EC 8073 – MEDICAL ELECTRONICS

UNIT – I: ELECTRO-PHYSIOLOGY AND BIO-POTENTIAL RECORDING

Sources of biomedical signals - Bio-potentials, Biopotential electrodes, biological amplifiers, ECG, EEG, EMG, PCG, typical waveforms and signal characteristics.

1. Basic components of biomedical system:

Discuss in detail about the basic components of biomedical system.

The block diagram of biomedical instrument system is shown in figure below.

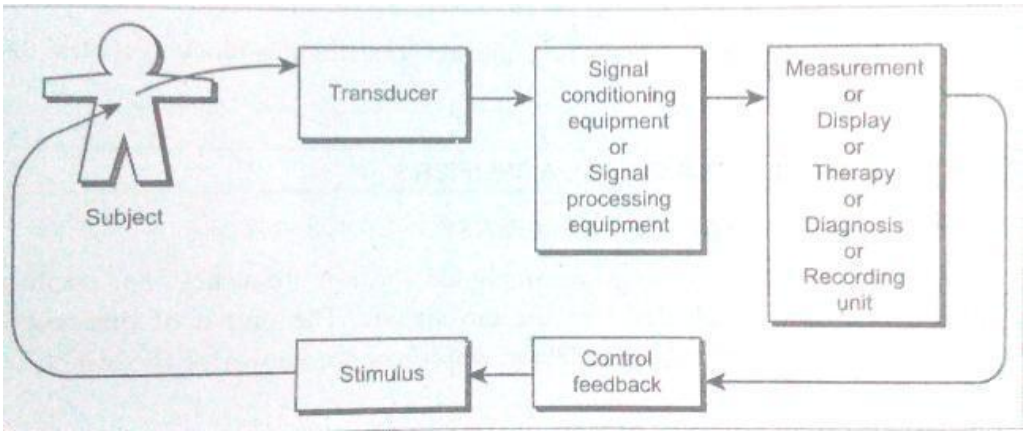

Fig 1.1 Basic components of biomedical

system The components of this system are given below.

1.1 The subject

- Human being is nothing but the subject. The measurements are made on the subject.

1.2 Stimulus

- The response to external stimulus is necessary in many biomedical instrument systems.
  E.g. Stimulus: Visual (flash of light), Auditory (tone), Tactile (sensitive to touch).

1.3 Transducer

- Usually the transducer is used to convert bio signal to electrical signal. **E.g.** EEG signal is converted to electrical waveform.

1.4 Signal Conditioning Equipment

- The electrical output coming from the transducer is amplified and modified by using the block of signal conditioning equipment (or) signal processing equipment.
- The block processes the signals from the transducer to the measurement block (or) display.
- Signal processing equipment makes the signal suitable to operate the recording (or) display unit.

1.5 Measurement (or) Display (or) Recording Unit

- This unit includes graphic pen recorder to record the data.
- The output can be displayed by using CRT Display (or) Digital Storage Oscilloscope (DSO).
- In EMG system, speaker is also connected in this block.

1.6 Control feedback

- The part of the measurement (or) Display unit is used to control the operation of this system.
- The block which is used for this purpose is known as control feedback block.
- The output of control feedback block is connected with stimulus block to control the input applied to the subject.

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2. Factors to be considered in the design of medical equipments – Selection Criteria:

What are the factors to be considered in the design of medical equipments?

- The most important step in an instrumentation system is the ***selection of transducer***.
- For that the ***performance characteristic of transducer*** is very essential for the proper choice of transducer.
- The performance characteristics are widely classified into ***static and dynamic***.
- The ***static*** means that the characteristics are ***not changed*** with time.
- The ***dynamic*** means that the characteristics are ***changed*** with time.
- Some of the characteristics that has to be considered in the design of medical equipment are:
  - Accuracy
  - Frequency Response
  - Hysteresis
  - Isolation
  - Linearity
  - Sensitivity
  - Signal to noise ratio
  - Simplicity
  - Stability
  - Precision

2.1 Accuracy:

- It is the closeness with which the instrument reading approaches the true value.
- It refers to the degree of conformity to the true value of the quantity of the measurement.

2.2 Frequency response:

- It is the response of the instrument for various frequency components present in a physiological signal.
- i.e. the instrument should faithfully reproduce the signals and respond to reproduce all frequency component of a waveform with equal sensitivity.

2.3 Hysteresis:

- The output does not follow the same path. i.e. the mechanical friction present in an analog meter can produce the elastic hysteresis, error in the measured value.
- Therefore, the indicating needle should be selected from perfect elastic material.

2.4 Isolation:

- Ground is necessary for the electrical safety and to avoid any interference between different instruments.
- Using isolation, the instrument does not have direct contact with the patient.

2.5 Linearity:

- Linearity is defined as the degree to which the variation in the output should follow the input variation.
- It is essential to get the accurate value.

2.6 Sensitivity:

- It is the ability of the instrument to detect even a very small change that is taken place in the input.
- The sensitivity is expressed in terms of resolution.

2.7 Signal to noise ratio:

- The magnitude of bio signals is very low.
- Hence, the S/N ratio should be very high to get reliable information about the input.
- There are various types of noises are present. Some of them are:
  - 1/F noise
  - Thermal noise
  - Shot noise

2.8 Simplicity:

- Simplicity is very essential to eliminate the human errors whereas in the complicated devices, the uncertainty measurement is very large.
- In order to avoid uncertainty we use simple instrument i.e. easy to use by any operator.

2.9 Stability:

- It is the ability of the instrument to produce the constant output for a given input.
- Generally, the drift in instrument will decrease the stability.
- The medical instrument, the stability is increased by the drift compensation circuit should be employed.

2.10 Precision:

- Precision is the measure of reproducibility of the measurement.
- It is the closeness among the readings.
- Precision depends on the conformity and number of significant figures.

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3. Bio-electric (Bio-medical) signals and their characteristics

Compare the signal characteristics of ECG, EEG, EMG and PCG. ***[April/May 2019]***

Name of Bio-electric signal	Frequency range in Hz	Voltage μV	Types of electrodes used	Origin (Origin produces bioelectric signal)
Electro cardiogram (ECG)	0.05 to 100	10 – 5000	Surface electrodes are used with jelly. Needle electrodes are also used.	Heart muscles
Electro Encephalogram (EEG)	0.1 to 100	2–200	Surface electrode or needle electrode.	Activity of the brain
Cerebral potential	It has pulse duration. 0.6ms – 0.1 sec.	10 – 100000	Deep needle electrodes are used.	Cerebrum of the brain.
Electromyogram (EMG)	5–2K	20 – 5000	Surface electrodes or needle electrodes are used.	Skin muscles
Electrogastrogram (EGG)	0.05 – 0.2	10 -350	Surface electrodes are used.	Peristaltic movement of the gastro-intestinal tract.
Electroretinogram (ERG)	0.01 – 200	-	Corneal electrode (Dedicated to ERG)	Retina of the eye.
Electrooculogram (EOG)	-	10 – 3500	Miniature surface electrodes are used.	Corneal-retinal potential variation.

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4. Bio-potentials

Discuss in detail about the origin of Bio-potentials. ***[Nov/Dec 2007][May/June 2016][Apr/May 2019]***

4.1 Cell:

- Cell is the basic living unit of the human body.
- Each organ in our human body consists of different cells.
- Each type of cells are responsible for one particular function.
- Entire body contains 100 trillion cells.
- All cells have the ability to reproduce new cells whenever the cells of a particular type are destroyed, until the appropriate number is filled.
- For example, 25 trillion red blood cells will transport oxygen from lungs to the tissues.

- i.e., the oxygen combines with carbohydrates, fat or protein in order to release the energy required for cell function.
- Generally, the structure of cell cannot be seen by naked eye, it can be viewed only by biological microscope.

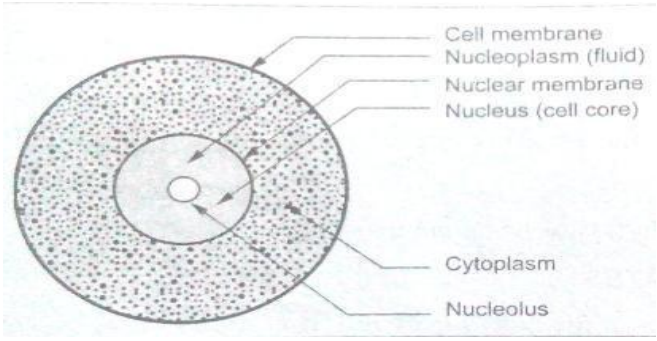

Fig 4.1 Structure of the cell

- Each cell consists of a centrally located nucleus (cell core).
- The cell core is surrounded by cytoplasm (cell body).
- The nucleus is separated from cytoplasm by nuclear membrane.
- The cytoplasm is separated from the surrounding fluid by the cell membrane.
- The different substances that make up the cell are collectively called as the protoplasm. (It is composed of water, electrolyte, proteins, lipids and carbohydrates)

4.2 Water:

- Water is the principle fluid in the cell and the concentration of water is 70 to 80%.
- It is used as the solvent for all chemicals in order to produce the chemical reaction.

4.3 Electrolyte:

Various electrolytes like large quantities of

- Magnesium
- Potassium
- Phosphate
- Bicarbonate

And small quantity of

- Calcium
- Chloride
- Sodium are present in the cell.

4.4 Protein:

- Concentration of protein in the cell is 10 – 20%.
- Two types of protein are available
  - Structural protein
  - Globular protein

- Structural proteins are long, thin filament, provide contractile mechanism of all muscles.
- The globular proteins will provide the energy for cell function i.e. chemical reaction.

4.5 Lipids: Lipids are soluble in fats, solvent and insoluble in water.

4.6 Carbohydrates: It plays a major role in the nutrition of cell. It is stored in the cell in the form of glycogen and they are used to supply the cell‟s energy.

4.7 Cytoplasm: Cytoplasm is filled with the cytosol i.e. clear fluid portion of the cytoplasm in which the large particles are dispersed.

4.8 Ribosome: Ribosomes are minute granular particles in the cytosol and they are composed with mixture of RNA (ribonucleic acid) + proteins.

4.9 Lysosomes: These are also used in the digestive system.

4.10 Mitochondria:

- It is otherwise called as the ***"Power house of the cell".*** Mitochondria extract energy from nucleus and oxygen.
- Mitochondria also contain DNA.
- DNA is responsible for replication of the cell.
- Large quantities of DNA are called "Genes".
- Size of human cell is 5 – 10 µm.

4.11 Transport of ions through the cell membrane

- Two fluids play a major role in the transportation of ions. They are ICF AND ECF.
  - ***ICF - Intra cellular Fluid:*** The fluid which lies inside the cell membrane.
  - ***ECF - Extra cellular Fluid:*** The fluid that lies outside the cell membrane.
- The correct concentrations of ions are necessary for normal function of the human cell and human body.
- The transport of the substances through the cell membrane will occur by diffusion. It is known as passive transport.
- The transport that is obtained by concentration gradient is known as active transport.
- According to the source of energy, active transport is classified into two types. They are:
  - Primary active transport
  - Secondary active transport

Primary Active Transport

In this method, energy is derived directly from the breakdown of "adenosine triphosphate" (ATP). **E.g.** Sodium – potassium pump, calcium pump

Secondary Active Transport

Energy is derived secondary by ionic concentration gradient that has been created in the first phase by the primary active transport.

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5. Resting and Action Potential

Explain in detail about Polarization and non-polarization. (8)

Write down the Nernst Equation. (4) ***[A.U. April 2005] [May/June 2016]***

- The diffusion and drift process gives rise to a balance of ions between inside and outside of the cell.
- Generally, the nerves and muscle cells readily permit the entry of potassium and chloride ions.
- But it blocks the entry of sodium ions.
- Due to the difference in permeability of different ions, charge balance is not achieved.
- So that an equilibrium condition is reached with the potential difference across the membrane, such that the negative potential on the inside and positive potential on the outside.

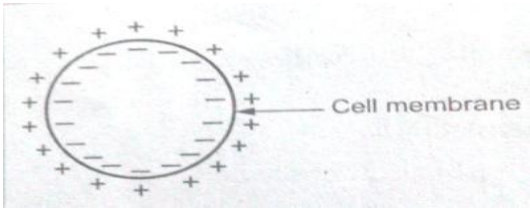

Fig 5.1 Resting Potential

- This membrane potential caused by different concentration of ions is called as "**Resting potential".**
- When the human cell is in ***resting stage***, is said to be ***polarized.***

5.1 Characteristics of Resting Potential

- The value of the resting potential is maintained as a constant until some kind of the disturbances will upset the equilibrium.
- It strongly depends on the temperature.
- The permeability of different cell types should vary.
- Hence, the corresponding resting potential should also vary.
- The range of resting potential is -60 to -100mV.
- The resting potential V_R is derived by Goldman"s equation.

$$V_R = \frac{-kT}{q} \ln \left[\frac{P_K[K^+]_i + P_{Na}[Na^+]_i + P_{Cl}[Cl^-]_o}{P_K[K^+]_o + P_{Na}[Na^+]_o + P_{Cl}[Cl^-]_i} \right] \quad \text{---------- (1)}$$

Where, the subscript o = Outside the cell

The subscript i = Inside the cell

K = Boltzmann constant

T = Absolute temperature in Kelvin

q = Charge of an electron [1.602×10^{-19} coulomb]

P_K = Permeability of potassium ion

P_{Na} = Permeability of sodium ion

P_{Cl} = Permeability of chloride ion

$[K^+][Na^+][Cl^-]$ = Concentration of potassium, sodium, chloride ions

According to Goldman"s equation resting potential,

$$V_R = -86.8 \text{ mV}$$

If $P_{Na} = 0$ and $P_{Cl} = 0$, then the Goldman"s equation is reduced to the following format.

$$V_R = \frac{-kT}{q} \ln \left[\frac{[K^+]_i}{[K]_o} \right] \quad \text{---------- (2)}$$

Equation (2) is referred as, "**Nernst equation"**.

$$V_R = -94.9 \text{ mV}$$

- When the cell membrane is excited by some external energy, then the permeability changes.
- So that the sodium ions are allowed to enter inside the cell.
- So that the cell has a slightly positive potential on the inside due to the imbalance of the potassium ions.
- The positive potential of the cell membrane during excitation is called as the action potential, in the range of 20 mV.

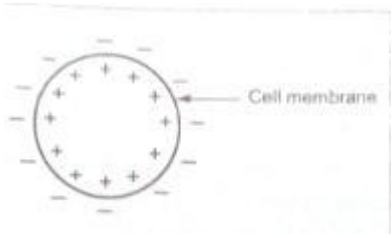

Fig 5.2 Action Potential

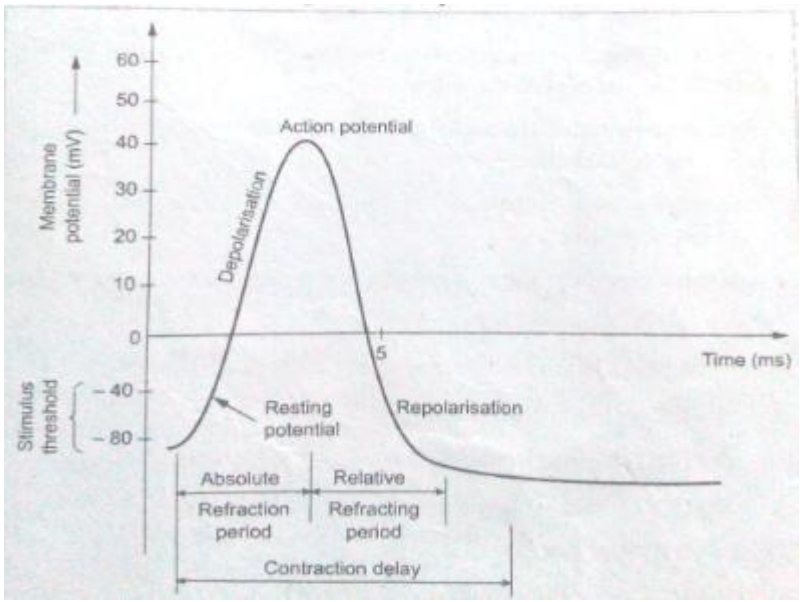

Fig 5.3 Relationship between action potential and muscle contraction

- As long as the ***action potential exists***, the cell is said to be ***"depolarized state".***
- After some time, when the passage of sodium ions is stopped, the cell membrane reversed back to the original condition, called as the Repolarization.

5.2 Absolute Refractory period:

- It is the time duration in which the cell cannot respond to any new stimulus.

- Generally it is about 1 ms, in nerve cells.

5.3 Relative Refractory period:

- It is one during which another action potential can be triggered.
- A higher stimulus is required to reinitiate the action potential and the subsequent contraction of muscles.
- Generally, the relative refractory period is several milliseconds.

5.4 Conduction velocity:

The rate at which an action potential moves down a fibre or propagated from cell to cell is termed as propagation rate or conduction velocity.

5.5 All-or-Nothing law:

All-or-nothing law states that regardless of the method of excitation of cells or by the intensity of the stimulus, the action potential is always the same for any given cell.

5.6 Bio-Electric Potentials:

- Bio-electric potential are generated at a cellular level.
- Each cell is a minute voltage generator, because +ve and –ve ions tend to concentrate unequally inside and outside the cell wall.
- Therefore, the potential difference (resting potential) is established and the human cell acts as tiny biological battery.
- The discharging and recharging of the cell is termed as ***depolarization*** and ***repolarisation*** respectively.
- There are many bioelectric signals present in our own human body. Some of them are:
  - ECG (Electro Cardiogram)
  - EEG (Electro Encephalogram)
  - EMG (Electro Myogram)
  - ERG (Electro Rectinogram)
  - EGG (Electro Gastrogram)

5.7 Sodium-Potassium Pump:

It is a device used to keep the sodium ions (Na^+) outside the cell and potassium ions (K^+) inside the cell.

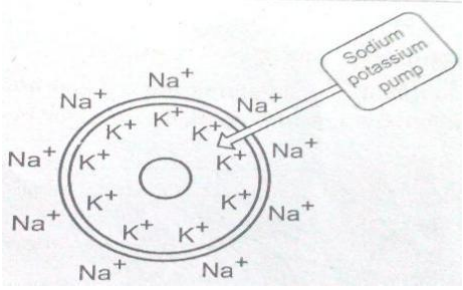

Fig 5.4 Sodium-Potassium pump

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6. Bio-potential electrodes

Discuss the events that generate half cell potential across an electrode-electrode interface. Also draw electrical equivalent circuit of the interface. ***[Nov/Dec 2013][April/May 2018]***

What is known as bio-potential electrodes? Draw its equivalent circuit. Explain various types of bio-potential electrodes with suitable diagram. ***[Nov/Dec 2016]***

6.1 Electrodes

- Electrodes are generally used to pick up the electric signals of the body.
- There are various electrodes that are used in instrumentation system. Some of them are:
  - Surface electrode
  - Micro electrode
  - Depth electrode
  - Needle electrode
  - Chemical electrode
- Generally, the surface electrodes are used to measure the potential available from the skin surface.
- They are also used to sense the potential from heart, brain and nerves.
- Micro electrodes are used to measure the bioelectric potential near or within a single cell.
- Micro electrodes are otherwise called as intracellular electrode.
- The depth and needle electrode are used to measure the bio-electric potential of extra cellular region in brain. They are also used to measure the bioelectric potential from specific group of muscles.

6.2 Half Cell Potential or Electrode Potential

- The voltage developed at an electrode - electrolyte interface is termed as ***half cell potential***.
- The half cell potential is obtained using the surface electrode.
- The potential based on the difference in rates between two opposing charges is termed as the half cell potential.
- When a metal electrode comes into contact with an electrolyte (body fluid), then there is a tendency for the electrode, to discharge ions into solution as a result of which charge gradient is created.
- The electrode in which no net transfer of charge occurs across the metal electrolyte interface is called as ***"perfectly polarized electrode".***
- The electrodes in which unhindered (infinite) exchange of charge occurs, across the metal electrolyte interface is termed as ***"perfectly non-polarized electrode".***
- The non-polarized electrode will create a variable noise termed as ***"Artifacts".***

6.3 Equivalent circuit of Surface Electrode:

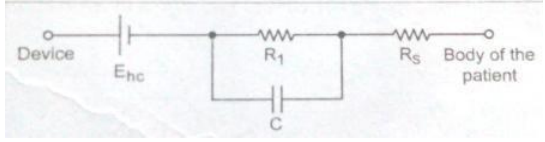

Fig 6.1 Equivalent circuit

- The electrode – electrolyte interface will resembles a voltage source having half cell potential (E_{hc}).
- It is developed due to charge gradient.
- In the equivalent circuit, R_S represents series electrolyte or skin resistance.
- R_l represents leakage resistance.
- C represents electrode capacitance.
- E_{hc} represents half cell potential.
- The half cell potential is measured with reference to hydrogen electrode that is placed in the electrolyte near the metallic electrode.
- The half cell potential or the voltage is expressed by **"*Nernst Equation*".**

$$E_{hc} = \frac{-RT}{nF} \ln \frac{C_1}{C_2} \cdot \frac{F_1}{F_2}$$

$$E_{hc} = -2.303 \frac{-RT}{nF} \log_{10} \frac{C_1}{C_2} \cdot \frac{F_1}{F_2}$$

Where, R = Gas constant

T = Absolute temperature in Kelvin

n = Valence of ions

F = Faraday"s constant

C_1, C_2 = Concentration of the selected ion on two sides of the membrane.

F_1, F_2 = Activity coefficient of the ions on the two sides of the membrane

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7. Types of Electrodes

Discuss about the different types of electrodes used in Bio potential measurement. [May/June 2013][April/May 2018]

7.1 Micro-Electrodes

- The micro electrodes are normally used to measure the potential within a single cell.
- The micro electrodes are very small in diameter.
- During insertion of micro electrode into the cell there will not be any damage to the human cell.
- Generally the micro electrode is located within the cell.
- Whereas, the reference electrode is placed outside the cell.
- Micro electrodes are broadly classified into ***metallic*** and ***non-metallic***. (Micropipet)

Metallic electrode

- The metal micro electrodes are formed by electrolytically etching the tip of fine tungsten filament or simple stainless steel wire, into a minute structure.
- The potential within the cell can be measured by using two electrodes.
  - Micro electrode

Reference electrode

E_A = the metal electrode-electrolyte potential at the tip of the micro electrode. E_R = Reference electrode – Electrolyte potential

- The final potential within the cell is the difference between the microelectrode potential and reference potential.

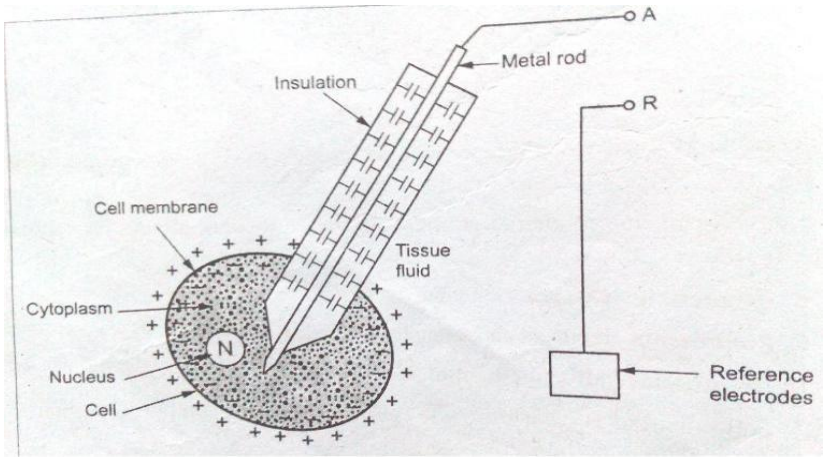

Fig 7.1 Metallic electrode

Non-metallic (Micropipet)

- It is also used to measure the potential within a single cell, but instead of metal electrolyte, non metallic material is used.
- Generally the simple glass instrument is used.
- The micro pipet is filled within an electrolyte that is compatible with the cellular fluids.

E_A = the potential between the glass and electrolyte filled in the micropipette.

E_R = Potential between the reference electrode and extra cellular fluid.

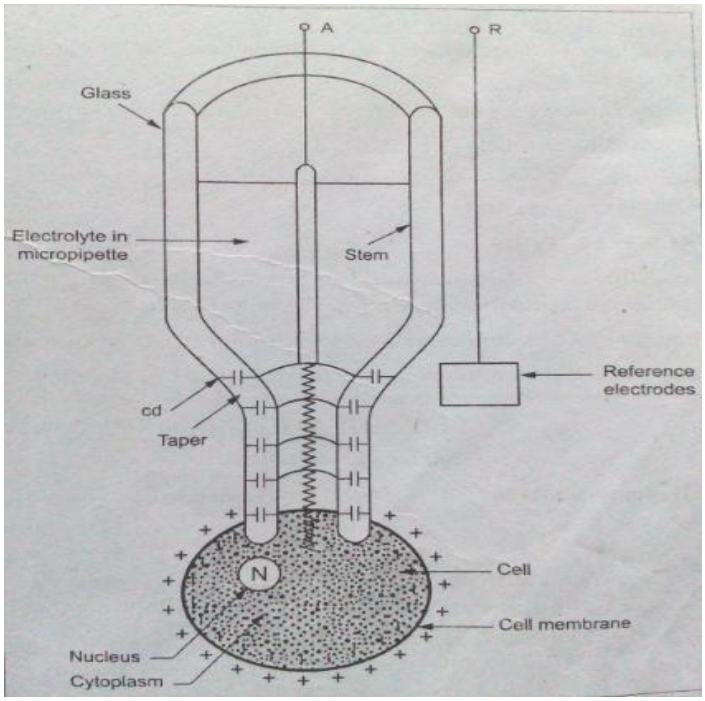

Fig 7.2 Non-metallic electrode

7.2 Depth Electrode

- These are used to study the electrical activity of neuron of superficial layers of the brain.
- In some depth electrode, the supporting element is in the form of a capillary tube that is used to inject the medicine into the brain.
- The depth electrodes are also used to measure the oxygen tension.

7.3 Needle Electrode:

- Needle electrodes are used to record the peripheral nerve action potential (Electro-neurography).
- The needle electrode will resemble a medicine dropper.
- There are two types of needle electrodes are available.
  - Monopolar needle electrode
  - Bipolar needle electrode
- In monopolar, only one reference electrode is used, whereas in bipolar one active and other reference electrode is available.

7.4 Surface Electrode:

Give an account on surface electrode and state its application. ***[Nov/Dec 2018]***

Discuss the different types of surface electrodes and its applications. ***[Nov/Dec 2017]***

- The surface electrodes are used to measure the potential available from the surface of the skin and there are used to sense the potential from heart, brain and nerves.
- The smaller area surface electrodes are used to measure EEG, EMG potentials.
- The larger area surface electrodes are used to measure the ECG potentials.

7.4.1 Classification:

Surface Electrodes	
Depends on area	**Depends on construction**
1. Smaller area surface electrode 2. Larger area surface electrode	1. Metal plate electrode 2. Suction cup electrode 3. Adhesive tape electrode 4. Multipoint electrode 5. Floating electrode

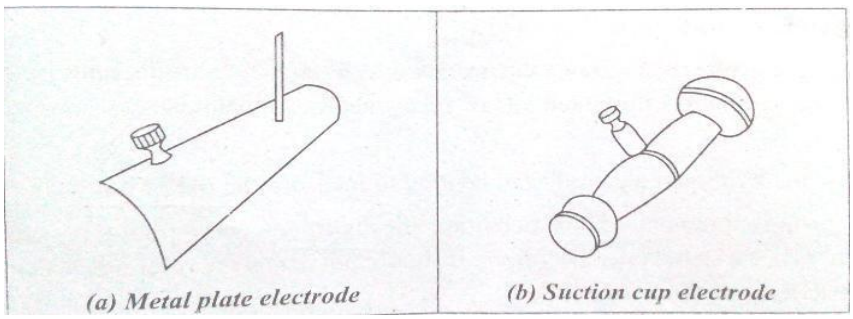

Fig 7.3 – Types of surface electrodes

(a) Suction Cup Electrode

- The suction of electrode is suited for black surfaces of the body i.e. where the human tissues is very soft.
- The adhesive tape electrode is used to hold the electrode in the respective place.
- It retards the evaporation of the electrolyte, present in the electro paste.

(b) Multipoint Electrode

- It is frequently used for ECG measurement.
- It contains nearly thousand active contact points, so that, it can be used under any environmental condition.

(c) Floating surface Electrode

- In floating electrode, the metal does not contact the body directly, i.e. the contact is made to an electrolytic bridge, so that, artifact is reduced.
- The floating electrode is otherwise known as liquid junction electrode.

7.5 Chemical Electrodes

- Various types of chemical electrodes are given below.
  - Hydrogen electrode [Reference electrode]
  - Practical reference electrode
  - pH electrode
  - pO_2 electrode
  - pCo_2 electrode
- The chemical electrodes are used to measure the pH content and pO_2 of blood.
- Chemical electrodes are also used to determine the oxygen content and CO_2 content in the blood.
- The effectiveness of respiratory and cardio vascular system is reflected in the measurement.

