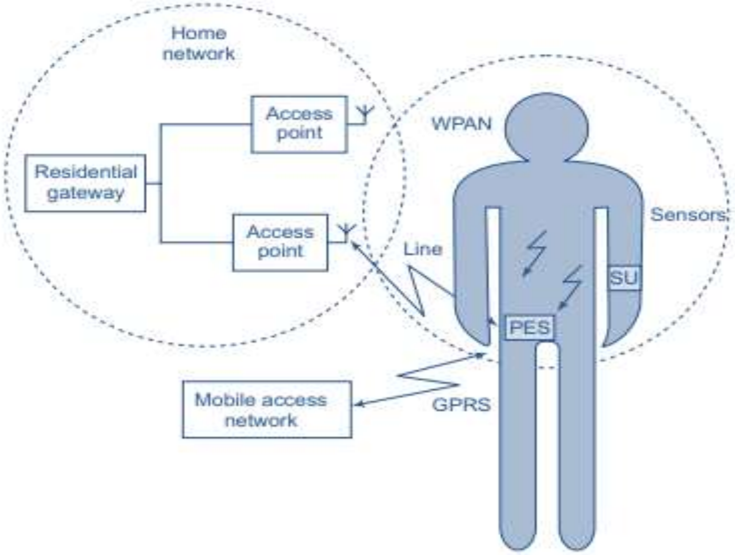


Image courtesy : Dan and Luprano, 2003

Medical implant monitoring using wireless LAN or cellular technology

- A patient worn device can act as a relay between the implant and the telemedicine infrastructure through cellular telephony or wireless LAN.

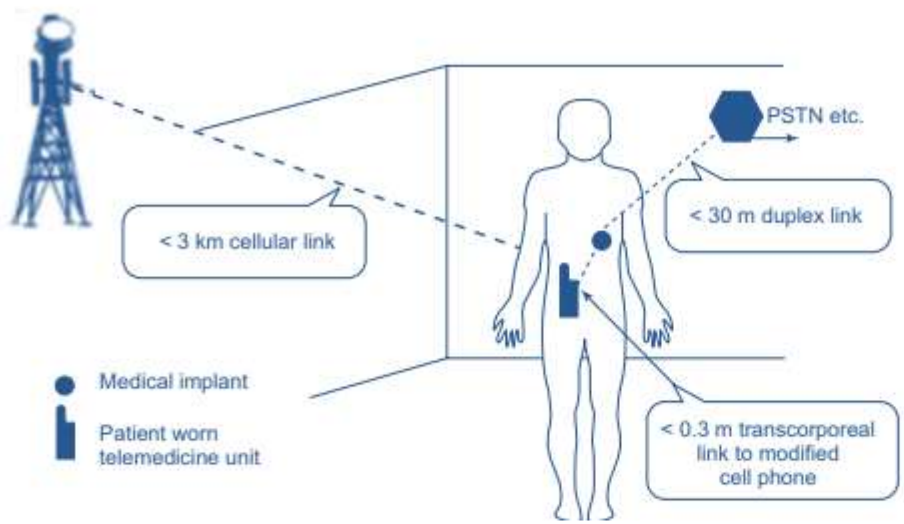


Image Courtesy , Scanlon, 2000

Basic concept of personal area network and body area network

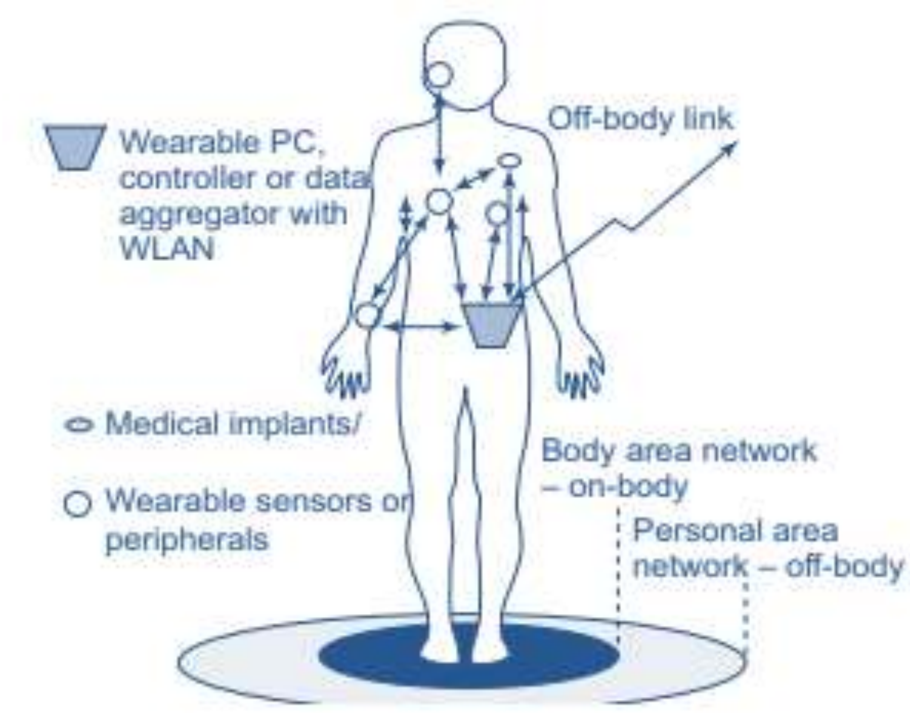


Image courtesy : Donoghue, 2006

Various Network Technologies, Bandwidths, and Typical Maximum Transfer Times (Source: http://radiographics.rsna.org/content)

Network Technology	Bandwidth	Transfer Times: Chest Radiograph 8.4 Mbytes	Transfer Times: Chest CT Scan 50 Mbytes
Modem (Switched-56)	56 kbits/sec	20 min	2 h
T1	1.54 Mbits/sec	43 sec	4.3 min
Ethernet	10 Mbits/sec	6.7 sec	40 sec
Fast Ethernet	100 Mbits/sec	0.7 sec	4 sec
ATM (asynchronous transfer mode)	155 Mbits/sec	0.4 sec	2.6 sec
Gigabit Ethernet	1 Gbits/sec	0.07 sec	0.4 sec

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

END OF UNIT III

Biomedical Instrumentation

(U18PCEC603)

UNIT IV

RADIOLOGICAL EQUIPMENTS

Topics

- Ionizing radiation
- Diagnostic x-ray equipment
- Use of Radio Isotope in diagnosis
- Radiation Therapy

IONIZING RADIATION

IONIZING RADIATION

- In general, ionizing radiation is harmful to living beings but can have **health benefits in radiation therapy for the treatment of cancer and thyrotoxicosis**.
- Most adverse health effects of radiation exposure may be grouped in two general categories:
- **Deterministic effects** (harmful tissue reactions) due in large part to the killing/ malfunction of cells following high doses; and
- **Stochastic effects**, cancer and heritable effects involving either cancer development in exposed individuals owing to mutation of somatic cells or heritable disease in their offspring owing to mutation of reproductive (germ) cells.

IONIZING RADIATION….

- Most widely accepted model posits that the incidence of cancers due to ionizing radiation increases linearly with effective radiation dose at a rate of 5.5% per sievert.
- Natural background radiation is the most hazardous source of radiation to general public health, followed by medical imaging as a close second.
- Other stochastic effects of ionizing radiation are teratogenesis, cognitive decline, and heart disease.
- High radiation dose gives rise to Deterministic effects which reliably occur above a threshold, and their severity increases with dose.
- Deterministic effects are not necessarily more or less serious than stochastic effects; either can ultimately lead to a temporary nuisance or a fatality.
- **Examples:** radiation burns, and/or rapid fatality through acute radiation syndrome, chronic radiation syndrome, and radiation-induced thyroiditis.

IONIZING RADIATION….

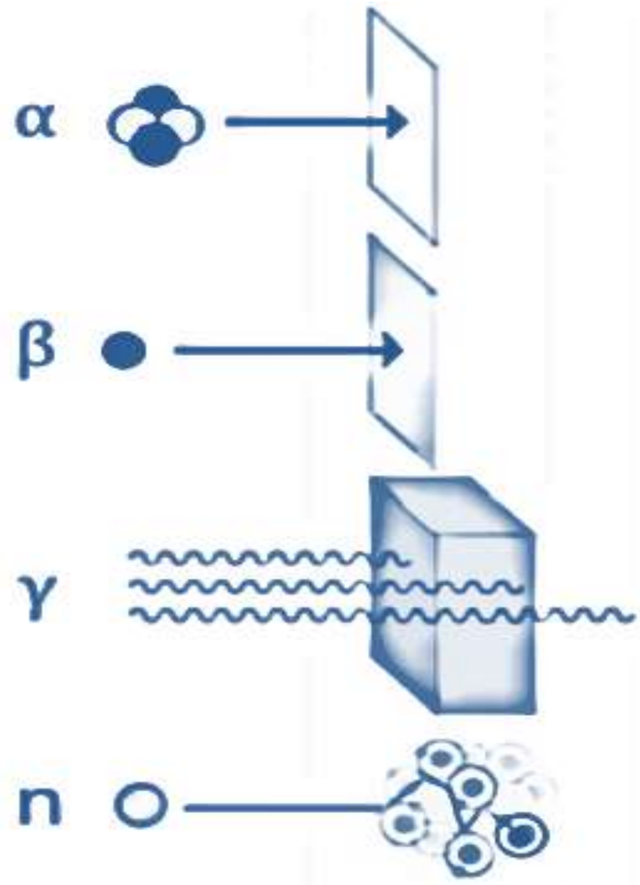
- **US National Academy of Sciences Biological Effects of Ionizing Radiation Committee** has concluded that there is no compelling evidence to indicate a dose threshold below which the risk of tumor induction is zero.
- When alpha particle emitting isotopes are ingested, they are far more dangerous than their half-life or decay rate would suggest.
- This is due to the high relative biological effectiveness of alpha radiation to cause biological damage after alpha-emitting radioisotopes enter living cells.
- Ingested alpha emitter radioisotopes such as transuranics or actinides are an average of about 20 times more dangerous, and in some experiments up to 1000 times more dangerous than an equivalent activity of beta emitting or gamma emitting radioisotopes.

IONIZING RADIATION….

Medical Use:

- Medical use of radiation based on the fact that that it can destroy cells (instrument sterilisation, treatment of cancer).
- Medical use of radiation based on the fact that radiation is easy to detect.

Types of ionizing radiation



Types of ionizing radiation..

- **Alpha (α)** radiation consists of a fast-moving helium-4 nucleus and is stopped by a sheet of paper.
- **Beta (β)** radiation, consisting of electrons, is halted by an aluminium plate.
- **Gamma (γ)** radiation, consisting of energetic photons, is eventually absorbed as it penetrates a dense material.
- **Neutron (n)** radiation consists of free neutrons that are blocked using light elements, like hydrogen, which slow and/or capture them.
- Ionizing radiation is categorized by the **nature of the particles or electromagnetic waves creating the ionising effect**.
- These have different ionization mechanisms, and may be grouped as **directly or indirectly ionizing**.

Types of ionizing radiation..

Directly ionizing:

- Any **charged massive particle can ionize atoms** directly by **fundamental interaction through the Coulomb force if it carries sufficient kinetic energy**.
- This includes atomic nuclei, electrons, muons, charged pions, protons, and energetic charged nuclei stripped of their electrons, all of which must be moving at relativistic speeds to reach the required kinetic energy.
- The first two to be recognized were given special names, which are used today: Helium nuclei at relativistic speeds are called alpha particles, and electrons at relativistic speeds are called beta particles.
- Natural cosmic rays are made up primarily of relativistic protons but also include heavier atomic nuclei like helium ions and HZE ions and muons. Charged pions are very shortlived and seen only in large amounts in particle accelerators.

Types of ionizing radiation..

Alpha particles

- Alpha particles consist of two protons and two neutrons bound together into a particle identical to a helium nucleus.
- They are generally produced in the process of alpha decay, but may also be produced in other ways.
- They are a highly ionizing form of particle radiation, and when resulting from radioactive alpha decay have low penetration depth.
- They can be stopped by a few centimetres of air, or by the skin.
- Long range alpha particles from ternary fission are three times as energetic, and penetrate three times as far.
- The helium nuclei that form 10-12% of cosmic rays are also usually of much higher energy than those produced by nuclear decay processes, and are thus capable of being highly penetrating and able to traverse the human body and dense shielding, depending on their energy.

Types of ionizing radiation..

Beta particles

- Beta particles are high-energy, high-speed electrons or positrons emitted by certain types of radioactive nuclei, such as potassium-40.
- The production of beta particles is termed beta decay.
- They are designated by the Greek letter beta (β).
- There are two forms of beta decay, $\beta-$ and $\beta+$, which respectively give rise to the electron and the positron.
- High-energy beta particles may produce X-rays known as bremsstrahlung ("braking radiation") or secondary electrons (delta ray)as they pass through matter.
- Both of these can subsequently ionize as an indirect ionization effect.

Types of ionizing radiation..

Beta particles …

- Bremsstrahlung is of concern when shielding beta emitters, because interaction of beta particles with the shielding material produces Bremsstrahlung radiation.
- This effect is greater with material of high atomic numbers, so material with low atomic numbers is used for beta source shielding.

Positrons

- The positron or ant electron is the antiparticle or the antimatter counterpart of the electron.
- The positron has an electric charge of +1e, a spin of ½, and has the same mass as an electron.
- When a low-energy positron collides with a low-energy electron, annihilation occurs, resulting in the production of two or more gamma ray photons (see electron–positron annihilation).

Types of ionizing radiation..

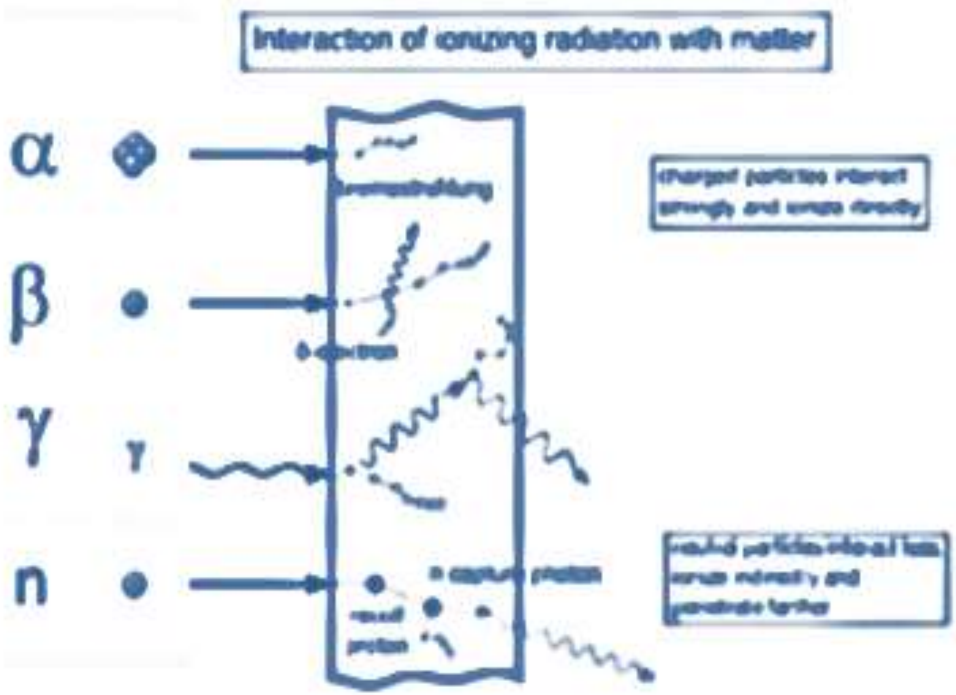
Positrons ..

Positron generated by emission radioactive decay (through weak interactions), or by pair production from a sufficiently energetic photon.

Positrons are common artificial sources of ionizing radiation in medical PET scans. As positrons are positively charged particle

Types of ionizing radiation..

Indirectly ionizing



Types of ionizing radiation..

Indirectly ionizing….

- Gamma rays are represented by wavy lines, charged particles and neutrons by straight lines.
- Small circles show where ionization occurs.
- Indirect ionizing radiation is electrically neutral and therefore does not interact strongly with matter.
- Bulk of the ionization effects are due to secondary ionizations.
- 3 main uses of ionising radiation in medicine:
  - ✓ Treatment
  - ✓ Diagnosis
  - ✓ Sterilisation

Application: Treatment of Cancer

- Cancers are growths of cells (cancerous tumours) which are out of control.
- As a result of this, they do not perform their intended function.
- Cancerous tumours can be treated using the following main methods:

➢ **Chemotherapy (drugs).**

➢ **Radiation therapy (radiotherapy and brachytherapy).**

DIAGNOSTIC X-RAY EQUIPMENT

Introduction to Diagnostic x-ray

- X-rays were discovered by the **German physicist Wilhelm Konrad Röntgen** in November 1895.
- He called it 'new kind of ray' or X-rays, **X** for the **unknown**.
- A radiological examination is the most important diagnostic aids available in the medical practice.

Working Principle:

- It is based on **various anatomical structures of the body have different densities for the X-rays**.
- When X-rays from a point source penetrate a section of the body, the **internal body structures absorb varying amounts of the radiation**.
- **The radiation that leaves the body has a spatial intensity variation.**

Introduction to Diagnostic x-ray..

- The main properties of X-rays, which make them suitable for the purposes of medical diagnosis, are their:
  - **Capability to penetrate matter coupled with differential absorption observed in various materials**
  - **Ability to produce luminescence and its effect on photographic emulsions.**
- The **X-ray picture is called a radiograph** (a shadow picture produced by X-rays from a point source).
- The X-ray picture is usually obtained on photographic film placed in the image plane.
- The skeletal structures are easy to visualize and even the untrained eye can observe fractures and other bone abnormalities.
- **Chest radiographs are mainly taken for examination of the lungs and the heart**.

Introduction to Diagnostic x-ray..

BREMSTRAHLUNG RADIATION

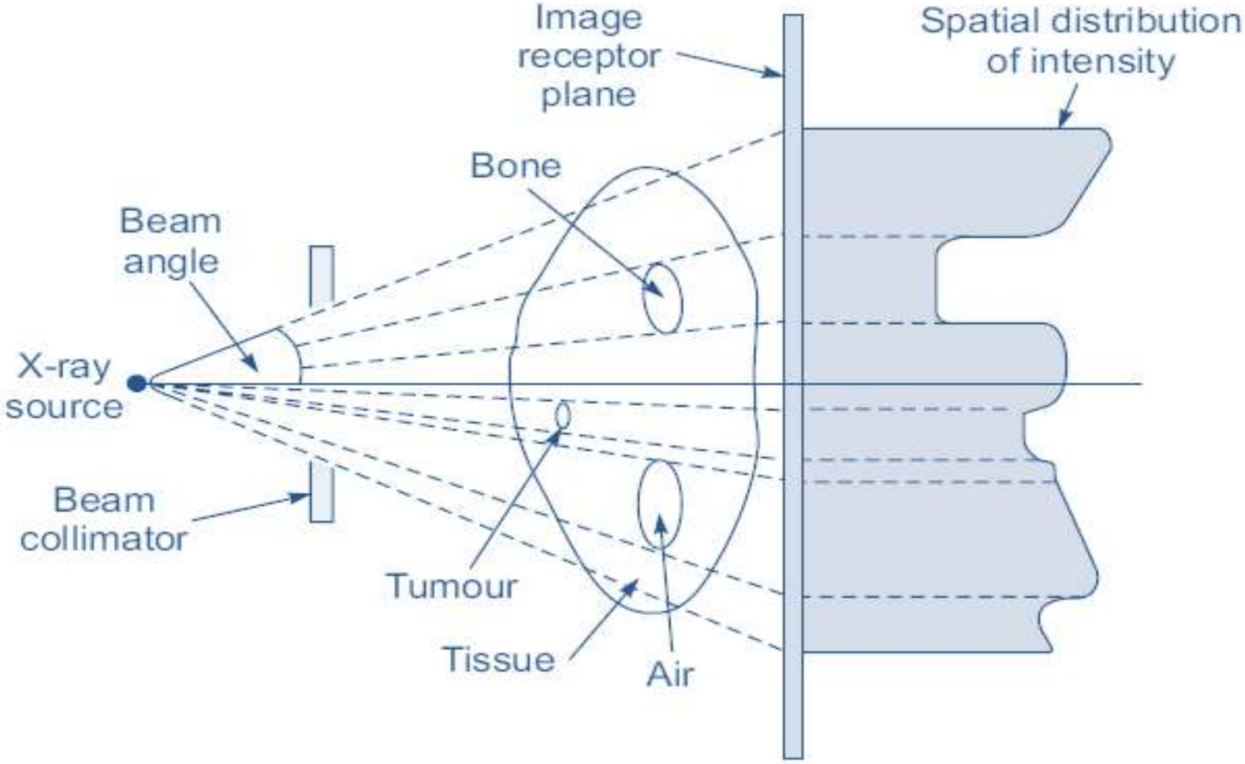
- When the fast moving electron enters into the orbit of anode material atom, its velocity is continuously decreased due to scattering by the orbiting electrons.
- Thus the loss of energy of that incident electrons will appear in the form of continuous X rays or white rays.
- This type of radiation is used in medical application based on the principle of energy absorption.

CHARACTERISTIC X RAY RADIATION

- It occurs when the incident electron ejects out of the K shell or L shell e- in the anode material atom.
- Immediately the higher orbit e- will falls into the vacancy to achieve equilibrium.
- During its transition, the extra energy is emitted in the form of characteristic X ray photon.

Introduction to Diagnostic x-ray

Basic set up for a diagnostic radiology image formation process



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Basic set up for a diagnostic radiology image formation process…

Collimator

- it is placed between the patient and aluminum filter.
- It is nothing but an aperture .

Aluminum filters

- The emitted X rays will contain a broad range of frequency generally the aluminum filters will observe the lower X ray frequency and hence the intensity of low frequency X ray incident on the patient is reduced.

NATURE OF X-RAYS

- X-rays are electromagnetic radiation located at the low wavelength end of the electromagnetic spectrum.
- The X-rays in the medical diagnostic region have wavelength of the order of 10^{-10}m.
- They propagate with a speed of 3 * 10^{10} cm/s and are unaffected by electric and magnetic fields.
- Electromagnetic radiation consists of photons, which are called as ‘packets’ of energy.
- Their interaction with matter involves an energy exchange.
- The relation between the wavelength & the photon is

$$E = h\nu = h\nu = h\frac{c}{\lambda}$$

NATURE OF X-RAYS…

$$E = h\nu = \ h\nu = h\frac{c}{\lambda}$$

- h = Planck’s constant = 6.32 * l0^{-34} J s.
- c = velocity of propagation of photons (3 * 10^{10} cm/s).
- n = frequency of radiation
- l = wavelength

Properties of X-rays

- Short wavelength
- Extremely high energy
- Able to penetrate through materials which readily absorb and reflect visible light.
- X-rays produce secondary radiation in all matter through which they pass.
- X-rays produce ionization in gases and influence the electric properties of liquids and solids.

PRODUCTION OF X-RAYS

- X-rays are produced whenever electrons collide at very high speed with matter and are thus suddenly stopped.
- The energy possessed by the electrons appears from the site of the collision as a parcel of energy in the form of highly penetrating electromagnetic waves (X-rays) of many different wavelengths, which together form a continuous spectrum.
- X-rays are produced in a specially constructed glass tube, which basically comprises

  (i) a source for the production of electrons

  (ii) an energy source to accelerate the electrons

  (iii) a free electron path

  (iv) a mean of focusing the electron beam

  (v) a device to stop the electrons.