Some of the chemical electrode types are explained below.

(a) Hydrogen Electrode

- Hydrogen electrode is used as the standard reference electrode and its potential is specified as zero, whereas the potentials of other metal to ion interfaces are measured with reference to it.
- Generally, the hydrogen electrode can be used to measure the pH of the body fluid.
- During the measurement of the potential, the hydrogen gas should be supplied.
- This measurement is not a stable one.
- Therefore, it should not act as the reference electrode.
- Hence we go for practical reference electrode.

(b) Practical reference electrode

- Usually silver-silver chloride is used as the reference electrode. [Silver-silver chloride or calomel or mercurous chloride]
- Here the measurement is done by using the electrolyte bridge.

(c) pH Electrolyte

- The chemical balance of the human body is identified by the measurement of pH content of blood and other body fluids.
- Generally, pH is defined as the logarithmic of reciprocal of H^+ ion concentration.

$$pH = \log_{10} \frac{1}{[H^+]} = -\log 10\,[H^+]$$

- Generally, the neutral solution has a pH value of 7.
- If pH is less than 7 means, it is ***acidic*** and pH is greater than 7 means, it is ***basic.***
- The human body is slightly basic such that pH value of venous blood about 7.35 and for arterial blood is about 7.40.
- Generally, the glass electrode is normally used as the pH electrode.

pH value of venous blood = 7.35

pH value of arterial blood = 7.40

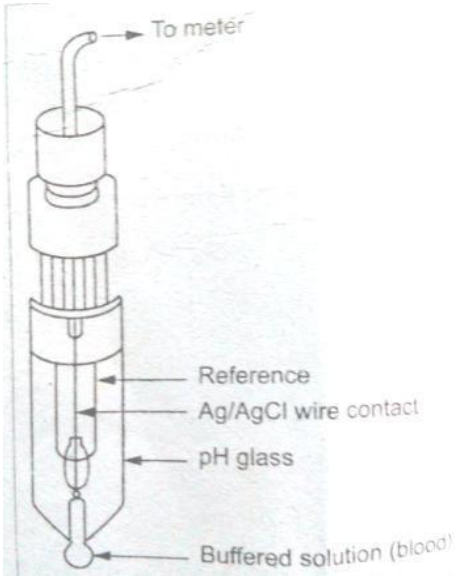

Fig 7.4 pH electrode

The glass electrode has the following advantages.

- The glass electrode is independent of oxidation-reduction potential.
- In case of glass electrode, it is not necessary to pass the gas through the solution i.e. the equilibrium condition is reached rapidly.
- The glass electrode can be used in colored or turbid solution.

(d) pCO_2 electrode

- It consists of standard glass pH electrode covered with the rubber membrane permeable to CO_2.
- Between the glass surface and membrane, there is a thin film of water.
- The solution under test which contains dissolved CO_2 is presented to the outer surface of the rubber membrane.
- After the equilibrium condition, the pH value is measured by the glass electrode.

- It is interpreted in terms of pCO_2 on the basis of linear relationship between log pO_2 and pH of the solution.

(e) pO_2 electrode

- The oxygen electrode consists of a piece of platinum (Pt) wire embedded in an insulating glass holder.
- And it is exposed to electrolyte into which oxygen from the solution under measurement is allowed to diffuse through the membrane.
- On the other end, Ag/AgCl reference electrode is used.
- A voltage of 0.7V is applied between the platinum through a micro ammeter.
- The reduction of O_2 can take place at the platinum.
- Due to that an oxidation-reduction current is developed.
- It is proportional to the partial pressure of the diffused oxygen.
- By this method, the oxygen electrode is used to monitor the partial pressure of oxygen in biological fluids.

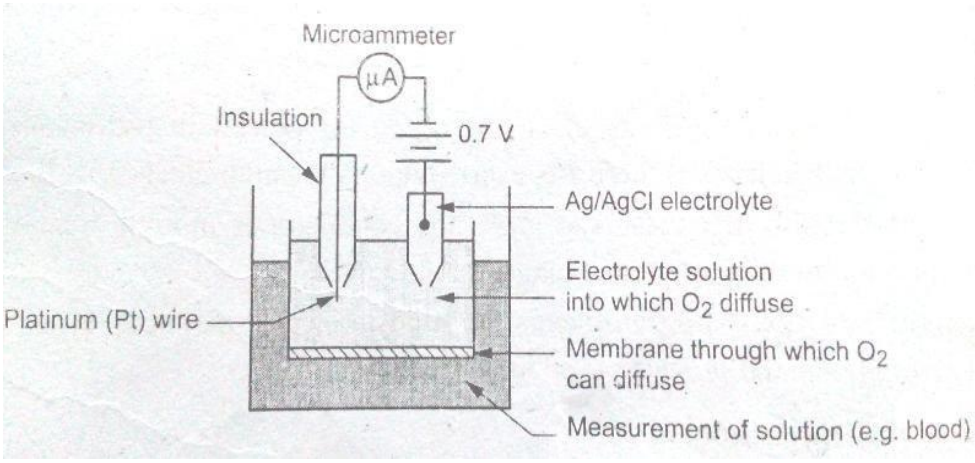

Fig 7.5 pO_2 electrode

- The oxygen electrode is also available in the integrated version consisting of both platinum electrode and reference electrode in the same enclosure called **"Clark electrode".**

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8. Bio Amplifier (or) Biological Amplifiers

Explain briefly about the various types of Biological amplifiers. ***[A.U. April 2005]***

8.1 What is the need of Bio amplifiers?

- Generally, the bio signals are having low amplitude and low frequency.
- So, amplifiers are needed to boost the amplitude level of the bio signals.
- The output of this amplifier is displayed as EEG (or) ECG waveform.
- These amplifiers are known as Bio Amplifiers (or) Bio Medical amplifiers.

8.2 Basic Requirements for Biological Amplifiers

List and discuss the important characteristics of bio-amplifier. ***[April/May 2017]***

Some of the basic requirements for Biological amplifiers are given below:

- Bio amplifiers must have high input impedance.
- Now, generally, Bio potential amplifiers with 2 MΩ of input impedance are used.
- For various applications 10 MΩ of input impedance is used as desired value.
- Bio amplifier circuit must have isolation and protection circuits.
- These circuits are used to protect the patients from micro shock and macro shock.
- Voltage gain of Bio amplifier should be more than 100 db.
- Constant gain should be maintained throughout the required bandwidth.
- Output impedance of Bio amplifiers should be small.
- Drift free amplifiers can act as good Bio Amplifiers.
- CMRR (Common Mode Rejection Ratio) of Bio Amplifiers should be more than 80 db.
- The gain of the amplifier must be correctly calibrated.

8.3 Types of Amplifiers

- The types of amplifiers are,
  - Differential amplifier
  - Operational amplifier
  - Instrumentation amplifier
  - Chopper amplifier
  - Isolation amplifier

8.3.1 Differential Amplifier:

Single Ended amplifier

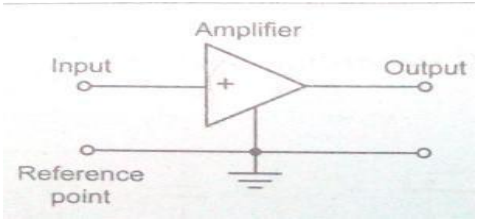

Fig 8.1 Single Ended amplifier

- One input is connected with common reference point.
- Another input is connected with positive terminal.
- But in this type of amplifier, it is not possible to record the real difference between pairs of electrodes.
- Because, various electrodes are used in the measurement.
- These electrodes use the same common point as reference.
- So, usually, we use the following type of differential amplifier.

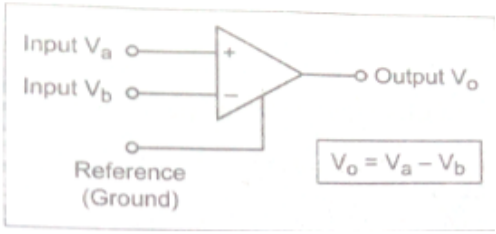

Fig 8.2

- Output voltage Vo is equal to the difference between the two input signals.

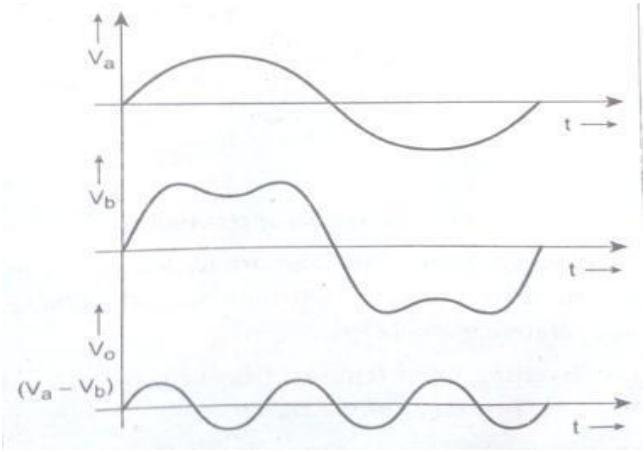

Fig 8.3 Input and Output of differential amplifier

- CMRR (Common Mode Rejection Ratio) should be high for the Bio amplifier.
- CMRR value is used to find the degree to which the bio amplifier is able to reject the common mode signal.

Differential Amplifier in ECG Recording System

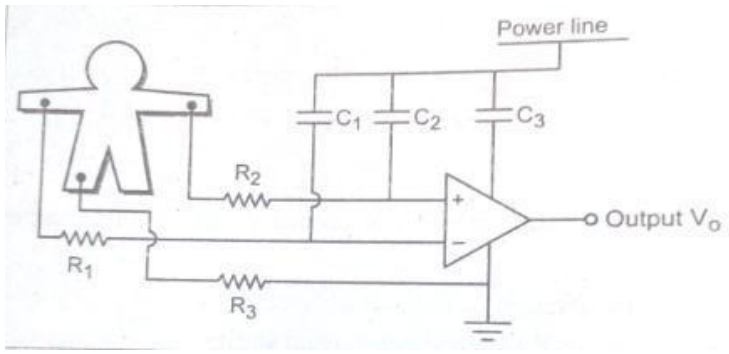

Fig 8.4

- C_1, C_2, C_3 are coupling capacitors. There is no interference created by using these capacitors.

$V_o = V_1 - V_2 = I_1 Z_1 - I_2 Z_2$

Z_1, Z_2 = Skin electrode resistances

($I_1 \sim I_2$ when 2 electrodes wires are nearer)

- So, $V_o = I_2 (Z_1 - Z_2)$

8.3.2 Operational Amplifiers

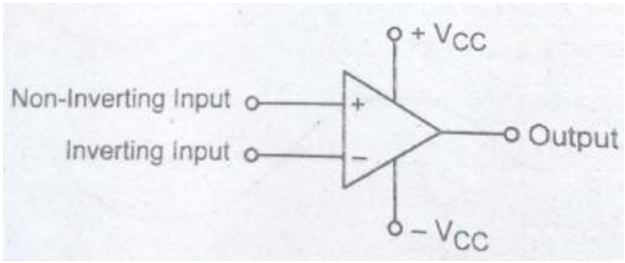

Fig 8.5 Symbol of Op-amp

- These are abbreviated as Op-amps.
- Op-amps are used to solve mathematical operations like addition, subtraction, differentiation, integration, scale changes etc.
- Hence these amplifiers are called as operational amplifiers.
- If input is applied to inverting input terminal (-), then, we can get the output with 180^o phase shift. This is known as ***„Inversion of the signal"***.
- If input is applied to non – inverting input terminal (+), then, we can get the output with 0^o phase shift.
- So, there is no phase inversion between input and output.

An ideal Op-Amp Properties

An ideal Op-Amp can have the following properties.

- Infinite input impedance
- Zero output impedance
- Infinite open loop voltage gain
- Zero noise level
- Infinite frequency response

Various Configurations of Op-Amp

Operational amplifiers can be configured in many ways as given below.

- Inverting amplifier
- Non-inverting amplifier

Inverting Amplifier

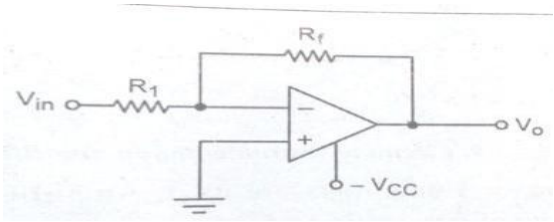

Fig 8.6 Inverting amplifier

In this configuration, input V_{in} is applied to inverting terminal through R_1 resistor. Feedback resistor R_f is connected between input and output.

$$A_V = \frac{V_o}{V_{in}} = \frac{-R_f}{R_1} \quad \text{---------- (1)}$$

So, equation (1) gives voltage gain formula.

Non-Inverting Amplifier

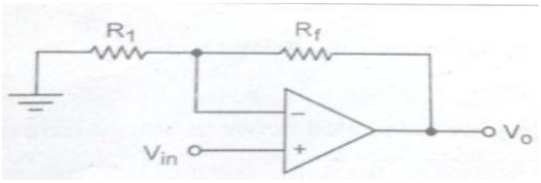

Fig 8.7 Non-inverting amplifier

❖ Here, input V_{in} is applied at non-inverting terminal (+). Here, voltage gain formula is given as below.

$$A_V = \frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1} \quad \text{---------- (2)}$$

8.3.3 Instrumentation Amplifier

With circuit diagram explain the instrumentation amplifier. ***[Nov/Dec 2017]***

❖ Instrumentation amplifier is used to provide high-gain and high-input impedance.

Circuit of Instrumentation Amplifier

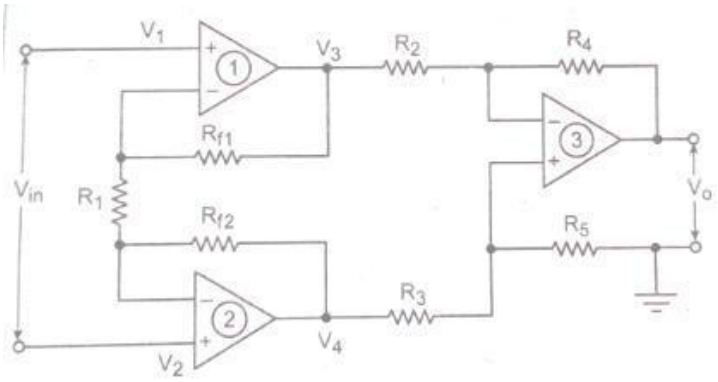

Fig 8.8 Circuit of Instrumentation amplifier

❖ In the above circuit, totally three amplifiers are used. Amplifier (1) and amplifier (2) are connected in non-inverting amplifier configurations.

In amplifier (1):

- V_1 is the input voltage applied to non – inverting terminal (+).
- R_{f1} is the feedback resistor, connected between input and output side.
- V_3 is the output voltage.

$$V_3 = V_1 \left(1 + \frac{R_{f1}}{R_1}\right) - V_2 \left(\frac{R_{f1}}{R_1}\right) \quad \text{---------- (3)}$$

In Amplifier (2):

- V_2 is input voltage applied to non-inverting terminal.

- V_4 is the output voltage.
- R_{f2} is the feedback resistor connected between output side and input side.

$$V_4 = V_2\left(1 + \frac{R_{f2}}{R_1}\right) - V_1\left(\frac{R_{f2}}{R_1}\right) \quad \text{---------- (4)}$$

$$V_o = V_3 - V_4 = \left[V_1\left(1 + \frac{R_{f1}}{R_1}\right) - V_2\left(\frac{R_{f1}}{R_1}\right)\right] - \left[V_2\left(1 + \frac{R_{f2}}{R_1}\right) - V_1\left(\frac{R_{f2}}{R_1}\right)\right]$$

If $R_{f1} = R_{f2}$, then

$$V_3 - V_4 = \left[V_1\left(1 + \frac{R_{f2}}{R_1}\right) - V_2\left(\frac{R_{f2}}{R_1}\right)\right] - \left[V_2\left(1 + \frac{R_{f2}}{R_1}\right) - V_1\left(\frac{R_{f2}}{R_1}\right)\right]$$

$$\left[\left(1 + \frac{R_{f2}}{R_1}\right)(V_1 - V_2) + \left(\frac{R_{f2}}{R_1}\right)(V_1 - V_2)\right]$$

$$(V_1 - V_2)\left(1 + \frac{R_{f2}}{R_1} + \frac{R_{f2}}{R_1}\right)$$

$$(V_3 - V_4) = (V_1 - V_2)\left(1 + 2.\frac{R_{f2}}{R_1}\right)$$

$$A_V = \frac{(V_3 - V_4)}{(V_1 - V_2)} = 1 + 2.\frac{R_{f2}}{R_1} \quad \text{---------- (5)}$$

$$A_v = \frac{V_o}{V_{in}} = \left(1 + 2.\frac{R_{f2}}{R_1}\right)\left(\frac{R_4}{R_2}\right) \quad \text{---------- (6)}$$

Practically, $R_{f1} = R_{f2}$

$R_2 = R_3$

$R_4 = R_5$, A_v → Voltage gain of instrumentation amplifier.

Here, Amplifier (3) acts as differential amplifier. Usually, R_5 is replaced by potentiometer to adjust the values.

Advantages of Instrumentation Amplifier

- High gain
- Extremely high input impedance
- CMRR is good

8.3.4 Chopper Amplifiers:

Introduction

- Noise and d.c drift are the serious problems at the time of recording bio-potentials.
- If we use high-gain amplifiers, these problems are considered as critical factors.

- Noise can be generated by various parts of recording apparatus and by the patient‟s body.
- Drift is the change in gain or DC-offset (DC-offset means base line) due to the thermal effects on the components of the amplifier circuit.
- Drift can be reduced by using large amount of negative feedback in an ac-coupled amplifier.
- Chop means sample.
- Analog signal is sampled in this amplifier circuit.
- Hence, this circuit is known as chopper amplifier.

Chopper Amplifier

- Used in the biomedical measurement.
- Bio signals have the frequency range from dc to few hundred Hz.
- Chopper amplifiers is further classified into
  - Mechanical choppers
  - Non-mechanical choppers
- Chopper is used to convert the dc or low frequency signal into high frequency.
- This modulated high frequency signal is amplified by conventional ac amplifier.
- The amplified signal is demodulated and filtered to get amplified d.c or low frequency signal.

Mechanical chopper amplifier:

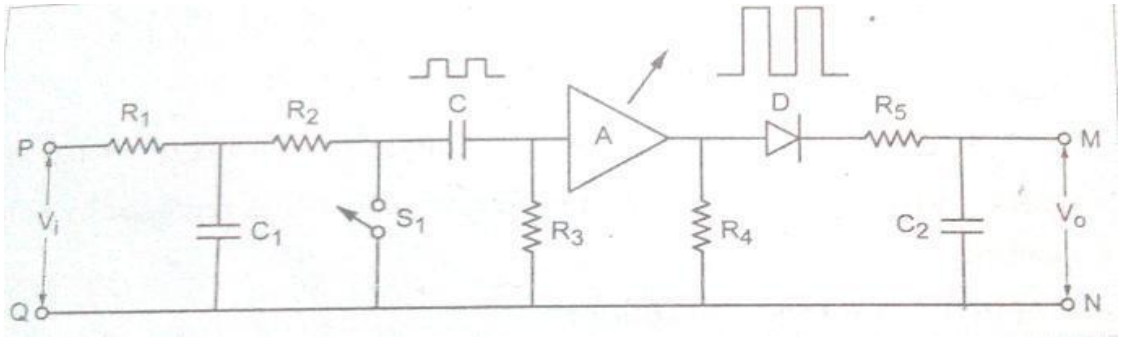

Fig 8.9 Chopper amplifier using a mechanical switch

- Chopper S_1 is an electromagnetically operated switch or relay.
- It connects alternatively the **input term** of the a.c amplifier **„A‟** to the **reference term „Q‟** which is usually connected to ground.
- When **chopper S_1 is closed** and the amplifier input term is connected with Q_1, it is short circuit and the input voltage is zero.
- When the **chopper S_1 is open**, the amplifier receives the signal volt from P.

- Therefore the input to the amplifier consists of an a.c voltage varying from zero to the value of the input voltage.
- By this process, a steady d.c or slowly varying signal is chopped into a train of square wave pulses having a frequency equal to the rate of the chopper.
- After amplification, the chopped signal is rectified with a diode "D".
- The rectified signal is then filtered.
- The amplified d.c or slowly varying signal is obtained at the output terminal M and N.
- The response time of the chopper amplifier is governed by the chopping or sampling rate.
- For faithful reproduction, the chopping rate is not changed appreciably between samples (high chopping rate).
- The chopping rate should be at least 10 times greater than the highest frequency component of the signal for good fidelity.
- By means of placing relay, S_1 and S_2 at the input and output term of the amplifier, if they work in antisynchronism, (S_1 → open and S_2 → closed).
- Without the use of rectifier, we get the demodulated output.

Non-mechanical chopper amplifier:

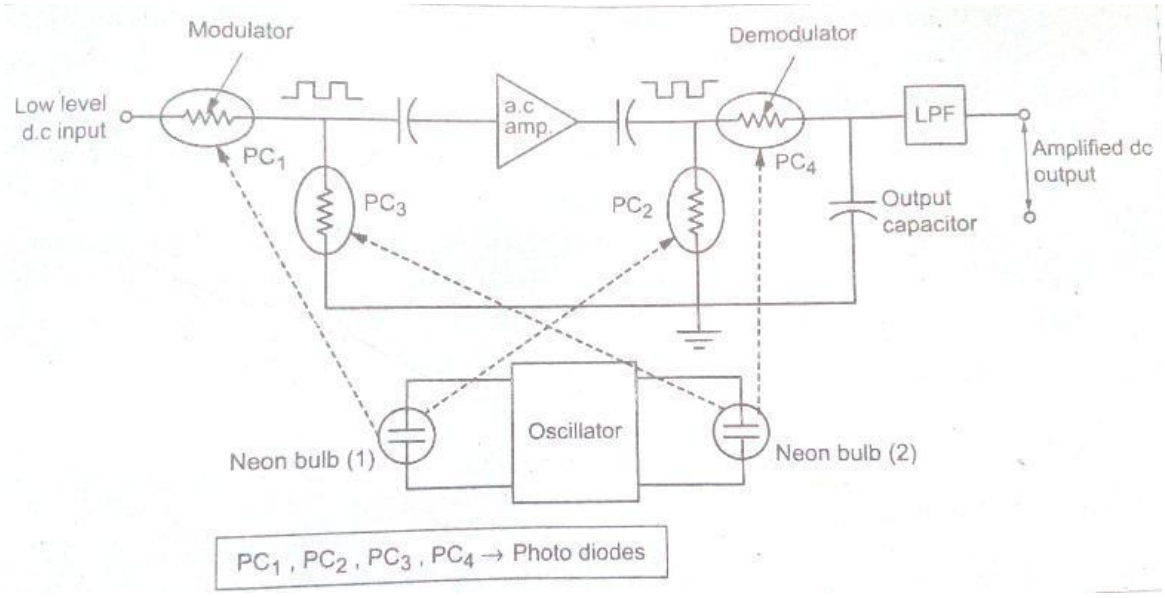

Fig 8.10 Non-mechanical photo conductive chopper amplifier

- The photo conductors or photo diodes are used as non-mechanical choppers for modulation (converts from d.c to a.c) and demodulation (converts from a.c back into d.c).
- When there is no incident light on the photo conductor, its resistance is so many mega ohms.
- Hence, it is in the reverse bias and no current is allowed to flow through it.
- When there is incident light on the photo conductor, its resistance is very low (few hundred ohms)
- Hence, it is in forward bias and current can easily flow through it.
- Thus, it can act as a switch by means of incident light.
- Fig. shows an oscillator, which drives two neon bulbs into illumination on alternate half cycles of oscillation.

- Neon bulb (1) gives flash of light on photo conductors PC_1 and PC_2 which are connected at the input and output.
- Neon bulb (2) gives flash of light on photo conductors PC_3 and PC_4.
- At the input we have low level d.c. input.
- Whenever light falls on PC_1, its resistance decreases and input capacitor charges.

Whenever there is no light on PC_1, light is on PC_3, the input flows through PC_3.

- Thus by the alternate incident light on PC1 and PC3, we have a square wave across the capacitor.
- Its amplitude is proportional to the input and frequency is equal to frequency of oscillator.
- The square wave voltage acts as an input for a.c amplifier.
- An amplified square wave voltage is obtained at the output of the amplifier.
- The two photo conductors PC_2 and PC_4 in the amplitude output circuit recover the d.c signal by their demodulating action.
- The output capacitor becomes charged to the peak of the output voltage.
- This d.c output voltage is passed through a LPF to remove any ripples and finally amplified d.c output is obtained.
- The transition time between high and low resistance states of photoconductors limits the chopping rate up to a few hundred hertz even though the oscillator can deliver high frequency driving voltage.

Advantages of Chopper Amplifier

- These amplifiers can give the stable gain.
- These amplifiers can provide low noise operation.

Differential Chopper Amplifier

- This circuit is used in EEG measurement systems.

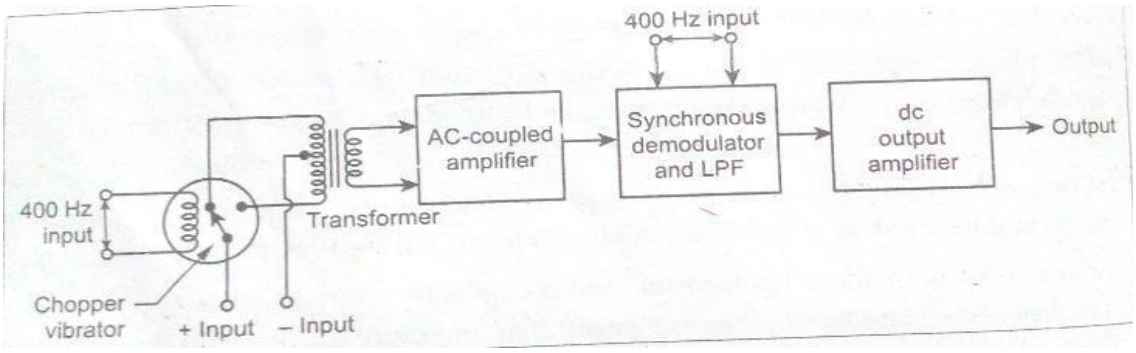

Fig 8.11 Differential chopper amplifier

- In this circuit, chopper vibrator is connected in the input side, center-tap taken from the transformer is used as one terminal of the input connector.
- The pole of the chopper switch is used as another terminal of the input connector.
- AC-Coupled amplifier is used to provide most of the gain to the circuit.
- The output of this amplifier circuit is given to the synchronous demodulator and low pass filter (LPF) block.
- If there is any remaining chopped version (sampled) of the signal available, then it is detected and filtered.

- AC-Coupled amplifier, synchronous demodulator, LPF and DC-output amplifier circuits are used to provide the gain in multiples of 1000 to multiples of 10, 00, 000.

8.3.5 Isolation Amplifiers

Explain the working principle of isolation amplifier. ***[Nov/Dec 2018]***

Introduction

- To prevent accidental internal cardiac shock, isolation amplifiers are used. (Isolation amplifiers are abbreviated as Iso-amp).
- Isolation amplifiers can provide 10^{12} Ω of insulation between the patient and the a.c power line.

Block Diagram of Isolation Amplifier

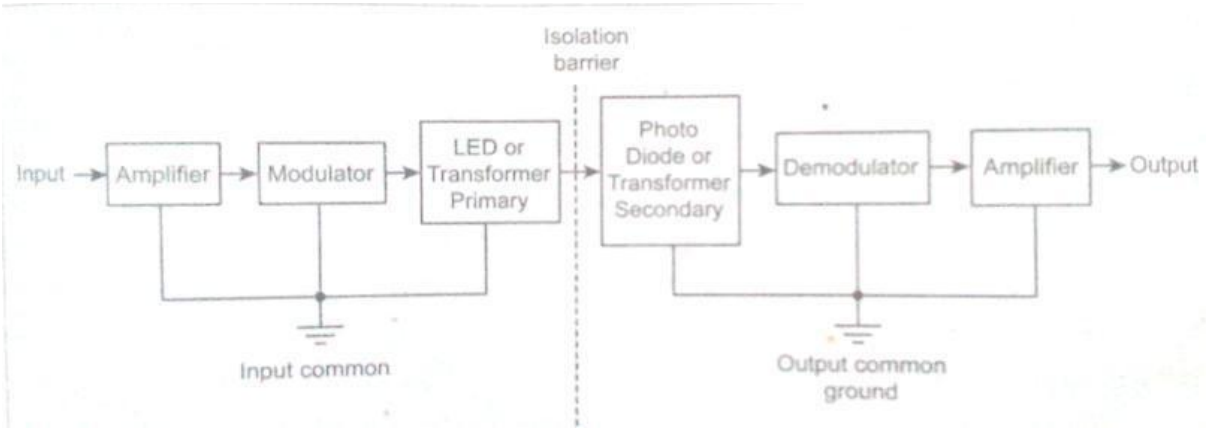

Fig 8.12 Block Diagram

Symbol of Isolation Amplifier

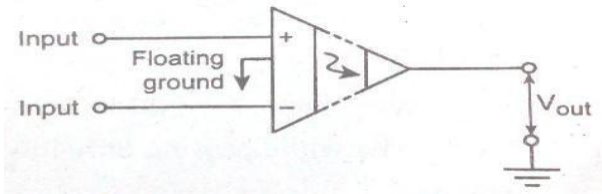

Fig 8.13 Symbol

Explanation for Block Diagram

- Electrical signal obtained from electrodes is applied to amplifier block.
- After amplification, the signal is applied to modulator block.
- Here, usually amplitude modulation process occurs.
- This block includes fly back loading circuit and voltage to frequency circuit, etc

Case (i): If optical cable is used as Isolation Barrier

- The output from the modulator is applied to LED.
- This LED converts electrical signal to light energy.
- This light energy is propagated through fiber optic cable.
- The same light is received by the photo detector.
- This photo detector converts light into electrical signal.
- This electrical signal is given to demodulator block.