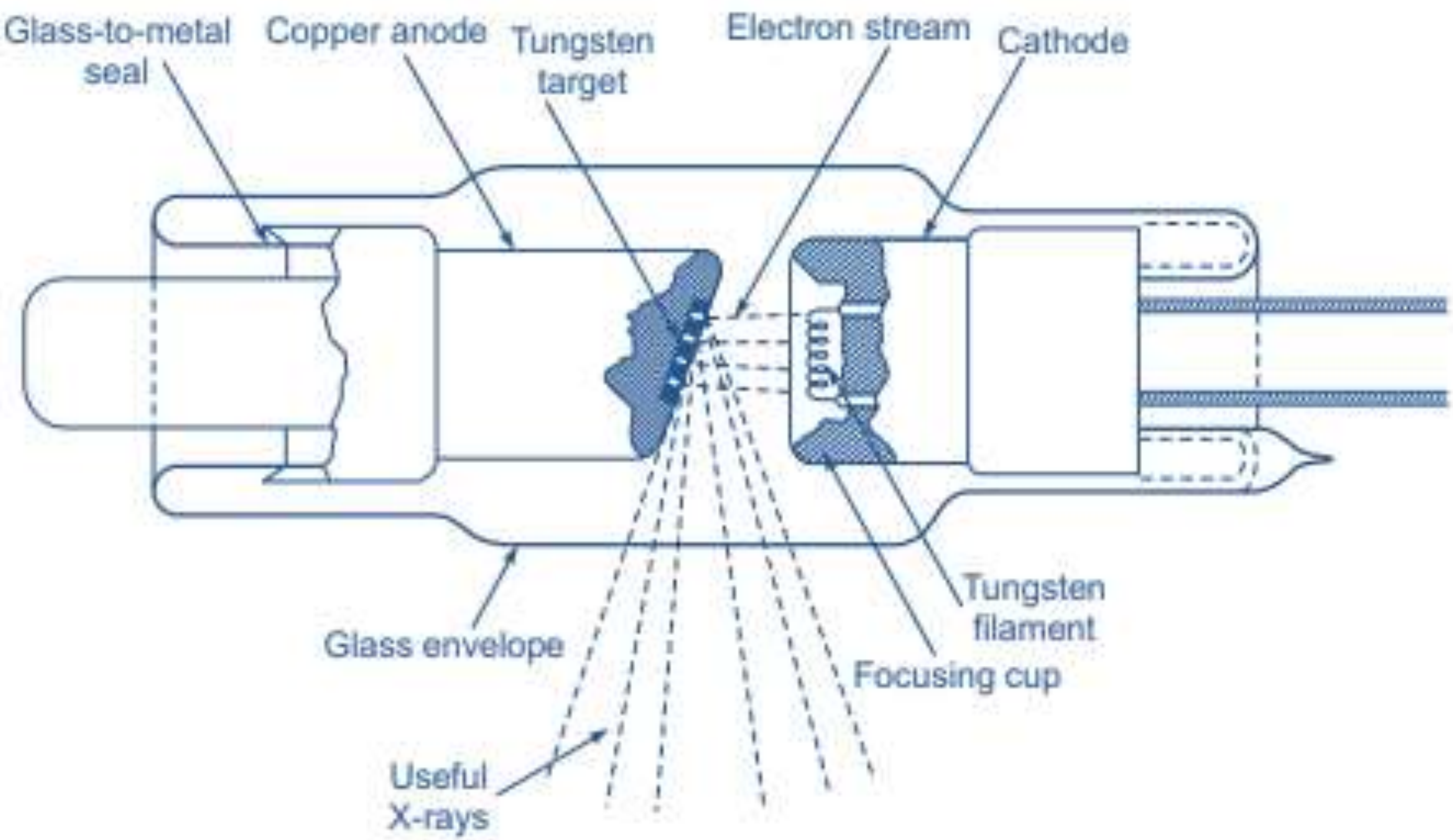
PRODUCTION OF X-RAYS…..

Two types X-Ray tubes:

- **Stationary mode tubes**
- **Rotating anode tubes**

Stationary Anode Tube

Construction of stationary anode X-ray tube



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Stationary Anode Tube…

- The normal tube is a vacuum diode in which electrons are generated by thermionic emission from the filament of the tube.
- The electron stream is electrostatically focused on a target on the anode by means of a suitably shaped cathode cup.
- The kinetic energy of the electrons impinging on the target is converted into X-rays.
- Most electrons emitted by the hot filament become current carriers across the tube.
- It is possible to independently set

(i) Tube current by adjusting the filament temperature

(ii) Tube voltage by adjusting primary voltage.

Stationary Anode Tube…

- The cathode block, which contains the filament, is made from nickel or stainless steel.
- The filament is a closely wound helix of tungsten wire, about 0.2 mm thick, the helix diameter being about 1.0–1.5 mm.
- The target is normally comprised a small tablet of tungsten about 15 mm wide, 20 mm long and 3 mm thick soldered into a block of copper.
- Tungsten is chosen since it combines a high atomic number (74) making it comparatively efficient in the production of X-rays.
- It has a high melting point (3400°C) enabling it to withstand the heavy thermal loads.
- In special cases, molybdenum targets are also used, as in the case of mammography, where in improved subject contrast in the breast is desirable.
- The lower efficiency of X-ray production and the lower melting point make molybdenum unsuitable for general radiography.

Stationary Anode Tube…

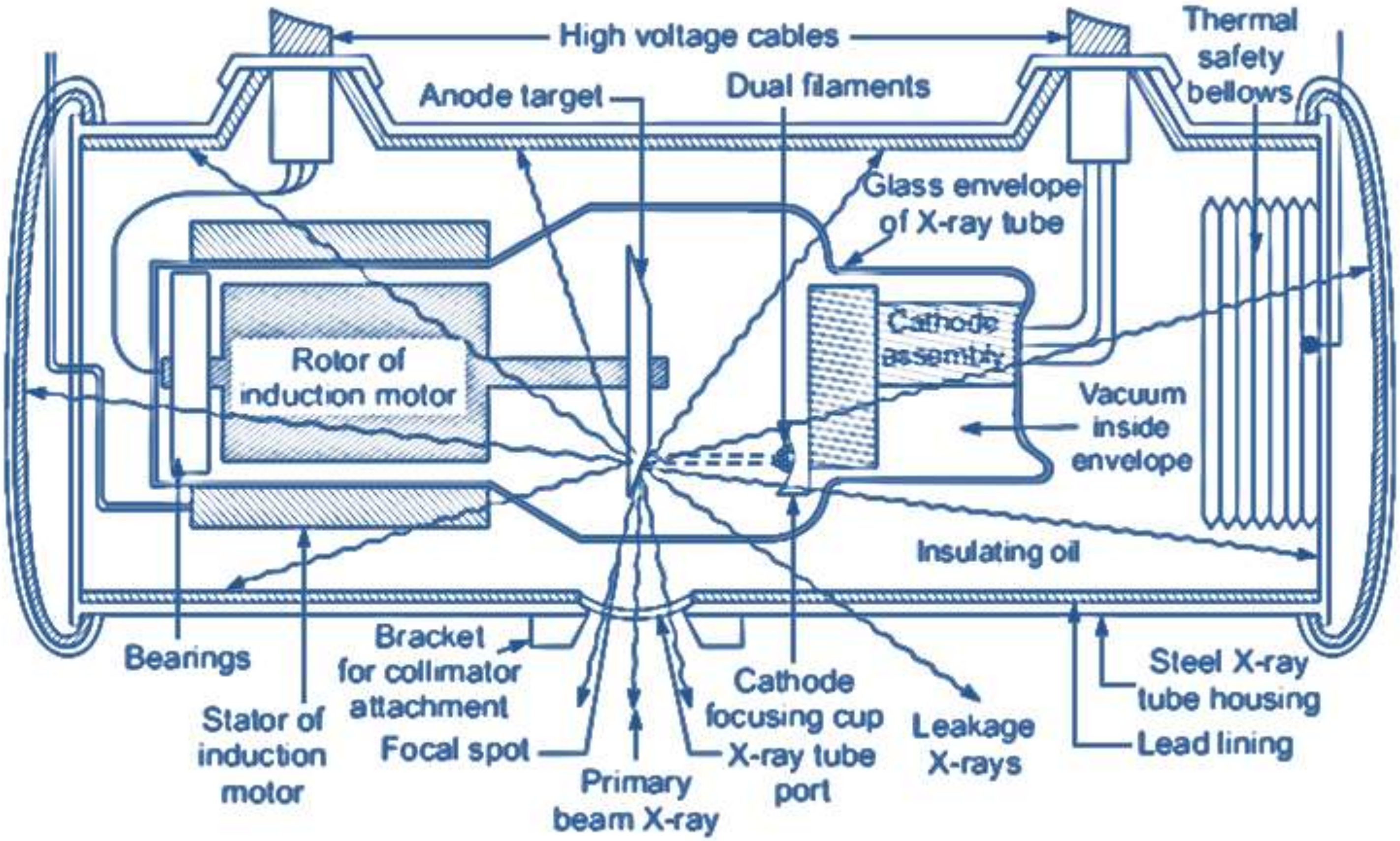
- Copper being an excellent thermal conductor, performs the vital function of carrying the heat rapidly away from the tungsten target.
- The heat flows through the anode to the outside of the tube, where it is normally removed by convection.
- Generally, an oil environment is provided for convection current cooling.
- In addition, the electrodes have open high voltages on them and must be shielded.
- The tube will emit X-rays in all directions and protection needs to be provided except where the useful beam emerges from the tube.
- In order to contain the cooling oil and meet the above-mentioned requirements, a metal container is provided for completely surrounding the tube (known as a shield).
- Stationary anode tubes are employed mostly in small capacity X-ray machines.

Rotating Anode Tube

- X-rays, requiring higher tube voltages and current, the X-ray tube itself becomes a limiting factor in the output of the system.
- This is due to the heat generated at the anode.
- The heat capacity of the anode is a function of the focal spot area.
- The absorbed power can be increased if the effective area of the focal spot can be increased.
- This is accomplished by the rotating anode type of X-ray tubes.
- The tubes with rotating anode are based on the removal of the target from the electron beam before it reaches too high a temperature under the electron bombardment and the rapid replacement of it by another cooler target.

Rotating Anode Tube…

Constructional details of rotating anode X-ray tube



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Rotating Anode Tube…

- The anode is a disk of tungsten or an alloy of tungsten and 10% rhenium.
- This alloy reduce the changes in the anode track due to stress produced in the track due to rapidly changing temperature.
- The **anode rotates at a speed of 3000–3600 or 9000–10000 rpm**.
- With the rotating anode, the heat produced during an exposure is spread over a large area of the anode.
- It **increasing the heat-loading capacity of the tube** and **allowing higher power levels** to **produce more intense x-radiation.**
- The rotor is made from copper, either cast or from special quality rod.

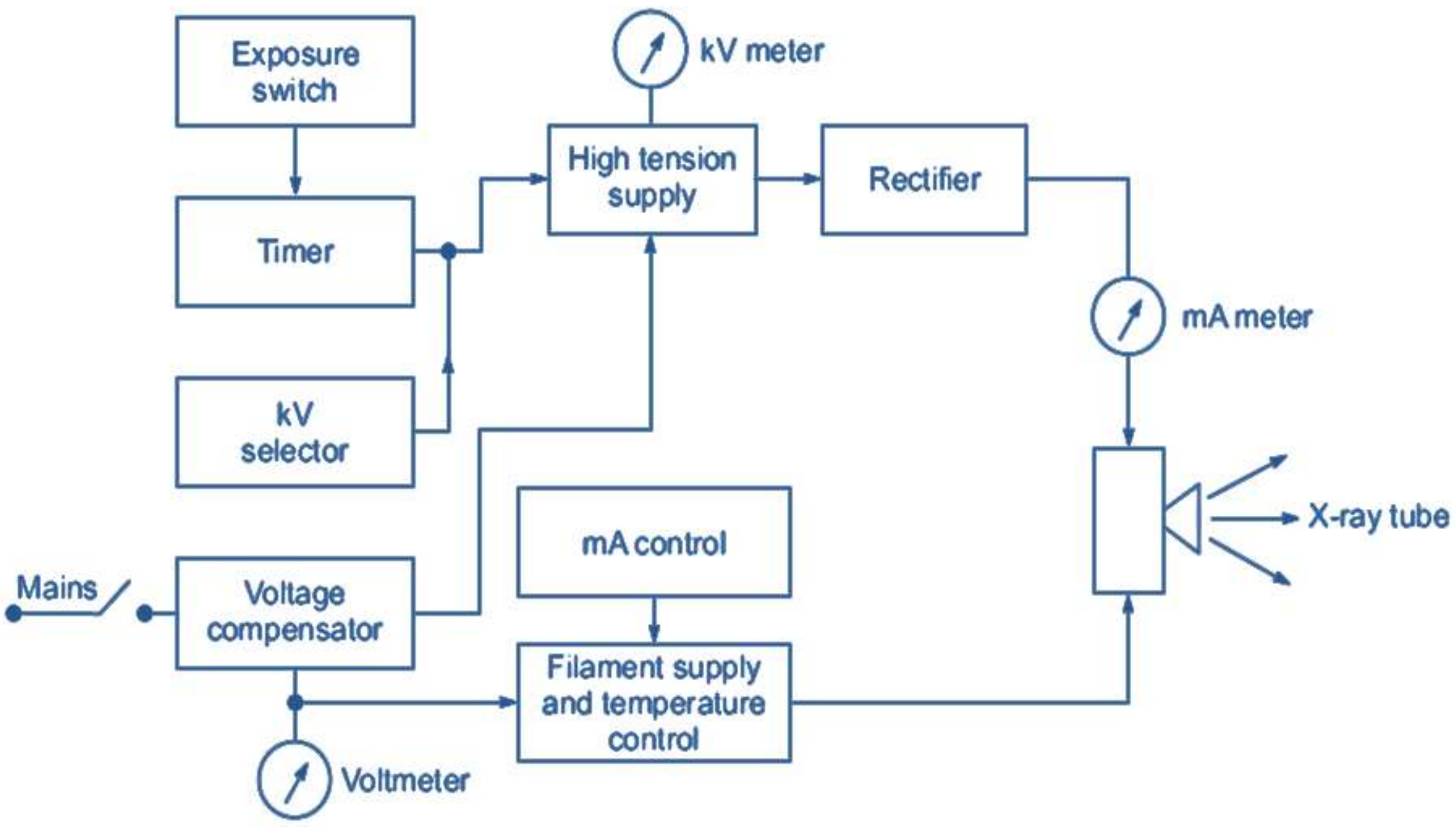
Rotating Anode Tube…

- The **anode rotation system is a high speed system**. Hence, the **bearings must be properly lubricated**.
- The high temperature environment inside the tube rule out most normal lubricants.
- Metal lubricants are used.
- The commonly used lubricants are lead, gold, graphite or silver.
- These lubricants are usually applied to the bearing surfaces in the form of a thin film.
- The tube housing serves several technical purposes.
- It is a part of the electrical isolation between the high voltage circuits and the environment.
- The housing is lead-lined to keep the amount of leakage radiation below legal levels, by providing radiation protection for both the patient and the operator.

Rotating Anode Tube…

- X-ray tubes are further classified on the basis of their application for diagnostic or therapeutic purposes.
- For diagnostic applications, it is usual to employ high milliamperes and lower exposure time whereas high kV and relatively lower mA are necessary for therapeutic uses.

Block Diagram of X-Ray Machine



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Block Diagram of X-Ray Machine..

- There are two parts of the circuit.
- One is for producing high voltage, which is applied to the tube's anode
- It has a high voltage step-up transformer followed by rectification.
- The current through the tube is measured by a mA metre.
- A kV selector switch facilitates change in voltage between exposures.
- The voltage is measured with the help of a kV metre.
- The exposure switch controls the timer and thus the duration of the application of kV.
- To compensate for mains supply voltage (230 V) variations, a voltage compensator is included in the circuit.

Block Diagram of X-Ray Machine..

- The second part of the circuit concerns the control of heating X-ray tube filament.
- The filament is heated with 6–12 V of AC supply at a current of 3–5 amperes.
- The filament temperature determines the tube current or mA &the filament temperature control has an attached mA selector.
- The filament current is controlled by using, in the primary side of the filament transformer, a variable choke or a rheostat.
- The rheostat provides a stepwise control of mA and is most commonly used in modern machines.

Block Diagram of X-Ray Machine..

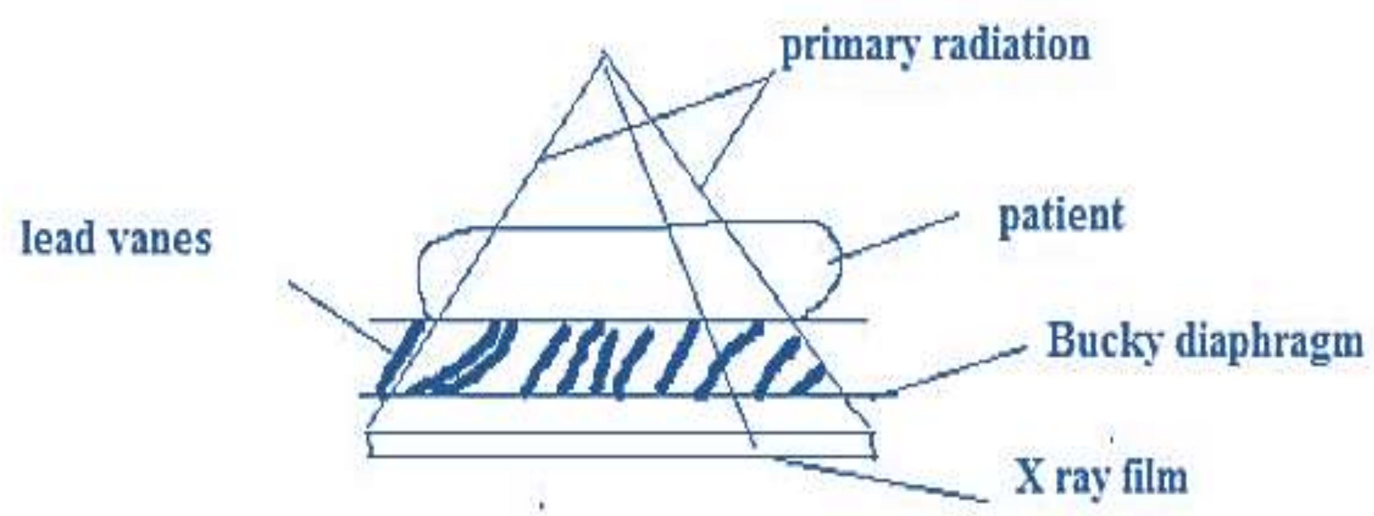
- A preferred method of providing high voltage DC to the anode of the X-ray tube bridge rectifier using four valve tubes or solid state rectifiers.
- The kV meter is connected across the primary of the HT transformer.
- It actually measures volts, whereas it is calibrated in kV, by using an appropriate multiplication factor of the turns ratio of the transformer.
- Moving coil meters are used for making current (mA) measurements.
- Moving coil meters have now been generally replaced by digital mA and mAs meters.

Block Diagram of X-Ray Machine..

- The basic design of X-ray generators has not changed for the last 50 years.
- However, considerable developments in the control elements as the demand has grown for increased accuracy, better information display and greater flexibility of selection of factors.
- The task to be performed by the control circuits of an X-ray generator can be performed by a microcomputer.

Bucky grid in X-Ray Imaging

- It is used to **reduce scattered radiation.**
- The bucky grid is placed between the patient and the film cassette to improve the sharpness of image.



VISUALIZATION OF X-RAYS

Radiography

- X-rays which have a much shorter wavelength than visible light, react with photographic emulsions in a similar fashion as that of light.
- X ray images developed by photography or photosensitive film
- High resolution in images can be obtained
- Wide range of contrast can be obtained
- Patient is not exposed to X rays during the examination of the X ray image
- The patient dose is very low
- Permanent record is available
- The image can be obtained after developing the film and examination can be made before developing the film
- Movement of organs cannot be observed
- Efficient is more

VISUALIZATION OF X-RAYS

Fluoroscopy

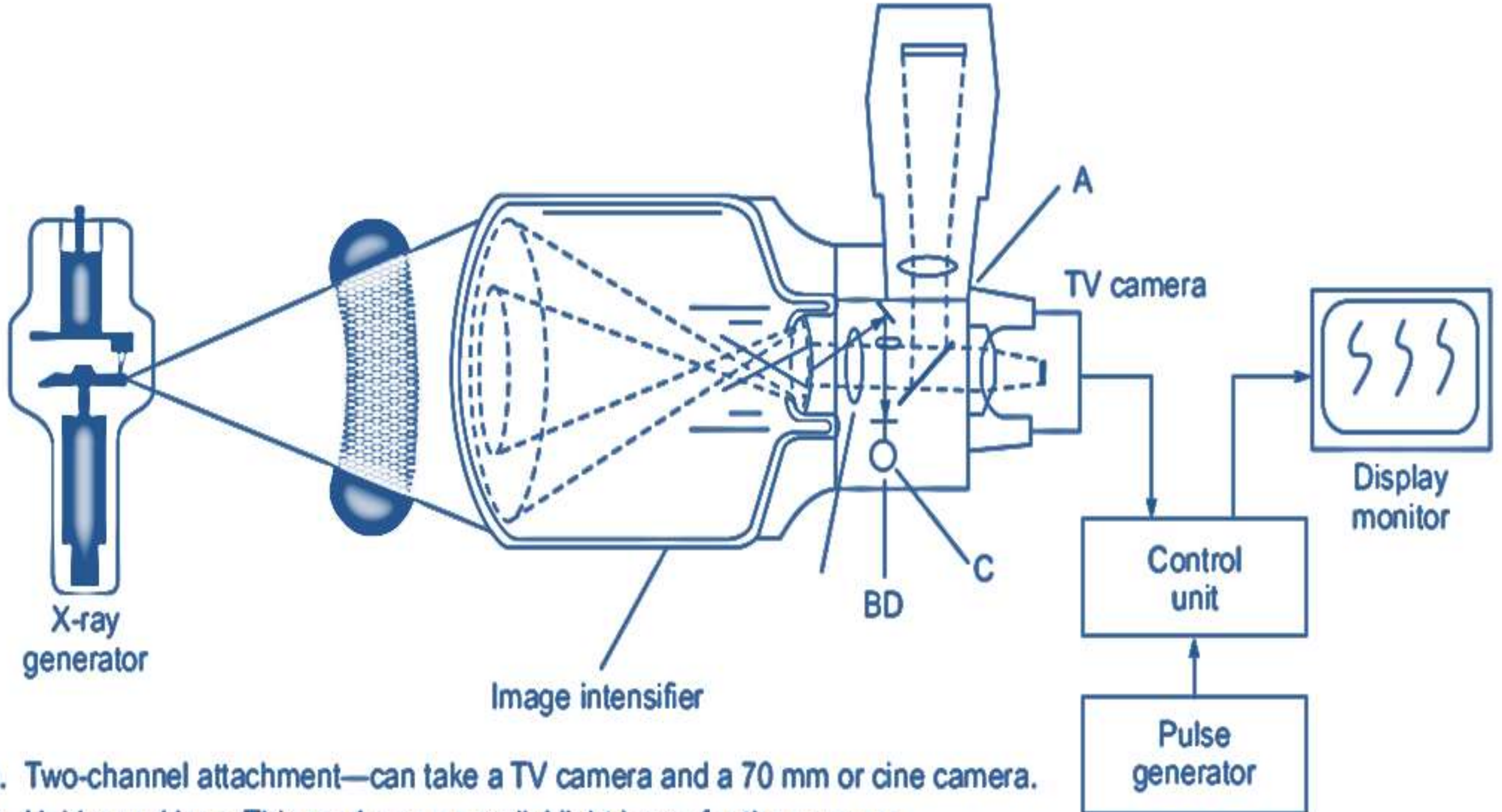
- Fluoroscopy is the method that provides real-time X ray imaging that is especially useful for guiding a variety of diagnostic and interventional procedures.
- In fluoroscopy, X-rays are converted into a visual image on a fluorescent screen which can be viewed directly.
- The ability of fluoroscopy to display motion is provided by a continuous series of images produced at a maximum rate of 25-30 complete images per second.
- This is similar to the way conventional television or video transmits images.

VISUALIZATION OF X-RAYS

Fluoroscopy…

- While the X ray exposure needed to produce one fluoroscopic image is low (compared to radiography), high exposures to patients can result from the large series of images that are encountered in fluoroscopic procedures.
- Therefore, the total fluoroscopic time is one of the major factors that determines the exposure to the patient from fluoroscopy.
- It facilities a dynamic radiological study of the human anatomy. The fluorescent screen consists of a plastic base coated with a thin layer of fluorescent material, zinc cadmium sulphide, which is bonded to a lead-glass plate.
- The image is viewed through the glass plate which provides radiation protection but allows the optical image to be viewed.
- Zinc cadmium sulphide emits light at 550 nm and is selected because the eye is most sensitive in the green part of the spectrum.