-

Case (ii): If transformer is used as Isolation Barrier

- The output from the modulator is given to the primary winding of transformer.
- Due to mutual induction, the energy in primary is transformed to secondary winding.

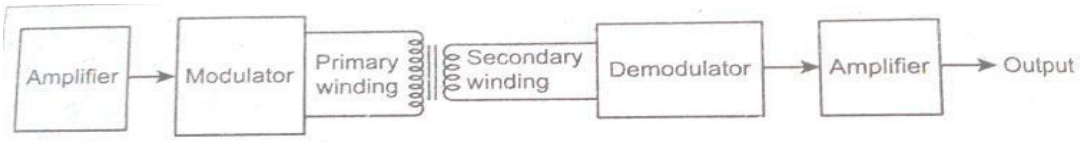

Fig 8.14 Transformer used as isolation barrier

- The output of secondary winding is connected to demodulator block.
- In this circuit, isolation is provided by transformer.
- The isolation barrier does not provide infinite impedance.
- A small voltage is present across the barrier.
- This voltage creates some error which is appeared in output voltage.
- This voltage is known as IMV (Isolation mode voltage).

IMR (Isolation Mode Rejection)

The degree to which rejection occurs in isolation amplifier is termed as Isolation Mode Rejection.

IMRR (Isolation Mode Rejection Ratio)

IMRR = $\log^{-1}$ (IMR in db / 20)

Advantages of Isolation Amplifier

- Isolation amplifiers withstand high voltage. So it protects the patients and circuits.
- These amplifiers amplify the signals while passing only low leakage current to prevent shock.
- They break ground loops to permit incompatible circuits to be interfaced together while reducing the noise.

ECG Isolation Amplifier Circuit

Design a suitable amplifier that can be used in the front end of an ECG machine. Justify by specifying the features of the selected amplifier. ***[Nov/Dec 2018]***

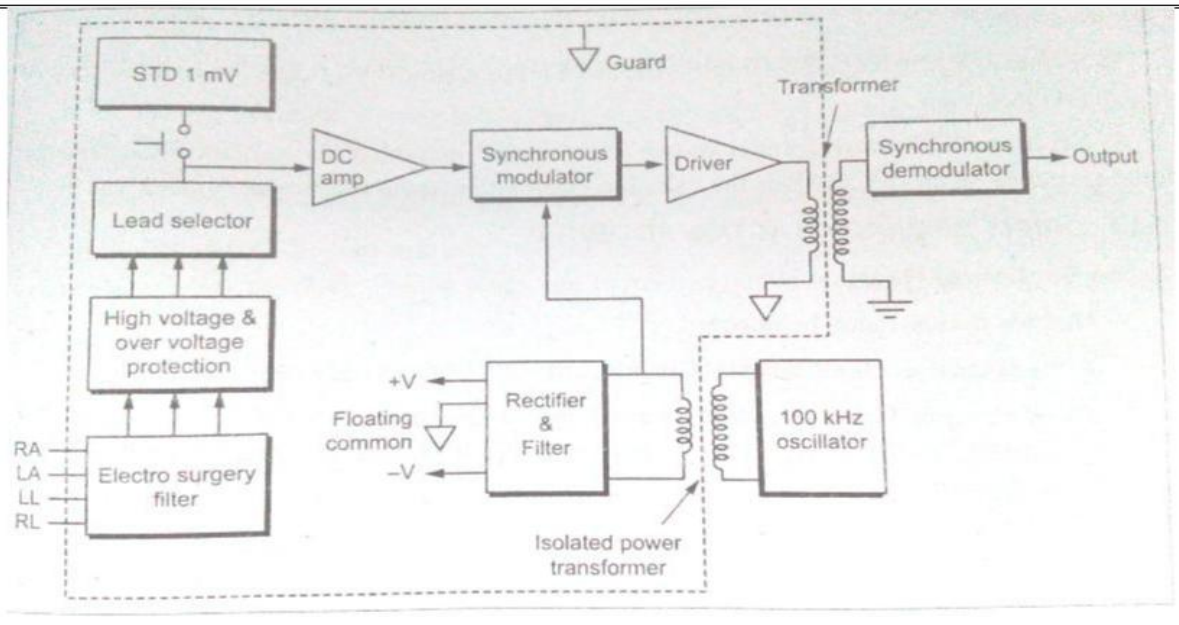

Fig 8.15 Block diagram of transformer coupled ECG isolation amplifier circuit

- Signals from different leads are given to LPF (having cutoff frequency of 10 KHz).
- This filter reduces the interference caused by electro surgery and radio frequency emission.
- The filter is also referred as electro surgery filter.
- This filter circuit is followed by high voltage and over voltage protection circuits, amplifiers to withstand large voltages during defibrillation.
- The signals are fed to the lead selector switch (used to derive the required lead configuration).
- Output of the lead selection switch is given to d.c amplifier.
- The primary of an isolated low capacity power transformer is connected with 100 KHz oscillator.
- The secondary of transformer along with rectifier and filter used to obtain isolated power supply of $\pm 6V$ for operating the devices in the isolated portion of the circuit.
- The synchronous modulator modulates the ECG signal from d.c amplifier at 100 KHz in a linear manner.
- Another transformer used to deliver the output from the driver of the modulator to the synchronous demodulator.
- The output of the demodulator, used as input of the power amplifier.

****

9. Electro Cardio Graphy (ECG):

Draw and explain the different lead configurations and its significances in ECG. (16) [May/June 2016][May/June 2013]

Discuss the genesis of ECG and explain the working of an ECG machine with suitable block diagram along with its various lead configurations. [Nov/Dec 2016]

9.1 Introduction

- ECG means Electro Cardio Graphy.
- Electro Cardio Graph shows the electrical activity of the heart muscles.
- The recorded ECG waveform is known as electro cardio graph.
- The instrument is termed as electrocardiogram.
- ECG gives the valuable information about the cardiac disorders.

9.2 Origin of Cardiac Action Potential

Cross section of Heart

- Heart is divided into four chambers.
- Four chambers are left atrium, right atrium, left ventricle and right ventricle.
- ***The Tricuspid valve (or) Right-Atrio Ventricular Valve:*** It is located in between the right atrium and right ventricle. It prevents backward blood flow from right ventricle to right atrium.
- ***Bicuspid Mitral valve (or) Left Atrio Ventricular valve:*** It is located in between left atrium and left ventricle. It prevents backward blood flow from left ventricle to left atrium.

- ***Pulmonary valve:*** It is located at the right ventricle. It has 3 half moon shaped cups. It does not allow blood to come back to the right ventricle.
- ***Aortic valve:*** It is located between left ventricle and aorta. It does not allow the blood to come back to the left ventricle.
- Heart consists of 3 layers namely,
    (a) Pericardium
    (b) Endocardium
    (c) Myocardium
- ***Pericardium:*** It is the outer layer of the heart. It keeps the outer surface and prevents the heart from the friction.
- ***Endocardium:*** It is the inner layer of the heart. It provides smooth path for blood flow.
- ***Myocardium:*** It is the middle layer of the heart. It act as the main muscle of the heart. It is made up of short cylindrical fibers.
- ***Blood vessels:*** These are hollow tubes through which the blood is carried to the various parts of the body.

Types of blood vessels:

- Arteries
- Veins

- ***Arteries:*** These are thick walled vessels used to carry the oxygenated blood away from the heart. Blood vessels that carry pure blood from heart to various organs.
- ***Veins:*** These are thin walled vessels through which impure blood returns to the heart.
- ***Capillaries:*** These are very small blood vessels. 8, 00,000 km capillaries are present in human being.
    - The heart pumps the blood by a movement termed as heart beat.
    - The normal heart beat rate is 72 beats / minute.
    - The heart pumps the blood through the pulmonary circulation to the lungs and through systemic circulation to other organs of the body.
    - Heart pumps the blood to the lungs through the pulmonary circulation (for the purpose of purification).
    - Heart pumps the pure blood to all the parts of our body through systemic circulation.
- ***Pulmonary circulation:*** The impure blood (which is to be oxygenated) flow from right ventricle to the lungs through pulmonary artery. In lungs, the blood is oxygenated (purified).
- The pure blood flows to the left atrium through pulmonary veins.

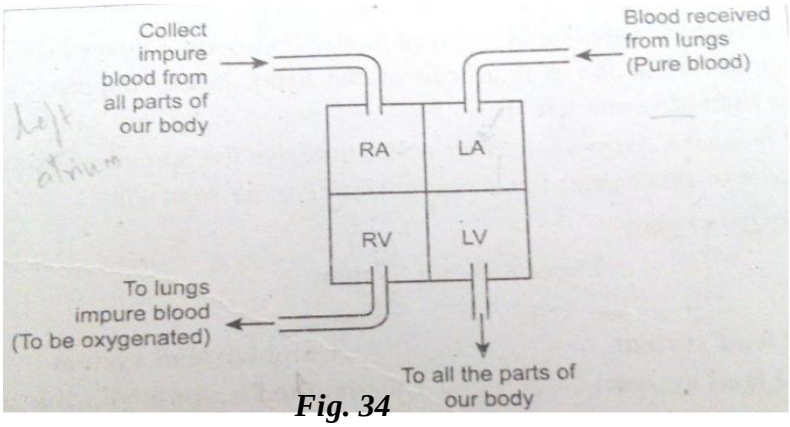

Fig. 34

- ***Systemic circulation:*** The blood from left atrium is pumped to the left ventricle. The blood is pumped from left ventricle to all the parts of our body through the aorta and its branches.

Cross section of the heart

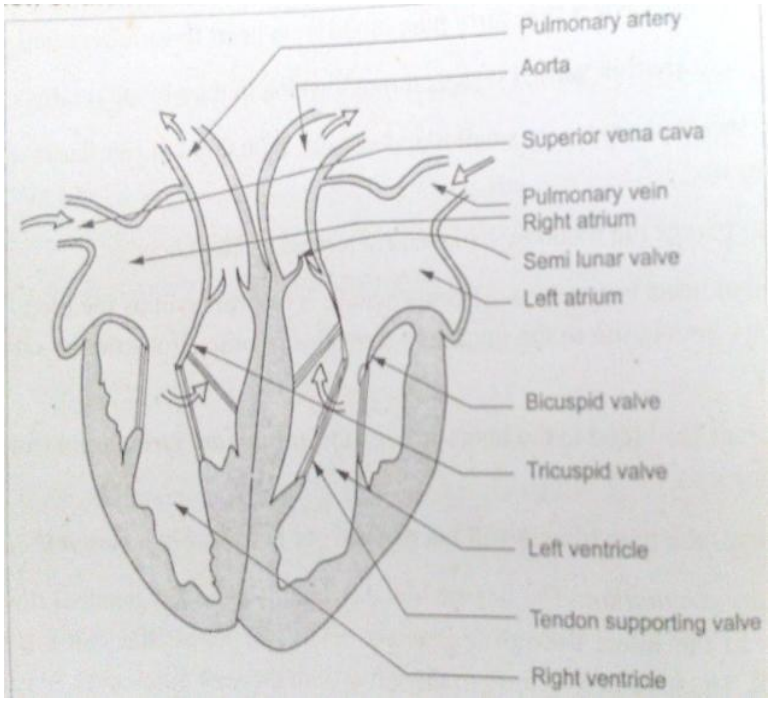

Fig.9.1

SA Node: It is abbreviated as Sino Atrial Node. This node initiates the heart activity. It generates impulses at the normal rate of the heart. These impulses are propagated through the right atria and left atria.

AV Node: It means Atrio-ventricular node. It delays the spread of excitation of about 0.12s. Bundle of this carries the action potential to the ventricle.

9.3 ECG – Lead Systems:

Draw the typical ECG waveform with its characteristics. [April/May 2019] Explain the different lead systems used in an ECG recorder. [April/May 2018][April/May 2017][May/June 2016]

Types of Lead System:

- Bipolar lead system (standard lead system)
- Unipolar lead system (Augmented unipolar limb lead system)

Bipolar Lead System:

- It is also known as Einthoven leads.
- In this lead system, ECG is recorded by using 2 electrodes.
- Final output is taken as the difference of electric potential between these 2 electrodes.
- In this system, electrodes are placed in 4 different places. These are:
  - Left arm (LA)
  - Left Leg (LL)
  - Right Arm (RA)
  - Right Leg (RL)
- Usually, right leg (RL) electrode act as ground reference electrode.

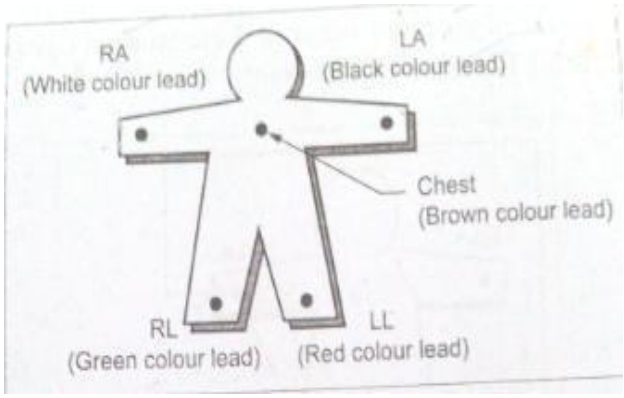

Fig 9.2 Recommended positions for electrodes

- These are the recommended positions to fix the electrode.

Lead I: The difference in potential between 2 electrodes (one electrode is in LA and another electrode is in RA) are measured. RL is the reference electrode.

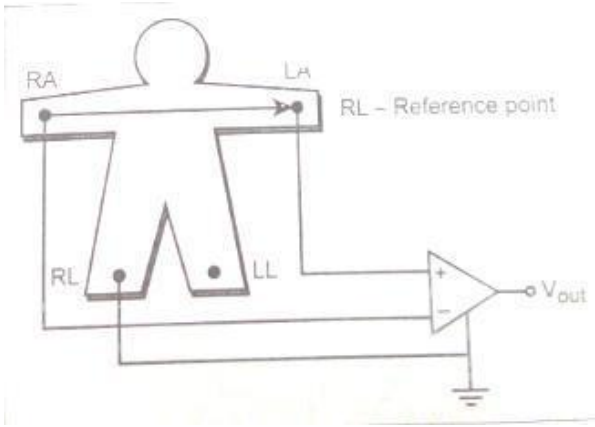

Fig 9.3 Lead - I

Lead II: The difference in potential between 2 electrodes (1 is in LL and another is in RA) is measured. RL is Reference Electrode.

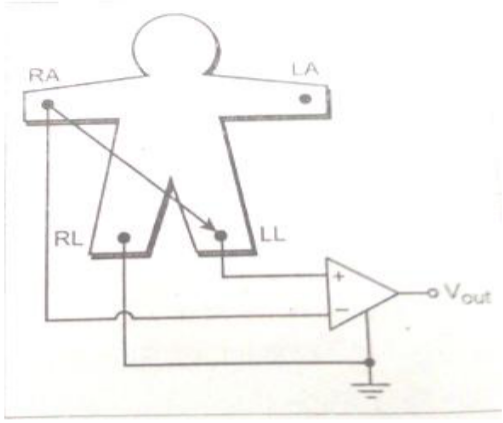

Fig. 9.4 Lead - II

Lead III: The difference in potential between 2 electrodes (1 is in LL and another is in LA) are measured. RL is the Reference Electrode.

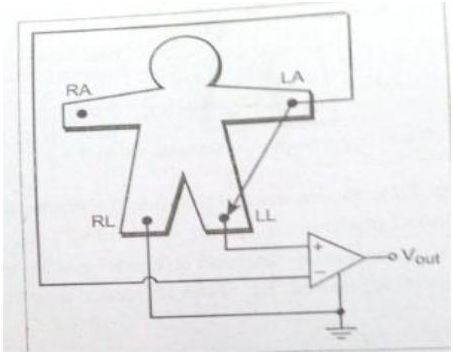

Fig. 9.5 Lead – III

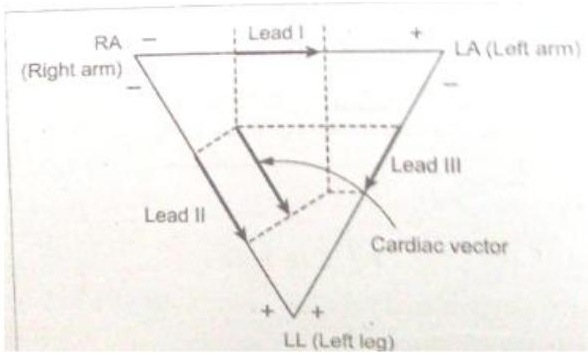

Fig. 9.6 Einthoven triangle

Lead-I position: It gives voltage drop V_1 from LA to RA.

Lead-II position: It gives voltage drop V_2 from LL to RA.

Lead-III position: It gives voltage drop V_3 from LL to LA.

The closed path from RA to LA to LL and back to RA is called as ***Einthoven triangle.*** According to Einthoven, the Cardiac electric field is a 2 dimensional one in the frontal plane of the body. The three projections of ECG vector are shown in Figure.

ECG Waveform for:

Lead-I	Lead-II	Lead-III
R-wave amplitude = 0.07 to 1.13 mV	R-wave amplitude = 0.18 to 1.68 mV	R-wave amplitude = 0.03 to 1.31 mV

Fig.9.7

If, V_1 = 0.53 mV (for lead – I)

V_2 = 0.71 mV (for lead –II)

V_3 = 0.38 mV (for lead – III)

Always $V_2 \sim V_1 + V_3$ (Kirchhoff's voltage law is followed)

Augmented Unipolar Limb Leads

- This system is introduced by Wilson.
- In this system, voltage is taken between ***single exploratory electrode*** and the ***central terminal***.
- Two equal resistors are connected to a pair of limb electrodes and the center point act as one terminal to measure the voltage.
- In this lead system, small increase in the ECG voltage can be realized.
- 3 Augmented lead connections are possible. They are
    1. Augmented Voltage Right Arm (aVR)
    2. Augmented Voltage Left Arm (aVL)
    3. Augmented Voltage Foot (aVF)

Lead aVR:

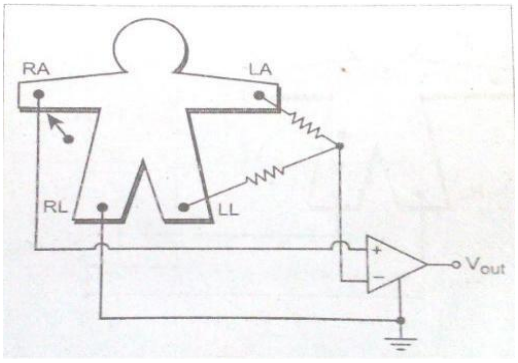

Fig. 9.8

$$aVR = -V_1 - \frac{V_3}{2} \qquad [V_1, V_3 \text{ are bipolar lead voltages}]$$

LA and LL are connected with two resistors and common point is connected to negative terminal. RA is connected to positive terminal of operational amplifier. RL is the Reference Terminal.

Lead aVL:

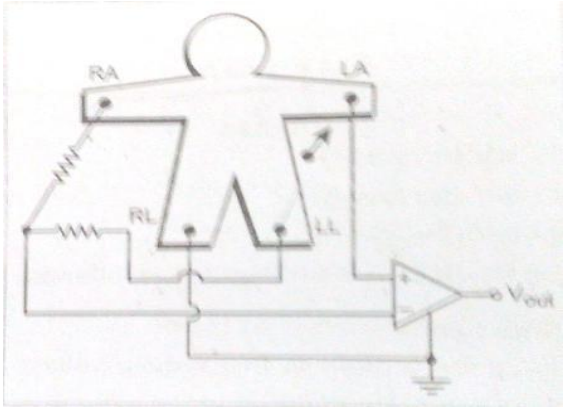

Fig. 9.9

RA and LL are connected with two resistors and common terminal is connected with negative terminal. LA is connected to positive terminal. RL is the reference point.

$$aVL = V_1 - \frac{V_2}{2} \qquad [V_1, V_2 \text{ are bipolar lead voltages}]$$

Lead aVF:

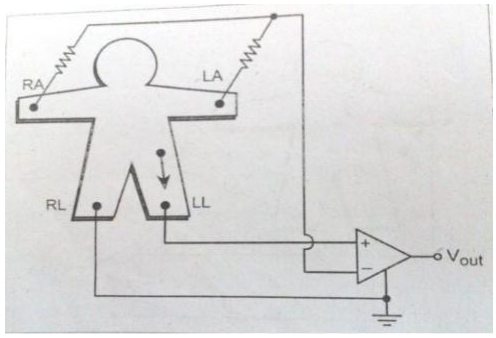

Fig. 9.10

RA and LA are connected with two resistors and common terminal is connected to negative terminal of amplifier. LL is connected with positive terminal of amplifier. RL is acting as Reference electrode.

$$aVF = V_2 - \frac{V_1}{2} \qquad [V_1, V_2 \text{ are bipolar lead voltages}]$$

Unipolar Chest Leads

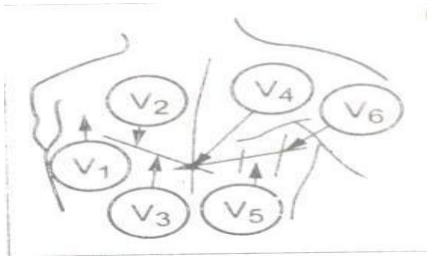

Fig. 9.11

V_1 – Fourth intercostals space of right sterna margin

V_2 – Fourth intercostals space at left sterna margin

V_3 – Midway between V_2 and V_4

V_4 – Fifth intercostals space at mid-clavicular line.

V_5 – same level as V_4 on anterior auxiliary line

V_0 – Same level as V_4 on mid auxiliary line

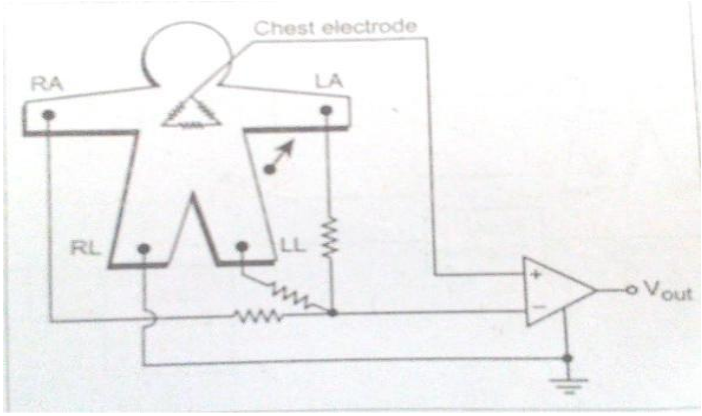

Fig. 9.12 Unipolar chest leads

- In Unipolar chest lead system explanatory electrode is one of the chest electrodes.

- The chest electrodes are placed on the six different places on the chest as in Fig 45.
- RA, LA, LL are connected with resistors and common point is taken and connected with negative terminal of amplifier.
- Chest electrode is connected to positive terminal of amplifier. RL is used as Reference point.

ECG Waveform:

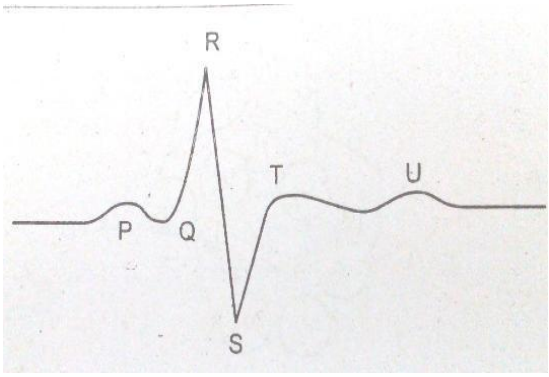

Fig. 9.13

9.4 ECG Recording Method:

With a neat block diagram, explain the working principle of ECG recorder. ***[Nov/Dec 2018]***

The following block diagram is used for recording electrocardiograph waveform.

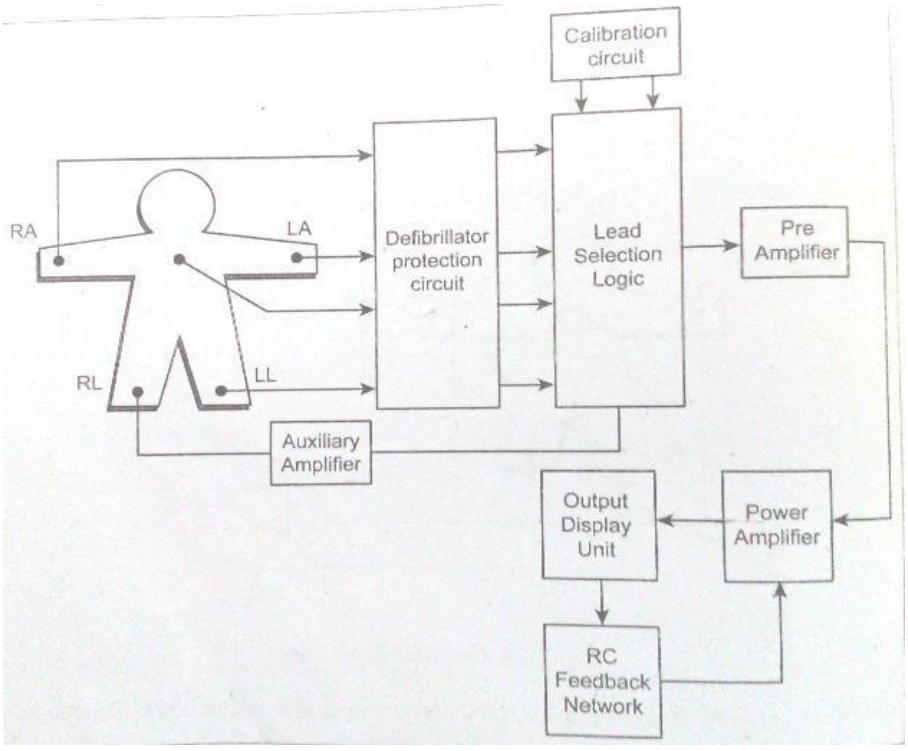

Fig.9.14

Defibrillator Protection Circuit:

- The electrodes used for taking ECG measurement are connected in RA, LA chest and LL of the patient.
- The other end of the electrodes is connected with lead selection logic through defibrillator protection circuit.

- The protection circuit employs ***buffer amplifiers*** and ***over voltage protection circuits***.
- 4 buffer amplifiers are utilized (1 buffer amplifier for each lead electrode).
- Input impedance is increased by using the buffer amplifier.
- Over voltage protection circuit is used to protect pre amplifier and power amplifiers from over voltage.

Lead Selection Logic

By using this block, we can choose either bipolar limb lead type (or) augmented unipolar limb lead type.

Calibration circuit

- If lead selection is changed, then some artifact is introduced in the output of the ECG.
- So, calibration circuit is used to help to the technicians to calibrate the output unit.
- When the lead selection is changed, then the amplifier is switched off for some time.
- After the passage of artifact (noise), the preamplifier is switched on.

Pre Amplifier

- Here the differential amplifier with high gain and high CMRR (Common Mode Rejection Ratio) is used as preamplifier.

Power Amplifier

- Power amplifier is used to drive the output unit.
- The pen motor is used in the output unit.
- This pen motor need sufficient electrical power to initiate recording.
- So, a power amplifier with high power gain is used here.

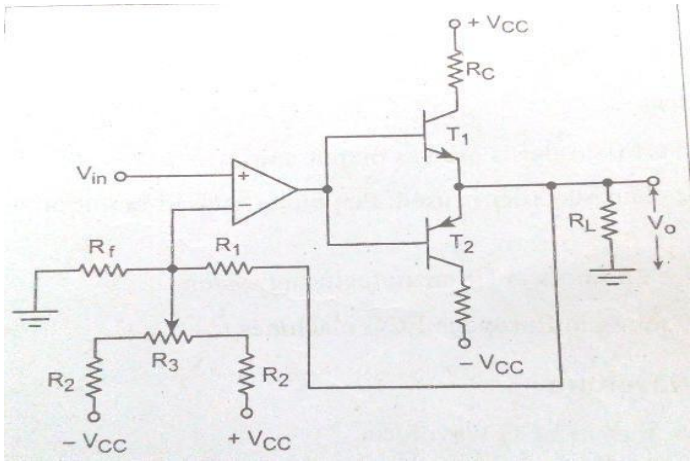

Fig. 9.15

R_1, R_2, R_3 = Biasing resistors

R_f = Feedback resistor

R_c = Collector resistor

- This circuit shows the power amplifier used in the ECG recorder.
- The transistors T_1 and T_2 act as the push pull power amplifier.