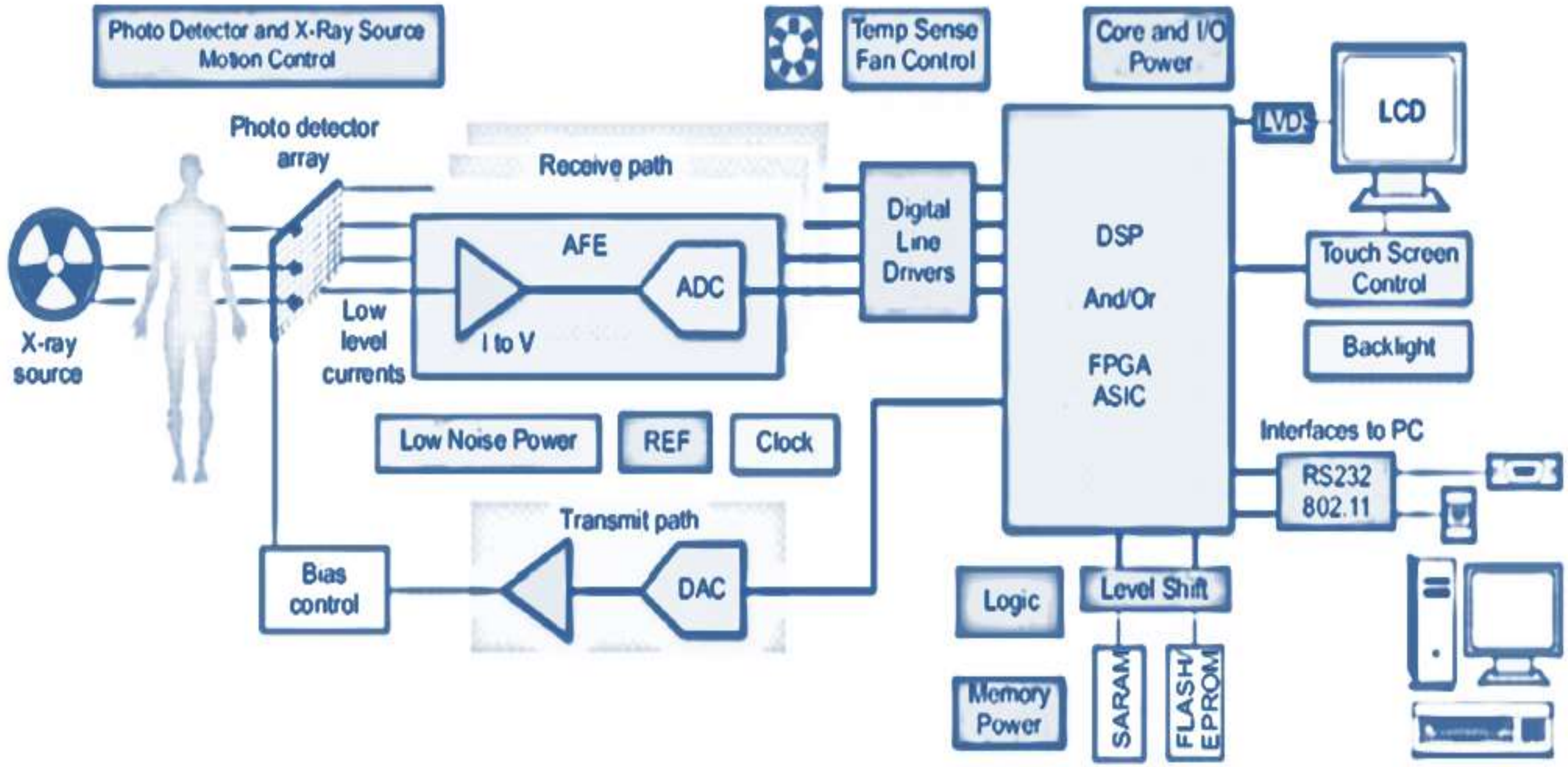
X-ray image intensifier system



A. Two-channel attachment—can take a TV camera and a 70 mm or cine camera.
B. Holder and lens. This produces a parallel light beam for the cameras.
C. Photo pick-up.
D. Electrical signal from photo pick-up. It provides the control for 70 mm and cinefluorography.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Digital X-ray System



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Digital X-ray System

- Electrical charges proportional to X-ray intensity seen by the pixel are stored in the thin film transistor (TFT) storage cap.
- A number of such pixels form the flat detector panel (FDP).
- The charges are deciphered by read-out electronics from the FDP and transformed into digital data.
- The circuit has two chains: the acquisition and the biasing chain.
- At the beginning of the acquisition chain, an analog front-end is capable of multiplexing the charges on different FDP (channels) storage caps and converting those charges into voltage.

Digital X-ray System...

- The biasing chain generates bias voltages for the TFT array through intermediate bias-and-gate control circuitry. Digital control and data conditioning are controlled by a DSP (Digital Signal Processor), an FPGA (Field Programmable Gate Array), an ASIC (Applications Specific Integrated Circuit) or a combination of these.
- These processors also manage high-speed serial communications with the external image processing unit through a high-speed interface.

Digital X-ray System….

- Temperature sensors, DACs (Digital to Analog Converter), amplifiers and high-input
- voltage-capable switching regulators are other key system blocks.
- Each block must synchronize frequencies to avoid crosstalk with other blocks in the acquisition chain.
- The number of FDP pixels determines the number of ADC (Analog to Digital Converter) channels versus ADC speed.
- The image signal levels are converted to digital data by an analog front end (AFE).

Applications of X ray

- X ray is used **to visualize skeletal structure**
- X ray is used **to take chest radiograph**
- Heart examinations are performed by taking frontal and lateral X ray film images
- Gastro intestinal tract can be imaged by using X ray
- Urinary tract can be examined by using X rays

Applications of X ray..

- **Angiography** is a special X ray imaging technique through which high contrasts can be obtained.
- The outline of the blood vessels are visible in angiogram
- **Angiocardiography:** It mean study of heart
- **Cerebral angiography:** It mean study of brain
- **Bronchography:** It maen study of lungs
- **Nephro angiography:** it mean study of kidney

USE OF RADIO ISOTOPE IN DIAGNOSIS

USE OF RADIO ISOTOPE IN DIAGNOSIS

- Nuclear medicine uses radiation to provide diagnostic information about the functioning of a person's specific organs, or to treat them.
- Radiotherapy can be used to treat some medical conditions, especially cancer, using radiation to weaken or destroy particular targeted cells.
- Tens of millions of nuclear medicine procedures are performed each year, and demand for radioisotopes is increasing rapidly.
- Radiation is used to both detect and treat abnormalities in the body.
- **Example:** **Iodine-131** is used in a diagnostic procedure to monitor the function of the thyroid.

USE OF RADIO ISOTOPE IN DIAGNOSIS..

- The rate at which the thyroid rakes up the iodine-131 can be monitored with a scanning device to see if it is functioning properly.
- Chromium, in the form of sodium chromate, attaches strongly to the hemoglobin of red blood cells.
- This makes **radioactive chromium-151** an excellent isotope for determining the flow of blood through the heart.
- This isotope is also useful for determining the lifetime of red blood cells, which can be of great importance in the diagnoses of anemias.

USE OF RADIO ISOTOPE IN DIAGNOSIS..

- **Radioactive cobalt (cobalt-59 or cobalt-60)** is used to study **defects in vitamin B12 absorption**.
- Cobalt is the metallic atom at the center of the B12 molecule.
- By injecting a patient with vitamin B12, labeled with radioactive cobalt, the physician can study the path of the vitamin through the body and discover any irregularities.
- One method is **teletherapy**, in which a high-energy beam of radiation is aimed at the cancerous tissues.
- A second method is brachytherapy, in which a radioactive isotope is placed into the area to be treated.

USE OF RADIO ISOTOPE IN DIAGNOSIS..

- This is usually done by means of a seed, which could be a glass bead containing the isotope.
- In this way the isotope delivers a constant beam of radiation to the affected area.
- The third method is called radiopharmaceutical therapy.
- This method involves oral or intravenous administration of the isotope.
- The isotope then uses the normal body pathway to seek its target.
- This is the method that is used to get iodine-131 to the thyroid gland.

USE OF RADIO ISOTOPE IN DIAGNOSIS..

- A synthetic radioisotope is a radionuclide that is not found in nature: no natural process or mechanism exists which produces it, or it is so unstable that it decays away in a very short period of time.
- **Examples :** technetium-95 and promethium-146.
- Many of these are found in, and harvested from, spent nuclear fuel assemblies.
- Some must be manufactured in particle accelerators.

USE OF RADIO ISOTOPE IN DIAGNOSIS

Production

- Some synthetic radioisotope are extracted from spent nuclear reactor fuel rods, which contain various fission products.
- For example, it is estimated that up to 1994, about 49,000 (78 metric ton) of technetium was produced in nuclear reactors, which is by far the dominant source of terrestrial technetium.
- However, only a fraction of the production is used commercially.
- Other synthetic isotopes are produced in significant quantities by fission but are not yet being reclaimed.
- Other isotopes are manufactured by neutron irradiation of parent isotopes in a nuclear reactor or by bombarding parent isotopes with high energy particles from a particle accelerator.

USE OF RADIO ISOTOPE IN DIAGNOSIS

Applications

- Most synthetic radioisotopes are extremely radioactive and have a short half life.
- Though a health hazard, radioactive materials have many medical and industrial uses.

Nuclear medicine

- The general field of nuclear medicine covers any use of radioisotopes for **diagnosis or treatment**.

RADIATION THERAPY

RADIATION THERAPY- INTRODUCTION

- Radiation therapy uses ionising radiation to treat cancer i.e. to destroy cancerous cells. There are two techniques in radiation therapy that are used to treat cancer using ionising radiation:

Radiotherapy

The apparatus is arranged so that it can rotate around the couch on which the patient lies.

• This allows the patient to receive radiation from different directions.

• The diseased tissue receives radiation all of the time but the healthy tissue receives the minimum amount of radiation possible.

• Treatments are given as a series of small doses because cancerous cells are killed more easily when they are dividing, and not all cells divide at the same time – this reduces some of the side effects which come with radiotherapy.

Brachytherapy

- This involves placing implants in the form of seeds, wires or pellets directly into the tumour.
- Such implants may be temporary or permenant depending on the implant and the tumour itself.
- The benefit of such a method is that the tumour receives nearly all of the dose whilst healthy tissue hardly receives any.

RADIATION THERAPY- INTRODUCTION..

- Therapeutic radiation comes from one of two types of sources: **gamma rays from radioactive material or X-rays from a particle accelerator.**
- Radioactive material is mostly used for **brachytherapy, in which the radioactive material is placed inside the body to treat the tumor**.
- For external beam treatment, where a device beams radiation into the body from outside, a linear accelerator is most often used.
- There are of course exceptions to this.
- There are X ray brachytherapy sources and some older therapy machines use Cobalt-60 to treat the patient with gamma rays.
- Gamma Knife is also currently used for radiation therapy.

Radiotherapy Treatment

- Every treatment using **radiotherapy has three phases**:

Planning

The cancerous tumour has to be located so that its size and position can be analysed. This information can be obtained from:

- **X-rays**
- **CT scans**
- **MRI scans**
- **Ultrasound images**

Simulation

- Once the amount of radiation to be given has been accurately calculated, the patient then goes to the simulator to determine what settings are to be selected for the actual treatment using a linear accelerator.
- The settings are determined by taking a series of x-rays to make sure that the tumour is in the correct position ready to receive the ionising radiation.

Radiotherapy Treatment..

Treatment

Cancerous tumours can be treated using radiotherapy as follows:

- Irradiation using high energy gamma rays.
- Irradiation using high energy x-rays.

Irradiation Using High Energy Gamma Rays

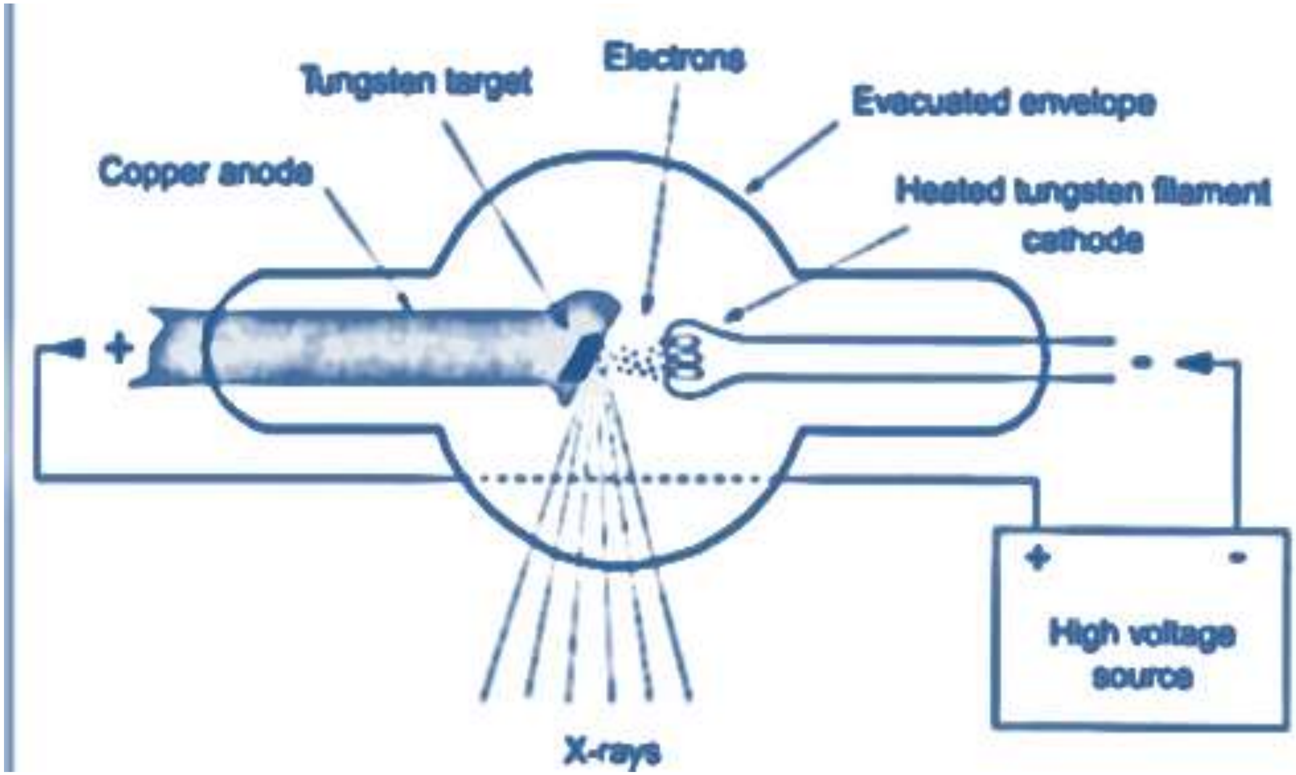
- Gamma rays are emitted from a cobalt-60 source – a radioactive form of cobalt.
- The cobalt source is kept within a thick, heavy metal container.
- This container has a slit in it to allow a narrow beam of gamma rays to emerge.

Radiotherapy Treatment..

Irradiation Using High Energy X-rays

- The x-rays are generated by a linear accelerator (linac).
- The linac fires high energy electrons at a metal target and when the electrons strike the target, x-rays are produced.
- The x-rays produced are shaped into a narrow beam by movable metal shutters

Low-energy Machines



Tracers

- There are many uses of ionising radiation based on the fact that it is easy to detect.
- In such applications, the radioactive material is used in the form of a tracer.
- In nuclear medicine, a tracer is a radioactive substance which is taken into the body either, as an injection, or as a drink.
- Such a substance is normally a gamma emitter which is detected and monitored.
- This gives an indication of any problems that may be present in body organs or tissues by how much, or how little, of the substance has been absorbed.

Nuclear Medicine Tracers

- It is important to be able to study internal organs, or tissues, without the need for surgery.
- In such cases, radioactive tracers can be injected into the body so such studies can take place.
- The path of these tracers can be detected using a gamma camera because of their radioactivity.
- **Such tracers consist of two parts:**
- A drug which is chosen for the particular organ that is being studied.
- A radioactive substance which is a gamma emitter.

Factors Which Affect the Choice of Tracer

- They will concentrate in the organ, or tissue, which is to be examined.
- They will lose their radioactivity (short t).
- They emit gamma rays which will be detected outside the body.
- Gamma rays are chosen since alpha and beta particles would be absorbed by tissues and not be detected outside the body.
- Technitium-99m is most widely used because it has a half-life of 6 hours.

The Gamma Camera

- The tracer is injected into the patient.
- The radiation emitted from the patient is detected using a gamma camera.
- A typical gamma camera is 40 cm in diameter – large enough to examine body tissues or specific organs.
- The gamma rays are given off in all directions but only the ones which travel towards the gamma camera will be detected.
- A **gamma camera consists of three main parts**:
  - A collimator.
  - A detector.
  - Electronic systems.

The Gamma Camera

The Collimator

- The collimator is usually made of lead and it contains thousands of tiny holes.
- Only gamma rays which travel through the holes in the collimator will be detected.

The Detector

- The detector is a scintillation crystal and is usually made of Sodium Iodide with traces of Thallium added.
- The detector is a scintillation crystal and it converts the gamma rays that reach it into light energy.

The Electronic Systems

- The electronic systems detect the light energy received from the detector and converts it into electrical signals.

Diagnosis Static Imaging

- There is a time delay between injecting the tracer and the build-up of radiation in the organ.
- Static studies are performed on the brain, bone or lungs scans

Dynamic Imaging

- The amount of radioactive build-up is measured over time.
- Dynamic studies are performed on the kidneys and heart.
- Renograms are dynamic images of the kidneys and they are performed for the following reasons:
  - To assess individual kidney and/or bladder function.
  - To detect urinary tract infections.
  - To detect and assess obstructed kidney(s).
  - To detect and assess vesico-ureteric reflux.
  - To assess kidney transplant(s).

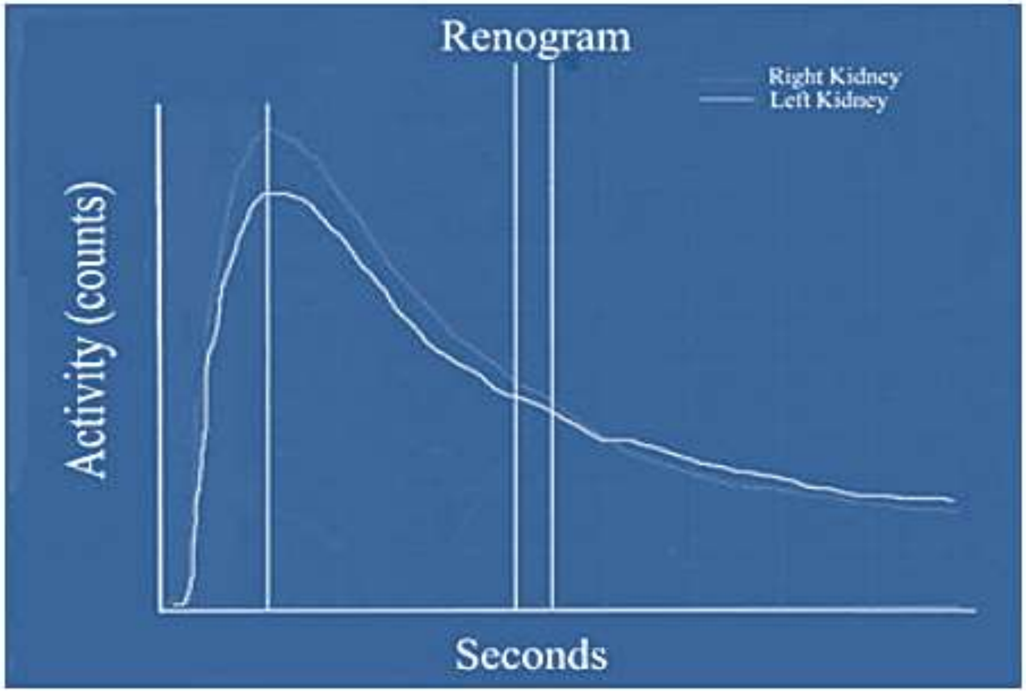
Renogram

Renogram Procedure

- The tracer is injected into the patient.
- The radioactive material is removed from the bloodstream by the kidneys.
- Within a few minutes of the injection, the radiation is concentrated in the kidneys.
- After 10 – 15 minutes, almost all of the radiation should be in the bladder.
- The gamma camera takes readings every few seconds for 20 minutes.

Renogram

Graph of activity versus time – a time-activity curve.



Sterilisation using Radiation

- Radiation not only kills cells, it can also kill germs or bacteria.
- Medical instruments (e.g. syringes) are pre-packed and then irradiation using an intense gamma ray source.
- This kills any germs or bacteria but does not damage the syringe, nor make it radioactive.

END OF UNIT IV

Biomedical Instrumentation

(U18PCEC603)

UNIT V

RECENT TRENDS IN MEDICAL INSTRUMENTATION

Topics

- Thermograph
- Endoscopy unit
- Laser in medicine
- Diathermy units
- Electrical safety in medical equipment

THERMOGRAPH

Introduction to Thermograph/ Thermography

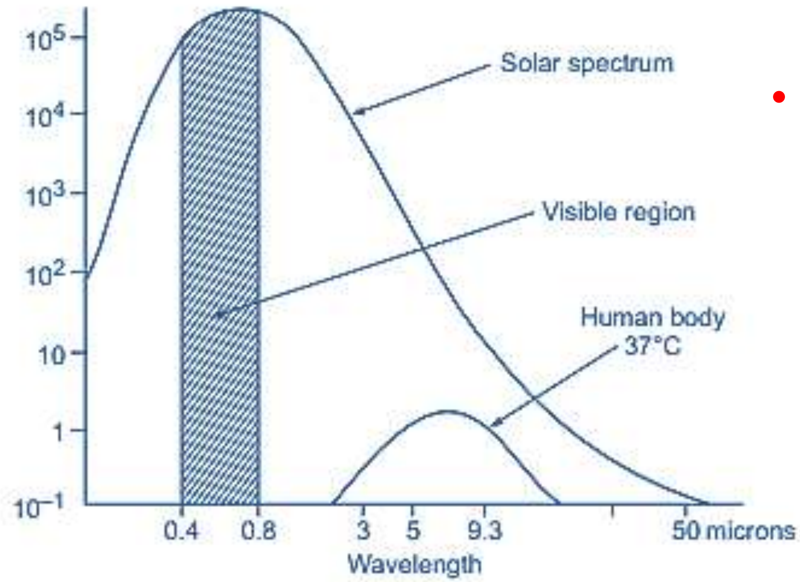
- The medical thermograph is a sensitive infrared camera which presents a image of the temperature distribution over the skin.
- This image enables temperature differences to be seen instantaneously, providing evidence of abnormality.
- Thermography cannot be considered as a diagnostic technique comparable to radiography.
- Radiography provides information on anatomical structures and abnormalities.
- Thermography indicates metabolic process and circulation changes.

Introduction to Thermograph/ Thermography…

- **Human body absorbs infrared radiation without reflection** and **emits part of its own thermal energy in the form of infrared radiation**.
- The intensity of this radiant energy corresponds to the temperature of the radiant surface.
- The varying intensity of radiation can be measured at a certain distance from the body and determine the surface temperature.

Introduction to Thermograph/ Thermography…

Spectral distribution of infrared emission from human skin



- **The emission peaks at around 9 microns regardless of pigmentation**

- In a normal healthy subject, the body temperature may vary considerably from time to time.
- The skin temperature pattern demonstrates characteristic features and remarkably consistent bilateral symmetry.
- Thermography is the science of visualizing these patterns and determining any deviations from the normal brought about by pathological changes.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

PHYSICS OF THERMOGRAPHY

Infrared Radiation

- The infrared ray is a kind of electromagnetic wave with a **frequency higher than the radio frequencies and lower than visible light frequencies**.
- The Infrared region of the electromagnetic spectrum is usually taken as **0.77 and 100 µm**.
- **Near infrared (0.77 to 1.5 µm), middle infrared (1.5 to 6 µm) and far infrared (6 to 40 µm) and far infrared (40 to 100 µm).**
- Infrared rays are radiated by all objects having a temperature above absolute zero.

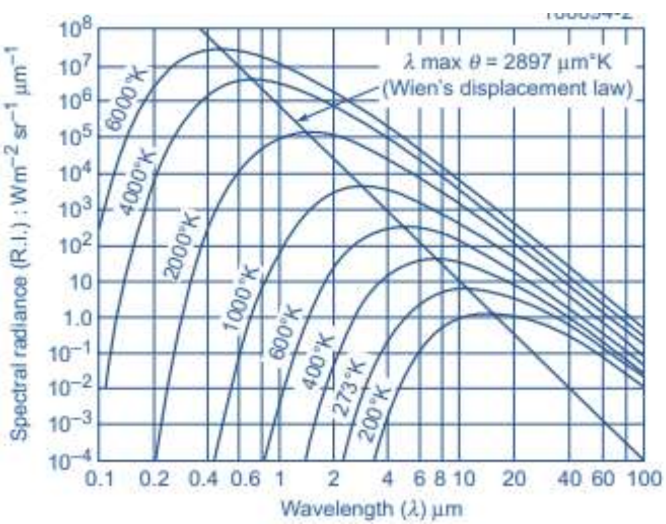
PHYSICS OF THERMOGRAPHY….