- Class-B push pull amplifier has the disadvantages of cross over distortion.
- To avoid this cross over distortion, non inverting amplifier circuit used in the input side of the class-B push pull amplifier.

  Here, $P_o = V_o^2 / R_L$

  P_o = Output power

  V_o = Output voltage

  R_L = Load resistor

Feedback network

- This feedback network consists of R-C circuit. It provides necessary damping to the pen motor.

Auxiliary Amplifier

- It is connected between the lead selection logic and RL (Right Leg) of the patient.
- The impedance of all the electrodes is not equal.
- The differential amplifier used in pre amplifier block is not sufficient to completely eliminate the common mode signals.
- So, auxiliary amplifier is used to reduce common mode signal.
- The output of auxiliary amplifier is connected with right leg.
- So, this output drives the body to zero common voltage.
- So, noise is reduced.
- Hence, CMRR ratio is also increased.

Output Display Unit

- CRO or paper chart recorder is used as output unit.
- Generally, paper chart recorder is used.
- Pen motor is used in output and pen motor is used in this recorder.
- The paper speed = 25 mm/s in US manufacturing system.
- Paper speed = 50 mm/s in European ECG machines.

9.5 Analysis of ECG waveform

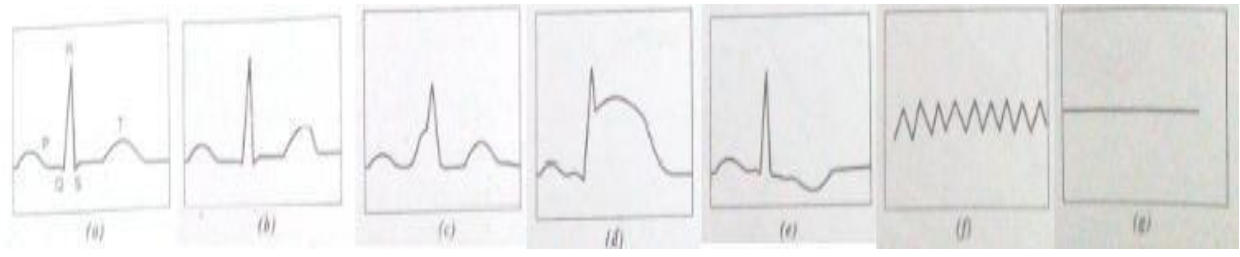

Fig. 9.16 Analysis of ECG waveform

- Fig (a) shows normal ECG waveform
- Fig (b) shows first degree AV block. Here PQ period has prolonged conduction time. (> 0.22 s)
- Fig (c) shows that widening of QRS complex. (QRS period > 0.1 s)

- Fig (d) shows the elevation occur in ST period. It results myocardinal infraction.
- Fig (e) shows the negative T-wave (normally it is positive). It results coronary insufficiency.
- Fig (f) shows the completely different ECG waveform. It is appeared as triangular waveform. It is due to ventricular fibrillation. It may lead to death. It should be immediately cured by defibrillator.
- Fig (g) shows the straight line. If the patient is dead, this waveform is obtained.

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10. Electro Encephalography (EEG)

With neat diagrams, explain the schematic diagram of EEG machine. Also, show the recording method of Unipolar and Bipolar EEGs. ***[May/June 2016][Nov/Dec 2013]***

10.1 Introduction

- Electro Encephalography is the study of the electrical activity of the brain.
- The biological name of brain is Encephalon.
- In EEG measurement, electrical activity of brain is measured from electrodes which are placed on the scalp.
- Before studying about EEG measurement, we have to know about the source of EEG signals.
- This source is nothing but brain.

10.2 Anatomy of the Brain

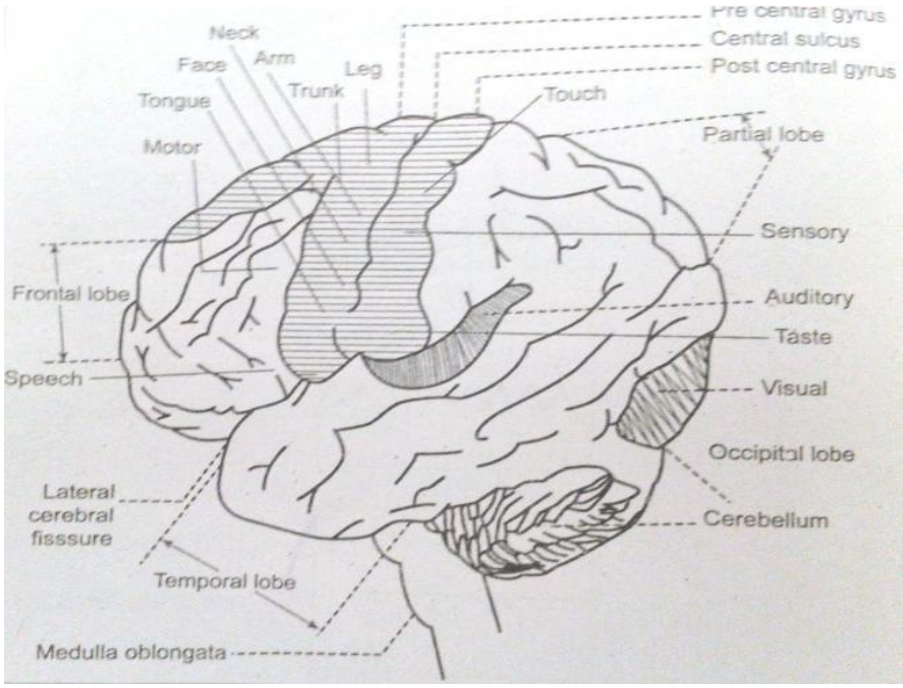

Fig.10.1 Anatomy of brain

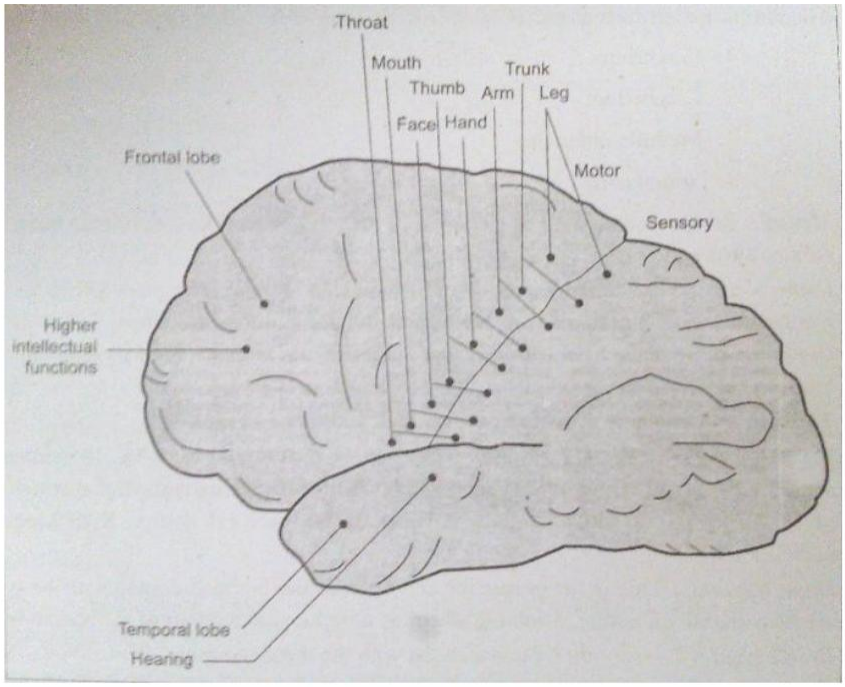

Fig. 10.2 Structure of brain

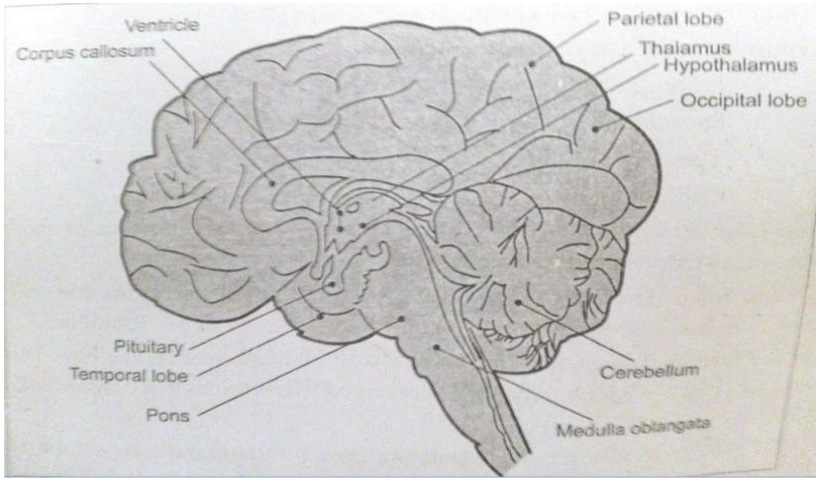

Fig. 10.3 Structure of brain

- The brain consists of four parts:
    1. Cerebrum
    2. Cerebellum
    3. Medulla oblongata
    4. Spinal cord
- Medulla is associated with the control of the functions like breathing, heart rate, kidney functions, etc.
- Pons is an interconnecting area.
- Some of nuclei in Pons are responsible for face expressions.
- Some relays in pons are responsible for auditory system.
- Cerebellum plays a vital role in the ability of the human being to maintain their balance.
- Thalamus contains many relays for visual, auditory systems.

- ***RAS (Reticular activation system):***
  - ✓ Thalamus is surrounded by RAS.
  - ✓ It receives the excitation from all of the sensory inputs.
  - ✓ RAS is not able to distinguish that which type of sensory input is activated.
  - ✓ But, RAS alerts the cerebral cortex.RAS keeps the person alert.
- ***Hypothalamus:***
  - ✓ This is the center for emotions in the brain.
  - ✓ It contains nuclei which are responsible for eating, drinking, sleeping, emotional behavior of the human being.
- ***Basail gaglia:*** It is in indirect connections with the motor neurons.
- ***Cerebral cortex:***
  - ✓ This is the important part of cerebrum.
  - ✓ It contains 9 -12 billion neurons in human brain.
  - ✓ Cortex is divided into various lobes.
- The cerebrum consists of two hemispheres, separated by a tissue.
- The hemisphere consists of 4 different lobes:
  1. Frontal lobe
  2. Parietal lobe
  3. Temporal lobe
  4. Occipital lobe

Frontal Lobe:

- ✓ Primary motor neurons lead to the various muscles of the body.
- ✓ The frontal lobe is responsible for intelligence.

Prefrontal lobe:

- ✓ The forward part of the brain contains neurons for special motor control functions like eye movement control.
- ✓ It is known as prefrontal lobe.

Occipital lobe:

- ✓ It is located at the back side of the head over cerebellum.
- ✓ This lobe has the visual cortex in which patterns are received from retina.
- ✓ It is responsible for vision centre.

Temporal lobe:

- ✓ Audio sensory inputs are traced to temporal lobes of the cortex.
- ✓ It is responsible for hearing centre and it is also used for the storage process in long term memory.

Olfactory bulb:

- ✓ It is near the center of the brain.

It is responsible for the perception of smell.

Parietal lobe: It contains sensors (afferent) nerves and motor centre (efferent) nerves.

10.3 Action Potential of the Brain

- Inhibitory Post Synaptic Potential (IPSP)
- Excitatory Post Synaptic Potential (EPSP)

- The resting potential along with a nerve fiber is used to transmit the information from one end to other.
- If the transmitter substance is inhibitory, then the membrane potential of the receptor neuron increases in a negative direction. So that it is less likely to discharge. This induced potential change is called as ***Inhibitory Post Synaptic Potential (IPSP).***
- If the transmitter substance is excitatory, then the receptor membrane potential will increase in a positive direction. So that it is more likely to discharge and produces a spike potential. This induced potential change is called as ***Excitatory Post Synaptic Potential (EPSP).***

Evoked Potential

- These are the potentials developed in the brain as the responses to external stimuli like light, sound, etc.
- The external stimuli are detected by sense organs that cause some changes in the electrical activity of the brain.
- The term "Event Related Potential" is also used, because these are some changes that are evoked by an external stimulus, but are related to an event.

10.4 Placement of electrodes in EEG measurement

Draw and explain the 10 – 20 electrode system used for EEG measurement. [April/May 2018] [Nov/Dec 2018][Nov/Dec 2017][April/May 2017]

Generally, 10 – 20 electrode placement system is used. In this system, the distance between 2 electrodes is 10% and 20% of the distance between specified points on the scalp.

(a) Anterior-Posterior (Front-Back) Measurement:

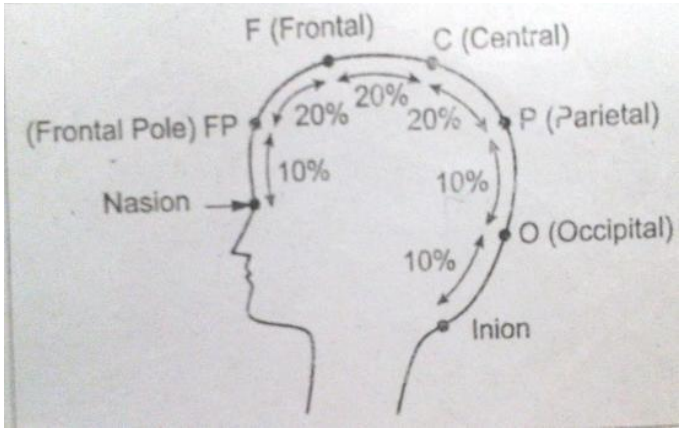

Fig 10.4. 10 – 20 Electrode placement system

The distance between the Nasion and Inion over the head is divided into 5 points:

1. ***Front pole (FP):*** 10% of Nasion-Inion distance above Nasion.
2. ***Frontal (F):*** 20% of Nasion-Inion distance from FP.
3. ***Central (C):*** 20% of Nasion-Inion distance from F.
4. ***Parietal (P):*** 20% of Nasion-Inion distance from C (Central point)
5. ***Occipital (O):*** 10% of Nasion-Inion distance from Inion.

(b) Lateral Measurements (21 Electrode system):

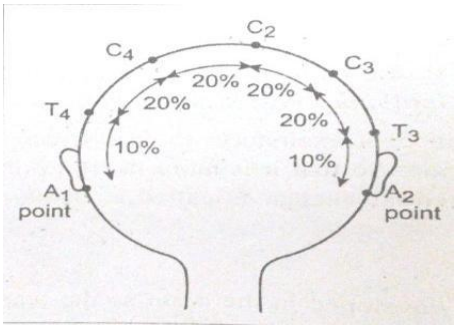

Fig.10.5 Lateral measurement

The distance is measured from left to right points. (From left ear to right ear)

1. ***Temporal points (T):*** 10% of the distance from the pre-auricular point (from one ear)
2. ***Central points (C):*** 20% of the same distance.

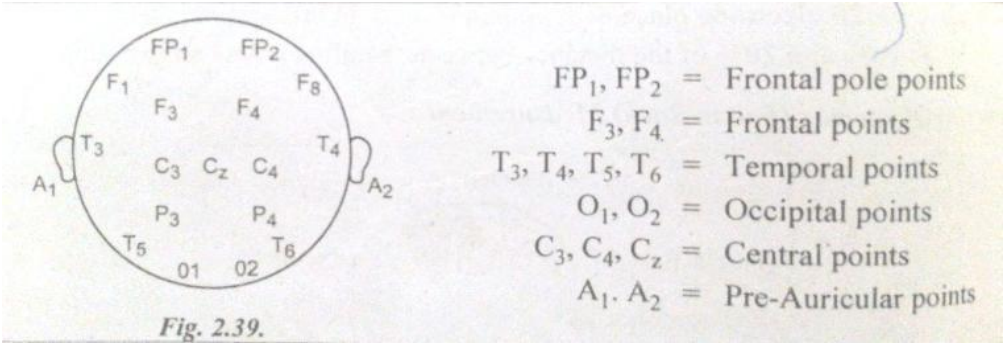

Fig. 2.39.

10.5 EEG Recording Setup:

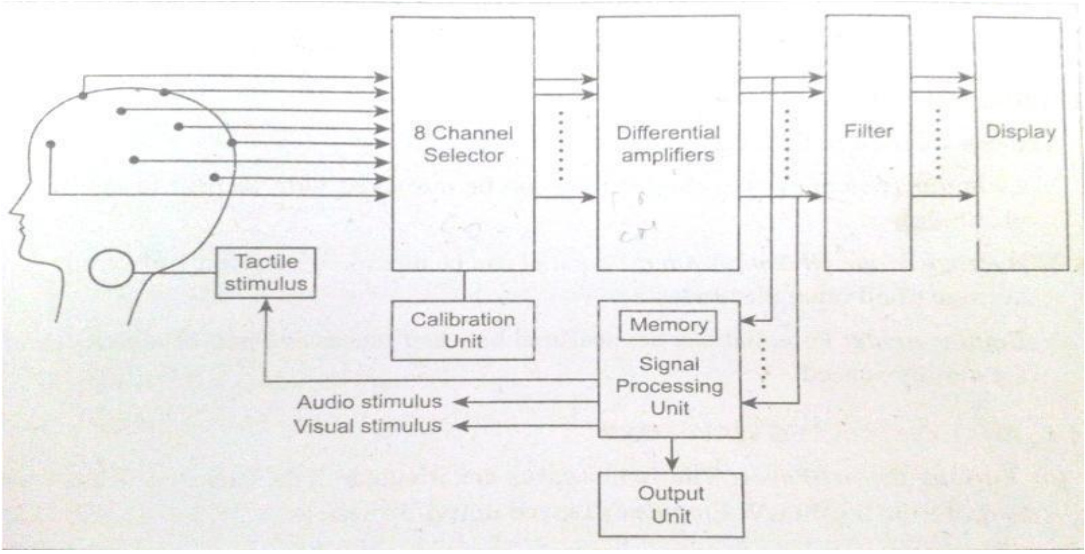

Fig.10.6 Block Diagram of EEG

- The above block diagram shows the EEG recorder.
- Here, 21-electrode system is used.
- These electrodes are connected with eight channel selector.
- Eight channel selector outputs are connected with differential amplifier unit.
- This unit is used to reduce the noise and these are used as preamplifiers.
- A.C interference creates 50 Hz of noise that can be reduced by this differential amplifier.
- The differential amplifiers have good CMRR (>80db) and input impedance greater than 10 MΩ.
- The outputs from differential amplifier are connected with the signal processing unit.
- These outputs are stored in a memory for further processing.
- After processing, the data is displayed in the output unit.
- Some extra facilities are also available in this EEG recorder.
- Potential generated from sensory parts of the brain can also be recorded by using this EEG recorder.
- So, signal processing unit outputs are connected with audio stimulus, visual stimulus, and tactile (touch) stimulus.
- EEG response for such a stimulus is measured.
- The time delay between stimulus and the response from the brain can also be measured by using this EEG unit.
- The outputs from the differential amplifier are connected with the filter bank unit.
- It consists of low pass filter, high pass filter, band pass filter.
- These are used to select different types of brain waves without noise.
- The outputs of the filters are connected with Display Recorder Unit.
- Pen recorders with 8 pens are used here. One pen is dedicated for each channel.
- The normal paper speed in this recorder = 30 mm / second.

10.6 EEG Recording Modes

3 modes are used in EEG recording.

1. ***Unipolar*** (potential of each electrodes can be measured with respect to one reference electrode).

2. ***Average Mode (Wilson mode)***: Potential can be measured between 1 electrode and the average of all other electrodes.

3. ***Bipolar mode:*** Potential can be measured between successive pair of electrodes which are closely spaced.

10.7 Analysis of EEG waveform:

***Explain the analysis of EEG waveform. [May/June 2016]**

(a) Various Brain waves:

The brain waves are irregular. The intensity of brain waves ranged from 0 – 300 μV. Frequency ranged upto 1 / 50 sec.

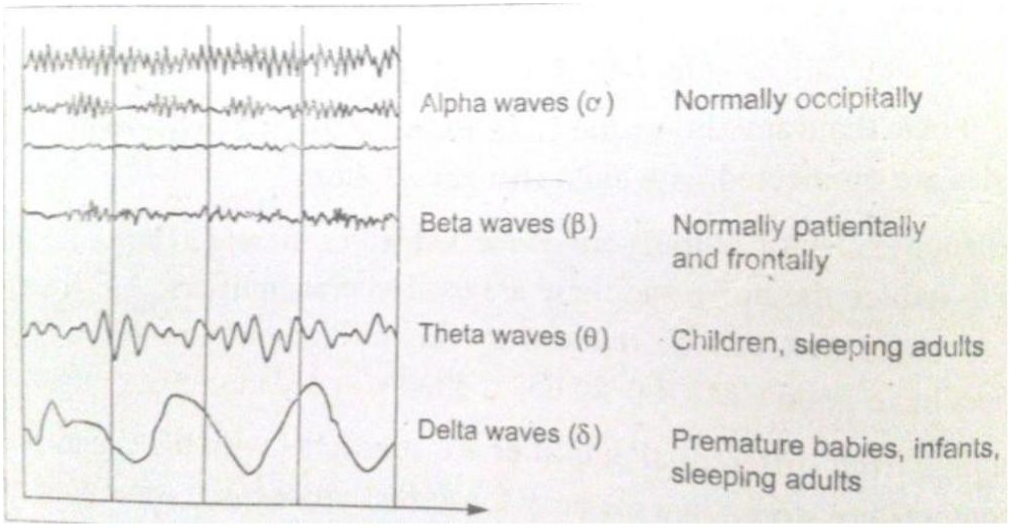

Fig.10.7 Brain waves

Various waves can be measured which are given below.

Alpha waves

- It is recorded from occipital region of brain.
- Its frequency range is 8 – 13 Hz.
- It can be measured from the normal person when he is awake (and he is in a resting position).
- Its amplitude is 20 – 200 μV (mean amplitude = 50 μV) when the person is sleeping.
- These waves are not appeared.

Beta waves (β waves)

- Its frequency range is 13 – 30 Hz. (frequency may be increased upto 50 Hz).
- It is recorded from parietal and frontal regions of the scalp.

Theta Waves (θ Waves)

- This wave is recorded from parietal and temporal region of the scalp.
- Its frequency range is 4 – 8 Hz.
- Usually this wave is measured from children.
- It can be measured from adults when they are in emotional stress.

Delta waves (δ waves)

- It is occurred in cortex of the brain.
- Its frequency range is 0.5 – 4 Hz.
- It is occurred in premature babies and when the person is in deep sleep.

Analysis of EEG Waveform:

By using EEG waveforms, doctors can easily diagnose brain tumors, epilepsy, etc.

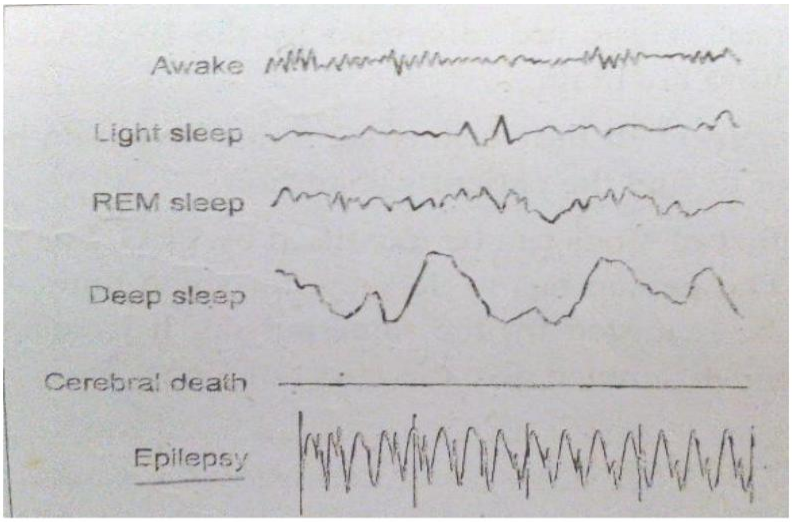

Fig.10.7 ECG waves

- Fig (a) shows EEG waveform when the person is awake.
- Fig (b) shows EEG waveform when the person is in light sleep.
- Fig (c) shows EEG waveform when the person is in dream. It is known as rapid eye movement (REM sleep)
- Fig (d) shows EEG waveform when anesthesia is applied to a person and when the person is in deep sleep.
- Fig (e) shows EEG waveform when the person is having cerebral death.
- In these conditions, ECG waveform is normally obtained, because his respiration and circulation are normal.
- Only brain waves are not obtained.
- Fig (a) shows EEG waveform due to epilepsy. Epilepsy is the symptom of brain damage.
- It may be due to defect in birth delivery (or) it may be due to head injury when the person met with an accident.
- ***Epilepsy*** is defined as synchronous discharge of large group of neurons often including the whole brain.
- If the person is having the brain tumour, EEG waveform is not obtained.
- If the tumor is large the electrical activity from the brain is affected.

10.8 Applications of EEG

EEG is helpful in finding

- Epilepsy
- Anesthetic level
- Brain injury
- Monitor during surgery
- Effect of yoga

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11. Electro Myograph (EMG)

Discuss in detail about Electro Myograph (EMG). ***[May/June 2016]***

Describe the typical EMG waveform and its characteristics. ***[April/May 2017]***

11.1 Introduction

- Electromyograph is an instrument used for recording the electrical activity of muscles to determine whether the muscle is contracting or not.
- Study of neuromuscular function is also possible by using EMG.
- Muscular contractions are caused by the depolarization of muscle fibers.
- Similarly, the recording of peripheral nerve"s action potentials is called as electroneurography.

11.2 Electrodes used for EMG

- Two types of electrodes are used in EMG measurement.
- ***Surface Electrodes:***
  - ✓ Usually this electrode is used for EMG.
  - ✓ But, by using this electrode, it is not possible to take the deeper potential.
  - ✓ So, needle electrodes are used to take such a potential.
- ***Needle Electrodes:***
  - ✓ These are inserted into tissue or closer to tissue to measure the electrical activity of muscle.

11.3 EMG Recording System

- EMG potentials are taken from the tissue by using electrodes.
- These EMG potentials are given to differential amplifier.
- This is the high gain amplifier.
- Its frequency range is given as 10 Hz to 10 KHz (and above also).
- Bandwidth of EMG is large.
- CMRR of this differential amplifier is 80 to 100 db.
- Input impedance of this amplifier is 10 MΩ.
- Here there is no lead selector switch.
- Because, only 2 electrodes are available.
- The output of the differential amplifier is given to loudspeaker system, tape recorder and CRO.

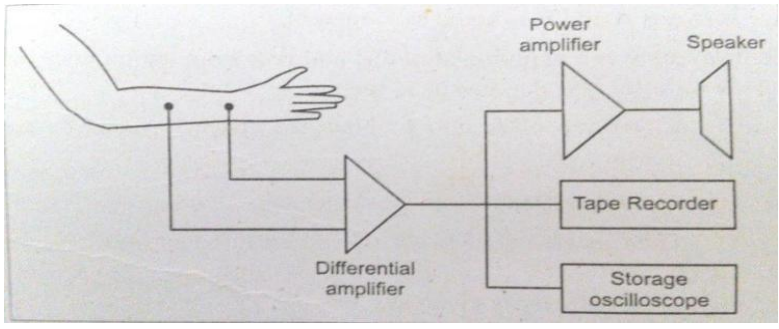

Fig.11.1 EMG Recording system

- Before giving the output of differential amplifier to loud speaker, it is given to power amplifier.
- Power amplifier amplifies the signal that is received by loud speaker.
- The amplified signal from the output of the differential amplifier is displayed by using CRO.
- Here storage oscilloscope is used.
- Output can be displayed and the same can be stored in the CRO.
- The signal from the differential amplifier is recorded by using tape recorder.
- It is used for future purpose.

11.4 Measurement of conduction velocity in motor nerves

- In modern EMG systems, nerve conduction time and nerve velocity are measured.
- For this measurement, initially nerve is stimulated and EMG is measured.

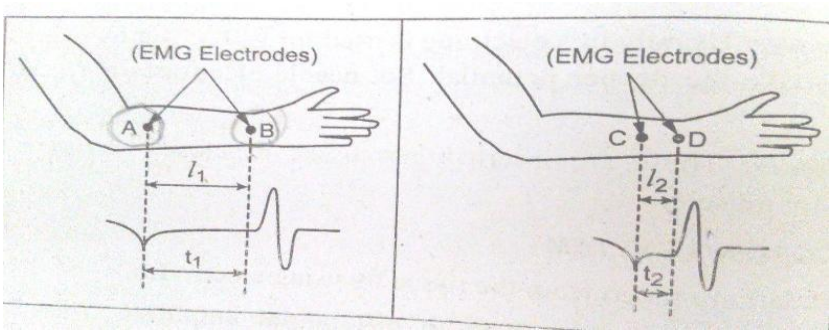

Fig.11.2 Conduction velocity measurement

- This conduction velocity is used to indicate the location and type of nerve lesion.

11.5 Steps Involved in Measurement of Conduction Velocity

- Stimulate is applied at point A.
- Electrical activity of muscle is measured at point B.
- The space between A and B is noted as l_1 meters.
- The time delay between applying stimulus and receiving action potential is known as latency.
- This time delay is denoted as t_1 second.
- Now change the position of A into C.
- Now the space is reduced.
- It is noted as l_2 meters.
- The time delay noted is t_2 second.
- Usually, $l_2 < l_1$ and $t_2 < t_1$.
- Now, the conduction velocity is given as, $V = \dfrac{l_1 - l_2}{t_1 - t_2}$
- Usually, V = 50 m/sec
- If V<40m/s, it means there is some disorder in nerve conduction.
- Thus conduction velocity is measured in motor nerves.

11.6 Applications of EMG

EMG is used in the field of:

- Electro physiological testing
- Clinical neurophysiology
- Neurology
- Psychiatry

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12. PHONO CARDIOGRAM (PCG)

How the PCG signals are generated? Explain the measurement of PCG. ***[April/May 2011]***

12.1 Introduction

- The graphical record of heart sound is known as Phono cardiogram.
- Here, „Cardio" means the heart.
- The device which is used to measure heart sound is known as phono cardiograph.
- ***Auscultation:*** The technique of listening sound produced by organs and vessels of the body is known as ***Auscultation.***
- In PCG, different types of heart sounds are measured.
- These heart sounds are due to the vibrations set up in the blood inside the heart by the sudden closure of valves.
- In abnormal heart, additional sounds are heard between the normal heart sounds.
- These additional sounds are known as murmurs.
- ***Murmurs*** are generally caused by improper opening of the valves or by regurgitation. (It results when the valves do not close completely and allow some backward flow of blood).

12.2 Classification of Heart sound

Heart sound is divided into 4 types

(a) Valve closure sound

(b) Ventricular filling sound

(c) Valve opening sound

(d) Extra cardiac sound

(a) Valve closure sound

- This sound occurs at the beginning of systole and at the beginning of diastole.

(b) Ventricular filling sound

- This sound is occurred at the time of filling (of blood) of the ventricles.

(c) Valve opening sound

- This sound occurs at the time of opening of atrio-ventricular valves and semi lunar valves.

(d) Extra cardiac sound

- This sound occurs in mid systole (or) late systole (or) early diastole.

Systole: The contraction of the heart muscle. The systolic pressure is 120mm of Hg.

Diastole: The relaxation of the heart muscle. The diastolic pressure is 80mm of Hg.

12.3 Origin of Heart Sounds

The following table gives various sounds and its characteristics.

Name of heart sound	Frequency	Duration	Asculatory area (Best heard area)	Reason for producing sound
First heart sound	30 – 50 Hz	0.1 to 0.12 sec	At apex of mid pericardium	It is due to sudden closure of mitral and tricuspid valve.
Second heart sound	Upto 250 Hz	0.08 to 0.14 sec	At aortic and pulmonary area	It is due to vibration set up by closure of semilunar valves.
Third heart sound	10 to 100 Hz	0.04 to 0.08 sec	At apex and left lateral position after lifting the legs.	Occur when ventricle relaxed. (And at this time atrio-ventricular valve is open).
Fourth heart sound (Atrial sound)	10 to 50 Hz	0.03 to 0.06 sec	Usually this sound is not audible in any area.	It is due to accelerated flow of blood into ventricles (or due to atrial contraction).

12.4 PCG Recording System

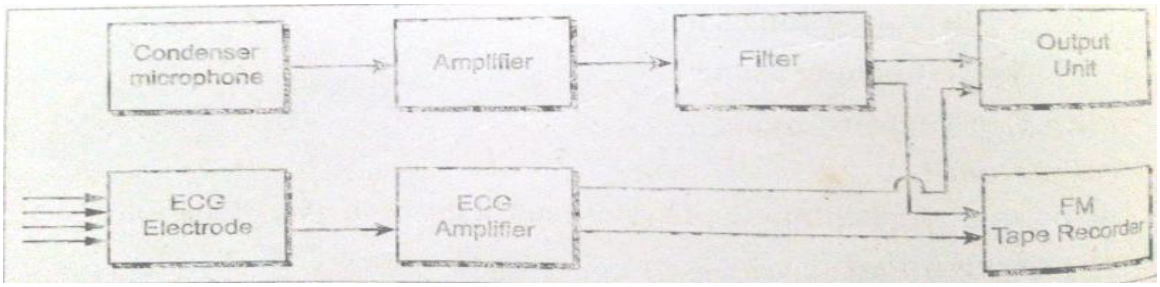

Fig. 12.1 PCG recording system

- The block diagram of PCG recording system is shown in the fig above.
- Microphone is used to convert heart sound into the electrical signals.
- Certain positions are recommended to pick up heart sound by using microphone.

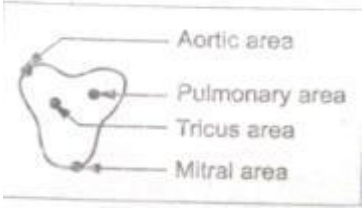

Fig. 12.2 Positions recommended for placing microphone

- The electrical signal picked by the microphone is amplified by the amplifier block.

- The amplified output is given to filter block.
- Here high pass filter is used.
- Its cut off frequency is 1 KHz.

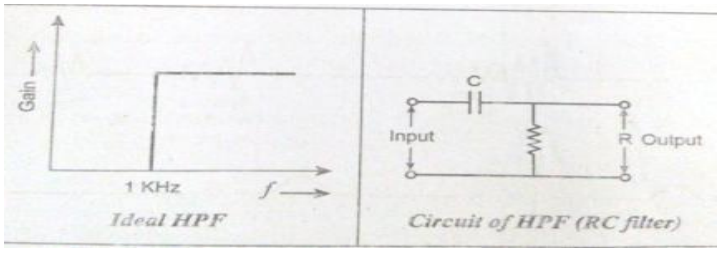

Fig.12.3

- Here, ECG electrode system and ECG amplifiers are used for reference for PCG.
- So, ECG and PCG outputs are connected to FM tape recorder and output display unit.

12.5 Types of microphones used in PCG

- ***Air-coupled microphone*** – Movement of the chest is transferred through the air cushion. It provides low mechanical impedance to the chest.
- ***Contact microphone*** – It is directly coupled to the chest wall and provides high impedance, high sensitivity, and low noise. Its light weight is also one of the advantageous factors.

12.6 Relationship between Heart Sounds and Function of Cardiovascular System

- The figure below shows the relationship between blood pressure, heart sounds and ECG waveforms.
- The first heart sound is developed during the opening of aortic valve and during the closing of mitral valve.
- Second heart sound is developed during the closing of aortic valve and during the opening of mitral valve.

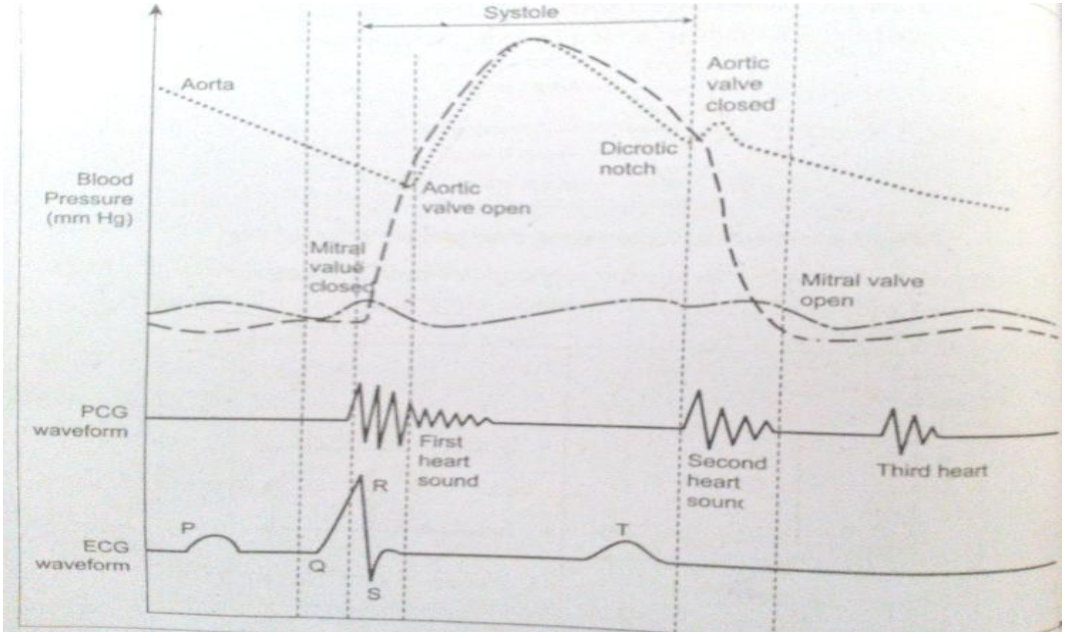

Fig.12.4 Relationship between blood pressure and heart sound and ECG waveform

12.7 PCG Waveform

Figure below shows the normal and abnormal sounds

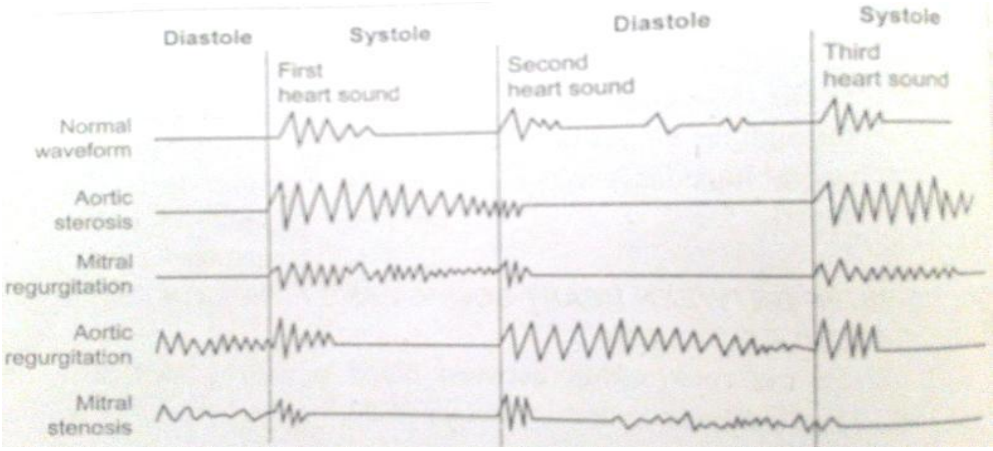

Fig.12.5 PCG waveform

- Frequency of first heart sound consists of 30 to 45 Hz.
- Second heart sound is usually higher in pitch than the first.
- Its frequency range is 50 Hz to 70 Hz.
- Third heart sound is extremely weak vibration.
- Its frequency is below 30 Hz.
- Murmur produce much high pitch sounds.
- Sometimes its frequency range is 100 Hz to 600 Hz.
- Aortic stenosis murmur occurred when the blood is ejected from the left ventricle through aortic valve due to the resistance to ejection, the pressure in the left ventricle increased.
- So, turbulent blood flow occurs.
- This turbulent blood impinges the aortic valve.
- So, intense vibration is produced. It produces loud murmur.
- ***Mitral regurgitation murmur:*** In this murmur, blood flows in backward direction through the mitral valve during systole.
- ***Aortic regurgitation murmur:*** During diastole, sound is heard. In diastole, blood flows in the backward direction from aorta to left ventricles when valves are damaged, then this sound is heard.
- ***Mitral stenosis murmur:*** This murmur is produced when blood is passed from left atrium to left ventricle. This sound is very weak.

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UNIT II BIO-CHEMICAL AND NON ELECTRICAL PARAMETER MEASUREMENT

pH, PO_2, PCO_2, colorimeter, Auto analyzer, Blood flow meter, cardiac output, respiratory measurement, Blood pressure, temperature, pulse, Blood Cell Counters.

Explain the blood pressure measurement using the following techniques

(i) Sphygmomanometer (8)
(ii) Ultrasonic (8)

Blood pressure is the most often measured and the most intensively studied parameter in medical and physiological practice.

(i) Sphygmomanometer:

- The classical method of making an indirect measurement of blood pressure is by the use of a cuff over the limb containing the artery.
- At first, 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.
- If the cuff pressure is allowed to fall further, just below the diastolic pressure value, the flow becomes normal and uninterrupted.
- The method given by korotkoff and based on the sounds produced by flow changes is the one normally used in the conventional sphygmomanometer.
- The sounds (korotkoff sound) first appear when the cuff pressure falls to just below the systolic pressure.
- The sounds disappear or change in character at just below diastolic pressure when the flow is no longer interrupted.
- These sounds are picked up by using a microphone placed over an artery distal to the cuff.

  - Phase 1: sharp thuds, start at systolic blood pressure
  - Phase 2: blowing sound; may disappear entirely (the ausculatory gap)
  - Phase 3: crisp thud, a bit quieter than phase 1
  - Phase 4: sounds become muffled
  - Phase 5: end of sounds -- ends at diastolic blood pressure

(ii) Ultrasonic:

- An occlusive cuff is placed on the arm in the usual manner, with an ultrasonic transducer on the arm over the brachial artery.
- The cuff is inflated first to above systolic pressure and then deflated at a specified rate.
- A low energy ultrasonic beam at a frequency of 2MHz is transmitted into the arm.
- The portion of the ultrasound that is reflected by the arterial wall shifts in frequency when the wall of the artery moves.
- Above systolic, the vessel remains closed due to the presence of the occluding cuff, and the monitor signals are not received.
- As the cuff pressure falls to the point where it is just over come by the brachial artery pressure, the artery wall snaps open.
- This opening wall movement, corresponding to the occurrence of the first korotkoff sound, produces a Doppler-shift which is interpreted by logic in the instrument as systolic and displayed accordingly.
- With each subsequent pulse wave, a similar frequency shift is produced until at the diastolic pressure the artery is no longer occluded.
- Its rapid motion suddenly disappears and the Doppler-Shift becomes relatively small.
- The instrument notes the sudden diminution in the amplitude of the Doppler-Shift and cuff pressure at this point is displayed as diastolic pressure.

2. Explain the principle of following:

(i) pH measurement (8)

(ii) Auto analyzer (8)

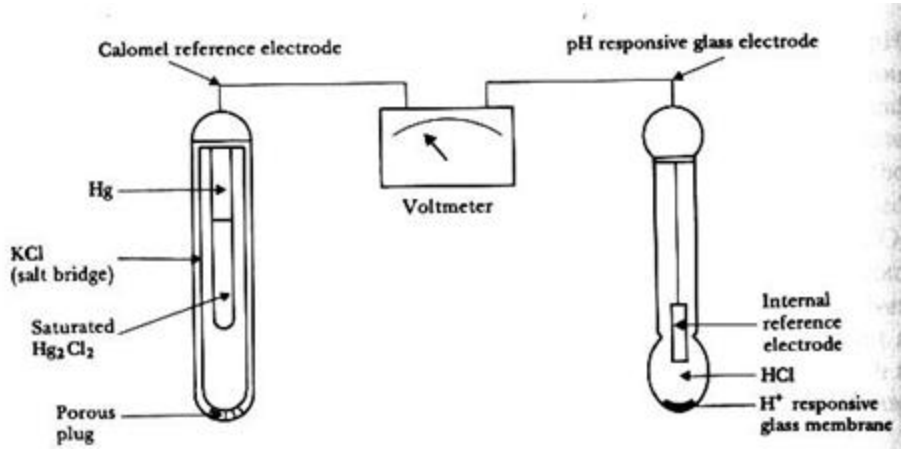
(i) pH measurement:

- The acidity or alkalinity of a solution depends on its concentration of hydrogen ions.
- Increasing the concentration of hydrogen ions makes a solution more acidic, de creasing the concentration of hydrogen ions makes it more alkaline.
- pH is thus a measure of hydrogen ion concentration, expressed logarithmically.
- Specifically, it is the negative exponent (log) of the hydrogen ion concentration

$$pH = -\log(H^+)$$

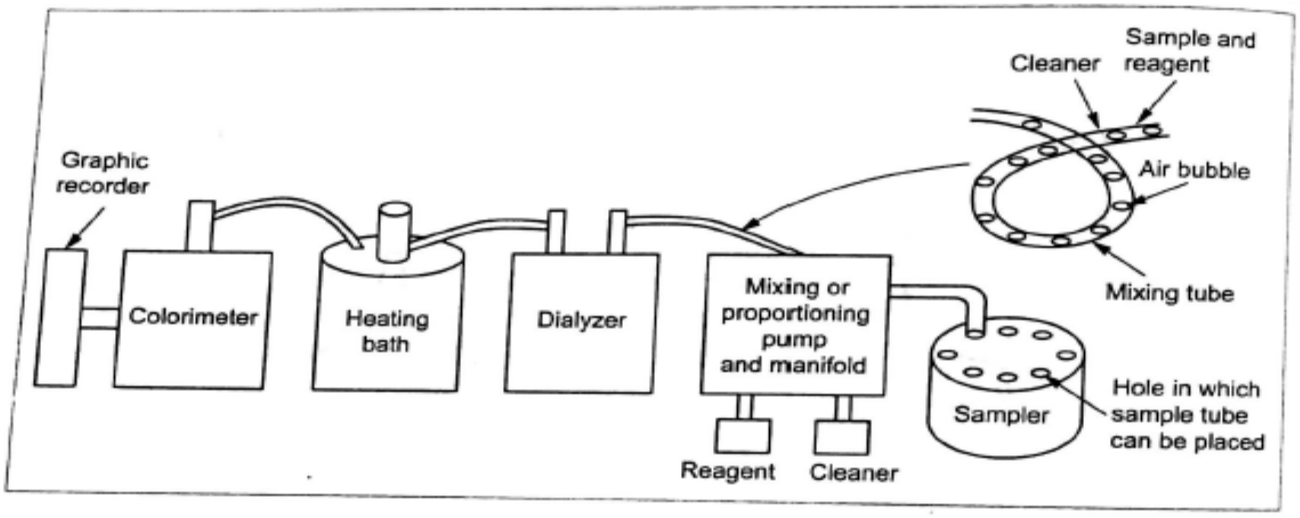
- A pH of +7 is considered a neutral solution, a pH of +6 represents an acid, a pH of +8 is an alkali.
- For making pH measurements, the solution is taken in a beaker. A pair of electrode: one glass or indicating electrode and the other reference or calomel electrode are immersed in the solution.
- The voltage developed across the electrode is applied to an electronic amplifier, which transmit the amplified signal to the display.
- The glass electrode exhibits a high electrical resistance, of the order 100-1000MΩ.
- The e.m.f measurement therefore necessitates the use of measuring circuits with high input impedance.

- Further, the high resistance of glass electrode renders them highly susceptible to capacitive pickup from AC mains.
- In order to minimize such effects, it is advisable to screen the electrode cable. The screen is usually grounded to the case of the measuring instrument.
- The error caused in pH measurement due to temperature effect can be compensated either manually or automatically.
- In manual adjustment the instrument is calibrated at 25°C.
- 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.
- It is desired to have the accuracy of a pH measurement as 0.001 pH, then the voltage must be measured with an accuracy of 0.058mV, assuming an ideal sensitivity of 58mV per pH unit.



(ii) Auto analyzer:

- The autoanalyzer sequentially measures blood chemistry and displays this on a graphic readout.
- The autoanalyzer is accomplished by mixing, reagent reaction and colorimetric measurement in a continuous stream.



Auto analyzer

Auto analyzer

- The system includes the following elements:
    1. **Sampler:** aspirates samples, standards and wash solutions to the autoanalyzer system.
    2. **Proportioning pump and manifold:** introduces samples with reagents to effect the proper chemical color reaction to be read by the colorimeter. It also pumps fluids at precise flow rates to other modules, as proper color development depends on reaction time and temperature.
    3. **Dialyzer:** separates interfacing substances from the sample material by permitting selective passage of sample components through a semipermeable membrane.
    4. **Heating bath:** heats fluids continuously to exact temperature. Temperature is critical to color development.
    5. **Colorimeter:** monitors the changes in optical density of the fluid stream flowing through a tubular flow cell. Color intensities proportional to substance concentrations are converted to equivalents electrical voltages.
    6. **Recorders:** converts optical density electrical signal from the colorimeter into a graphic display on a moving chart.
- The heart of the autoanalyzer system is the proportioning pump. This consists of a peristaltic pump.
- Air segmentation in the mixing tube separates the sample/ reagent mixture from the cleaning fluid and other samples.
- As these air separated fluids traverse the coil of the mixing tube, effective mixing action is achieved.

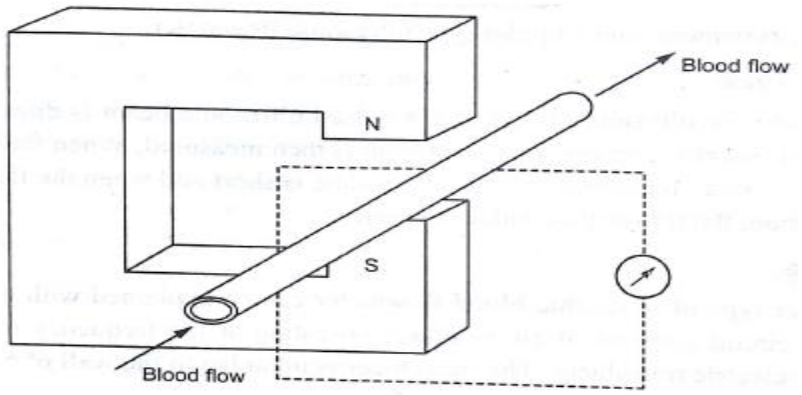
3. Explain the working principle of electromagnetic blood flow meter. (16)

Blood flowmeters are used to monitor the blood flow in various blood vessels and to measure the cardiac output.

- The electromagnetic blood flowmeter is at present the most widely used device for measuring pulsatile blood flow.
- The fundamental quantity measured by these flowmeter is blood velocity. It is sutable for determining the instantaneous flow rates in intact vessels.

Basic principle:

- Continuous measurements of blood velocity can be obtained by placing the electromagnetic probe around arteries and veins.
- The resulting velocity can be correlated with blood flow.
- In the ideal situation the flow values obtained should be independent of velocity distribution and the electrical conductivity of the blood vessel and the surrounding instruments.
- The electromagnetic flow probe operates as a result of Faraday's law of induced e.m.f
- Blood is a conductor of electricity. Consequently when a magnetic field is applied to a blood vessel, the blood flow in the vessel causes an electrical field to be induced in a direction mutually perpendicular to the direction of the applied magnetic field and the blood velocity.



Principle of Electromagnetic flowmeter

- If the magnetic field is assumed to be uniform, the induced electrical field strength E, is proportional to the magnitude of the magnetic field B, and the mean blood velocity V.

$$E = VB\sin\theta$$

where θ is the angle between the direction of the applied magnetic field and that of the blood velocity.

- The direction of the magnetic field is generally arranged to be perpendicular to the direction of blood velocity so that $\sin\theta = 1$ and hence E = VB and the largest signal is obtained.

- The induced electric field strength is measured by means of two electrodes mounted in opposite side of the blood vessel.
- The potential difference 'ε' between these electrodes can be obtained from the equation

$$\varepsilon/2r = E = VB$$

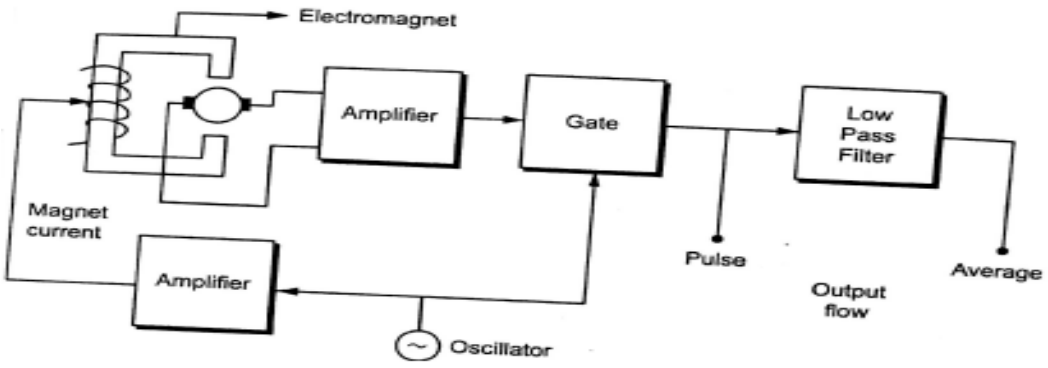
where 'r' is the radius of the blood vessel. Thus the mean velocity is given by

$$V = \varepsilon/2rB$$

- If the radius of the blood vessel remains constant, blood flow rate 'F' which is the volume of the blood flowing per second can be written as

$$F = V\pi r^2 = \pi r^2 \varepsilon/2rB = \pi r \varepsilon/2B$$

- Thus the blood flow rate is proportional to the induced e.m.f 'ε' if the magnetic induction 'B' remains constant.
- Flowmeters using permanent magnets and DC amplifiers have been found to give rise to errors due to the presence of electrical potentials which cannot be distinguished from flow induced potentials.
- Hence these have been discarded and replaced by electromagnets excited by alternating current.



Block diagram of blood flowmeter

- With a.c field flow meters an alternating signal is detected at the pickup electrodes, the signal is amplified and then under goes synchronous rectification.
- This result in a good signals to noise ratio and prevents the development of polarization effects.
- Alternating magnetic field system also produces unwanted signals. These are independent of flow and are proportional to the rate of change of the magnetic field.
- The error signals are resulted. Thus the output consist of a small wanted floe=w signal and unwanted (noise) signal called transformer e.m.f
- The potential difference between the two electrodes can therefore be written as

$$\varepsilon = \frac{2BF}{\pi r} + k\frac{dB}{dt}$$

$$= (\text{flow signal}) + (\text{transformer e.m.f})$$

where 'k' can be considered as a constant.

- The size of the second term depends on the design of the transducer and on the uniformity of the fluid but may be as much as ten times the first.
- With the sinusoidal excitation the transformer e.m.f has the same shape as the flow signal.
- This effects may be reduced by the addition of a voltage, k' $\frac{dB}{dt}$.
- The potential difference between the electrodes then becomes

$$\varepsilon = \frac{2BF}{\pi r} + (k\text{-}k')\frac{dB}{dt}$$

- If k = k' the signal is extracted without noise. For sufficient amplification, the signal is modulated.
- After amplification and demodulation, the signal proportional to 'F' can then be extracted.
- However, if square wave excitation is employed, the transformer voltage consist of two sharp spikes of opposite polarity coinciding with the leading and trailing edges of the square wave.
- The source impedance of an electromagnetic flowmeter is the sum of the electrode impedance and the impedance of the fluid.
- Two factors affecting source impedance are
  (i) Alternation in polarization impedance at the electrode interface
  (ii) Change in the medium adjacent to the electrodes.

4. Explain the blood flow measurement using following technique

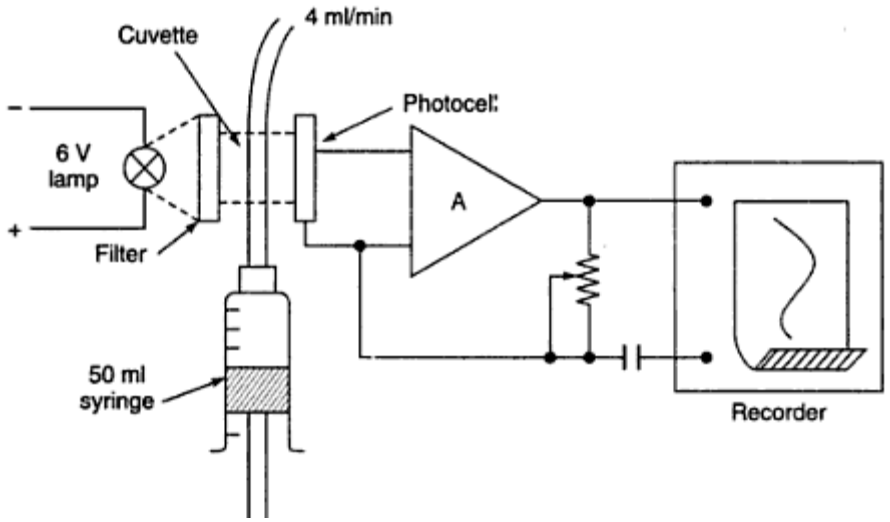
(i) Dye dilution (8)
(ii) Thermal dilution (8)

Cardiac output is the quantity of blood delivered by the heart to the aorta per minute. It is the major determination of oxygen delivery to the tissues.

(i) Dye dilution:

- The most commonly used indicator substance is a dye. Indocyanine green dye which is usually employed for recording the dilution curve.
- The procedure consists in injecting the dye into the right atrium by means of a venous catheter.
- 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.