- The total energy 'W' emitted by the object and its temperature are related using the **Stefan-Boltzman formula.**

$$W = \sigma \in T^4$$

where W = radiant flux density and is expressed in W/cm^2
ε = Emissivity factor
σ = Stefan-Boltzman constant = $5.67 \times 10^{-12}\ W/(cm^2 \times K^4)$
T = Absolute temperature

Black body spectral radiance



$$\lambda_{max} = \frac{2897\ (\mu m)}{T(K)}$$

The human body has a temperature of 37°C (310 K)

$$\lambda_{max}(\text{human body}) = 10\ \mu m$$

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Spectral distribution of the reflectivity of human skin

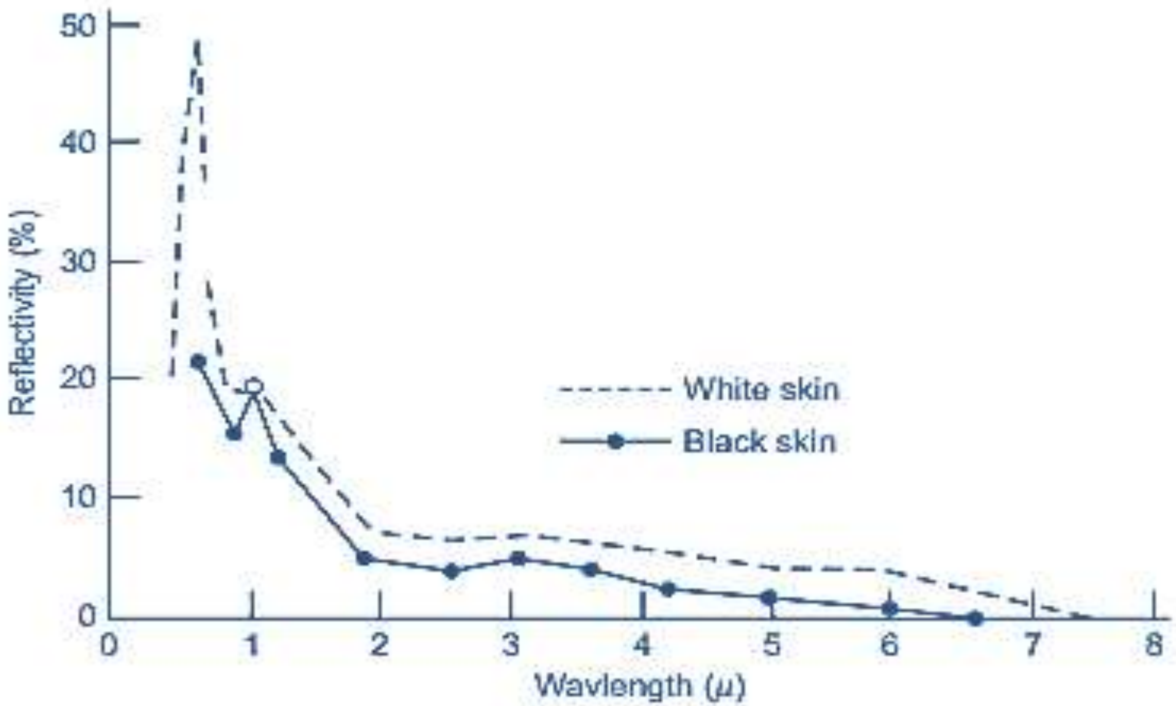
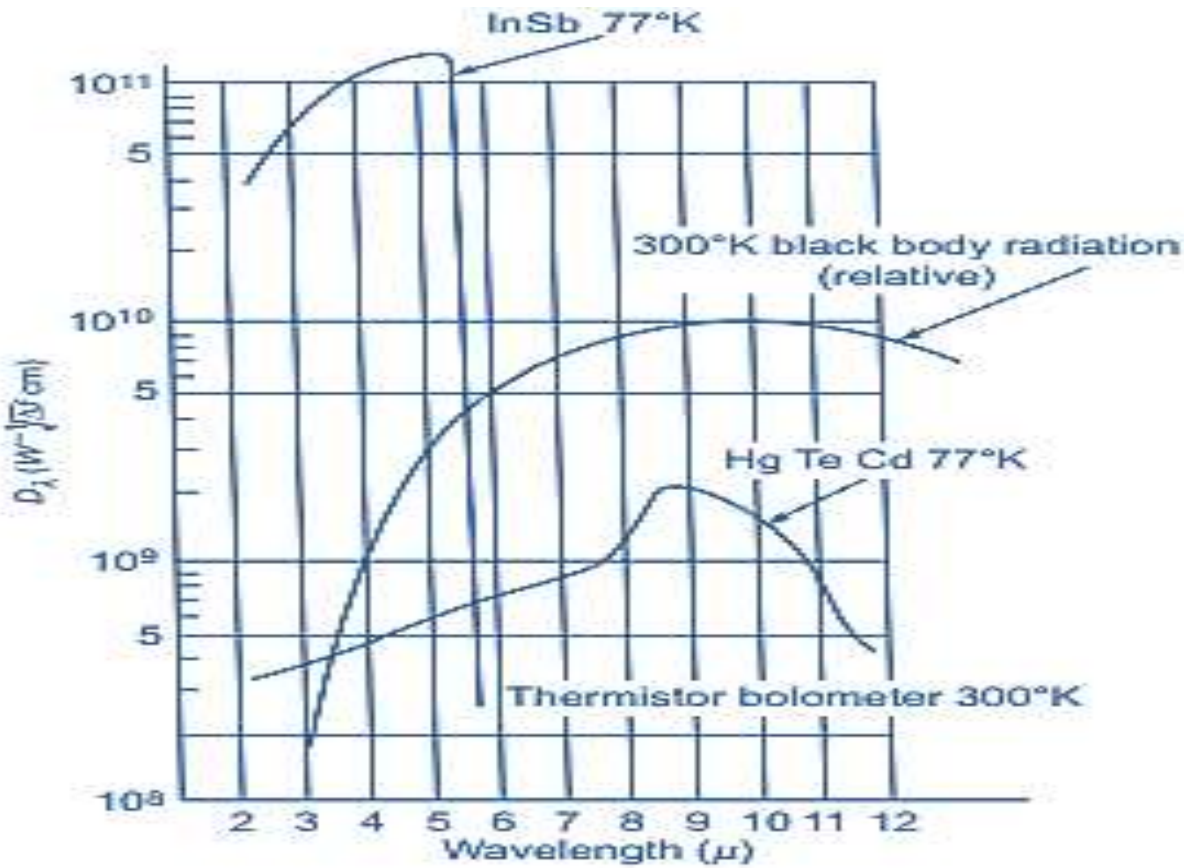


Image Courtesy: Hardy

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

INFRARED DETECTORS

Spectral characteristics of various types of infrared detectors



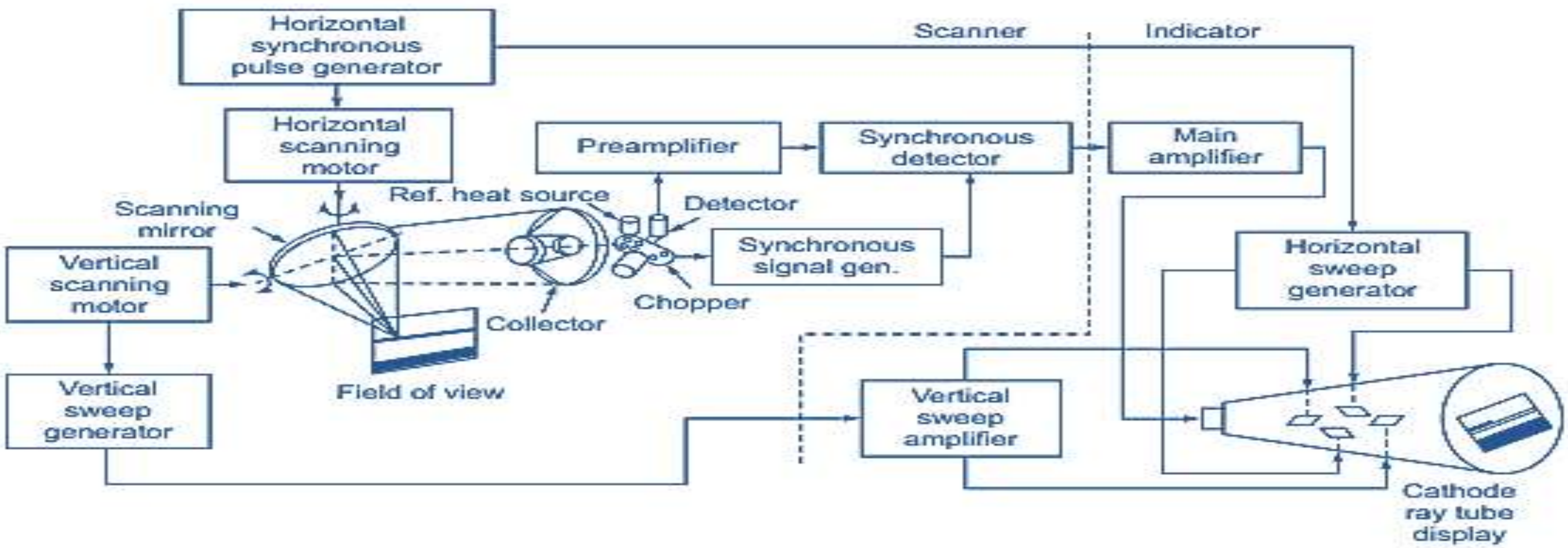
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

THERMOGRAPHIC EQUIPMENT

- Thermographic cameras incorporate scanning systems which enable the infrared radiation emitted from the surface of the skin within the field of view to be focused on to an infrared detector.
- The equipment used in thermography consists of two units:
  - **A special infrared camera that scans the object**
  - **A display unit for displaying the thermal picture on the screen.**
- The camera unit contains an optical system which scans the field of view at a very high speed and focuses the infrared radiation on a detector that converts the radiation signal into an electrical signal.
- The signal from the camera is amplified and processed before being used to modulate the intensity of the beam in the picture tube.
- The beam sweeps across the tube face in a pattern corresponding to the scanning pattern of the camera.
- The picture on the screen can be adjusted for contrast (temperature range) and brightness (temperature level) by means of controls on the display unit.

THERMOGRAPHIC EQUIPMENT…

Block diagram of the scanning and displaying arrangements for infrared imaging



- The double-scanning movement of the plane mirror causes each spot on the patient's body to be focused in turn on the cooled detector of Indium Antimonide.
- The detector is mounted in a Dewar flask which is cooled with nitrogen in order to obtain optimum sensitivity and eliminate thermal noise.
- An optical collector system is employed in an infrared detecting system. This is due to a weak infrared input from the subject.
- Scanning is carried out by a reflecting mirror.
- The instantaneous field of view which can be scanned is decided by the optics and detector size.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

THERMOGRAPHIC EQUIPMENT…

- The horizontal and vertical movements of the scanning mirror are controlled by individual motors.
- The scanning mechanism rapidly oscillating the flat mirror to give a horizontal line scan, and slowly tilting it for the frame scan.
- Horizontal synchronous pulses and vertical sweep signals for the display unit are also generated.
- A chopper disc interrupts the infrared beam so that an AC signal is produced from the detector.
- The AC signal developed at the detector is amplified by the pre-amplifier.
- It is then rectified and fed into the band pass filter whose central frequency is determined by the chopping frequency.
- A CRT is used for display of scanned image.

Digital Analysis of Thermograms

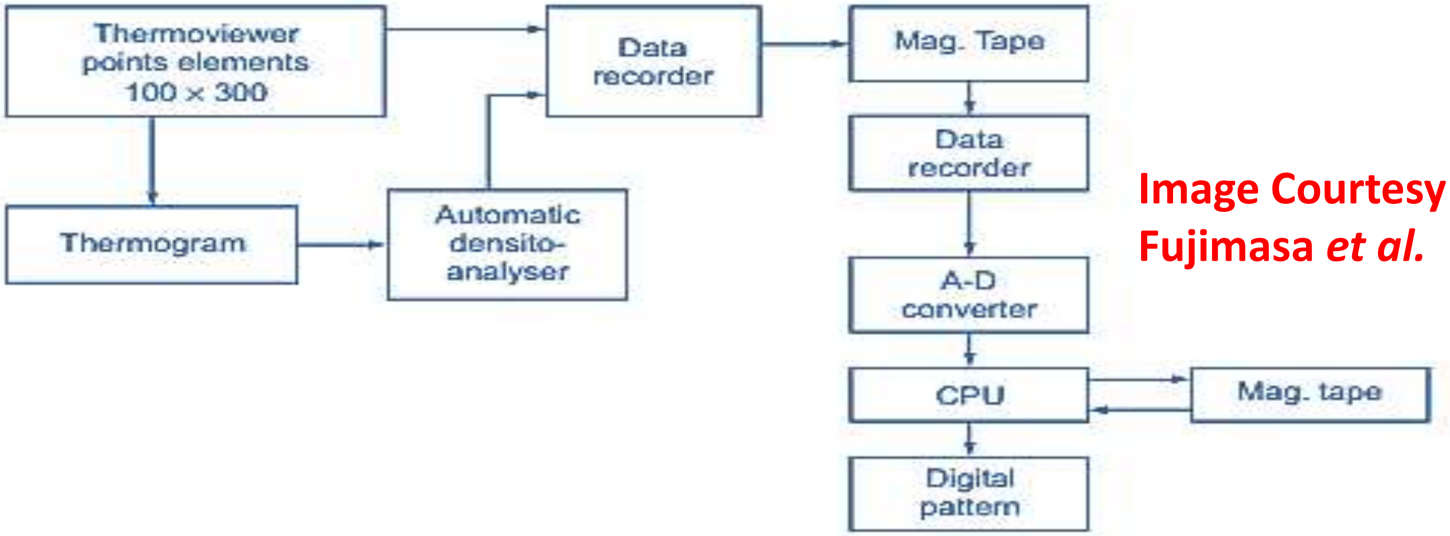


Image Courtesy: Fujimasa *et al.*

- The output signal of the infrared radiation camera is recorded on a magnetic tape.
- Analog outputs from the camera are converted into digital thermo-profiles by the A-D converter of a computer.
- The control processing unit of the computer converts digital values into true temperature values based on the calibration data stored in the memory or magnetic tape.
- The thermographic patterns can be scanned and converted into analog electrical signals by a scanning densitometer and are converted into digital form.
- For a precise analysis of surface temperatures, the thermogram digitization and computers are useful in the automatic analysis of thermograms.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Advantages of Thermography

- Get a picture so we can compare temperatures over a large area.
- Capable of catching moving targets
- Able to find deteriorating components prior to failure.
- Measurement in areas inaccessible or hazardous for other methods.
- Non-destructive test method.

Limitations & Disadvantages

- Quality cameras are expensive and are easily damaged.
- Images can be hard to interpret accurately even with experience.
- Accurate temperature measurements are very hard to make because of emissivity.
- Most cameras have ±2% or worse accuracy (not as accurate as contact).
- Training and staying proficient in IR scanning is time consuming.
- Ability to only measure surface areas.

Applications

- Tumours
- Diseases of peripheral Vessels
- Brain and Nervous Diseases
- Hormone Diseases

Applications….
Mammography

Image Courtesy: M/s Meditherm Inc.

ENDOSCOPY UNIT

Endoscopy unit

- An **endoscope was first introduced into a human in 1822 by William Beaumont**, an army surgeon at Mackinac Island, Michigan.
- The use of electric light was a major step in the improvement of endoscopy.
- **An endoscopy is a test that looks inside the body.**
- **The endoscope is a long flexible tube that can be swallowed**.
- **It has a camera and light inside it**.
- Some doctors call it as a telescope.
- Endoscopy to look at the inside of Gullet (oesophagus) Stomach Duodenum - the first part of the small bowel that attaches to the stomach Large bowel (colon)

Endoscopy unit..

A flexible Endoscope

Need of Endoscopy

- Endoscopy allows physicians to peer through the body's passageways.
- Endoscopy is **the examination and inspection of the interior of body organs**, joints or cavities through an endoscope.
- An endoscope is a device that uses **fiber optics and powerful lens systems to provide lighting and visualization of the interior of a joint**.
- The **portion of the endoscope inserted into the body may be rigid or flexible, depending upon the medical procedure**.
- An endoscope uses two fiber optic lines.
- A "**light fiber**" carries light into the body cavity and an "**image fiber**" carries the image of the body cavity back to the physician's viewing lens.
- There is also a separate port to allow for administration of drugs, suction, and irrigation.

Observation using Endoscopy

Observation using Endoscopy…

- Reflected light rays are collected by CCD and electrical signals are produced, which are fed to the video monitor to get image.
- Thorough one channel of endoscope water and air is conducted to wash and dry the surgical site.
- The endoscope also has a channel through which surgeons can manipulate tiny instruments, such as forceps, surgical scissors, and suction devices.
- A variety of instruments can be fitted to the endoscope for different purposes.
- A surgeon introduces the endoscope into the body either through a body opening, such as the mouth or the anus, or through a small incision in the skin.
- The endoscope gives visual evidence of the problem, such as ulceration or inflammation It can be used to collect a sample of tissue; remove problematic tissue, such as polyps.
- It is used to take photograph of the hollow internal organs.

Endoscope Components

An endoscope can consist of :

- A rigid or flexible tube
- A light delivery system to illuminate the organ or object under inspection.
- The light source is normally outside the body and the light is typically directed via an optical fiber system
- A lens system transmitting the image to the viewer from the fiberscope
- An additional channel to allow entry of medical instruments or manipulators.

Endoscopy Equipment

Video systems	Fiber Endoscopes	Video Endoscopes

Endoscopy Equipment…

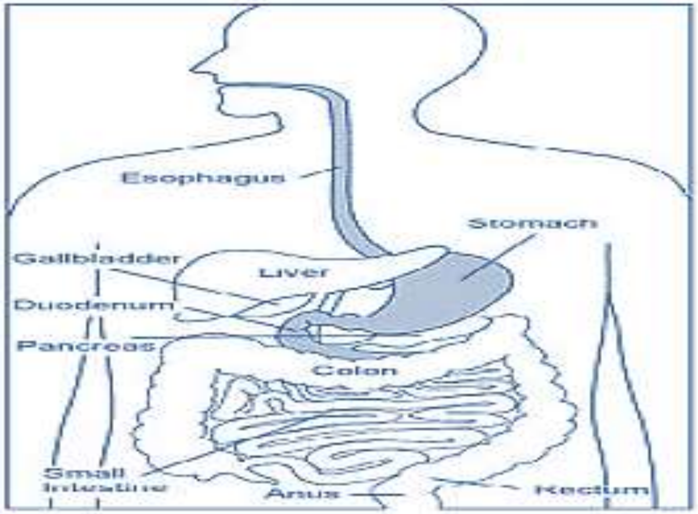
- An endoscope and related endoscope products and equipment are usually composed of three components:
  - An optic system that allows the doctor to look through the scope into the organ or cavity, or to attach a video camera to the scope.
  - A fiber optic cable to light up the bodily area.
  - A lumen (e.g. the bore of a tube, like a needle or catheter) to take tissue samples of the area being viewed.

Type of Endoscopy (Based on human body parts)

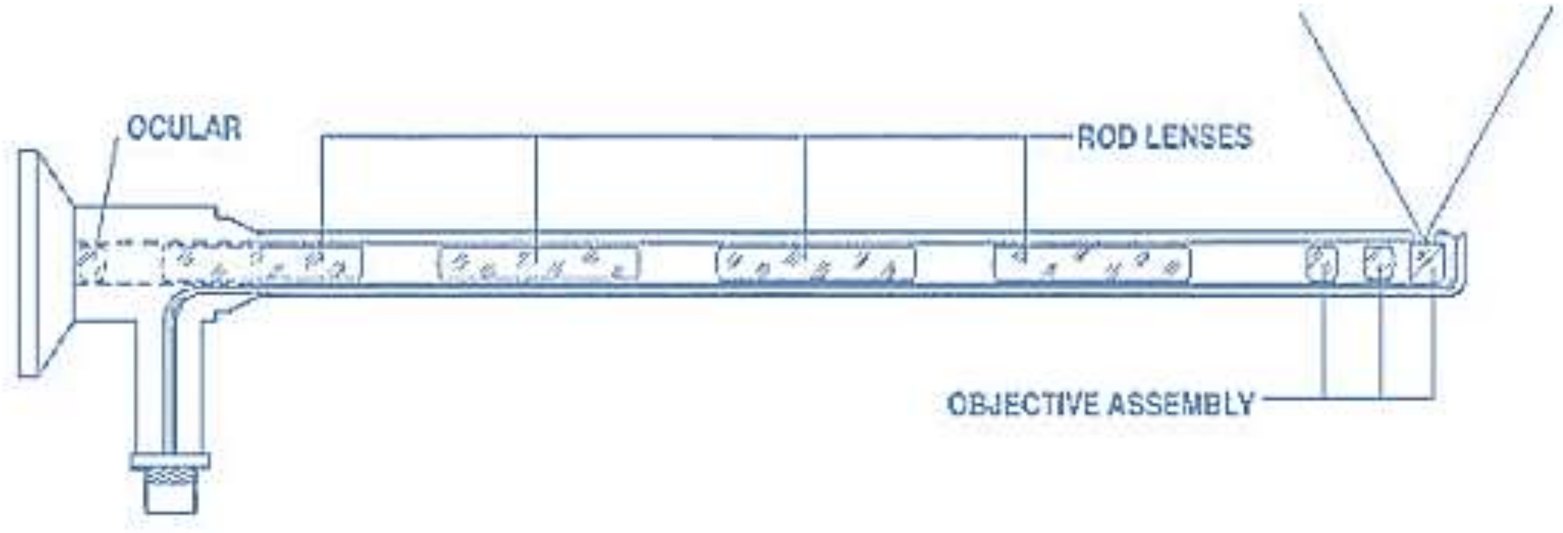
- Laparoscopy (abdomen, uterus, fallopian tube)
- Laryngoscopy (vocal cords)
- Bronchoscopy (lungs)
- Colonoscopy (colon)
- Arthroscopy (joint)
- Gastroscopy (Stomach)
- Proctoscopy, sigmoidoscopy, proctosigmoidoscopy: (examination of the rectum and sigmoid colon)
- EGD (Esophogealgastroduodensoscopy): visual examination of the upper gastro-intestinal (GI) tract. (also referred to as gastroscopy) to reveal hemorrhage, hiatal hernia, inflammation of the esophagus, gastric ulcers.

Upper Endoscopy

- Upper endoscopy enables the physician to look inside the esophagus, stomach, and duodenum (first part of the small intestine).
- The procedure might be used to discover the reason for swallowing difficulties, nausea, vomiting, reflux, bleeding, indigestion, abdominal pain, or chest pain.
- Upper endoscopy is also called EGD, which stands for esophagogastroduodenoscopy.



Rigid Endoscope



- The "image fiber" leads from the ocular (eye piece) to the inserted end of the scope.
- The "light fiber" is below and leads from the light source to the working end of the endoscope.

LASER IN MEDICINE

Laser in medicine

- LASER (**Light Amplification by Stimulated Emission of Radiation**)
- Lasers are presently used for a variety of applications in the medical field.
- The **high radiance, monochromaticity and spatial and temporal coherence** make the laser a unique light probe for non-invasive applications.
- The information contained in laser light reflected or scattered by structures can be detected and analysed for diagnostic purposes.
- The most widespread medical application for laser technology in medicine has occurred in **ophthalmology**.
- This is due to the easy accessibility of the human eye, its transparency and the absorption properties of its internal tissues.

Laser in medicine…

Characteristics of Lasers Applied in medicine

Laser	Wavelength nm	Solid or Gas	Typical power (Watt) Continuous Wave	Peak	Type of beam	Applied Field
Argon	490 520 (visible)	Gas	5	100	Continuous tunable pulsed	Neurosurgery, ophthalmology, general surgery, gynaecology, dermatology, biological research
Helium-Neon	630 1150 3390 (visible)	Gas	0.1	2	Continuous	Diagnostic applications like study of light, permeability of blood containing tissues, laser holography, etc.
Krypton	350 (ultraviolet)	Gas	5	100	Continuous	Ophthamology and for general diagnostic use
Ruby	694 (visible)	Solid	5	50	pulsed	Ophthamology, dermatology
CO_2	10600 (infrared)	Gas	200	75,000	Continuous	Neurosurgery, general surgery dermatology, gynaecology
Nd-YAG	1064 (infrared)	Solid	50	1,000	Q-switched Continuous	Neurosurgery, dermatology, gynaecology
Ho:YAG Holmium	2070	Solid	30	80	Pulsed	Tissue ablation, lithotripsy, endoscopic sinus surgery
Excimers			(Pulse energy)			
ArF	193 (ultraviolet)	Gas	30	400 (mJ)	Pulsed	Surgery
KrF	249 (ultraviolet)	Gas	45	550 mJ	Pulsed	Surgery
XeCl	308 (Ultraviolet)	Gas	30	200 (mJ)	Pulsed	Surgery
XeF	350 (Ultraviolet)	Gas	20	275 (mJ)	Pulsed	Surgery

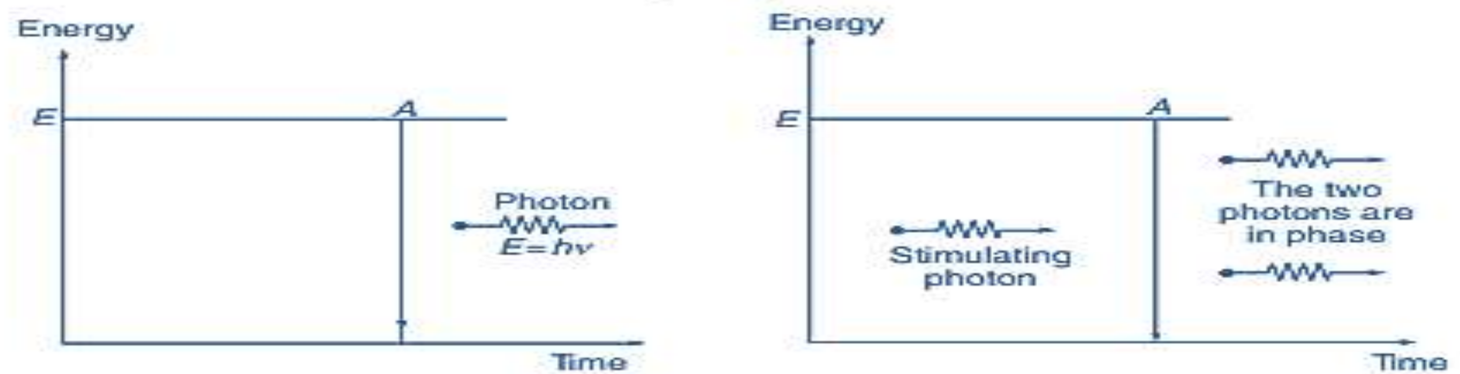
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Principle of Operation of Laser

- The laser action depends upon the **phenomenon of stimulated emission**.
- Single atom in an excited state can come back to its normal state by **emitting a "photon"** / light quantum whose frequency is **related to the excitation energy E**.

$$E = h\nu$$

h is Planck's constant and ν is frequency of emission.