- Densitometer which can be used for the quantitative measurement of dye concentration. The photometric part consist 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 amplitude of 805nm is used to permit only infrared radiation to be transmitted.
- This wavelength is the isobestic wavelength for hemoglobin at various levels of oxygen saturation.
- The sampling syringe has a volume of 50ml/min. The output of the photocell is connected to a low drift amplifier.
- A potentiometric recorder records the amplifier signal on a 200nm wide recording paper and a paper speed of 10mm/s.



Diagrammatic representation of Densitometer

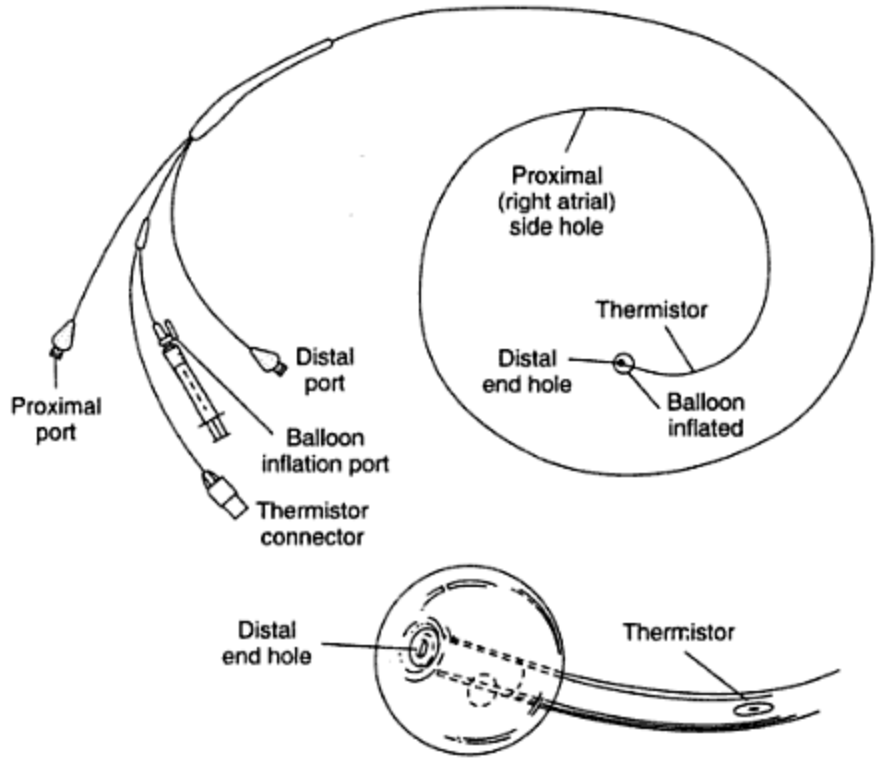
- In the recording of dye dilution curves, it is generally necessary that the densitometer be at some point removed from the site of interest.
- A catheter is used to transport the blood containing the dye from the sampling site, inside the cardiovascular system, to the densitometer located outside the body.
- Sampling through the catheter densitometer system distorts the concentration time curve.
- First, the velocity of flow within the catheter is not uniform, which causes the dye to mix within the tube as it travels downstream.
- The mixing is a function of the flow rate and the volume of the sampling system, the viscosity of the sampled fluid and the shape of the configuration of the sampling tube.
- The second source of distortion is the measuring instrument itself, which may not have response characteristics fast enough to record instantaneous dye concentration as it actually occurs in the lumen.
- To reduce distortion, computer software based corrections have been devised.

(ii) Thermal dilution:

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

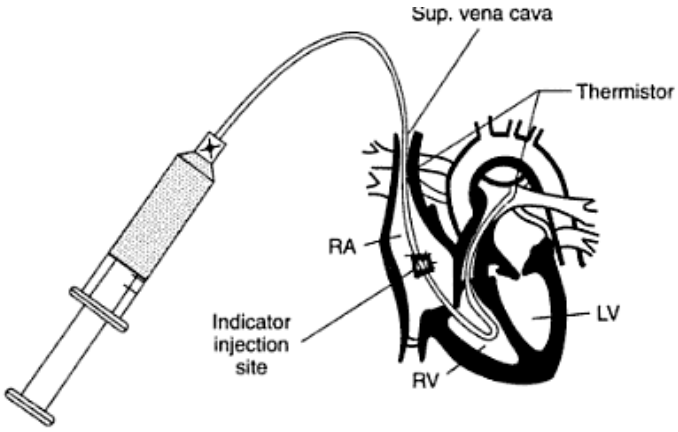
$$\text{Cardiac output} = \frac{\text{a constant} * (\textit{blood temperature} - \textit{injectate temperature})}{\textit{area under dilution curve}}$$

- Cardiac output is measured by determining the resultant change in the blood temperature in pulmonary artery.
- For this purpose 2 thermistors are used. One of them is placed in the inferior vena cava with the help of a catheter and the second one is placed in the pulmonary artery.
- A known quantity of known dextrose solution or cold saline is injected into inferior vena cava. The thermistors determine the temperature of blood entering the heart via inferior vena cava and the temperature of blood leaving the heart via pulmonary artery.
- From the values of temperature, cardiac output is measured by applying indicator dilution technique.
- A multi- lumen thermistor catheter, known today as the Swan-Ganz triple lumen balloon catheter.
- The balloon located at or near the tip is inflated during catheter insertion to carry the tip through the heart and into the pulmonary artery.
- One lumen terminates at the tip and is used to measure the pressure during catheter insertion.
- Later, it measures pulmonary artery pressure and intermittently, pulmonary- capillary wedge pressure.
- A second lumen typically terminates in the right atrium and is used to monitor the right atrial pressure and to inject the cold solutions for thermal dilution.
- A third lumen is used to inflate the balloon. For use with thermal dilution, the pulmonary-artery catheter carries a thermistor proximal to the balloon.
- The thermistor is encapsulated in glass coated with epoxy to insulate it electrically from the blood.
- The wires connecting the thermistor are contained in a fouth lumen.



Swan-Ganz-Catheter

- 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 catheter probe.
- The injectate temperature is also sensed by a thermistor and the temperature difference between the injectate and the blood circulating in the pulmonary artery is measured.
- The reduction in temperature in the pulmonary artery is integrated with respect to time and the blood flow in the pulmonary artery is then computed electronically by an analog computer which also applies correction factor.



Cardiac output – Thermal dilution setup

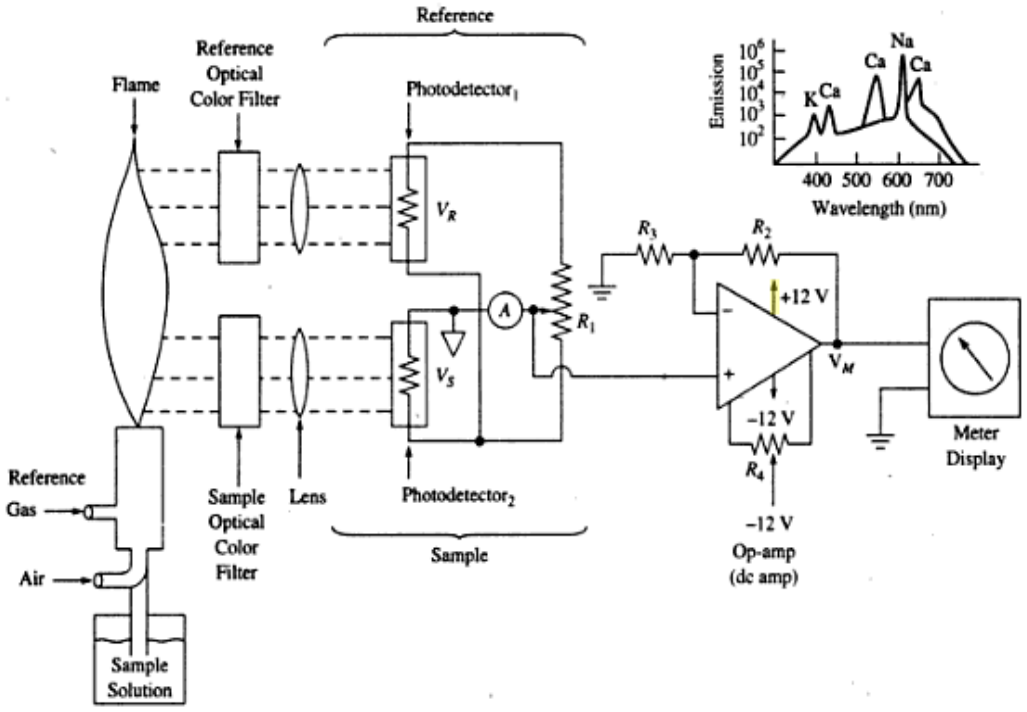
5. Explain the following

(i) Photometer (8)
(ii) Measurement of $PHCO_3$ (8)

(i) Photometer:

- The photometer measures the colour concentration of a substance in the solution. This is accomplished electronically by detecting the colour light intensity passing through a sample containing the reaction products of the original substance and a reagent.
- (a) Flame photometer
  (b) Spectro photometer

(a) Flame photometer:

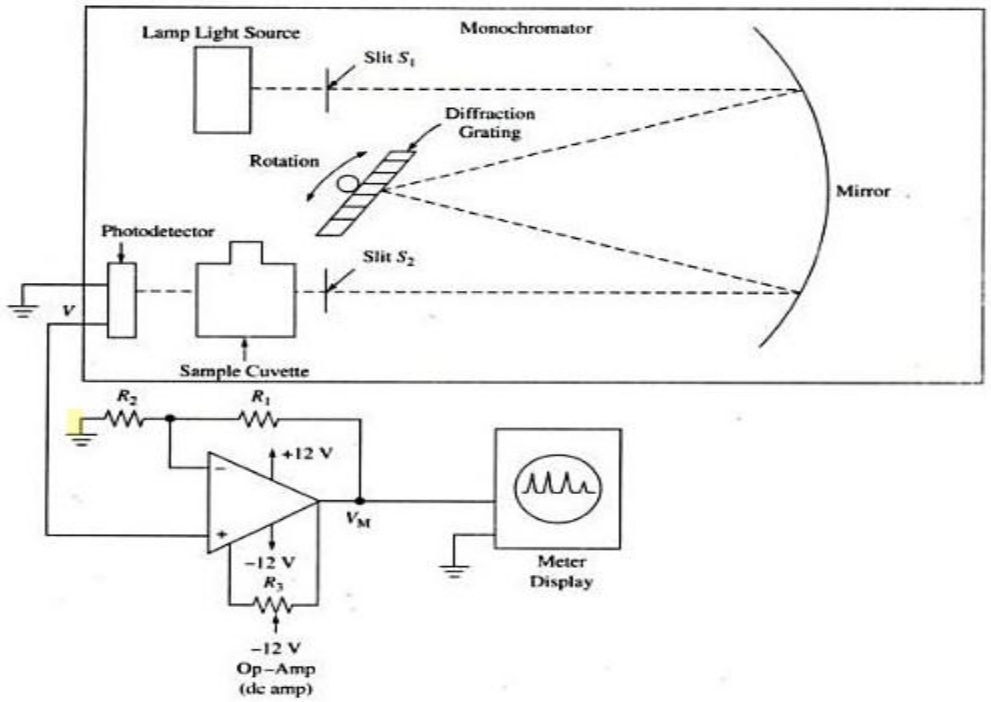


Flame Photometer

- The flame phtotmeter measures the colour intensity of a flame that is supported by oxygen and a specific substance.
- The basic schematic shows that a reference gas containing a lithium salt causes a red light to shine on the reference photodetector through the reference optical filter.
- A yellow or violet light from sample solution or potassium falls on the sample photodetector.

- Basically the flame photometer is calibrated in a manner similar to that of the colorimeter. However, continuous calibration can be accomplished by inspiration of air and lithium. The output is read in units of sodium or potassium concentration.
- Maintenance includes calibration adjustment and replacement of bulbs and photodetectors.
- Aspiration devices and flame chambers occasionally require cleaning.

(b) Spectro photometer:



Spectrophotometer

- The spectrometer measures the light absorption by a liquid substance at various wavelengths. From this, the components of an unknown material can be determined or the concentration of number of known substances can be measured.
- A monochromator uses a diffraction grating or prism to disperse the light from the lamp (slit S_1).
- The light is broken into its spectral components as it arises from slit $S_2$and falls on the sample in the cuvette. Narrower slits give rise to shorter wavelength.
- The angle of the diffraction grating determines light wavelength if all other parameter are fixed and the mirror reduces equipment size.
- Light output, phtodetector sensitivity and sample substance absorption change with wavelength and this necessitated zero calibration for each wavelength measurement. The ratio of path absorbance can be computed.

(ii) Measurement of $PHCO_3$:

- Acid base balance determinations are based on several calculations, which are routinely used in conjunction with blood pH and gas analysis.
- An accurate picture of acid-base balance can be determined from the equilibrium

$$CO_2 + H_2O \longrightarrow H_2CO_3$$
$$H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

which for bicarbonate has an equilibrium constant

$$K_{H2CO3} / HCO_3^- = \frac{[H+][HCO3-]}{H2CO3}$$

where $[H^+]$, $[HCO_3^-]$ and $[H_2CO_3]$ refer to the concentration of these substances.
Since $H_2CO_3 = 0.03pCO_2$ and since $pH = -\log[H^+]$
Therfore, $pH = pK + \log \frac{[HCO3-]}{0.03\,PCO2}$

where pK equals 6.11 for normal plasma at 37°C. This formula is ised in blood gas analyzer for calculating actual bicarbonate.

- Total CO_2 is calculated from the relationship:

$$[HCO_3^-] + (0.03pCO_2) = \text{total } CO_2 \text{ in millimoles/liter}$$

- Base excess is calculated from the formula described by Siggaard – Anderson.

$$\text{Base excess} = (1-0.0143Hb)[HCO_3^-] - (9.5+1.63Hb)x(7.4-pH)-24$$

where Hb represents the patients haemoglobin value.

- Base excess is the number of milliequivalents of a strong acid or base which would be required per liter of blood to restore it to a pH of 7.400 at 37°C in a sample of blood using Siggaard – Anderson's alignment monogram.

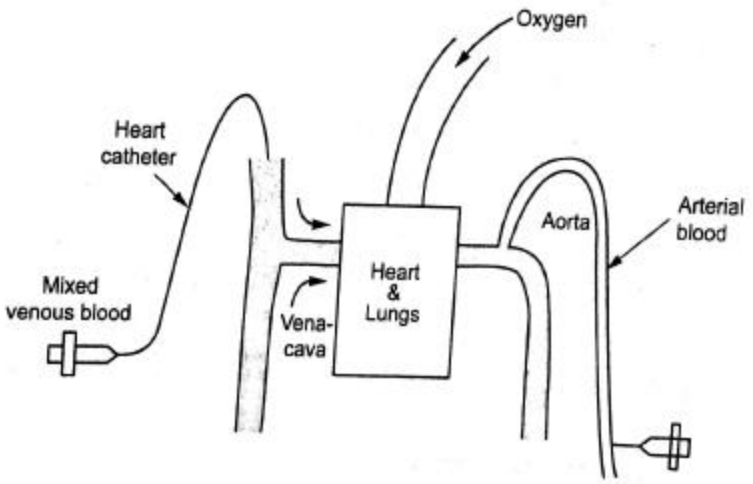
6. Explain the following:

(i) Fick's method for the determination of cardiac output. (8)

(ii) Ultrasonic blood flow meter. (8)

(i) Fick's method for the determination of cardiac output:

- 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.



Fick's method

- Fick's method is based on the determination of cardiac output by the analysis of the gas keeping of the organism.
- Thus the cardiac output can be calculated by continuously infusing oxygen into the blood or removing if from the blood and measuring the amount of the oxygen in the blood before and after its passage.
- Let I bet the amount of infused or removed oxygen per unit time and is equal to the difference between the amounts in the blood arriving at and departing from the site of measurement.

  Thus, $I = C_A Q - C_V Q$ (or) $Q = I/(C_A - C_V)$

  where Q = cardiac output

  C_A = concentration of oxygen in arterial blood

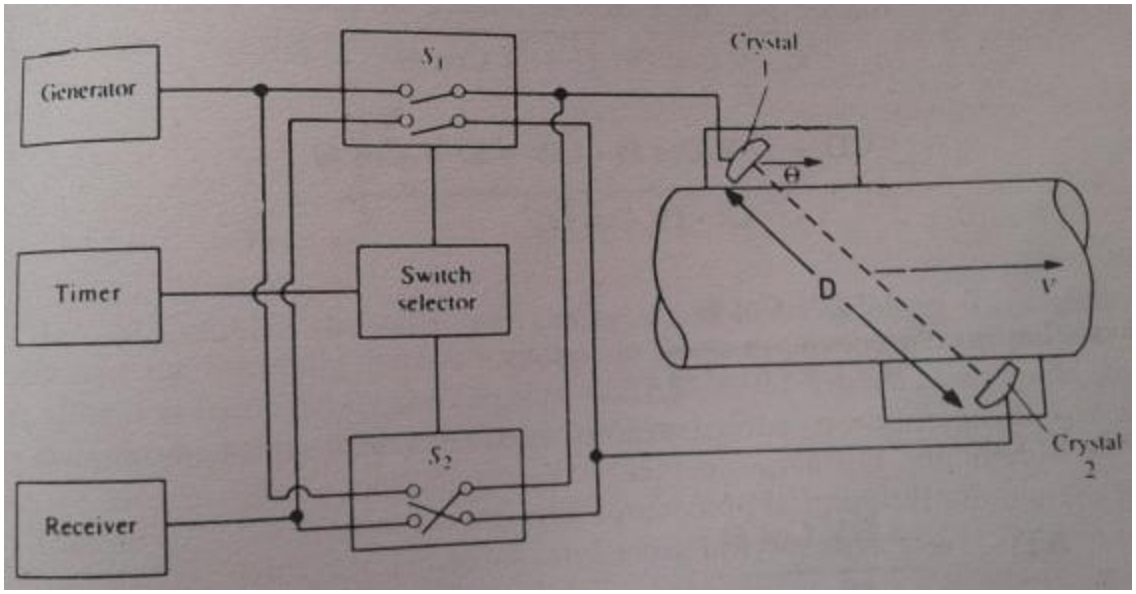
  C_V = concentration of oxygen in mixed venous blood

  I = volume of oxygen uptake by ventilation

(ii) Ultrasonic blood flow meter:

Ultrasonic blood flowmeeters are used to measure the velocity of a stream of blood, a moving heart valve or the motion of an artery in response to a pressure pulse.

Ultrasonic blood flowmeter based on transit time principle:



- A piezoelectric crystal emits a brief pulse of ultrasound which propagates diagonally across the blood vessel.
- If the flow is in the same direction as the pulse, then the pulse reaches a receiving crystal situated on the opposite side wall of the blood vessel.
- Appropriate electronics can convert the change in transit time to velocity.
- If T_D is the corresponding downstream transit time and V is the velocity of the blood flow and C is the ultrasound velocity in the stationary blood, then the ultrasonic velocity in the downstream is written as

$$C + V\cos\boldsymbol{\theta} = D/T_D$$

Similarly in the upstream, the velocity written as

$$C - V\cos\boldsymbol{\theta} = D/T_U$$

where T_U is the upstream transit time.

- The difference in transit time is then,

$$\Delta T = T_U - T_D$$

$$\Delta T = \frac{D}{C - V\cos\theta} - \frac{D}{C + V\cos\theta}$$

$$\Delta T = \frac{\cancel{CD} + DV\cos\boldsymbol{\theta} - \cancel{CD} + DV\cos\boldsymbol{\theta}}{C^2 - (V\cos\boldsymbol{\theta})^2}$$

$$= 2DV\cos\boldsymbol{\theta} / C^2 - V^2\cos^2\boldsymbol{\theta}$$

Since $C^2 >>> V^2\cos^2\boldsymbol{\theta}$

$$\Delta T = 2DV\cos\boldsymbol{\theta} / C^2$$

(or)

$$V = \Delta T\, C^2 / 2D\cos\boldsymbol{\theta}$$

Thus the blood flow velocity can be measured by determining the difference between upstream and downstream transit time.

- The small time difference ΔT can be measured by which at first the switch selector closes S_1 and opens S_2. This connects the R.F generator to crystal 1 and the receiver to crystal 2 and the upstream transit time is measured.
- Subsequently the switch selector opens S_1 and closes S_2. This connects the R.F generator to crystal 2 and the receiver to crystal 1 and measures the downstream transit time.
- In this ΔT is about 0.01% of transit time. Therefore the measurement of such a small time difference or the corresponding phase difference creates error and limits the accuracy of the measurements.

7. Explain the principle of operation of coulter counter. (8)

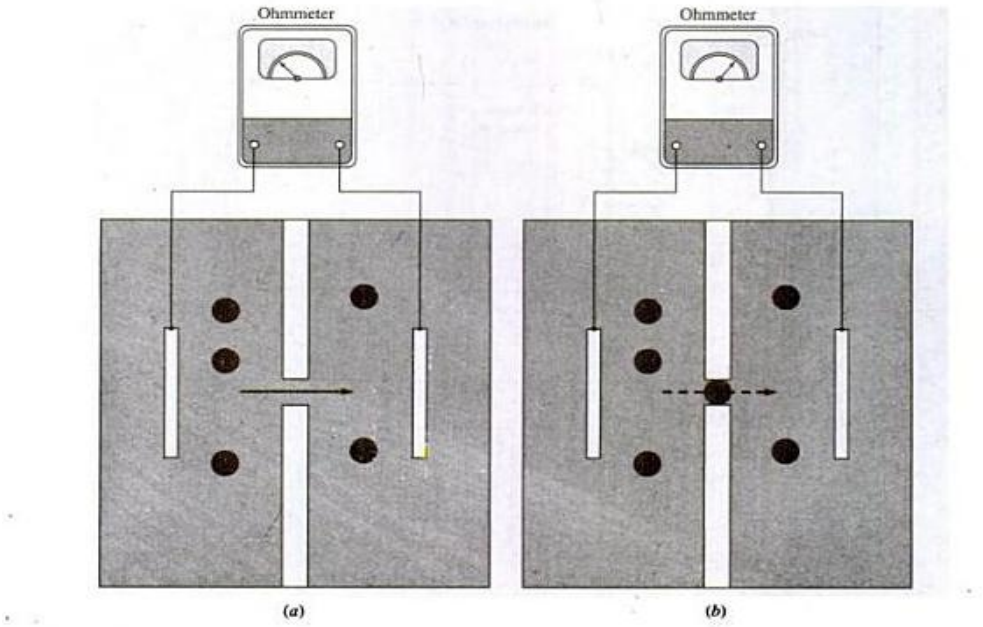
The blood cell counters count the number of RBC's or WBC's per unit of volume of blood using either of two methods:

(i) An electrical method called aperture impedance change (Coulter counter)

(ii) An optical method called flow cytometry.

Aperture impedance change (ΔR_A) counters [coulter counter]:

- The aperture impedance method of counting blood cells depends on the fact that, when blood is diluted in the proper type of solution, the electrical resistivity of blood cells (ρ_c) is higher than the resistivity of the surrounding fluid (ρ_f).
- By contriving a situation in which these resistivities can be differentiated from each other we can count cells.



Blood sensing cell

- The original impedance aperture cell counter was in an instrument called the coulter counter.
- The sensor consist of a two chamber vessel in which the dilute incoming blood is on one side of a barrier, and the waste blood is to be discarded on the other.

- A hole with a small diameter (50µm) is placed in the partition between the two halves of the cell.
- A pair of electrodes from an ohmmeter are placed one in each chamber so that the resistance of the path through the hole is measured.
- When no blood cell is in the aperture the resistance of the path is low. The resistance is given by

$$R = \rho_f L / A$$

where, R = resistance in ohms (Ω)

ρ_f = resistivity of the fluid (Ω-cm)

L = length of the path (cm)

A = is the cross sectional area of the aperture (cm)

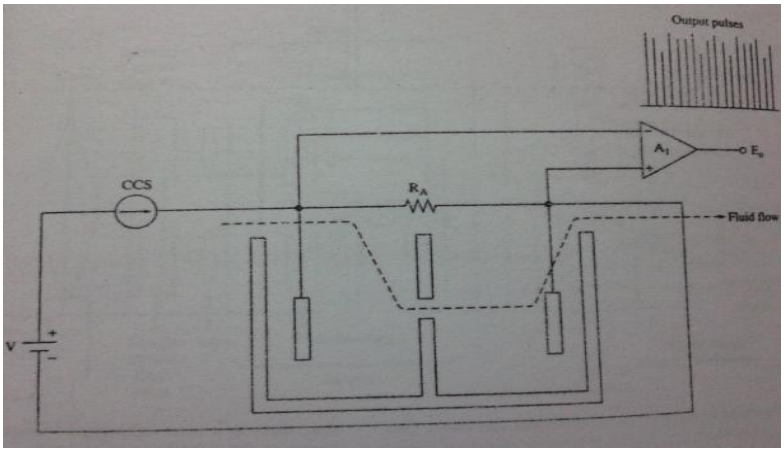
- But when the aperture is filled with a blood cell which has a significantly higher resistivity, the resistance of the path rise sharply.
- The change of resistance (R) is described by:

$$\Delta R = KV[1 + \frac{4X}{5} + \frac{843X2}{1120} + \ldots\ldots\ldots]$$

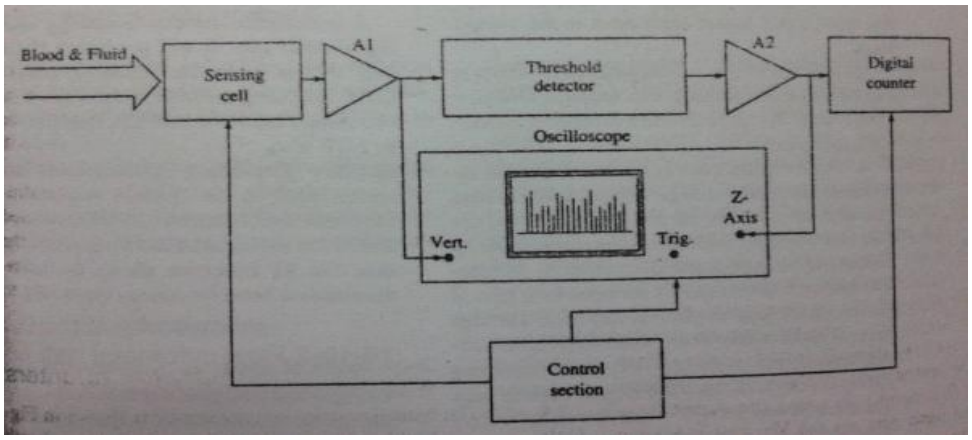
where, K = ratio of the aperture resistance to its volume.

V = volume of the sphere being measured

X = ratio of the cross- section of the aperture.



Blood cell counters



Impedance aperture cell counter

- The sensor and differential amplifier (A1) which is to measure the voltage drop across R_A converts the current pulses into voltage pulses.
- There are two outputs from the amplifier A1. One goes directly to the vertical input of the oscilloscope while the other goes to a threshold detector circuit.
- The threshold detector is a circuit that determines against pulses that are too high or too low.
- Because the signal from the sensor is quite weak compared with ordinary Johnson (1/F) noise, it is necessary to provide such discrimination.
- The output of the threshold detector is supplied to a digital counter and to the oscilloscope z-axis input.
- A control section of the circuit provides gating to the counter, triggering to the oscilloscope time base and blood sample acquisition commands to the pump used to move the fluid.

UNIT – III

ASSIST DEVICES

Cardiac Pacemakers, DC Defibrillator, Dialyzer, Ventilators, Magnetic Resonance Imaging Systems, Ultrasonic Imaging Systems.

1. Cardiac pacemakers

Explain the function and characteristics of the various types of cardiac pacemakers. [May/June 2014][May/June 2013][Nov/Dec 2012][May/June 2012][April/May 2011][Nov/Dec 2016]

Explain the different modes of cardiac pacemakers. [April/May 2019]

1.1 Definition:

- A device capable of generating artificial pacing impulses and delivering them to heart is known as pacemaker system or pacemaker.
- It consists of a pulse generator and electrodes.
- Sino Atrial (SA) node is responsible for the starting of heart beat.
- Hence it is called as Natural Pacemaker.