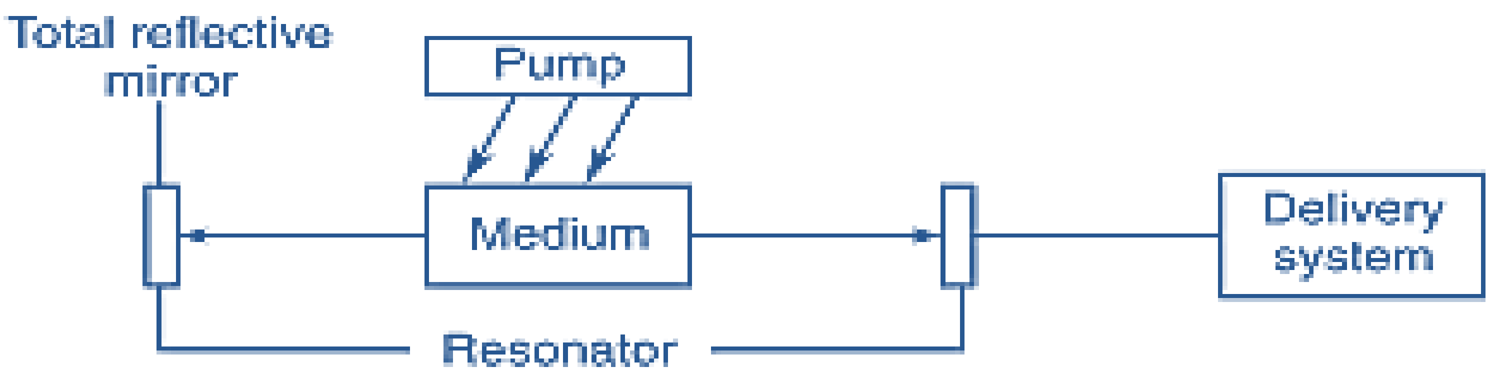
(a) Spontaneous emission (b) Stimulated emission

- If during the period the atom is still excited, it can be stimulated to emit if it is struck by an outside photon having precisely the energy of the one that would otherwise be emitted spontaneously.
- The stimulating photon or wave is augmented by the one released by the atom.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Major elements of a laser

- In **active medium** atoms are kept in an excited state and stimulated by an outside photon to emit light in a particular direction.
- The **process of medium activation is called 'pumping'.**
- This injecting electromagnetic energy into the medium at a wavelength different from the stimulating wavelength.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Major elements of a laser…

- The active medium is usually enclosed in a resonator box with highly reflecting walls.
- The photons released by the stimulated emission undergo multiple reflections and result in a coherent wave of growing strength.
- The laser output is obtained if the resonator box is transparent to the emitted laser beam.
- A double-mirrored resonating chamber is used to reflect the light beam so that the rays of light are superimposed as a single, high-density energy beam.
- The high energy stored within the resonating chamber can be directed through the partially reflective mirror by releasing the shutter in a precisely controlled manner.
- A **laser's properties are determined by three primary considerations**:
- **The gain medium, the pumping mechanism and the resonator design**.

TYPES OF LASERS

- Several types of lasers are : **solid-state, gaseous and semiconductors.**
- They are classified according to the **two fundamental modes of operation**:

The pulsed operation :

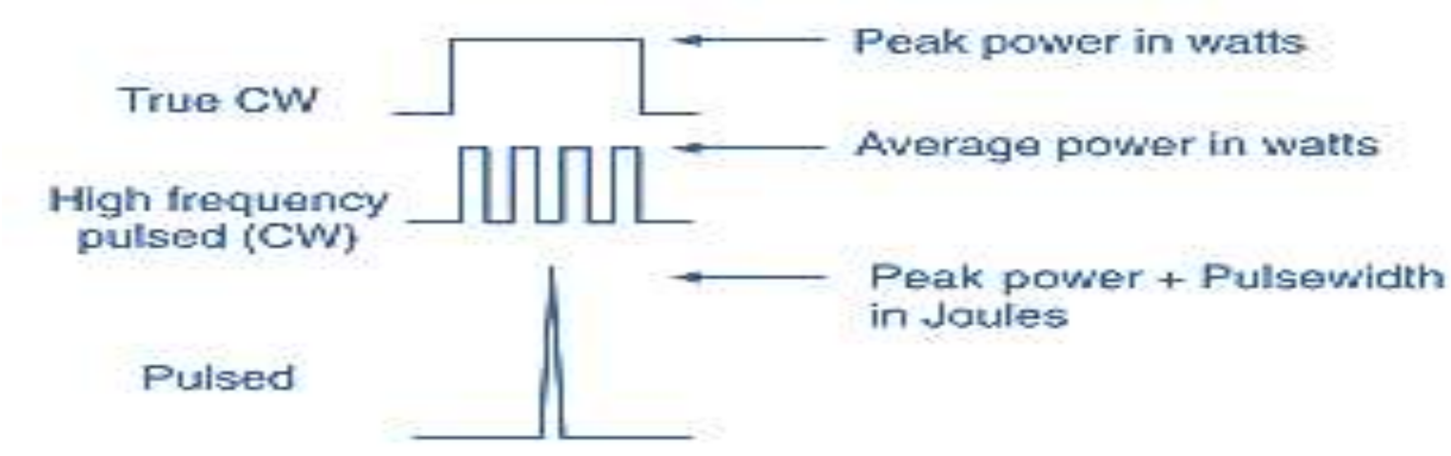
It is achieved with the ruby and neodymium glass.

The Continuous wave operation :

CW is achieved with helium-neon, argon, krypton, carbon dioxide lasers.

TYPES OF LASERS…

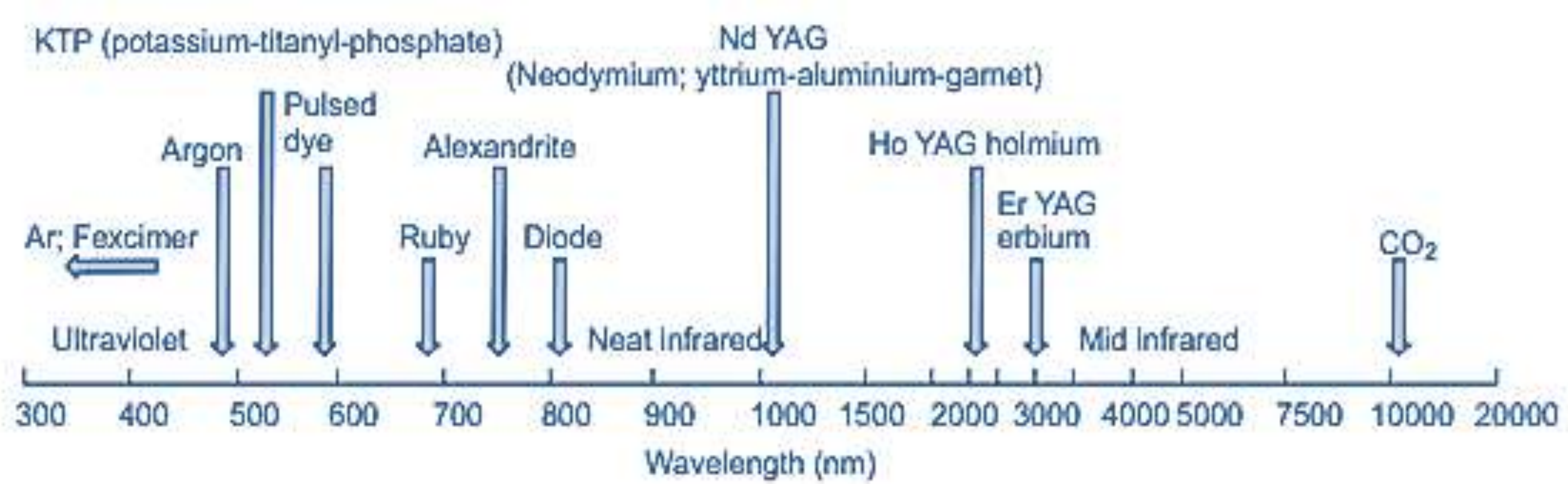
- The output of continuous wave lasers is measured as power in watts, and for pulsed lasers the output is measured as energy in joules.
- In a laser, Irradiance, or power density, refers to laser power per unit area (W/cm2) and Fluence, or energy density, is irradiance multiplied by exposure time.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Wavelength of medical lasers

- The interaction between the laser beam and the tissue is determined by the wavelength, power density and exposure time.



- **Monochromatic nature of laser light is responsible for its selective** effect on biological tissues.
- When the **light comes into contact with the tissues, it can be transmitted, scattered, reflected or absorbed**.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Wavelength of medical lasers

- The laser light has to be **absorbed by the tissue** in order to exert biological effects.

  Example :

  - **Water - absorbs infrared light**
  - **Haemoglobin - absorbs visible light**
  - **Green Melanin - absorbs visible and ultraviolet light**
- The wavelength also determines the depth of penetration.
- If wavelength decreases towards the ultraviolet spectrum more scattering occurs which limits the depth of penetration within the tissues.

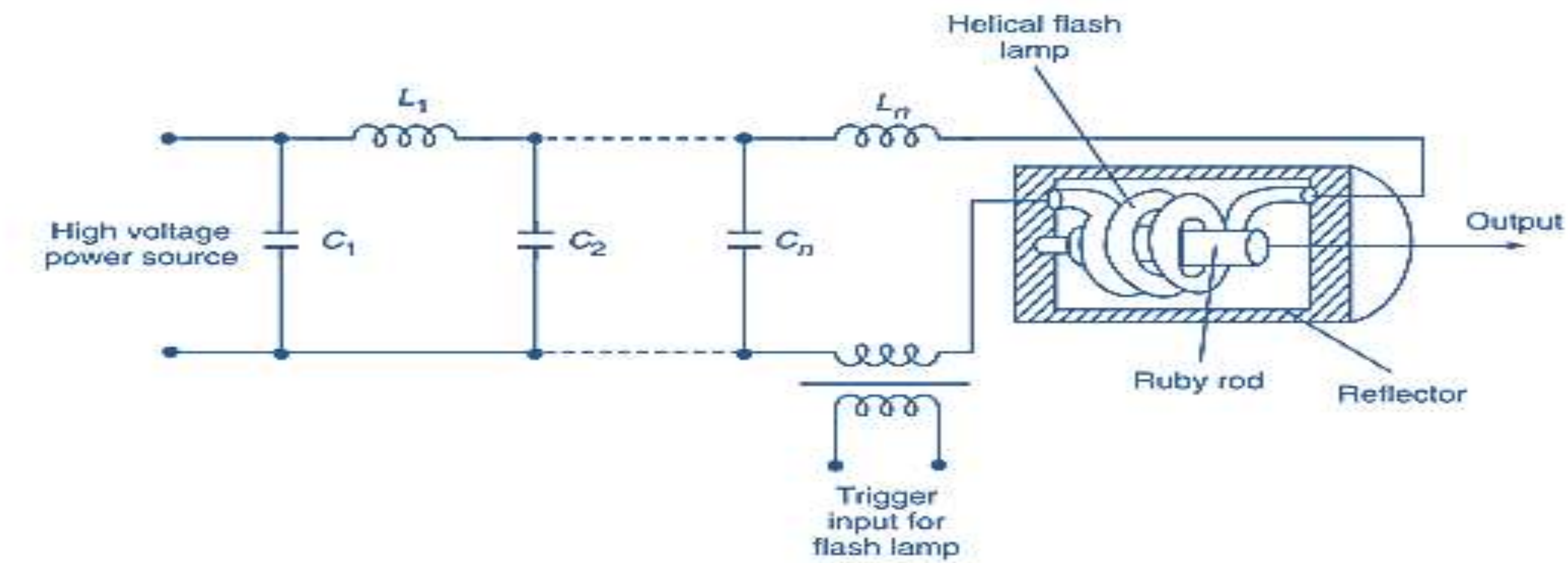
  Example:

  - **The Argon laser is used for retinal surgery and port-wine birthmarks.**
  - **The Nd:YAG laser operates at the near infrared spectrum has a greater depth of penetration and is therefore used for the cutting and coagulation of tissues.**

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Pulsed Ruby Laser

- First operational laser was developed by T. H. Maiman in 1961.
- It employed a ruby crystal as the active medium.
- Ruby is aluminium trioxide in which about 0.05% of the aluminium atoms have been replaced by chromium atoms.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Pulsed Ruby Laser

- In a typical pulsed laser system, a high voltage transformer (4000–10000 V) is connected to a bank of capacitors and pulse forming inductances.
- This network is further connected to a xenon flash lamp which may be straight or helical.

Nd:YAG Laser

- **Nd:YAG (Neodymium doped-Yttrium aluminium garnet)**
- It has very high output energies, repetition rates and wavelength outputs.
- The active element is a Nd:YAG crystal optically pumped by two krypton arc lamps.
- **The wavelength of emission is 1064 nm.**
- **Neodymium has a four-level transition**.
- The laser transition is more easily inverted with respect to the intermediate transition level than the three-level transition of ruby.
- The laser arrangement consists of a Nd:YAG rod placed within an elliptical cavity.

Nd:YAG Laser…

- A typical commercially available Nd:YAG laser consists of a power supply and laser head fitted with light guide and focusing handpiece.
- The system operates on 380 V, 20 A, 3 phase supply. The power supply unit contains the thyristor control for the lamp current and a control circuit for automatic switching and monitoring of the laser.
- To manage high power requirements, the lamp fittings and the YAG crystal are cooled by a single circuit cooling system safeguarded by flow monitors and magnetic valves.
- Approximately 10 L per minute water at a pressure of 3.5 bar is required for cooling.
- The maximum power output available out of the light guide is approximately 70 W

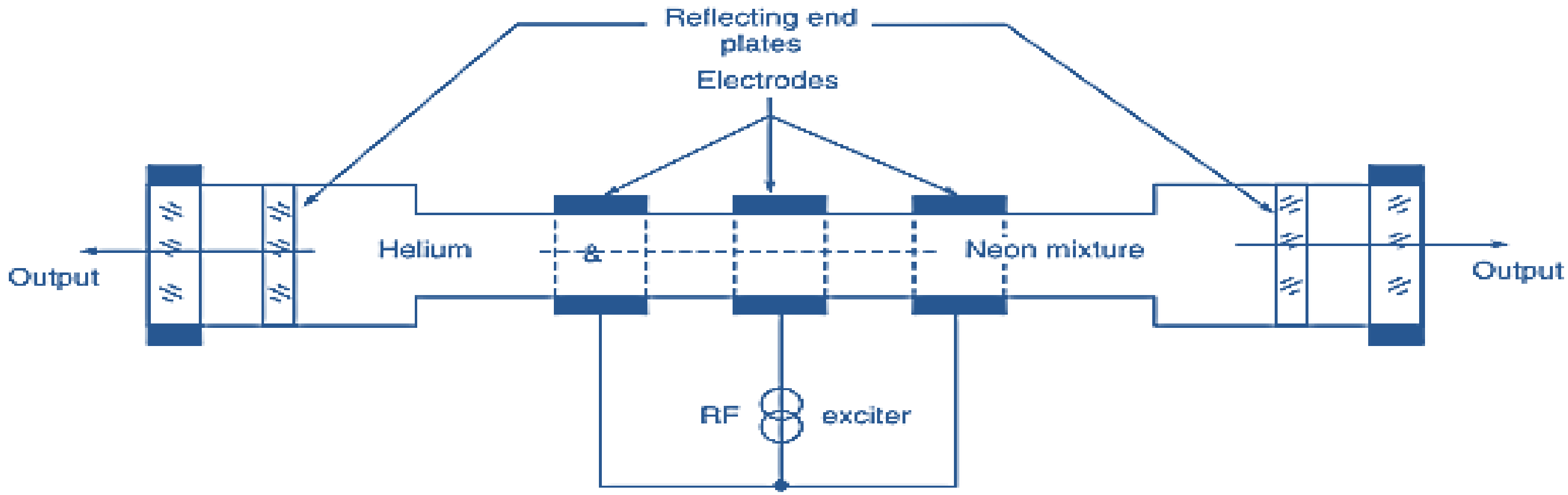
Nd:YAG Laser…

Applications

- Nd:YAG laser for interstitial photo-coagulation for **destroying solid tumour tissue in the brain, head and neck, liver, breast and pancreas**.
- Nd:YAG laser used for **photo-dynamic therapy** of human **cancer**.

Helium-Neon Laser

- It employs a gaseous active medium in which the atoms of one gas (neon) pump themselves up through collisions with the excited atoms of another (helium).
- A discharge tube containing 10 parts of helium and one part of neon is maintained at a very low pressure of approximately 1 mm of Hg.
- For continuous laser beam, pumping is achieved by an electrical discharge in the gas by radio frequency excitation.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Helium-Neon Laser…

- The two electrons of helium can have either parallel or anti-parallel spins.
- In the former case, they possess an energy level which is considerably higher than the ground level.
- A certain number of this type of electrons in the metastable state exists in the unexcited helium gas.
- Collisions between metastable helium atoms and unexcited neon atoms result in energy transfer to the neon so that the number of neon atoms in the excited level will increase.
- When these atoms return to their ground state, they do so by several transitions which lead to output in the optical region.

Compared with Ruby Laser

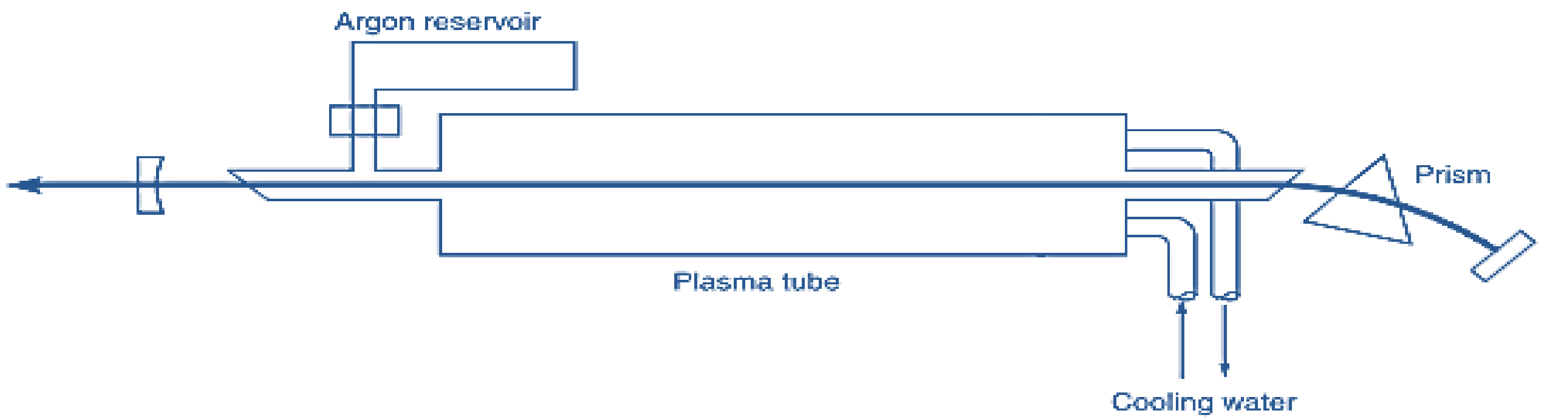
- **Helium-Neon laser can operate at several wavelengths.**
- **The line width of the radiation emitted is much smaller than the ruby laser.**
- **It can operate continuously but the power output is limited only to a few milliwatts.**

Helium-Neon Laser…

Applications

- Measurement of visual acuity
- Helpful to the ophthalmologist in deciding about the necessity of cataract surgery.
- laser ophthalmoscope has been developed for viewing the retina& its supporting structures such as blood vessels, nerve bundles and underlying layers.

Argon Laser

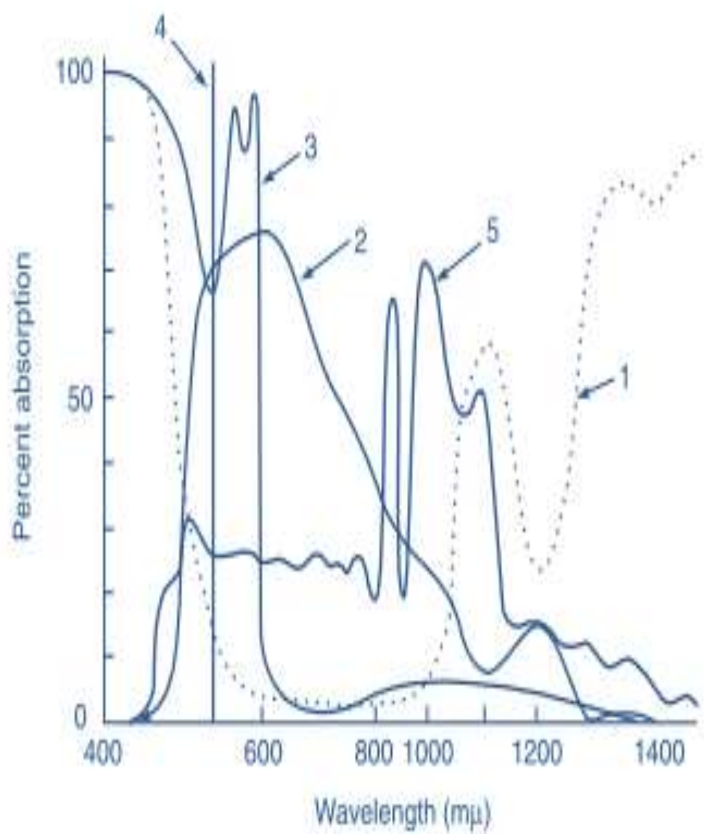


- The heart of the system is the plasma tube wherein a very high current discharge passes down the barrel of the tube through argon gas.
- The discharge ionizes the argon gas and also populates the excited ion states which are involved in the lasing.
- A strong electrical current is forced to flow through argon gas within the tube, each end of which has a mirror.
- The current excites the argon atoms to a higher energy level and some of them begin to emit light spontaneously.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Argon Laser…

Principle of use of argon laser as a source for photocoagulation

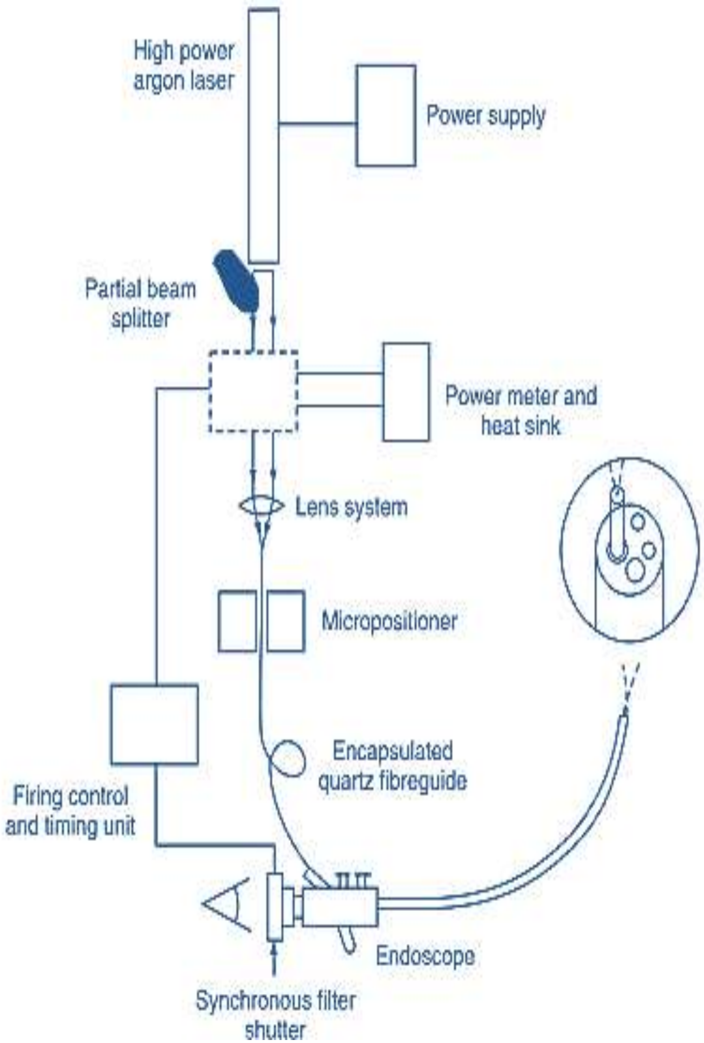


- Absorption in the ocular media (**curve 1**) has a 'window' from the visible spectrum to the near infrared. Energy in this part of the spectrum is transmitted to the retina with little loss in the media
- The window corresponds to the peak absorption of the pigment epithelium and choroid combined (**curve 2**).
- Haemoglobin also has its peak absorption in the same part of spectrum (**curve 3**)
- (curve 4) is ideally matched to the absorption characteristics of the eye.
- the continuum of the xenon gas emission (curve 5) covers the whole window extending into the near infrared where absorption in the media occurs.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Argon Laser…

Block diagram of fibre-optic gastric photocoagulator



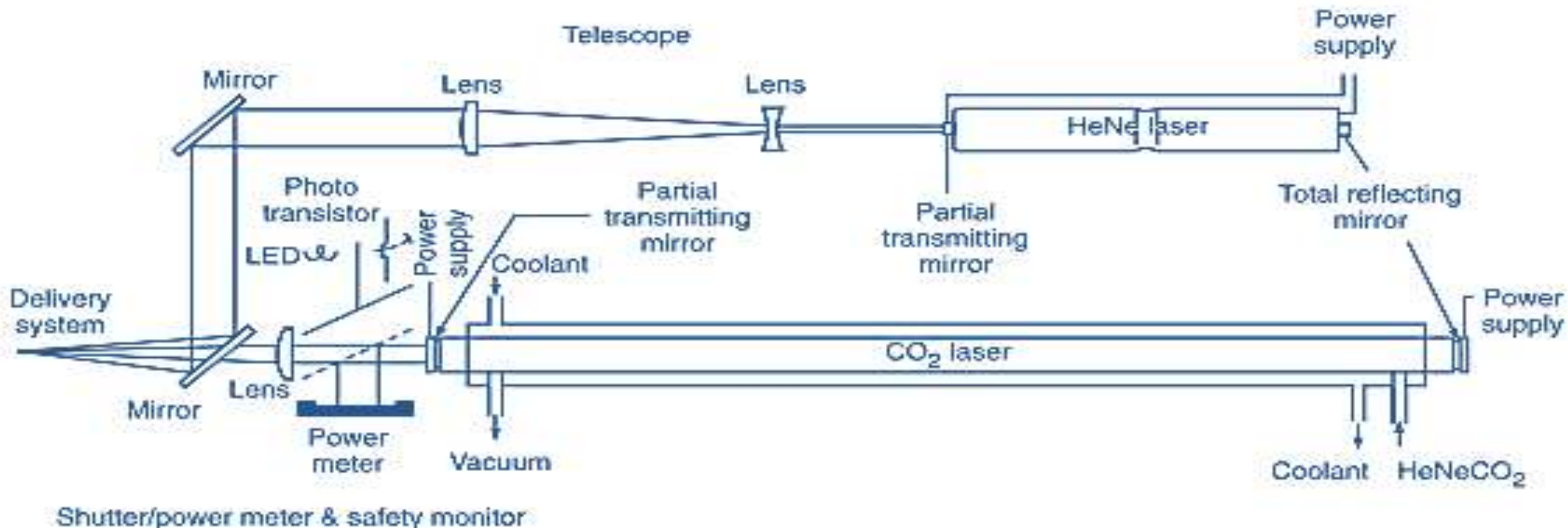
- The system employs a water-cooled argon laser capable of delivering more than 13 W continuous radiation when operating with all standard atomic lines.
- beam-splitter is used to provide an 'aiming' beam for the endoscopist at a pre-set and well-controlled operating power level.
- high power beam is transmitted to the flexible quartz wave guide by triggering an electronically controlled solenoid.
- The solenoid shutter can be adjusted in 0.1 second steps from 0 to 760 s.
- The quartz fibre is encapsulated in a laminated sheath of non-toxic polyethylene with an overall diameter of less than 2 mm.
- This provides physical protection and enables easy transport through the biopsy channel of a conventional endoscope.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

CO_2 Laser

- **CO2 laser provides bloodless surgery**
- CO2 laser has been extensively used for surgical applications.
- CO2 laser is a mixture of carbon dioxide, nitrogen and helium.
- The CO2 laser has a high conversion efficiency of the order of 15% as compared with the ruby which has an efficiency of about 1–2%.
- It operates with a simple cooling system of tap water and is relatively inexpensive.
- The beam can be reflected or focused by appropriate mirrors and lenses, thus lending itself to passage through a surgical manipulator.
- The normal operation of the laser is multimode.
- By inserting an annular diaphragm into the resonator, a single mode output can be obtained and the focal spot reduced to about 0.5 mm.
- The operating microscope can be used in conjunction with the CO2 laser as an aid to good visualization of tissues undergoing treatment.

CO_2 Laser…



- The laser head contains the CO2 laser which produces the invisible infrared (10.6 micron) beam used for surgery.
- A continuously adjustable power up to 25 W is available.
- A small helium-neon laser provides a visible red (0.8 mW, 630 nm) aiming beam.
- This beam provides accurate visualization of the operating area for precise laser removal of pathological tissue.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

CO_2 Laser…

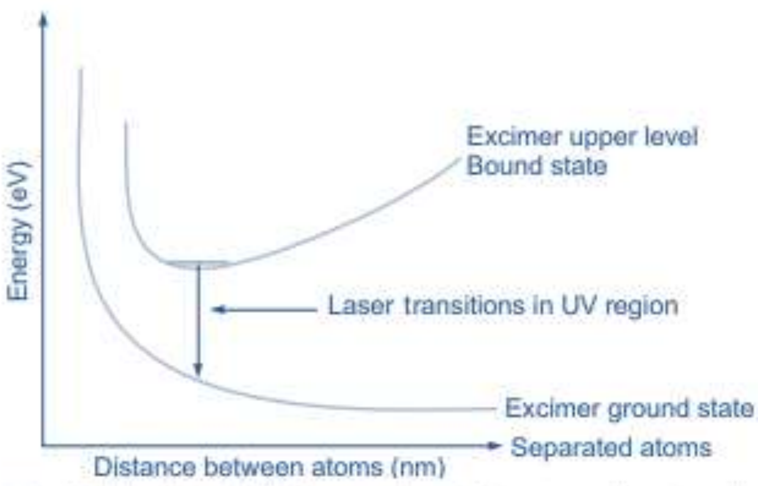
APPLICATIONS

- microsurgery: the laser beam is focused to be parfocal with the operating microscope.
- In general surgery, the laser can be directed through a surgical handpiece which allows large or easily accessible areas to be treated efficiently.
- For areas that are difficult or impossible to reach by conventional methods, the laser is used with an endoscope.

Excimer Lasers

- Excimer lasers operate primarily in the ultraviolet spectral region.
- They use mixtures of rare gases such as argon, krypton, or xenon with halide molecules such as chlorine and fluorine.
- The most common excimer lasers are argon-fluoride (193 nm), krypton-fluoride (248 nm), xenon-chloride (308 nm), and the xenon-fluoride (351 nm).

The energy level diagram of excimer laser



Relative Power of Various Excimer Lasers

Wavelength	Active Gas	Relative Power
248nm	Krypton Fluoride	100
193nm	Argon Fluoride	60
308nm	Xenon Chloride	50
351nm	Xenon Fluoride	45

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Excimer Lasers…

APPLICATIONS

- A major advantage of an excimer laser is its intense ultra-violet beam which can vapourize tissue with almost no heat transfer into surrounding tissue.
- The two most important applications of excimer lasers in medicine are improving vision by controlled ablation of the cornea with ArF (193 nm) excimer laser
- Removal of artherosclerotic plaque from arteries with XeCl (308 nm) excimer laser.
- An attractive application of excimer laser is corrective eye surgery which is commonly called as LASIK (“laser assisted in situ keratomileusis”).
- The laser is used to correct the refractive error of the eye, which simply means short sightedness (myopia) or long sightedness (hyperopia) or astigmatism (a condition where the cornea is oblong instead of spherical).
- The main purpose of Lasik is to eradicate the need of wearing glasses or contact lenses and correct the vision.

Excimer Lasers…

APPLICATIONS…

- The principle of Lasik Surgery is to alter the incorrect shape of the cornea of the eye to the desired standard so that the newly acquired shape helps to refract the rays of light in the right manner and the need for glasses is abolished.
- This lasik eye surgery is performed using a computer which, with the help of a software, analyses the shape of the cornea and determines the necessary corrective changes to be incorporated in its shape.
- The surgery is performed using an excimer laser which emits concentrated light and operates as per the feed from the computer.
- Excimer laser light is typically absorbed in less than a nanometer of tissue.
- By means of intense excimer pulses, the surface of the human cornea is reshaped to change its refractive power and thus to correct for short or long sightedness.
- This surgery is performed by a highly skilled lasik eye surgeon.

Semiconductor Lasers

- Semiconductor lasers are highly efficient laser light emitting devices which are extremely small.
- constructed from several semiconductor material systems such as the **gallium arsenide/aluminum gallium arsenide system** and **the indium phosphide/indium gallium arsenide phosphide system**.
- The **first semiconductor laser device was made from chips of gallium arsenide**.
- The gallium arsenide was grown such that p-n junction or diode was formed.
- Laser diodes which contain a medium semiconductor material are pumped electrically and have a resonator.
- Without pumping, most of the electrons are in the valence band.

Semiconductor Lasers…

The physical origin of gain in a semiconductor

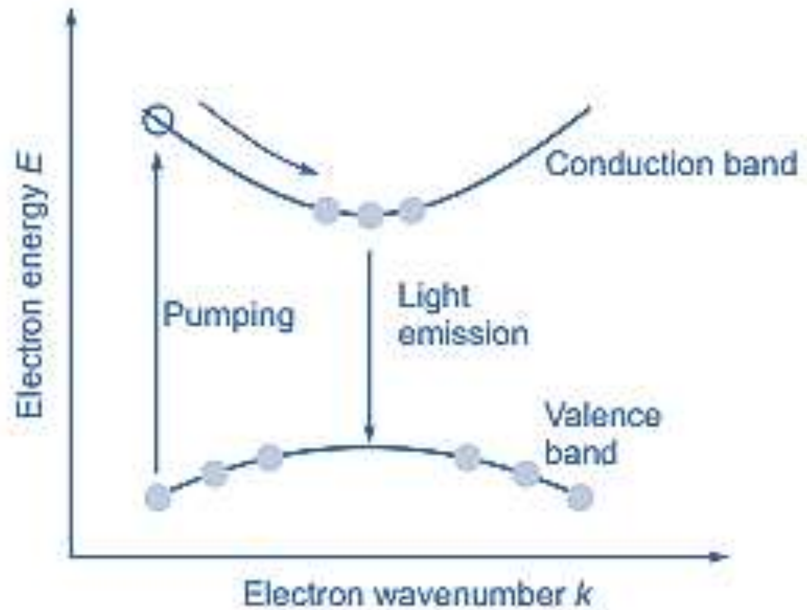


Image Courtesy: http://www.rp-photonics.com/semiconductor_lasers.html

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Semiconductor Lasers…

- **Most semiconductor lasers are laser diodes, which are pumped with an electrical current** in a region where an n-doped and a p-doped semiconductor material meet.
- There are also **optically pumped semiconductor lasers**, where carriers are generated by **absorbed pump light**, and quantum cascade lasers, where intraband transitions are utilized.
- The early devices suffered from a lack of coherence due to the wide spectral bandwidth and low power output.
- These drawbacks have been overcome and the techniques used today for producing semiconductor lasers are identical to the technology which is used for manufacturing electronic devices.
- **High brightness semiconductor diode laser technology is enabling diode lasers to be used directly in a new range of medical applications where previously gas or solid state lasers were the only solution.**

Semiconductor Lasers…

- A variety of medical applications today utilize diode lasers as direct diode sources for treatment because of their compact size, efficiency, low cost and ability to produce large optical energies.
- **Hair removal, dental, ophthalmic, and other dermatological applications utilize diode laser light directly**.
- The wavelength of the light is critical to the treatment efficacy, and a laser illuminator is chosen to match the absorption of various skin, blood or organ constituents.
- In many cases, the light is delivered through a fibre by way of a catheter or scope which needs to be extremely small, resulting in the need for high brightness fibre coupled diode lasers.
- Other medical applications of lasers include skin rejuvenation, wrinkle treatment, varicose vein treatment, photodynamic therapy, pain treatment, lipolysis, and surgery

LASER SAFETY

- Both **direct and reflected laser beams are potentially dangerous**.
- The principle dangers are **injury to the eye, burns and ignition**.
- Laser **light from the ultraviolet to the far infrared wavelengths can cause burns to the skin**.
- Laser dangers can include fires to unprotected drapes and endotracheal tubes, wherein oxygen-enriched environments increase the chance of fire.
- Special precautions must be taken.
- If a **laser output beam is focused** on a **smaller spot using a lens**, it **greatly increases the power density at the focal point**.
- The **lens of the eye refocus** stray visible or near infrared laser light onto the retina, causing **painless retinal burns which can result in a permanent blind** in the field of vision due to damage to the photoreceptor.

LASER SAFETY…

- Staring directly into a laser beam should be avoided.
- **Safety goggles giving protection** at the appropriate wavelength.
- This eyewear must be labelled for the wavelength and optical density.
- **The patient's eyes should be protected by protective eyewear or wet towels over the eyes**.
- **Laser safety standards** have been worked out such as **ANSI-Z136.1, American National Standard for safe use of lasers, and ANSI-Z136.3**, for the safe use of lasers in health care facilities.

DIATHERMY UNITS

Diathermy units

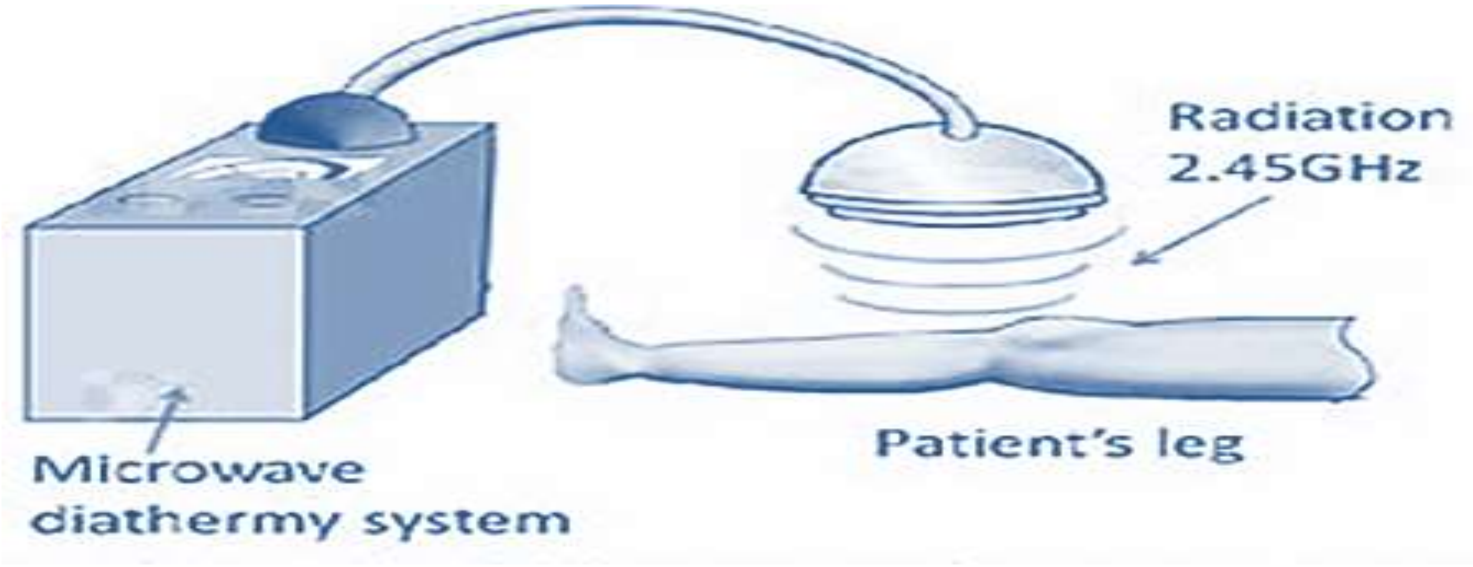
- Diathermy is **electrically induced heat or the use of high-frequency electromagnetic currents as a form of physical therapy and in surgical procedures.**

- The term diathermy is derived from the Greek words **dia** and **therma**, and literally means "**heating through**".

- The extreme heat produced by diathermy may be used to destroy neoplasms, warts, and infected tissues, and to cauterize blood vessels to prevent excessive bleeding.

- The technique is particularly valuable in neurosurgery and surgery of the eye.

Diathermy units…



Diathermy units…

- The three forms of diathermy employed by physical therapists are :

I. **Short wave diathermy**
II. **Microwave diathermy**
III. **Ultrasound diathermy**

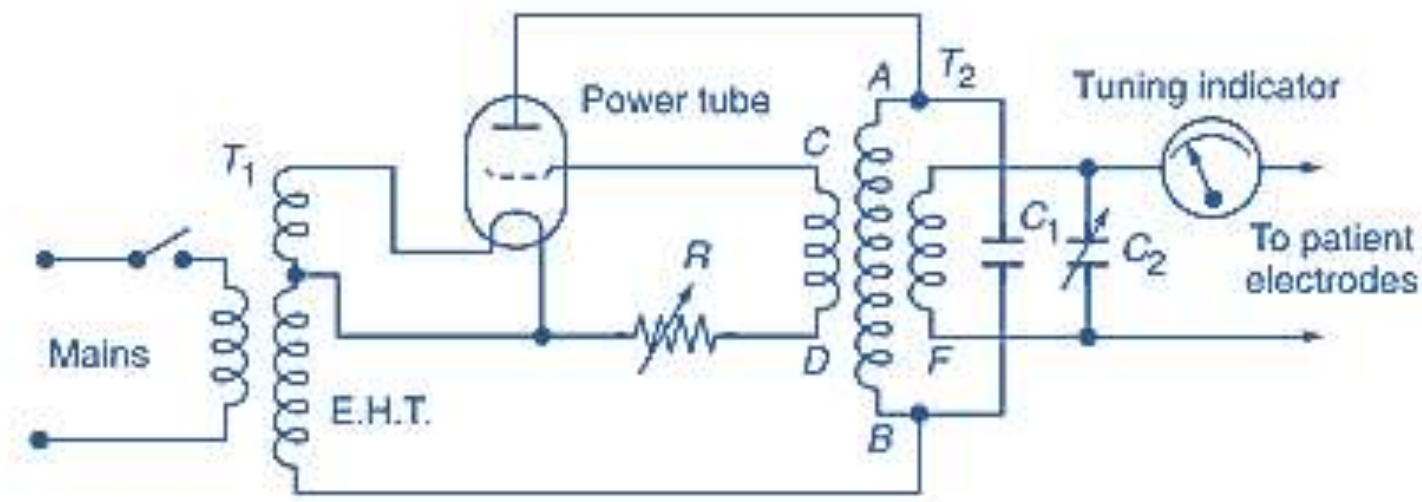
Diathermy units…

I. SHORT WAVE DIATHERMY

- **Shortwave diathermy** uses high-frequency electromagnetic energy to generate heat.
- It may be applied in pulsed or continuous energy waves.
- It has been used to treat pain from kidney stones, and pelvic inflammatory disease.
- The short wave diathermy machine consists of two main circuits:
  - **an oscillating circuit which produces a high frequency current**
  - **a patient circuit, which is connected to the oscillating circuit and through which the electrical energy is transferred to the patient.**

Diathermy units…

I. Short wave diathermy….



- Transformer T_I : the primary of which can be energized from the mains supply, is a step-up transformer for providing EHT for the anode of the triode valve.
- A second winding can provide heating current for the cathode of the triode valve.
- The tank (resonance) circuit is formed by the coil AB in parallel with the condenser C_I .
- The positive feedback is generated by coil CD.
- There is another coil EF and a variable condenser C2 which form the patient's resonator circuit due to its coupling with the oscillator coil AB.

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Diathermy units…

I. Short wave diathermy….

- There are several ways of regulating the intensity of current supplied to the patient from a short-wave diathermy machine.
- This can be done by either
  - **(i) controlling the anode voltage**
  - **(ii) controlling the filament heating current**
  - **(iii) adjusting the grid bias by change of grid leak resistanceR1**
  - **(iv) adjusting the position of the resonator coil with respect to the oscillator coil.**
- The best way of finely regulating the current is by adjusting the grid bias, by putting a variable resistance as the grid leak resistance

Diathermy units…

Application Techniques of Short-wave Therapy:

- The pattern of tissue heating is greatly affected by the method of short-wave diathermy delivery.
- The two most common forms of application are
  - **The capacitor plate method**
  - **The inductive method**

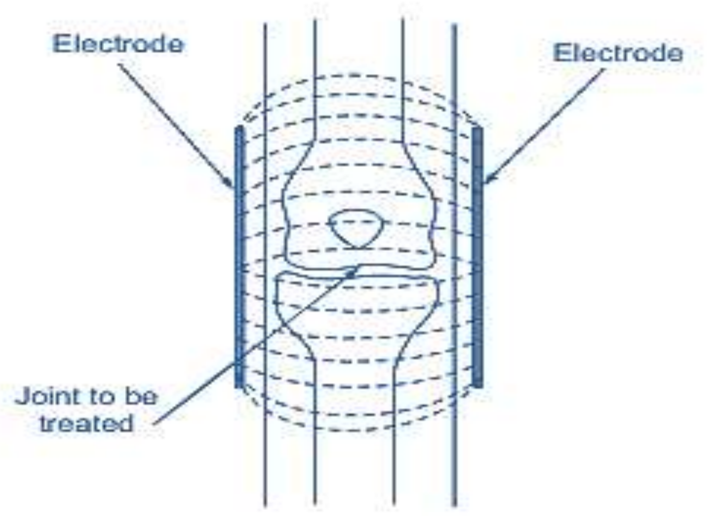
Shortwave diathermy (with capacitive electrodes)

- **In the capacitor plate method, the output of the short-wave diathermy machine is connected to metal electrodes (also known as PADS) which are positioned on the body over the region to be treated**
- **The pads are placed so that the portion of the body to be treated is sandwiched between them.**
- **This arrangement is called the 'Condenser Method'.**

Diathermy units…

Application Techniques of Short-wave Therapy….

- The metal pads act as two plates while the body tissues between the pads as **dielectric** of the capacitor.
- When the radio frequency output is applied to the pads, the dielectric losses of the capacitor manifest themselves as heat in the intervening tissues.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Diathermy units...

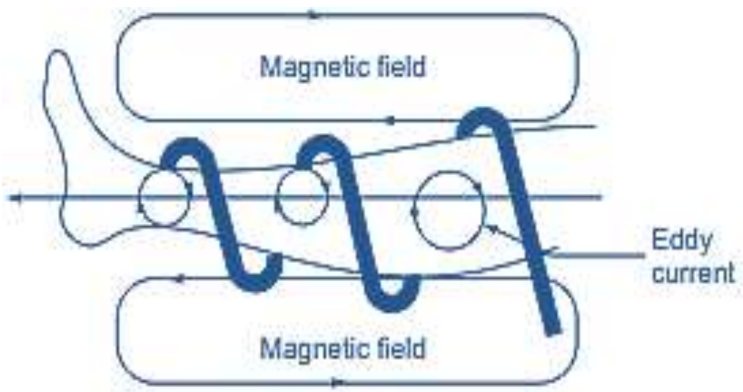
Application Techniques of Short-wave Therapy....

- There are two types of electrode arrangements for condenser method:
  - **Contraplanar technique:** the electrodes are placed over the opposite aspects of the trunk or limb, so that the electric field is directed through the deep tissues.
  - **Coplanar technique:** the electrodes are placed side by side on the same aspect of the part, provided there is an adequate distance between them.

Diathermy units…

Application Techniques of Short-wave Therapy….

Inductive method



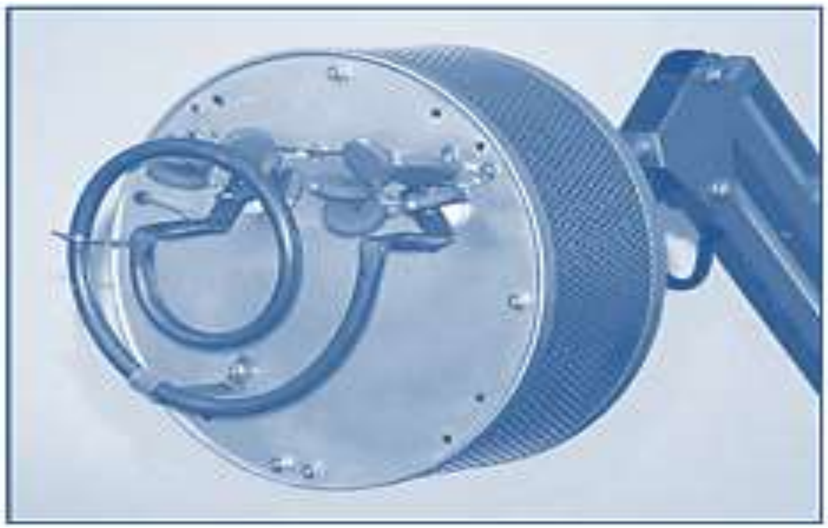
- The output of the diathermy machine may be connected to a flexible cable instead of pads.
- This cable is coiled around the arm or knee.
- RF current is passed through such a cable, an electrostatic field is set up between its ends and a magnetic field around its centre.
- Deep heating in the tissue results from electrostatic action whereas the heating of the superficial tissues is obtained by eddy currents set up by a magnetic effect.
- This technique is known as ‘inductothermy’

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Diathermy units…

Application Techniques of Short-wave Therapy….

Inductive heating by a coil housed in a drum



- Another form of inductive heating is by a coil which is housed within a drum.
- The current flowing within the coil produces a rotating magnetic field, which in turn produces eddy currents in the tissues.
- Due to the friction caused by the Eddy currents, heat is produced in the tissues.

Diathermy units…

II. MICROWAVE DIATHERMY

- Microwave diathermy consists in irradiating the tissues of the patient's body with very short wireless waves having frequency in the microwave region.
- Microwaves are a form of electromagnetic radiation with a **frequency range of 300-30,000 MHz and wavelengths varying from 10 mm to 1 m**.
- The most commonly used **microwave frequency for therapeutic heating is 2450 MHz corresponding to a wavelength of 12.25 cm**.
- The **heating effect is produced by the absorption of the microwaves in the region of the body under treatment**.