1.2 Types of pacemakers:

- Internal pacemaker
- External pacemaker

1.2.1 INTERNAL PACEMAKER

- It is placed inside the body.
- It may be permanently implanted on the patients whose SA nodes are failed to function or those who suffered from permanent heart block**.**

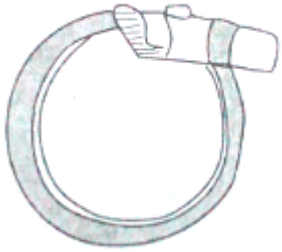


Fig. 1.1 Internal Pacemaker

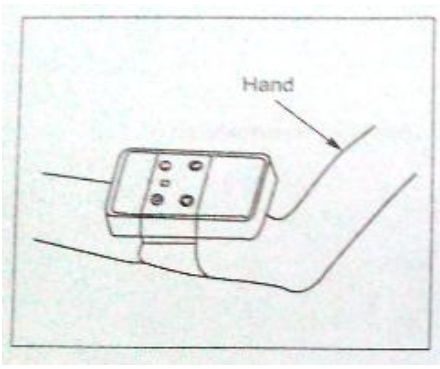
- Internal pacemaker systems are implanted with the pulse generator placed in a surgically developed pocket below the right or left clavicle, in left sub costal region.
- In case of women it is placed beneath the left or right major pectoral's muscle.
- Internal leads are connected to the electrodes that directly contact the surface of the myocardium**.**
- The exact location of the pulse generator used in the internal pacemaker system depends on the following factors.
  - Type and nature of the electrode used.
  - Nature of the cardiac problems.

- Mode of operation of the pacemaker system.

- There is no external connection for applying power.
- So the pulse generator should be completely self-contained with a battery, which is capable of operating continuously for a specified period.

1.2.2 EXTERNAL PACEMAKER

- It consists of an externally placed pulse generator circuit connected to the electrodes placed on the myocardium.
- Temporary heart irregularities or disorders.
- Treating the patient from arrhythmias.
- Treatment of coronary patient and during the cardiac surgery.
- The external pacemaker consists of pulse generators.
- They are placed outside the body and connected normally to the electrode with the help of wires introduced into the right ventricle.
- The pulse generator may be strapped to the lower arm of the patient.



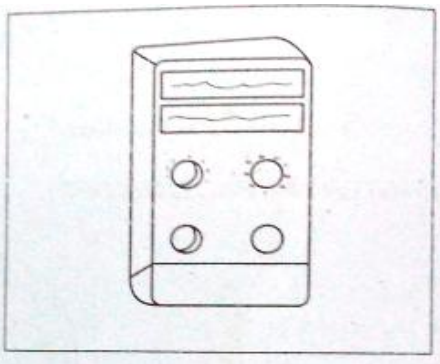


Fig.1.2 Portable external pacemaker strapped on arm

Fig 1.3 External demand pacemaker

1.3 TYPES OF PACING MODES

Based on the modes of operation of the pacemakers, they are classified into five types,

1. Ventricular asynchronous pacemaker (Fixed rate pacemaker)
2. Ventricular synchronous pacemaker (Standby pacemaker)
3. Ventricular inhibited pacemaker (Demand pacemaker)
4. Atrial synchronous pacemaker
5. Atrial sequential ventricular inhibited pacemaker

1.3.1 VENTRICULAR ASYNCHRONOUS PACEMAKER (FIXED RATE PACEMAKER)

- This type of pacemaker is intended for patients having permanent heart blocks.
- This pacemaker can be implemented in atrium or ventricle.
- It is suitable for the patients who are suffered by total AV block, atrial arrhythmia.
- The circuit shown below produces a stimulus at a fixed rate.
- There is a competition between the natural heart beats and the beats generated by this pacemaker.

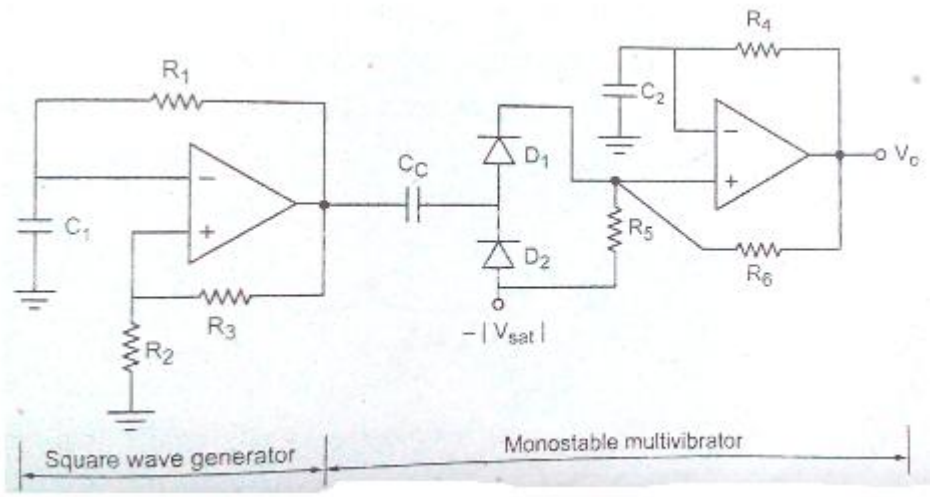


Fig. 1.4 Ventricular asynchronous pacemaker

- The figure consists of square wave generator and monostable multivibrator circuit.
- The period of the square wave generator is given as,

$$T = -2\,(RC)\ln\left(\frac{R_3}{2R_2 + R_3}\right)$$

T can be modified by changing the R, C, R_2 and R_3 values.

- The pulse duration is given by the following formula,

$$T_d = 5\,C_C\left(\frac{R_5 R_6}{R_5 + R_6}\right)$$

- The output of the square wave generator is connected with the monostable multivibrator circuit.

Disadvantages:

- Heart beat rate cannot be changed.
- If it is fixed in atrium, atrium beat at a fixed rate.
- If ventricle beat at a different rate, then it leads to a severe problem.
- Ventricular fibrillation may be occurred.

1.3.2 VENTRICULAR SYNCHRONOUS PACEMAKER (STANDBY PACEMAKER) [Nov/Dec 2016]

- Suitable for the patients who are suffered by short period of AV block.

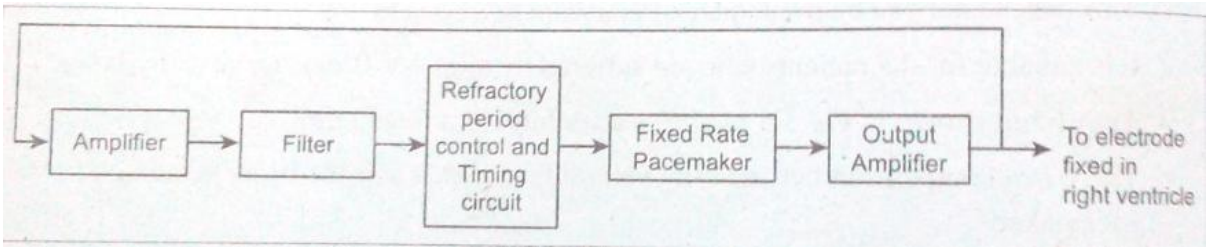


Fig.1.5 Ventricular synchronous pacemaker

- 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.

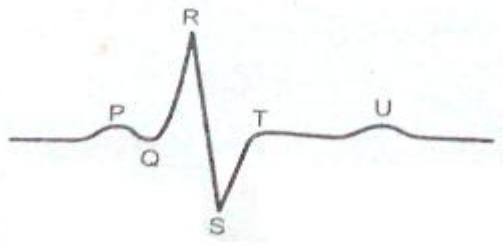


Fig.1.6 R-Wave

- 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.

Advantages:

- Ventricular fibrillation is avoided.
- When R-wave is normal, then fixed rate pacemaker block is not in ON condition, so power consumption is reduced.

Disadvantages:

- Very sensitive to electromagnetic interferences.
- No synchronization between atrial and ventricular contraction.

1.3.3 VENTRICULAR INHIBITED PACEMAKER (DEMAND PACEMAKER)

Explain working principle of demand pacemaker with a diagram. [Nov/Dec 2017][Nov/Dec 2016]

- The functional block diagram of demand pacemaker is shown in figure.

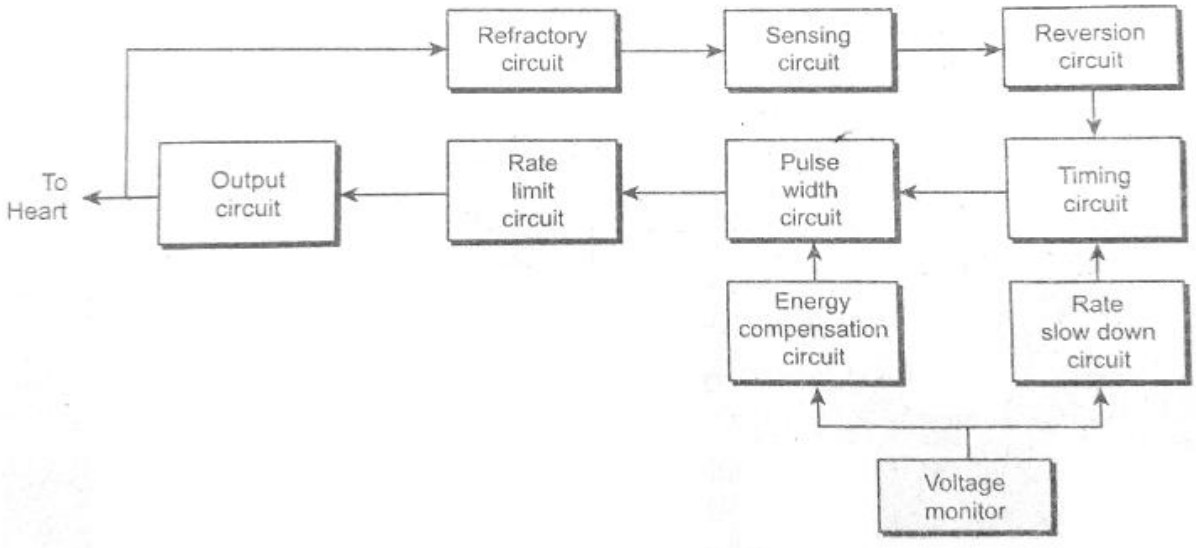


Fig.1.7 Ventricular Inhibited pacemaker

- Comparator determines the pacing rate of the pulse generator.

- Output is given to second RC network.
- The pulse width circuit determines the duration of the stimulating pulses.
- Rate limiting circuit disables the comparator for a short interval and limits the pacing rate.
- Output circuit provides a voltage pulse to stimulate the heart.
- Voltage monitor circuit senses the cell depletion and controls the rate slow down circuit and energy compensation circuit.
- Rate slow down circuit shuts off some current to the basic timing to slow down pulse rate during cell depletion.
- Energy compensation circuit causes the pulse duration unit to increase the battery voltage, when it decreases and it is used to supply the energy to heart.
- Sensing circuit detects a spontaneous R-wave and resets the oscillator timing capacitor.
- Reversion circuit helps the amplifier to detect spontaneous R wave in the presence of low level continuous wave interference.
- In the absence of R wave the circuit allows the oscillator to produce pacing pulses at its present rate.
- The inhibited pacemaker allows the heart to pace at its normal rhythm when it is able to do.
- If the R wave is missing for a preset period of time, then the pacemaker will turn ON and provide the heart a stimulus.
- Hence it is termed as Demand pacemaker.

1.3.4 ATRIAL SYNCHRONOUS PACEMAKER

Describe the working of atrial synchronous pacemaker. ***[Apr/May 2017]***

- It is used for temporary pacing for young patients with a mostly stable block.

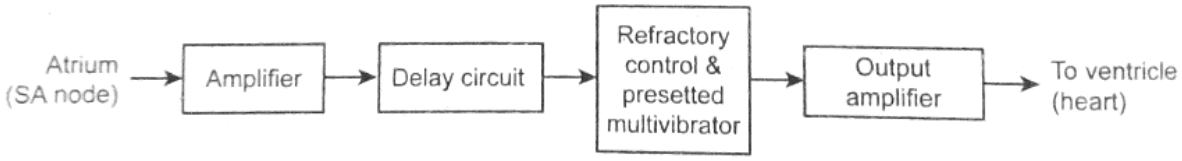


Fig.1.8 Atrial synchronous pacemaker

- 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.
- 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 provides some time delay, because pacemaker pulse is too large.

1.3.5 ATRIAL SEQUENTIAL VENTRICULAR INHIBITED PACEMAKER

- It is used to stimulate both atrial and ventricles.
- It is a demand pacemaker, so based on the patients need, it provides the impulses.
- In the modern pacemakers, magnet is placed over the pacemaker on the skin of the patient.
- This magnet is used to activate the reed switch.
- This switch, switches the pacemaker into any one of the mode of operation, either to give the impulse for atrial or to ventricle.

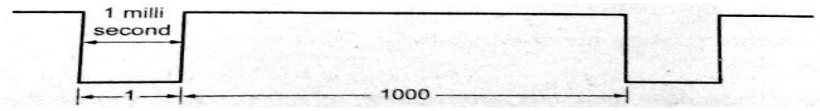


Fig. 1.9 Pacemaker pulses

1.4 COMPONENTS OF PACEMAKER

- Pulse generator
- Electrodes
- Battery

1.5 METHODS OF STIMULATION OF PACEMAKER

- **External stimulation -** Used to restart the normal rhythm of the heart in case of cardiac standstill.
- **Internal stimulation** - It prevents normal self triggering of the heart.

1.6 Pacemaker Batteries:

- ✓ **Mercury cell:** The lifetime is 2 – 3 years.
- ✓ **Lithium cells:** The lifetime is more than five years.
- ✓ **Rechargeable battery:** The lifetime is not reliable even for a year.
- ✓ **Nuclear cell:** The lifetime is more than ten years.

****

2. Difference between Internal and External pacemaker

Distinguish Internal and External pacemaker. ***[April/May 2015]***

Internal (Implanted) pacemaker	External pacemaker
The pacemaker is a surgically implanted in the skin near the chest or abdomen.	The pacemaker is placed outside the body.
Its output lead is connected directly to the heart muscle.	It may be in the form of wrist watch or in the pocket. From that one terminal will go in the heart through the vein.
Myocardiac electrodes are in contact with the outer wall of the myocardium (heart muscle).	Endocardiac electrodes are applied to the heart. They are in contact with the inner surface of the heart chamber.
It requires open chest minor surgery to place the	It does not require open chest surgery.

pacemaker.	
Battery can be replaced only by minor surgery and doctor's help is needed to rectify the defects.	Battery can be easily replaced and any defect can be easily attended without the help from doctor.
During placement, swelling and pain are due to maximum foreign body reaction.	During the placement of pacemaker swelling and pain do not arise due to minimum foreign body reaction.
There is 100% safety for circuit from the external disturbances.	There is no safety for the pacemaker, particularly in case of child carrying the pacemaker.
Implanted pacemakers are used for permanent heart regularity.	The external pacemakers are used for temporary heart regularity.

****

3. DC Defibrillator

What is Defibrillator? With block diagram explain the operation of various defibrillators. [April/May 2015][Nov/Dec 2014][May/June 2013][Nov/Dec 2012][May/June 2012][April/May 2011][Nov/Dec 2017]

3.1 Fibrillation:

- ✓ During fibrillation the normal rhythmic contractions of either atria or the ventricles are replaced by rapid irregular switching of the muscular wall.
- ✓ ***Types of fibrillation:*** Fibrillation of atrial muscles is called ***atrial fibrillation*** and fibrillation of ventricles is known as ***ventricular fibrillation.***
- ✓ ***Electrodes used for fibrillation:***

  Two types of electrodes are used for defibrillation such as ***internal electrodes*** and ***External electrodes.***
- ✓ ***Internal electrodes*** are used during the ***open heart surgery. Spoon shaped electrodes*** are used here.

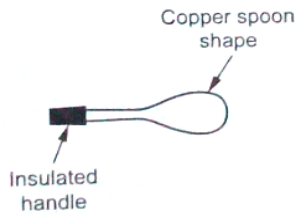


Fig.3.1 Internal Electrodes

- ✓ ***External electrodes*** use ***paddle shaped electrodes*** for external defibrillation***.***

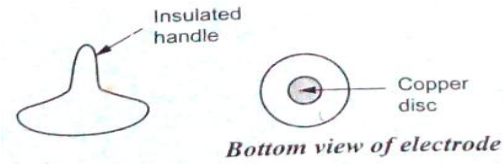


Fig.3.2 Paddle shaped electrode

3.2 Defibrillator

- ✓ Mechanical methods like heart massage have been tried over the years for fibrillating patients.
- ✓ The successful method of defibrillation is the application of an electric shock to the area of heart.
- ✓ If sufficient amount of current is applied for some period and then released.
- ✓ In this method, all the muscle fibers enter their refractory period together, and then the normal heart action takes place.
- ✓ The instrument for administering the electric shock is called as defibrillator.
- ✓ Defibrillator is an electronic device that creates a sustained myocardial depolarization of a patient's heart in order to stop ventricular fibrillation or atrial fibrillation.

3.3 Types of Defibrillators

- AC Defibrillators
- DC Defibrillators
- Dual peak DC Defibrillators
- Synchronized DC Defibrillators

3.3.1 AC Defibrillation

- ✓ This type of defibrillation method is widely used by applying a shock of 50 Hz a.c. to the chest of the patient through appropriate electrodes.
- ✓ The phenomenon of application of an electrical shock to resynchronize the heart is called as ***counter shock.***
- ✓ If the patient does not respond, the process is continued until defibrillation occurs. It is shown in figure below.

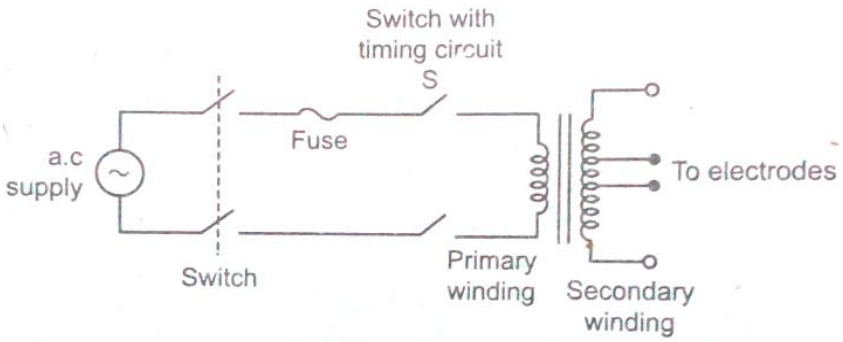


Fig. 3.3 A.C Defibrillator

Working

- ✓ A.C supply is applied to primary winding of the transformer through switches and fuse.
- ✓ The switch is connected with timing circuit.
- ✓ This timing circuit is used to set some particular time up to which the defibrillator delivers a shock to the patient.
- ✓ In secondary winding, various tapping's are available.
- ✓ These are connected to an electrode which is used to deliver the shock to the patient.

- ✓ 250V to 750V is applied by using this type of defibrillator.

Problems in A.C Defibrillation

- ✓ Since ventricular fibrillation is more dangerous than atrial fibrillation, successive methods are adopted to correct it.
- ✓ When atrial fibrillation is corrected by applying electric shock, then serious ventricular fibrillation occurs.

3.3.2 DC Defibrillator

With a neat diagram, illustrate the working of D.C. defibrillator. [Apr/May 2017][April/May 2019]

INTRODUCTION

- ✓ To overcome the disadvantage of defibrillation method in 1962, Bernard lawn from Harward School of public health and peter bent of Brigham hospital developed a new method known as dc defibrillation.
- ✓ In this dc defibrillation method, capacitors charged to a high dc voltage and then rapidly discharged through electrodes across the chest of patient.
- ✓ DC defibrillation is capable of correcting both the atrial fibrillation and ventricular fibrillation.
- ✓ DC method produces some harm to the patient.

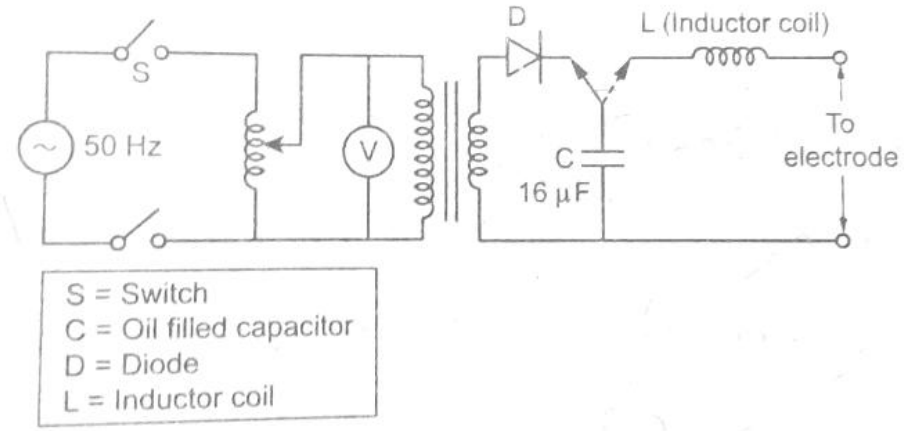


Fig.3.4 DC Defibrillator circuit

- ✓ Depending on the energy setting in the defibrillator, the amount of electrical energy discharged by the capacitor ranges between 100 to 400 joules.
- ✓ Discharge portion is approximately 5 ms.
- ✓ In discharge waveform, the peak value of current is nearly20 A and the wave is monophasic in nature.
- ✓ Monophasic means most of the excursion of curve is above the base line.
- ✓ Energy level of a defibrillator can be controlling the voltage amplitude V_P of the defibrillator by varying the setting on the varactor or Duration of the defibrillator pulse.
- ✓ The energy (W_A) stored in the capacitor C and available for the defibrillation is:

Lown waveform: *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 is 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).

3.3.3. DUAL PEAK DC DEFIBRILLATOR

✓ If peak voltage is as high as 6000V is used there is a possibility of damaging myocardium and the chest walls.

✓ Produce dual peak waveform of longer duration at lower voltage.

✓ Effective defibrillation is achieved in adults with lower level of delivered energy.

✓ Energy range is between 50 to 200 W-sec or joules.

✓ A typical dual peak waveform is shown below.

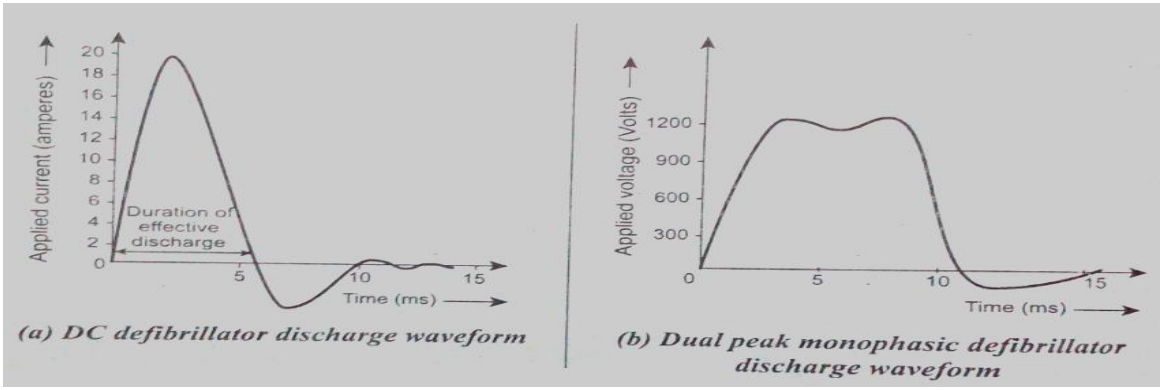


Fig.3 5 Dual peak waveform

✓ Effective defibrillation at the desirable lower voltage levels is also possible with the truncated waveform.

✓ The amplitude of the waveform is relatively constant, but is varied to get required energy.

✓ Large electrodes are used for the proper delivery of large current through the surface of the skin.

✓ These electrodes are called as paddles. A typical truncated waveform is shown in figure below.

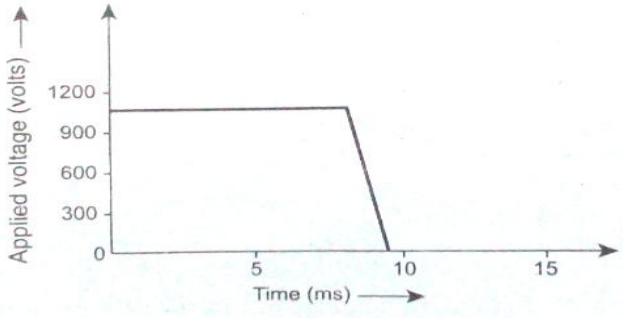


Fig.3.6 Truncated defibrillator discharge waveform

3.3.4 EXTERNAL DEFIBRILLATOR:

✓ A unit based on computer technology and designed to analyze the heart rhythm itself, and then advise whether a shock is required.

✓ It is designed to be used by lay persons, who require little training.

- ✓ It is usually limited in their interventions to delivering high joule shocks for VF and VT rhythms.
- ✓ The automatic units also take time (generally 10-20 seconds) to diagnose the rhythm, where a professional could diagnose and treat the condition far quicker with a manual unit.
- ✓ Automated external defibrillators are generally either held by trained personnel who will attend incidents, or are public access units which can be found in places including corporate and government offices, shopping centers, airports, restaurants,
- ✓ AEDS 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.
  - It allows faster and more accurate analysis of the ECG and better shock decisions.
  - Hands off defibrillation are a safer procedure for the operator, especially if the operator has little or no training.

3.3.5 DC DEFIBRILLATOR WITH SYNCHRONIZER

Draw the block diagram of synchronized DC defibrillator and explain its working principle. [Nov/Dec 2018]

- ✓ Synchronization means, 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.

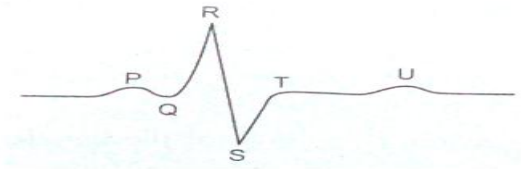


Fig.3.7

- ✓ During the T-wave, the electric shock should not be applied to the patient.
- ✓ Electric shock is delivered approximately 20 to 30 ms after the peak of R wave of patients ECG.

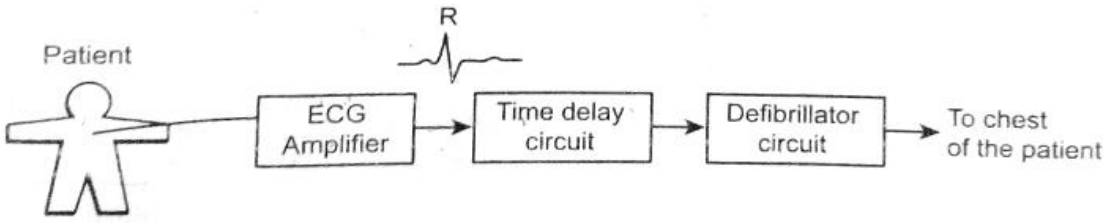


Fig.3.8 Block diagram of defibrillator with synchronizer

Working

- ✓ 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.
- ✓ So that, 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 it is given within one minute of the attack.

Electrodes used for defibrillation

- ✓ These paddles have metal disks of 8 to 10 cm in diameter for external use.
- ✓ For internal use smaller paddles are used on infants and children.
- ✓ For external use, pair of electrodes is firmly pressed against the patient's chest.

Need of Insulation Handle

- ✓ To prevent the person applying the electrodes from accidental 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.
- ✓ So thumb switches are mostly preferred.

Charging of Defibrillators

- ✓ In some defibrillators charging is done by means of a charge switch located in the front panel of the unit.
- ✓ The charge switch is located in the handle of one of its paddles.
- ✓ In few defibrillators the charging process begins automatically after discharge.

Types of Electrodes

- ✓ Two electrodes are
  - ➢ Anterior-anterior
  - ➢ Anterior-posterior
- ✓ Anterior-anterior paddles are applied to the chest.
- ✓ Anterior-posterior paddles are applied to both the patient's chest wall and back so that energy is delivered through the heart.
- ✓ Specially designed pediatric paddles are available with diameter ranging from 2 to 6 cm.
- ✓ Internal paddles can be either gas-sterilized or autoclaved.

Indication Meter

- ✓ Most of the defibrillators include a watt second meter to indicate the amount of energy stored in the capacitor before discharge.
- ✓ The energy indicated on the meter is lost or dissipated as heat in the components inside the unit.

4. Dialyzer

Explain the two types of dialyses.

With a neat block diagram explain the principle of operation of haemo dialyzer machine. [Nov/Dec 2018]

4.1 Dialysis:

- Kidney failures can be treated by dialysis.
- Dialysis is a process by which the waste products in the blood are removed and restoration of normal pH value of the blood is obtained by an artificial kidney machine.
- It consists of three important processes.
    - Diffusion
    - Osmosis
    - Ultra filtration
- Two methods are used to perform dialysis.
    1. Extra corporeal dialysis (Haemodialysis)
    2. Intra corporeal dialysis (Peritoneal cavity dialysis)

These methods are explained in the section given below.

4.2 Extra Corporeal Dialysis (Haemodialysis)

Haemodialysis machine is shown in figure below. We can see all the parts of machine one by one.