Diathermy units…

II. MICROWAVE DIATHERMY….

- The microwaves are transmitted from an emitter, and are directed towards the portion of the body to be treated.
- Hence, no tuning is necessary for individual treatments.
- These waves pass through the intervening air space and are absorbed by the surface of the body producing the heating effect.
- The special design of the treatment heads and shapes focuses the field directly at the target area.
- The whole device is used to direct the waves onto the tissues.
- This device is sometimes termed the emitter, the director or the applicator. In this kind of treatment, the patient does not form a part of the circuit, so no tuning is necessary.

Diathermy units…

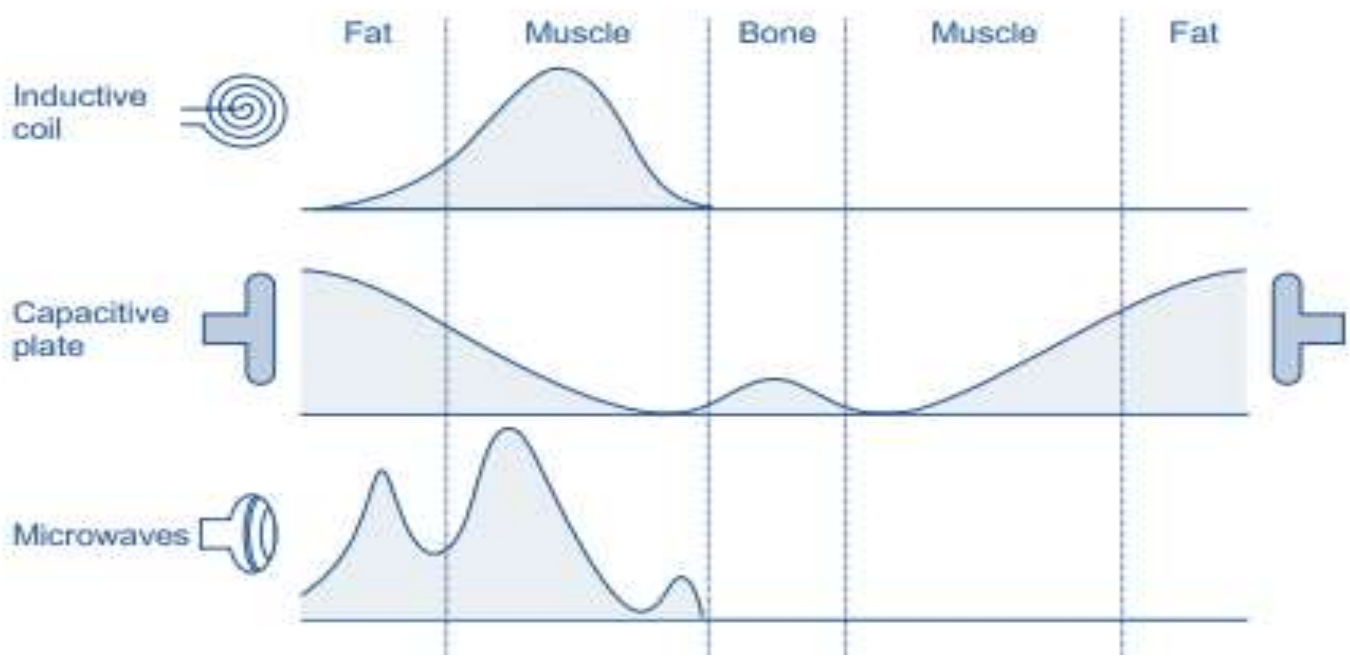
II. MICROWAVE DIATHERMY….

- Microwave penetrates more deeply than infrared rays but not deeply as shortwave diathermy, so microwave is not suitable for deeply placed structures.
- The effective depth of microwave penetration is about 3 cm so the depth of heating is intermediate between that of infrared radiation and short wave diathermy.
- Microwaves are strongly absorbed by water, tissues with high fluid content are heated most, while less heat is produced for tissues with low fluid content as fat.

Diathermy units...

II. MICROWAVE DIATHERMY....

Comparison of the heat distribution in the body tissues with the shortwave inductive diathermy, capacitive plate of diathermy applicator& microwave diathermy. (Courtesy: Cameron, 2009)

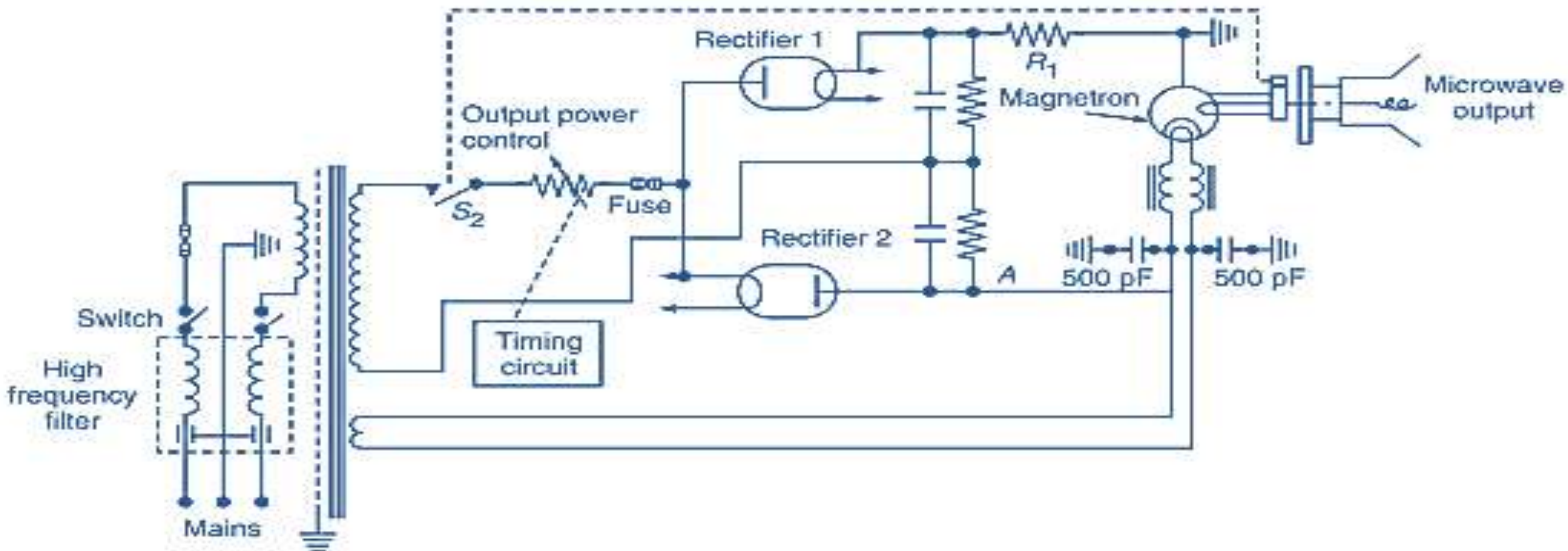


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Diathermy units…

II. MICROWAVE DIATHERMY….

Circuit diagram of a microwave diathermy machine



- The mains supply voltage is applied to an interference suppression filter.
- This filter helps to bypass the high frequency pick-up generated by the magnetron.
- A fan motor is directly connected to the mains supply.
- The fan is used to cool the magnetron

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

Diathermy units…

II. MICROWAVE DIATHERMY….

Circuit diagram of a microwave diathermy machine…

The Delay Circuit:

- The magnetron to be warm up for 3 to 4 minutes before power may be derived from it.
- A delay circuit is incorporated in the apparatus which connects the anode supply to the magnetron only after this time elapses.
- The arrangement is such that a lamp lights up after 4 minutes indicating that the apparatus is ready for use.

Diathermy units…

II. MICROWAVE DIATHERMY….

Circuit diagram of a microwave diathermy machine…

The Magnetron Circuit:

- The magnetron filament heating voltage is obtained directly from a separate secondary winding of the transformer.
- The filament cathode circuit contains interference-suppression filters.
- The anode supply to the magnetron can be either DC or AC. A DC voltage is obtained by a full wave rectifier followed by a voltage doubler circuit.
- A high wattage variable resistance is connected in series which controls the current applied to the anode of the magnetron.

Diathermy units…

II. MICROWAVE DIATHERMY….

Circuit diagram of a microwave diathermy machine…

Safety Circuits:

- There are chances of the magnetron being damaged due to an excessive flow of current.
- It is thus protected by inserting a fuse (500 mA) in the anode supply circuit of the magnetron.
- The protection of both the patient and the radiator is ensured by the automatic selection of the control range depending on the type of the radiator used.

Diathermy units…

III. ULTRASOUND DIATHERMY

- Ultrasonics are used for therapeutic purposes similar to short-wave diathermy machine.
- The heating effect is produced by the ultrasonic energy absorption property of the tissues.
- The property of specific heat distribution in tissue and the additional effect of a mechanical component have given rise to a number of special therapeutic applications of ultrasonic.
- The effect of ultrasonic on the tissues is thus a high speed vibration of micro-massage.
- Ultrasonic generators are constructed on the piezo-electric effect.

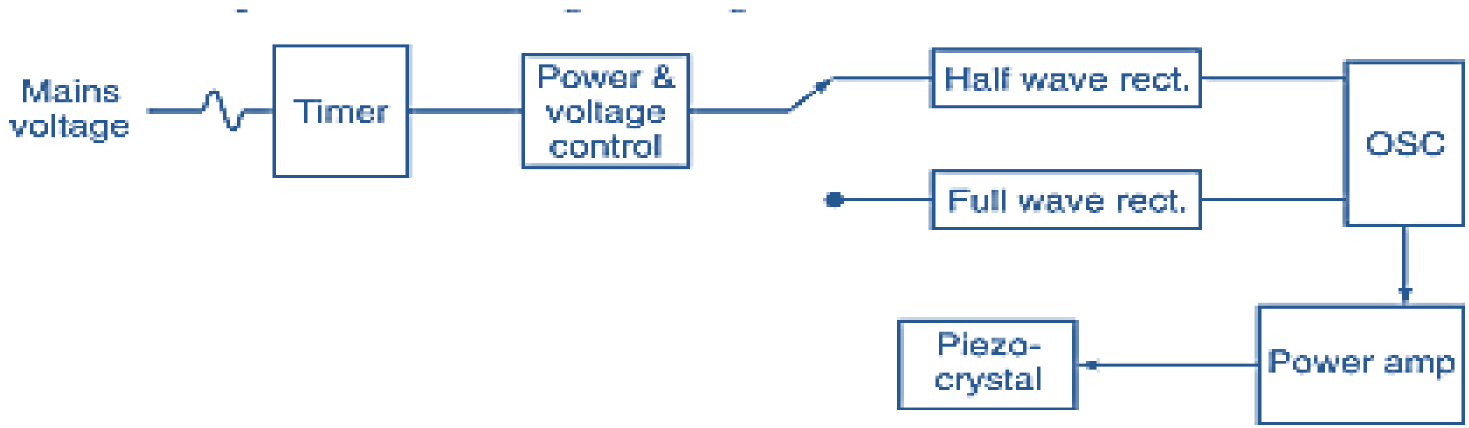
Diathermy units…

III. ULTRASOUND DIATHERMY…

- A high-frequency alternating current (0.75-3.0 MHz) is applied to a crystal whose acoustic vibration causes the mechanical vibration of a transducer.
- These mechanical vibrations pass through a metal cap and into the body tissue through a coupling medium.
- The therapeutic ultrasonic intensity varies from 0.5 to 3.0 W/cm^2 .
- Applicators range from 70 to 130 mm in diameter.
- The larger the diameter of the applicator, the smaller would be the angle of divergence of the beam and the less the degree of penetration.

Diathermy units...

III. ULTRASOUND DIATHERMY...



- The heart of the system is a timed oscillator which produces the electrical oscillations of the required frequency.
- The oscillator output is given to a power amplifier which drives the piezo-electric crystal to generate ultrasound waves.
- Power amplification is achieved by replacing the transistor in typical LC tuned Colpitt oscillator by four power transistors placed in a bridge configuration.
- The delivery of ultrasound power to the patient is to be done for a given time.
- This is controlled by incorporating a timer to switch on the circuit.
- The timer can be a mechanical spring-loaded type or an electronic one, allowing time settings from 0 to 30 minutes.

Diathermy units…

III. ULTRASOUND DIATHERMY…

- The output of the oscillator can be controlled by either of the following two methods:
  - ➢ Using a transformer with a primary winding having multi-tapped windings and switching the same as per requirement.
  - ➢ Controlling the firing angle of a triac placed in the primary circuit of the transformer, and thereby varying the output of the transformer.

- The machine can be operated in **continuous or pulsed mode**.
- A full-wave rectifier comes in the circuit for continuous operation.
- The mains supply is given to the oscillator without any filtering.
- The supply voltage is therefore at 100 Hz which causes the output 1 MHz to be amplitude modulated by this 100 Hz.
- **In pulsed mode,** the oscillator supply is provided by the half-wave rectifier and the oscillator gets the supply only for a half cycle.
- Thus the output 1 MHz is produced only for one half of the cycle and is pulsed.

Diathermy units…

III. ULTRASOUND DIATHERMY…

Dosage Control:

- The dosage can be controlled by varying any of the following variables.

  - **Frequency of ultrasound**
  - **Intensity of ultrasound**
  - **Duration of the exposure**

Diathermy units…

III. ULTRASOUND DIATHERMY…

Application Technique:

Image courtesy : https://www.joharidigital.com/

Diathermy units…

III. ULTRASOUND DIATHERMY…

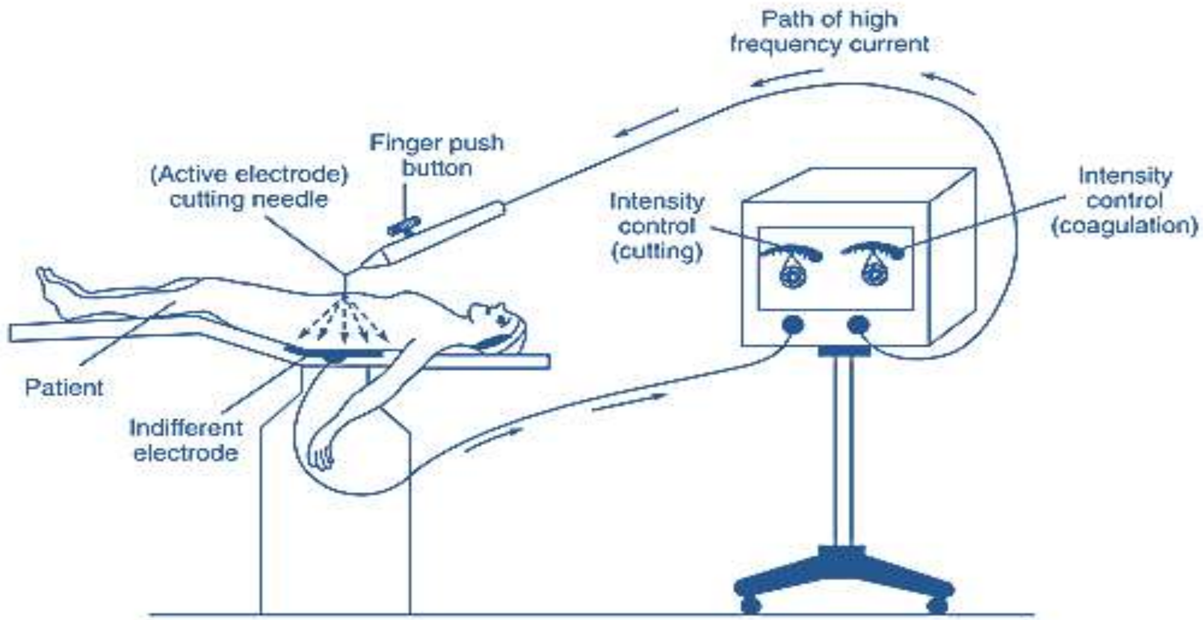
Application Technique:

- The probe can be put in direct contact with the body through a couplant provided the part to be treated is sufficiently smooth and uninjured.
- In case a long area is to be treated, the probe is moved up and down, and for small areas it is given a circular motion to obtain a uniform distribution of ultrasonic energy.
- If there is a wound or an uneven part (joints etc.), the treatment may be carried out in a water bath.
- This is to avoid mechanical contact with the tissues which may damage an already injured surface.
- It should be ensured that air bubbles are not present either on the probe or the skin.

SURGICAL DIATHERMY

PRINCIPLE OF SURGICAL DIATHERMY

- High frequency currents can also be used 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 **s**
- **Surgical diathermy machines depend on the heating effect of electric current**.



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

PRINCIPLE OF SURGICAL DIATHERMY..

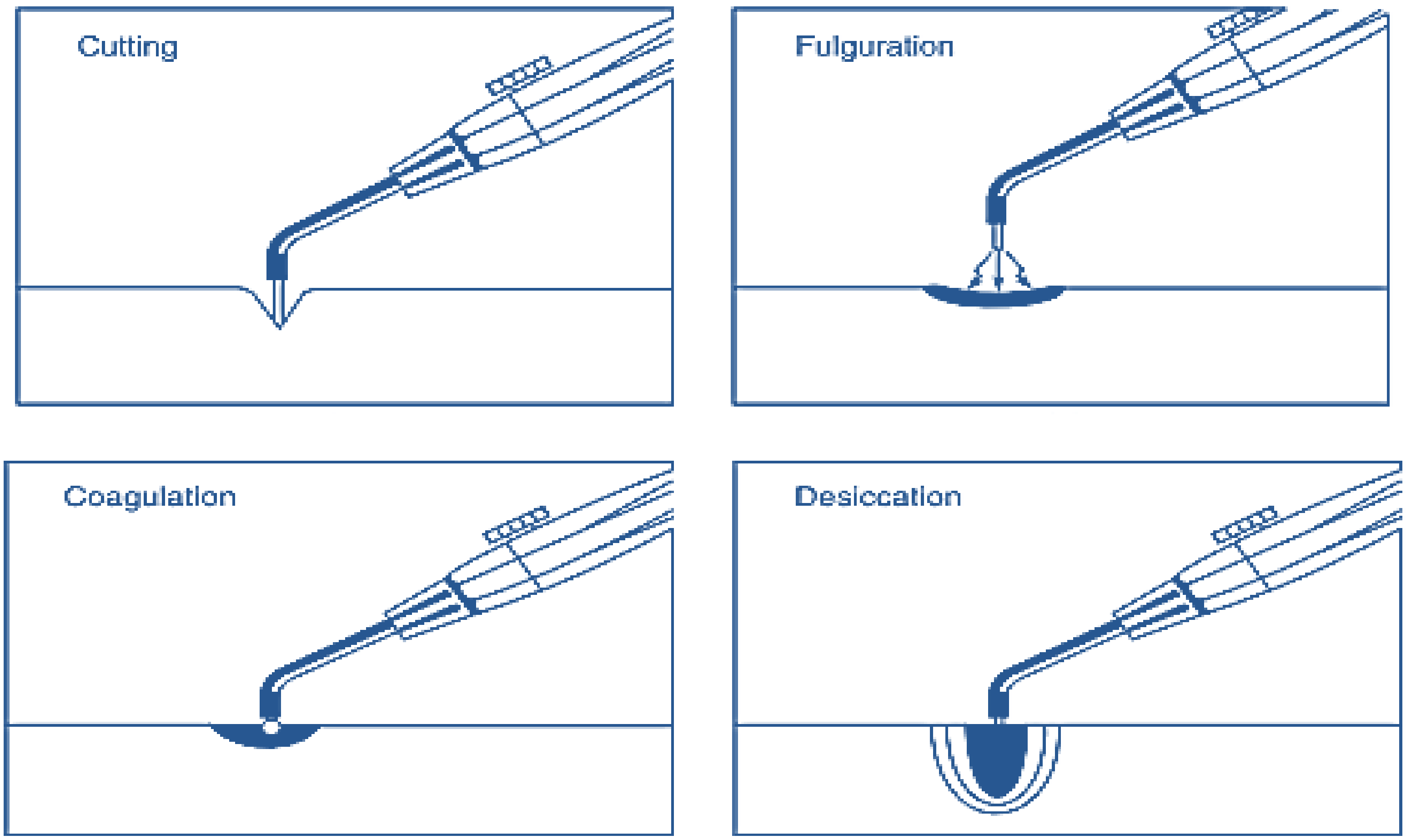
- If **high frequency current flows through the sharp edge** of a **wire loop / band loop / the point of a needle** into the tissue **short-wave therapeutic diathermy** machines.
- The tissue is heated to an extent that the cells are immediately under the electrode, are torn apart by the boiling of the 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 **electrosurgical cutting**.
- **Electrosurgical coagulation** of tissue is caused by the high frequency current flowing through the tissue and heating it locally so that it coagulates from inside

PRINCIPLE OF SURGICAL DIATHERMY..

- ‘**fulguration**’ refers to a superficial tissue destruction without affecting deep-seated tissues.
- This is done by passing sparks from a needle/ a ball electrode of small diameter to the tissue.
- If the electrode is held near the tissue without touching it, an electric arc is produced and heat dries out the tissue.
- Fulguration permits fistulas and residual cysts to be cauterized and minor haemorrhages to be stopped.
- In **desiccation**, needle-point electrodes are stuck into the tissue and then kept steady.
- Depending upon the intensity and duration of the current, a high local increase in heat will be obtained.
- The tissue changes due to drying and limited coagulation.
- The concurrent use of continuous radio-frequency current for cutting and a burst wave radiofrequency for coagulation is called Haemostasis mode.

PRINCIPLE OF SURGICAL DIATHERMY..

Various types of electro-surgery techniques

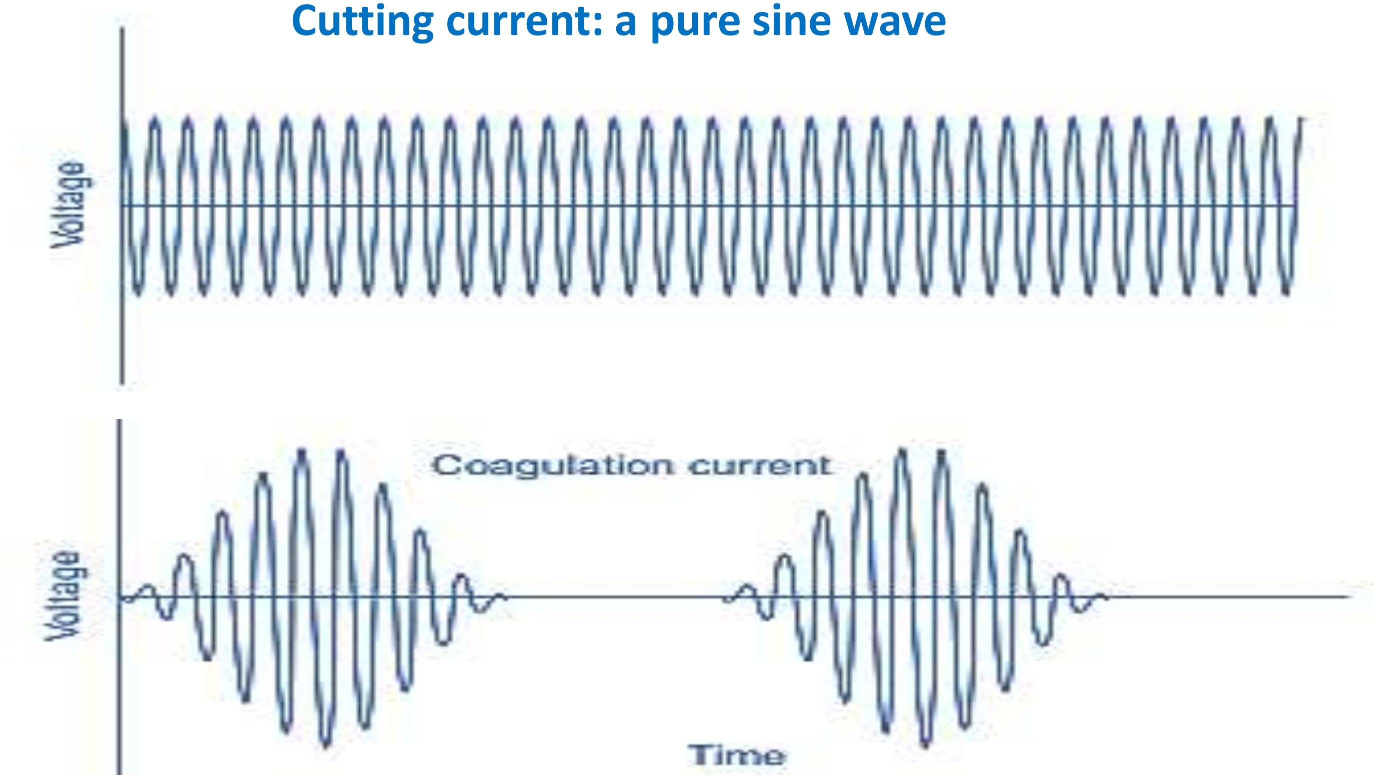


Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

PRINCIPLE OF SURGICAL DIATHERMY..

Types of waveforms generated by surgical diathermy machines

Cutting current: a pure sine wave



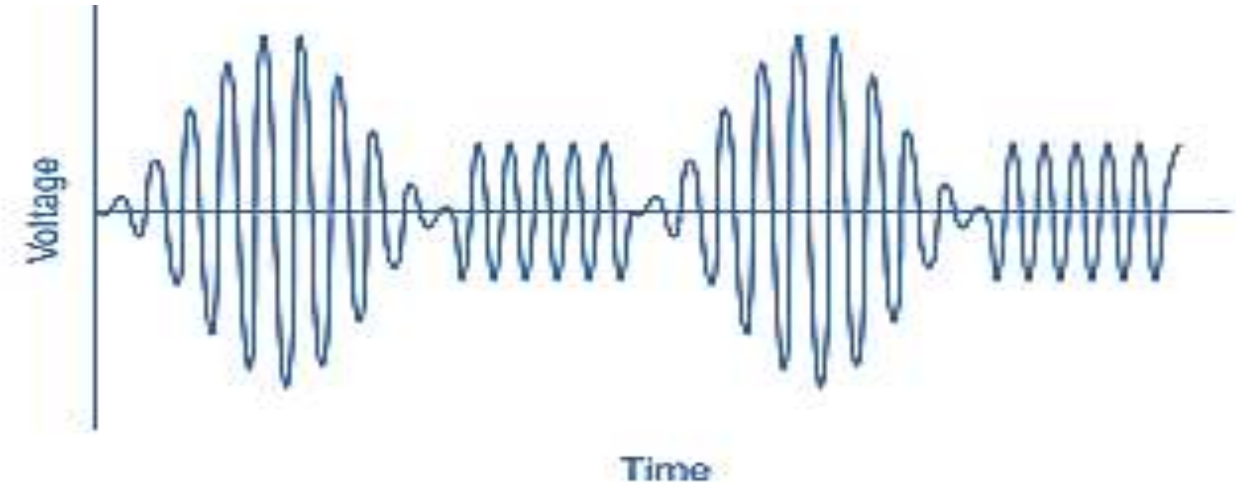
intermittent bursts of high voltage current

Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

PRINCIPLE OF SURGICAL DIATHERMY..

Types of waveforms generated by surgical diathermy machines....

Blended current: A combination of cutting and coagulation currents



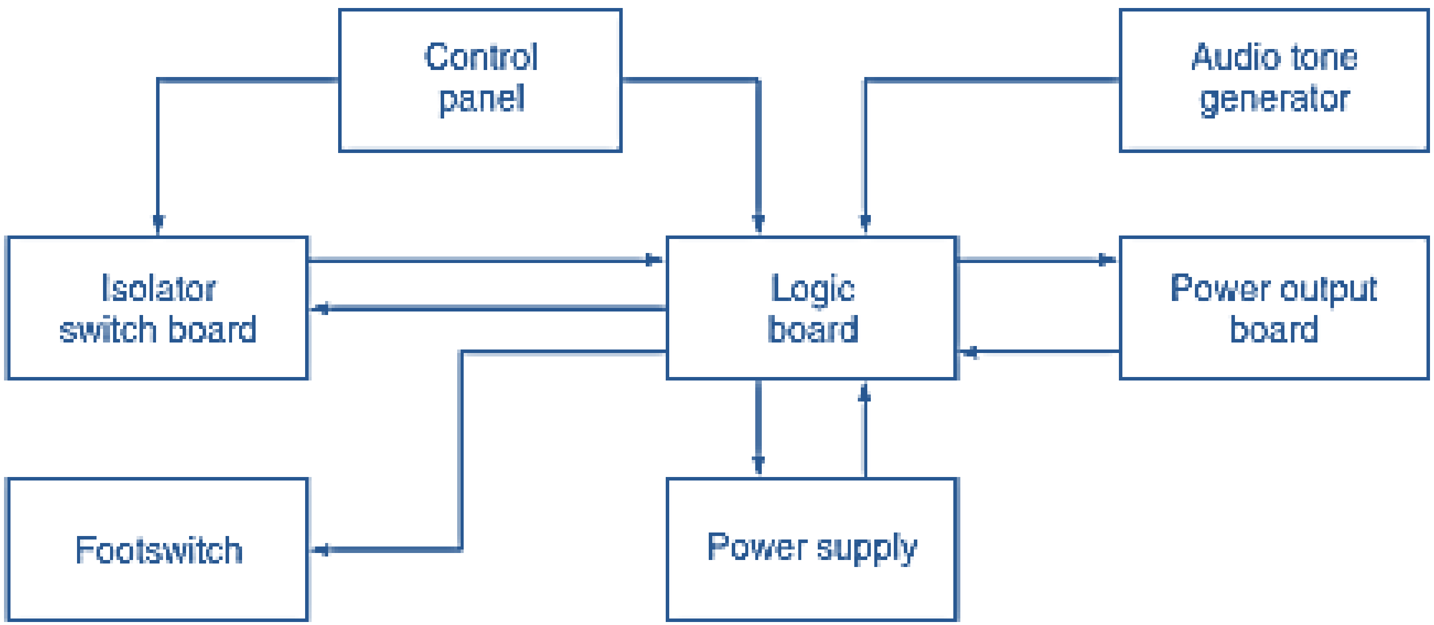
Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

- The cutting current usually results in bleeding at the site of incision, whereas the surgeon would require bloodless cutting.
- The frequency of this blended waveform is generally the same as that used for cutting current.

SURGICAL DIATHERMY MACHINE

- Surgical diathermy machine consists of a high frequency power oscillator.

Block diagram of solid state electro-surgical unit



Reference: R.S. Khandpur , Handbook of Biomedical Instrumentation

SURGICAL DIATHERMY MACHINE..

Block diagram of solid state electro-surgical unit…

- The heart of the system is the logic & control part which produces the basic signal and provides various timing signals for **cutting, coagulation and haemostasis modes** of operation.
- An astable multivibrator generates 500 kHz square pulses.
- The output from this oscillator is divided into a number of frequencies by using binary counters.
- These are the frequencies which are used as system timing signals.
- A 250 kHz signal provides a split phase signal to drive output stages on the power output circuit.
- A 15 kHz gating signal produces the repetition rate for the three cycles of the 250 kHz signal which make up the coagulating output.
- The pulse width of this output is set at about 12 µs.

SURGICAL DIATHERMY MACHINE..

Block diagram of solid state electro-surgical unit…

- The 250 kHz signal used for cutting is given to power output stage where it controls the push- pull parallel power transistor output stage.
- The output of this high power push-pull amplifier is applied to a transformer which provides voltage step-up and isolation for the output signal of the machine.
- In order to facilitate identification of each mode of operation, the machines incorporate an audio tone generator.
- The tone signals are derived from the counter at 1 kHz (coagulation), 500 Hz (cutting) and 250 Hz (haemostasis).
- The isolator switch provides isolated switching control between the active hand switch and the rest of the unit.
- A high frequency transformer coupled power oscillator is used in which isolated output winding produces a DC voltage.
- The load put on the DC output by the hand switch is reflected back to the oscillator, accomplishing isolated switching.

SURGICAL DIATHERMY MACHINE..

Block diagram of solid state electro-surgical unit…

- The gases used in anaesthesia tend to settle near the floor.
- Hence, the construction of the foot switch should be such that no explosion should occur in the atmosphere surrounding this switch caused by the operation of the electrical contacts within the switch.

ELECTRICAL SAFETY IN MEDICAL EQUIPMENT

Electrical safety in medical equipment

Introduction to Medical Equipment

Medical electrical equipment is provided with no more than one connection to a particular mains supply and is intended to:

- Diagnose the patient
- Treat the patient
- Monitor the patient under medical supervision
- Make physical or electrical contact with the patient
- Transfer energy to or from the patient and/or detect such energy transfer to or from the patient

Electrical safety in medical equipment

Introduction to Medical Equipment..

Medical Electrical Equipment Classification

There are three classification types of applied parts:

I. **Type B (Body)** – No electrical contact with patient and maybe earthed.

II. **Type BF (Body Floating)** – Electrically connected to patient but not directly to heart.

III. **Type CF (Cardiac floating)** – Electrically connected to the heart of the patient.

Electrical safety in medical equipment

Introduction to Medical Equipment..

Medical Electrical Equipment Classification

Type	Symbol	Definition
Type B		Non-Isolated Applied Part
Type BF		Isolated Applied Part
Type CF		Isolated Applied Part. Suitable for direct cardiac application
Type F		Fixed Device
Type T		Transportable Device

Electrical safety in medical equipment

Introduction to Medical Equipment..

Medical Electrical Equipment Symbols

Electrical safety in medical equipment..

- Electro-Medical Devices are powered by the mains or an internal power source (batteries) and often attached to the patient by wires.
- Some devices have active parts inserted into the patient body and may come in direct contact with the heart.
- There is a risk to the patient in the event of current leaking from the device.
- Current can also be transmitted through a caregiver such as a nurse in contact with an electronic device near the patient.
- Electrical shock can cause disruptions during health care procedures and result in injury or death.
- This makes electrical safety a topic of very high importance in medical device quality assurance.

Electrical safety in medical equipment..

Electrical hazard

- **Electrical hazard** or **Electric Shock** may be defined as "Dangerous event or condition due to direct or indirect electrical contact with energized conductor or equipment and from which a person may sustain electrical injury from shock, damage to workplace environment, damage to property or both.
- The use of electricity for medical diagnostic, measurement and therapy equipment potentially exposes patients and even caregivers to the risk of electrical shock, burns, internal organ damage, and cardiac arrhythmias directly due to **leakage current** resulting from improper grounding and electrical isolation.
- The electrical conductivity of body fluids and the presence of various conductive solutions and gels in the patient care system make this environment even more vulnerable.

Electrical safety in medical equipment..

Hazard current from electrical failure being safety shunted to ground through an alternative pathway.

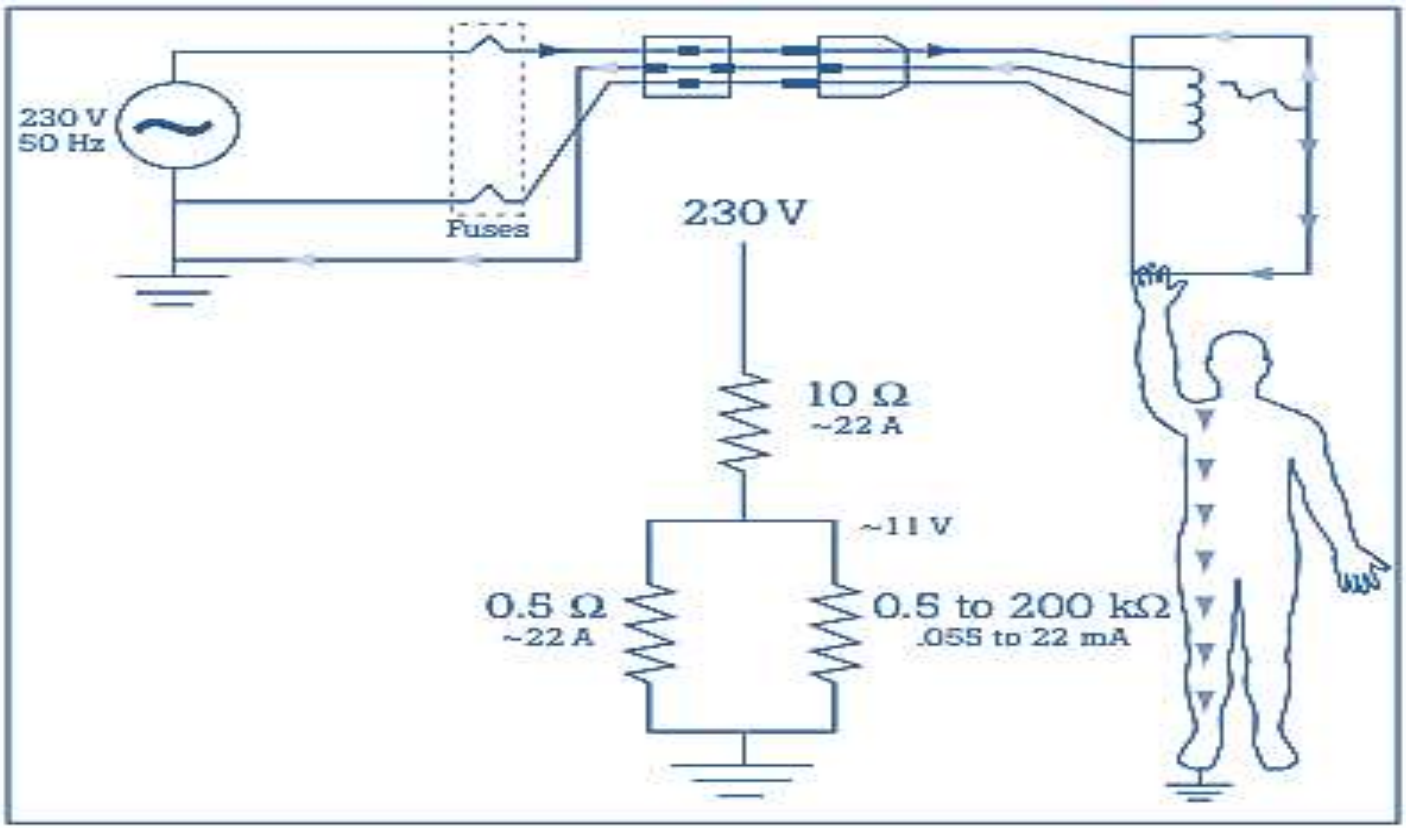


Image courtesy: Fluke Biomedical Introduction to Electrical Safety Testing: Part I

Electrical safety in medical equipment..

Current Range & Its Effects on human body

Current	Effect
1mA	Barely perceptible
1-3mA	Perception threshold (most cases)
3-9mA	Painful sensation
9-25mA	Muscular contraction (can't let go)
25-60mA	Respiratory paralysis (may be fatal)
60mA or more	Ventricular fibrillation (probably fatal)
4 A or more	Heart paralysis (probably fatal)
5 A or more	Tissue burning (fatal if vital organ)

Data Courtesy : https://www.electricaltechnology.org/

Hazard current

- **Earth Leakage Current path.** Earth leakage current is the current that normally flows in the earth conductor of a protectively earthed piece of equipment.

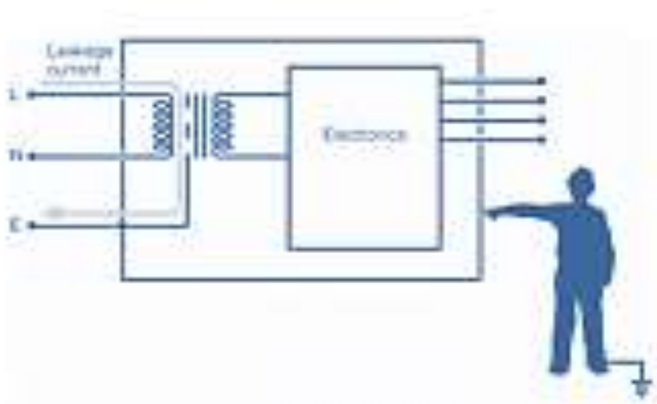


Image Source: Ebme.co.uk, articles, Electrical Safety, available in: http://www.ebme.co.uk/arts/articles-electrical-safety.php

Hazard current…

- **Enclosure Leakage Current path.** Enclosure Leakage current is the current that would flow if a person came into contact with the housing (or any accessible part not intended for treatment or care) of the appliance.

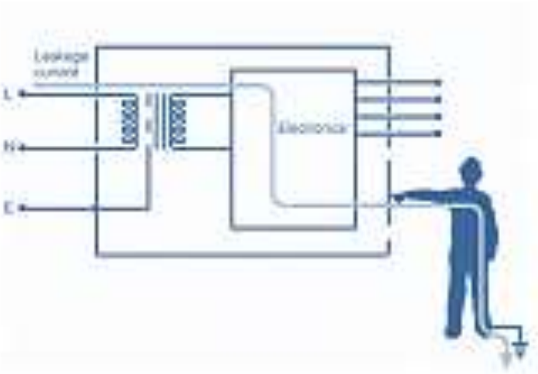
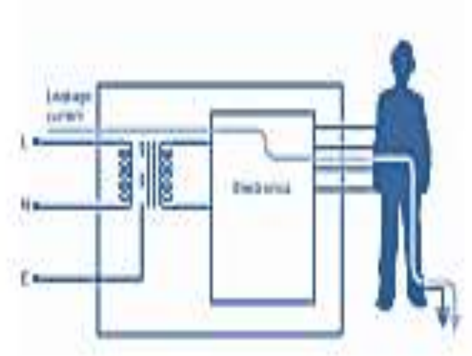


Image Source: Ebme.co.uk, articles, Electrical Safety, available in: http://www.ebme.co.uk/arts/articles-electrical-safety.php

Hazard current…

- **Patient Leakage Current path-** This is the current flowing from the Applied Part via the patient to earth or flowing from the patient via an Applied Part to earth, which originates from an unintended voltage appearing on an external source.



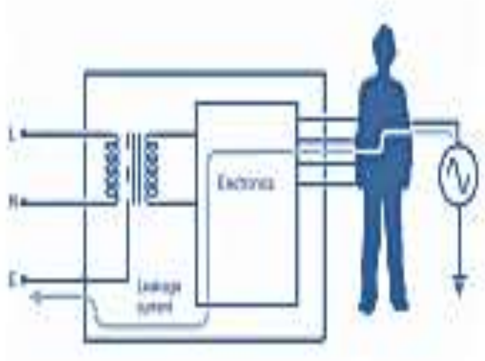


Image Source: Ebme.co.uk, articles, Electrical Safety, available in: http://www.ebme.co.uk/arts/articles-electrical-safety.php

Hazard current…

- **Patient Auxiliary Current path.** This is the leakage current that would flow between Applied Parts under normal and fault conditions.

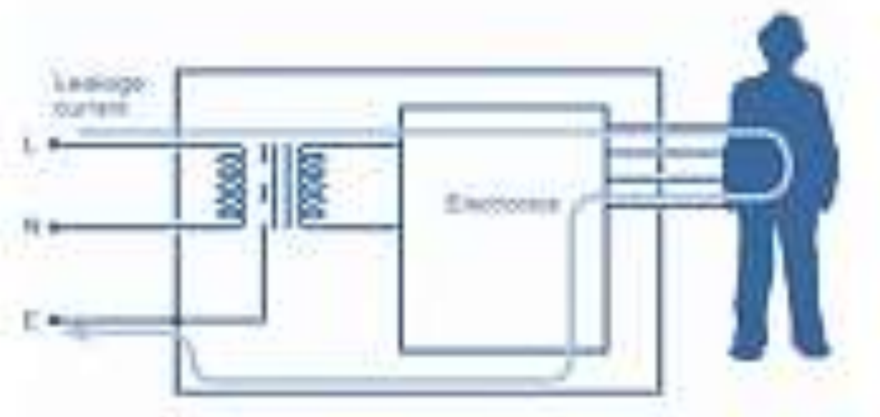


Image Source: Ebme.co.uk, articles, Electrical Safety, available in: http://www.ebme.co.uk/arts/articles-electrical-safety.php

Electrical safety in medical equipment..

Safety Classifications in Medical Standards

- **MOPP (Means of Patient Protection) — Electrical equipment with direct patient contact** must fulfil the highest safety requirements.

- **MOOP (Means of Operator Protection) — Electrical equipment without direct patient contact** must fulfil high safety requirements.

- It is the responsibility of the medical product manufacturer to determine the likelihood of a patient coming into contact with the product, and decide whether to use patient protection (MOPP) or operator protection (MOOP).

- The insulation between primary to secondary must meet at least 2 × MOP under and at least 1 × MOP between primary to protective earth (FG) at normal conditions.

Electrical safety in medical equipment..

Safety Classifications in Medical Standards…

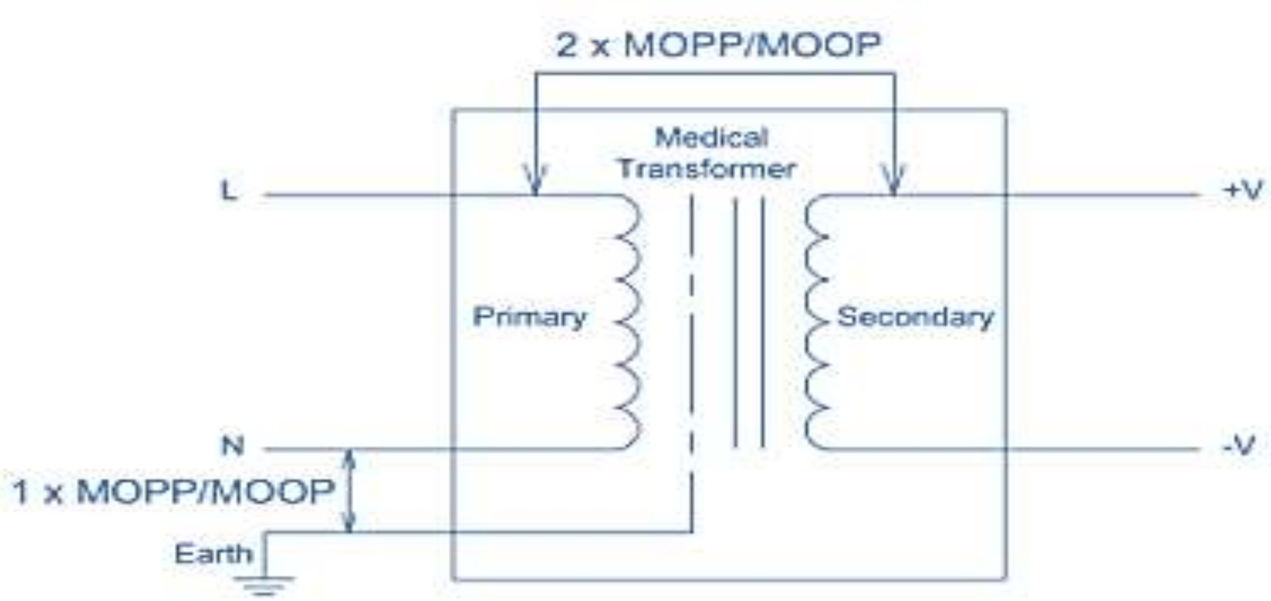


Image courtesy: https://talema.com/

Electrical safety in medical equipment..

Basic electrical safety test:

It includes

- Visual inspection of cables, plugs and connectors.
- Measurement of ground wire resistance.
- Measurement of chassis and patient lead/ contact isolation.
- **The main instrument :Electrical Safety Tester**

(**Example:** **Rigel 288** - a hand-held medical electrical safety analyzer manufactured by Seaward Electronic Ltd, Bracken Hill, South West Industrial Estate Peterlee, Country Durham, SR8 2SW, England.)

Electrical safety in medical equipment..

Complete electrical safety test:

A. **Protective Earth Continuity**

- The purpose of the **earth continuity** test is to ensure that accessible conductive parts, which rely upon **protective earthing** , protection against electric shock, are connected to the **protective earth** of the supply

B. **Insulation Tests**

- Insulation Resistance Test, or simply referred to as Insulation Test, is the standard test assessing the quality of insulation in wires, cables and electrical equipment.

C. **Leakage Current Tests (Earth Leakage Current, Enclosure Leakage Current, Patient Leakage Current)**

- The leakage current test takes place during the actual use of the electrical product. For this purpose, the electrical device is connected to the operating voltage and tested to see whether too high

D. **Mains on Applied Parts etc.**

IEC Lead Test

- IEC Lead Test: This test provides a means of testing the Load current in Amps and power in KVA.
- The primary standard for medical devices is IEC 60601.
- In this standard, each instrument has a class:
- Class I—Live part covered by basic insulation and protective earth
- Class II—Live part covered by double or reinforced insulation
- Class IP—Internal power supply

IEC Lead Test..

- **According to IEC 60601-1, the leakage current limits**

Leakage Current	Type B		Type BF		Type CF	
	NC	SFC	NC	SFC	NC	SFC
Earth Leakage Current	500 μA	1 mA	500 μA	1 mA	500 μA	1 mA
Enclosure Leakage Current	100 μA	500 μA	100 μA	500 μA	100 μA	500 μA
Patient Leakage Current	100 μA	500 μA	100 μA	500 μA	10 μA	50 μA

NC = Normal Conditions SFC : Single Fault Conditions

Medical Equipment Regulation

- **In the United States**, the **Federal Food, Drug and Cosmetic Act** (and succeeding acts) requires that all medical devices be "safe and effective," and FDA recognizes consensus standards as a means to support a declaration of conformity (new 510(k) paradigm, "abbreviated 510(k)").
- FDA lists **IEC 60601 + national deviations (UL 2601-1)** as a recognized consensus standard.
- **In Europe**, the Medical Devices Directive (93/42/EEC, Article 3) requires medical devices to meet the "essential requirements." Compliance is presumed by conformity to the harmonized standards in the Official Journal of the EC (93/42/EEC, Article 5).
- **IEC 60601 + regional deviations (EN 60601)** is a harmonized standard.
- **Similarly, IEC 60601 forms the basis for national medical equipment safety standards in many countries, including Japan, Canada, Brazil, Australia, and South Korea**.

Medical Equipment Regulation

- **In INDIA (Information Source: https://arogyalegal.com/)**
- All **medical devices in India to be regulated as "drugs" – Medical Devices (Amendment) Rules, 2020.**
- The **standards of quality and safety of medical devices are regulated in India by a law called The Drugs and Cosmetics Act, 1940 ("DCA").**
- The scope of DCA is restricted to only those medical devices which are notified by the Government from time to time as "drugs" (commonly referred to as "**notified medical devices**").
- The **Medical Devices Rules, 2017 ("MDR")** have been framed under DCA.
- These rules lay down comprehensive quality requirements to be followed by marketers / importers / manufacturers / sellers of notified medical devices.

END OF UNIT V