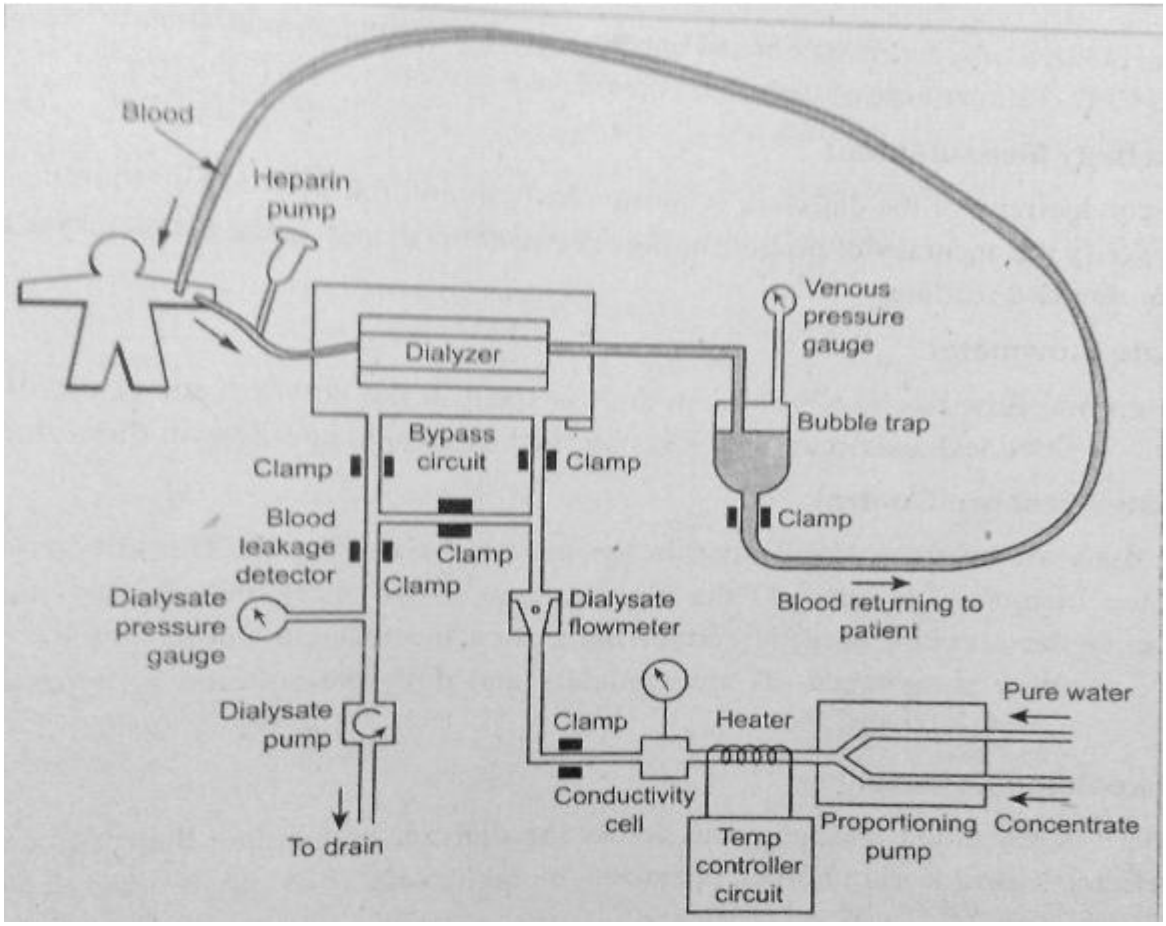


Fig 4.1 Haemodialysis machine

4.2.1 Proportioning pump

- It is used to mix the pure water with dialysate.
- Usually, 34:1 ratio of water and concentrate is maintained.
- There are two types of proportioning system available.

  1. Fixed ratio type: In this type, fixed ratio is maintained. Generally it is 34:1 (water: concentrate)

  2. Variable ratio type: In this type, variation of $\pm$ 5% on the standard ratio 34: 1 is possible.
- The output of the proportioning pump is given to heater circuit.

4.2.2 Dialysate temperature control

- The dialysis is normally done at specific temperature.
- The temperature of the dialysate should be monitored and controlled by using temperature control circuit before it is given to the dialyzer.
- If the temperature exceeds 40^{o}C, then the components of blood are damaged.
- So, safety valve is used to turn off the heater, if the temperature exceeds 43^{o}C.
- In the modern microprocessor based haemodialysis machine, temperature control circuit is given to CPU.
- Temperature of dialysate is displayed.

4.2.3 Conductivity Measurement

- The conductivity of the dialysate is continuously monitored by using conducting cell.
- It is used to verify the accuracy of proportioning.
- The result is displayed as a percentage deviation from the standard reading.

4.2.4 Dialysate Flow meter

- The normal flow rate is 500 ml/minute.
- It is fixed in the downstream of the dialyzer.
- If there is any blood leakage occurs, then it is observed by change of color in the fluid.

4.2.5 Dialysate Pressure control

- The dialysate pressure is indicated in the pressure gauge meter.
- The effective pressure across the membrane is equal to the algebraic sum of the dialysate pressure and venous pressure.
- If the pressure exceeds certain limit, then the effluent pump which creates the negative pressure is switched off automatically and dialysate solution is bypassed to the drain.

4.2.6 Blood Leakage Detector

- If there is any blood leakage occurs across the dialyzer membrane, then it is detected by photo electric transducer.
- In normal operation, blood leakage is 25 mg of haemoglobin/litre.
- If blood leakage is detected, then the dialysate is by-passed to the drain.

4.2.7 Bubble Trap

- Air embolism is serious hazard in dialysis.
- Now, ultra sound method is used for detecting the presence of air in the blood line.

4.2.8 Heparin Pump

- It is used to deliver heparin from the pump to the blood line.

4.2.9 Ultra Filtration Circuit

- It is used to monitor the amount of fluid removed from the patient.

$$\text{Ultra filtration rate} = \frac{\text{Total fluid removed in litres}}{\text{Treatment time in hours}}$$

4.2.10 Dialyzer

- Dialyzer is very important part in the artificial kidney.
- It consists of two circuits.
- In one circuit blood is circulated and in another circuit, dialysate solution is circulated.
- Three types of dialyzers can be used.
- These are ***parallel plate dialyzer, coil dialyzer, hollow fiber type of dialyzer.***
- The rate of clearance of waste products from the blood depends upon the rate of blood flow.
- The dialyzing surface area of parallel flow dialyzer is 1 square meter.
- The rate of blood flow is 200 ml/minute.
- The rate of dialysate flow is 500 ml/minute.
- The rate of clearance of waste product is 64 ml/minute.
- The membrane used in the dialyzer is used for ultra filtration.
- This dialyzer is not a disposable part.
- It should be cleaned before reuse.

*****Write short notes on peritoneal dialysis. [Nov/Dec 2016]**

4.3 Peritoneal Dialysis

The peritoneal dialysis is shown in figure below.

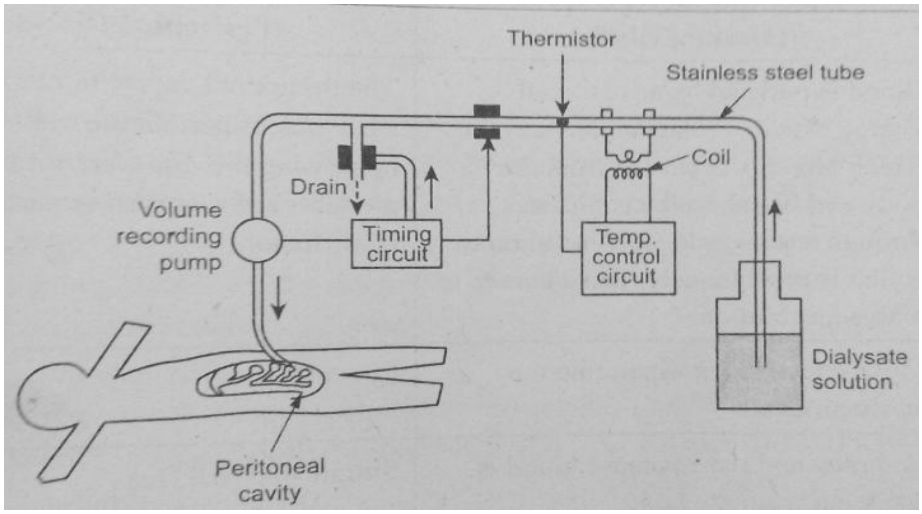


Fig.4.2 Peritonial dialysis

- ✓ In this technique, peritoneal cavity in the abdomen is used as semi permeable membrane.
- ✓ A catheter (sharp knife) is inserted in the abdomen.
- ✓ Dialysate solution of 1.5 – 2 litres is allowed to flow into the peritoneal cavity.
- ✓ Then diffusion takes place for 30 minutes.
- ✓ Then the dialysate solution is removed from the cavity.
- ✓ This same procedure is repeated for 20 to 30 times.
- ✓ Finally all waste substances are removed from the blood.
- ✓ Temperature control circuit is used to maintain the temperature of dialysate solution at 37^{o}C.
- ✓ In this control circuit, thermistor is used.
- ✓ Here timing circuit is used to monitor the volume of the dialysate solution.
- ✓ If 2 litres of solution is allowed, then the circuit delivers the signal to stop the dialysate flow into the peritoneal cavity.
- ✓ The same timing circuit is used to monitor the diffusion time also.
- ✓ After 30 minutes of diffusion time, the timing circuit delivers a signal to stop the diffusion process.
- ✓ Then the dialysate solution is removed from the abdomen using suction pump.
- ✓ After that, the fresh dialysate solution is allowed to enter into the peritoneal cavity.
- ✓ If the volume of the dialysate solution sucked from the peritoneal cavity is less than 2 litres, then the alarm circuit is operated.
- ✓ If alarm is operated, then sudden action should be taken to take care of the patient.

5. Differences between Extraporeal dialysis and Intracorporeal dialysis:

Write the differences between the Extraporeal dialysis and Intracorporeal dialysis.

S.No	Extra Corporeal Dialysis (Haemodialysis)	Intra Corporeal Dialysis (Peritoneal Dialysis)
1.	Blood is purified by an artificial kidney machine (Haemodialyzer), in which blood is taken out from the body and waste products diffuse through a semi permeable membrane which is continuously rinsed by a dialyzing solution.	The peritoneal cavity in our body is used as semi permeable membrane and by passing the dialysate into it; waste products are removed from the blood by diffusion.
2.	More effective for separating the waste products.	Less effective
3.	Complex and risk, because blood is taken out from the body.	Simple and risk free.
4.	Dialyzing time is about 3 to 6 hours.	Dialyzing time is about 9 to 12 hours.

****

6. Ventilators (Respirators)

Explain the principle and working of ventilators.

6.1 Introduction

- The terms ventilator and respirator are used ***interchangeably*** that may be employed ***continuously*** or ***intermittently*** to ***improve ventilation*** of the lungs and to supply humidity to the pulmonary tree.
- Ventilators may be defined as any machine designed to mechanically ***move breathable air into and out of the lungs*** to provide the mechanism of breathing for a patient who is ***physically unable to breathe.***
- Most ventilators in clinical settings use ***positive pressure*** during inhalation to inflate the lungs with various gases or mixture of gases (air, oxygen, CO_2, helium).
- ***Negative airway pressure*** is used under ***rare circumstances*** during expiration.
- Expiration is usually ***passive.***
- Under certain conditions, pressure may be applied during expiration.
- Also to improve ***"arterial oxygen tension".***

6.2 Modes of operation (Mechanical methods)

- Most respirators commonly used are classified as ***"Assistor-Controllers".***
- There are three different modes and modes differ by which type of inspiration is initiated (i.e. positive and negative).

6.2.1 Negative pressure:

1. Assist mode
2. Control mode
3. Assist - Control mode

In this three mode, ***a slight negative pressure*** is applied that respond by pressure sensor to begin inflating the lungs.

Assist mode

- Assist mode inspiration is triggered by the patient.
- Respirator helps the patient when they wants to breathe.
- A sensitivity adjustment is provided to select the amount of patient effort required to trigger the machine.
- It is used by the patients who are able to control their breathing but unable to inhale sufficient of air without assist.

Control mode

- Breathing is controlled by a timer set to provide the desired respiration rate.
- Controlled ventilation is required to patients who are unable to breathe their own.
- Respirator has complete control over the patient respiration.

Assist-Control mode

- The apparatus is normally triggered by the patient attempt to breathe like assist mode.
- If patient fails to breathe within the predetermined time, timer automatically triggers the device to inflate the lungs, like control mode.
- This mode is most frequently used in critical care settings.

6.2.2 Positive pressure:

- In this, many ***respirators can be triggered manually*** by means of a control on the panel.
- Once inspiration has been triggered inflation of the lungs is continuous until one of the following conditions occurs.
    1. Pressure - cycled
    2. Volume – cycled ventilators
    3. Time-cycled ventilators

Pressure-cycled

- The delivered gas reaches a predetermined pressure in the upper airways.
- A ventilator that ***operates primarily*** in this manner is said to be pressure cycled.

Volume-cycled

- A predetermined volume of gas has been delivered to the patient.
- This is the ***primary mode*** of operation of volume-cycled ventilators.

Time-cycled

- The air has been applied for a predetermined period of time.
- This is the ***characteristic mode*** of operation for time-cycled ventilators.

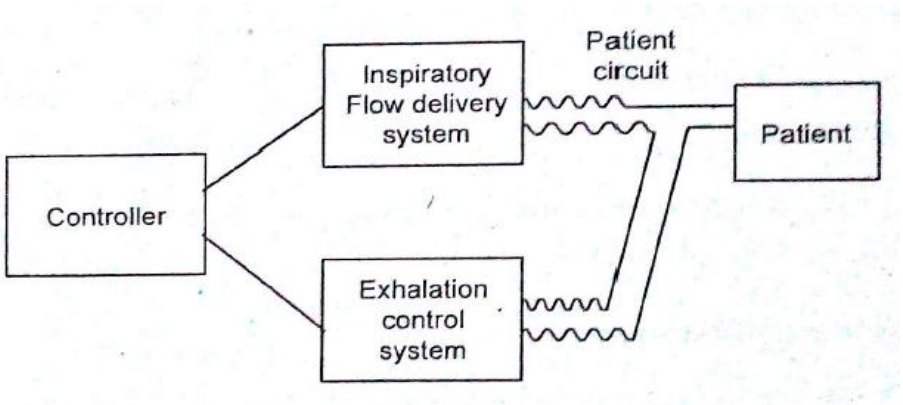


Fig 6.1 Functional diagram of a positive pressure ventilators

6.3 Types of ventilators

Based on the clinical usage, ventilators are categorized by two basic types.

1. Pressure-cycled (positive-pressure assistor) controller
2. Volume-cycled ventilator (volume respirator)

6.3.1 Pressure-cycled

- The first type ventilator is a "Positive-pressure assistor-controller".

- In this, the device is powered pneumatically from a source of gas and requires no electrical power.
- Device with electrically powered compressor are used to permit ventilation with ambient air.
- It is quiet small and includes all necessary equipments to control the flow of gas.
    - ❖ Sense the patient's effort to inspire.
    - ❖ Terminate the inspiration when the desired pressure is reached.
    - ❖ Permit adjustment of the sensitivity of triggering mechanism and desired pressure level.
    - ❖ Generate a negative pressure to assist expiration.
- Special type of valve with magnet, sense the small negative pressure created by a patient to inhale.
- In the time of operation ***controlled mode*** is used to filling a chamber with gas.

6.3.2 Volume-cycled ventilators

- This is the second category of respirators often called "***volume respirator***".
- Device use a piston to dispense a precisely controlled volume for breathes.
- Where patients have pulmonary abnormalities and require predictable volumes and gas, this type of ventilators are preferred.
- It is ***much large than pneumatically*** operated units.
- Volume respirators are electrically operated and provide much greater degree than pressure cycled types.
- Most devices of this type have adjustable pressure limits and alarms for safety.
- Volume-cycled ventilators used in critical cases and supplied with a spirometer to the accurate monitoring of patient's ventilation.
- Other available features includes,
    - ❖ Heated humidifier
    - ❖ Nebulizers
    - ❖ Aspirators
    - ❖ Optional capabilities negative pressure
    - ❖ PEEP (positive and expiratory pressure)

Humidifier

- ❖ To prevent patient's lungs from damage, air (or) oxygen applied during respiratory, therapy must be humidified.
- ❖ All equipment humidifies the air by ***heat vaporization*** (stream).

Nebulizer

- When therapy requires water, it is ***suspended*** in the inspired air as an aerosol a device used for this process is called ***nebulizer.***
- Using high velocity oxygen it is nebulized and then applied to the patient via a respirator.
- More effective type of nebulizer is ***"ultrasonic nebulizer".***

Aspiration

- It is a part of a ventilators (or) inhalators to remove ***mucus and other fluids*** from airways.

6.4 Non-mechanical methods

- In emergency situation, it is very important to ensure that the air way is clear.
- First, clothing around the neck and chest should be loosened.
- Mouth and throat should be cleared of fluid.
- Tongue should be drawn forward.
- Two non-mechanical methods are,
    1. Holgen-Nielson method (Back pressure arm lift method)
    2. Mouth-to-mouth breathing (Expired air Resuscitation).

6.5 Modern ventilators

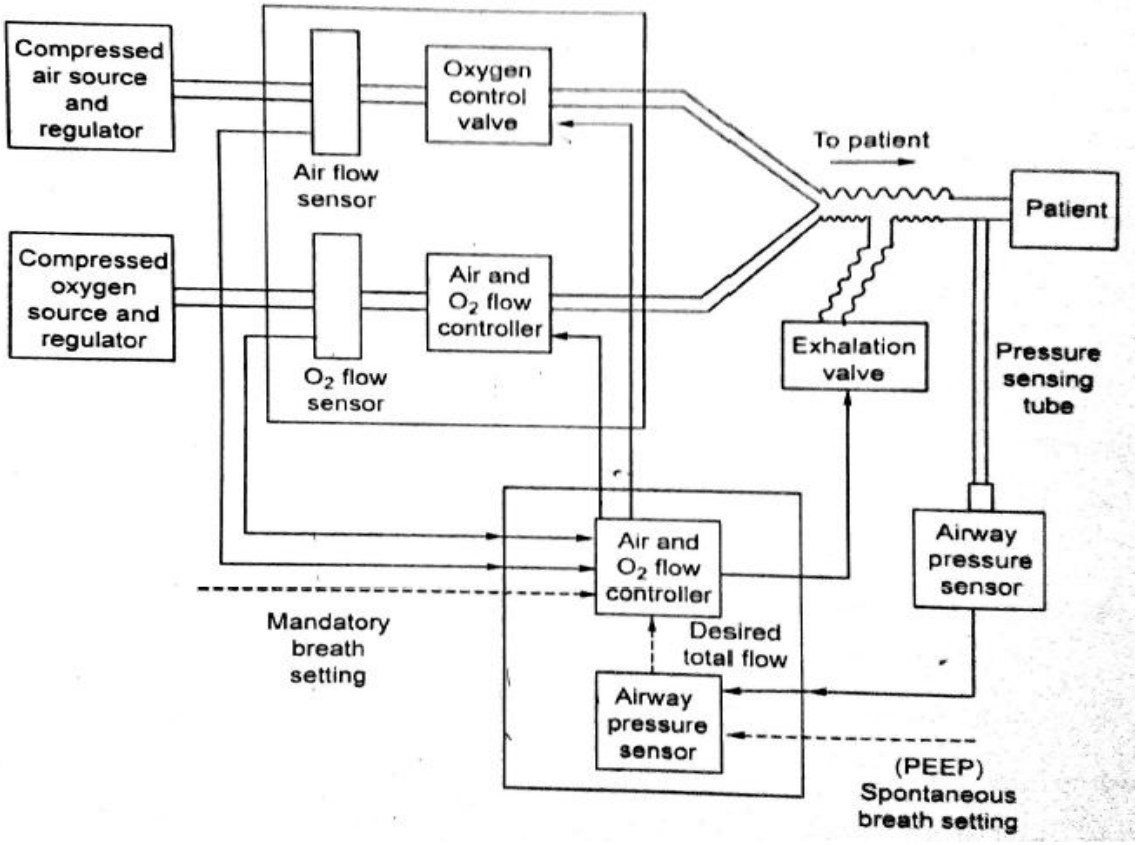


Fig 6.2 Microprocessor based controlled ventilators

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7. Magnetic Resonance Imaging (MRI) Systems

Explain MRI systems in detail.

7.1 Introduction

- Magnetic resonance imaging technique use RF region of the electromagnetic spectra to provide an image.
- First, a patient is placed in an external magnetic field which causes the magnetization of protons of hydrogen atoms in his body.

- Due to magnetization, these protons align and process about the external magnetic field.
- Now, a radio frequency pulse at resonance frequency is transmitted in to the patient under controlled and prescribed condition.
- Due to resonance condition the individual proton responds by emitting a radio frequency signal.
- This is called "**Nuclear Magnetic Resonance *(NMR)*** signal".
- These emitted signals by the protons, during their return from higher nucleus energy states to ground state.
- These are picked by RF coils and processed by computers using Fourier transforming techniques to produce an image.

7.2 Block diagram of MRI system

- The block diagram consists of super conducting magnetic coil, RF transmitter and receiver coil, (X, Y, Z gradient coil), computer and display unit.

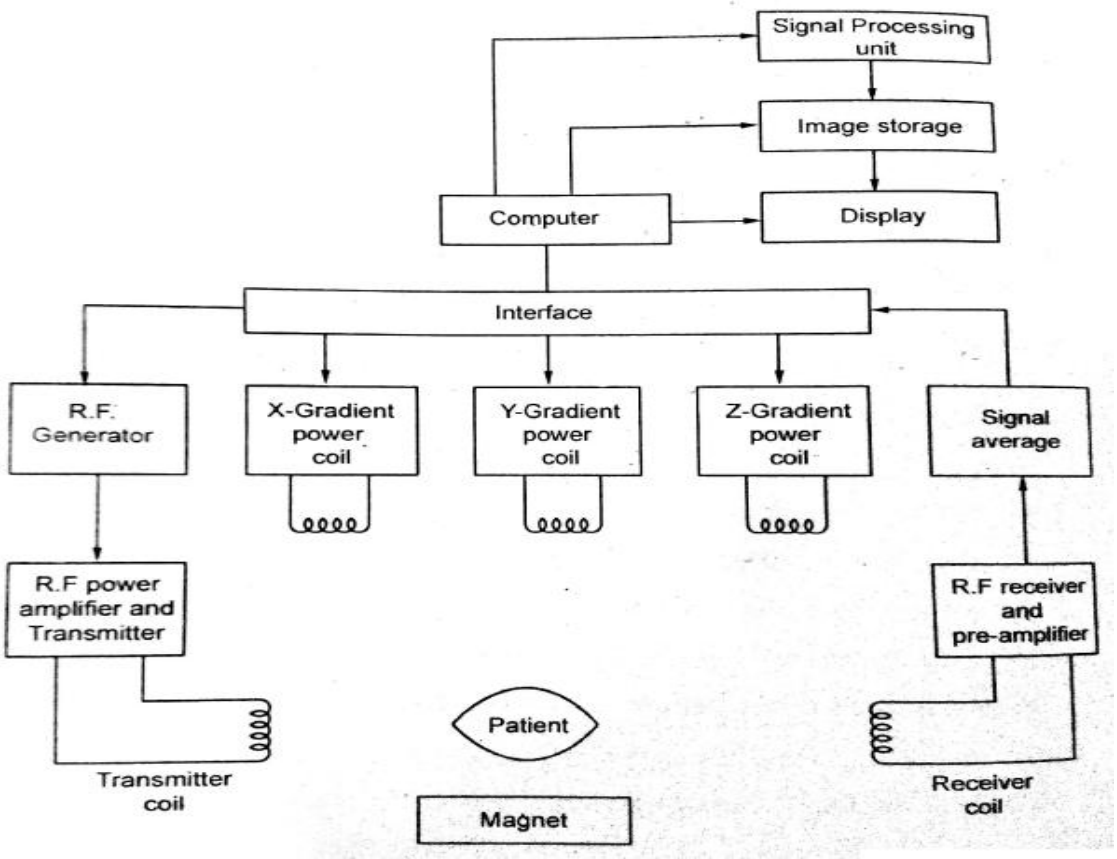

Fig 7.1 Block diagram of MRI system

- There is a super conducting magnetic coil which provides a strong, uniform steady magnetic field
- The coils are used to cool to liquid helium temperature and it can produce very high magnetic field.
- Therefore, the SNR (signal to noise ratio) of the received signals and image quality are better than the conventional magnets used in the MRI system.
- Different gradient coils (X, Y, Z) systems produce a time varying controlled spatial non uniform magnetic fields in different directions.

- By taking a series of these projections at different direction a two (or) three dimensional image can be obtained.
- Now the patient is kept in this gradient field space between the transmitter and receiver RF coils surrounding the site on which the image is to be constructed.
- A superposition of a linear magnetic field gradient on to the uniform magnetic field is applied to the patient.
- When this superposition takes place, the resonance frequencies of the processing nuclei will depend primarily and produces a one dimensional projection of the structure of the three dimensional object.
- The slice of the image depends upon the gradient.
- Magnetic field is controlled by computer and that field can be positioned in three time invariant planes i.e. (X, Y, Z).
- The transmitter provide the RF signal pulses and the received nuclear magnetic resonance signal is picked up by the receiver coil and is fed into the receiver for signal processing.
- By using two dimensional Fourier transformation, the image is constructed by the computer and displayed on the television screen.

7.3 Advantages

- Superior contrast resolution
- Direct multiplaner imaging
- Non invasive imaging technique

7.4 MRI parameter

There are three principal MRI parameters. They are,

- Spin density
- Spin-lattice (Longitudinal) relaxation time, T_1
- Spin-spin (or) transverse relaxation time, T_2

7.4.1 Spin density

- To measure the concentration of mobile hydrogen nuclei available to produce an NMR (Nuclear Magnetic Resonance) signal is called the spin density (SD).

7.4.2 Spin-lattice (Longitudinal) relaxation time, 'T_1'

- The time constant that describes the rate at which the Z-component of net magnetization will return to its equilibrium value.
- M_0 is the T_1 relaxation time and this happen due to the excited nuclei transforming their energy to the surrounding molecular environment, called the lattice and also called as spin-lattice (or) longitudinal relaxation.

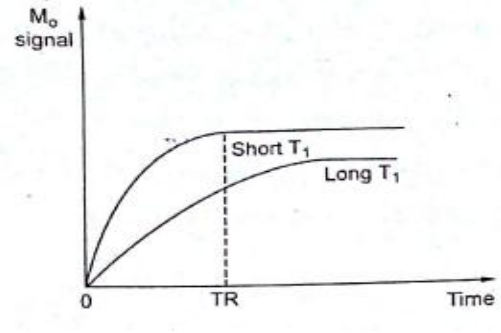

Fig 7.2 Spin-lattice relaxation time, 'T_1'

7.4.3 Spin-spin Relaxation time, 'T_2'

- T_2 represents the time constant associated with loss of magnetization M_{xy} in the XY plane.
- The spin-spin relaxation time is normally measured with a spin-echo pulse sequence involving multiple echoes.
- The relaxation of peak height of a spin echo at time te to the peak height of a FID is

$$M_{xy}(te) = M_{xy}(0) \exp[-te/T_2]$$

A pulse sequence in MRI is basically a set of instructions to the magnet telling it how to make an image.

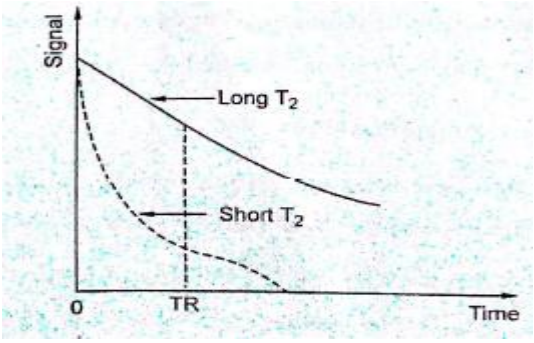

Fig 7.3 Spin-spin Relaxation time, 'T_2'

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8. Ultrasonic Imaging Systems

Explain briefly on ultrasonic imaging systems.

8.1 Introduction

- Ultrasound is a form of energy which consists of mechanical vibrations as the frequencies of high, above the range of human hearing.
- Most biomedical applications of ultrasound employ frequencies in the range of 1 to 15 MHz.
- The velocities of ultrasound in soft tissues and bones are 1570 m/sec and 3600 m/sec.
- Ultrasonic diagnostic aids are based on
  - ❖ Echo aspect
  - ❖ Doppler shift aspect
- Ultrasonic therapeutic aids are based on
  - ❖ The thermal effect
  - ❖ Cavitation effect (developed during the irradiation of ultrasound on the body).

8.2 Doppler ultrasonic blood flow meter

- It is used to determine the flow rate of blood in various blood vessels.
- It can cure cancer and also used to detect the ordinary begin tumors.
- The ultrasonic bondings are useful to fix the fractured bones at their proper place in the body.

8.3 Ultrasonography

- In this technique ultrasonic energy is used to detect the state of the internal body organs.
- When this energy strikes an interface between two issues of different acoustical impedance, reflections (echoes) are returned to the transducer.
- The transducer converts these reflections to an electrical signal.
- This echo signal is amplified and displayed on the oscilloscope at a distance proportional to the depth of the interface.

8.4 Block diagram of ultrasonic imaging instrumentation

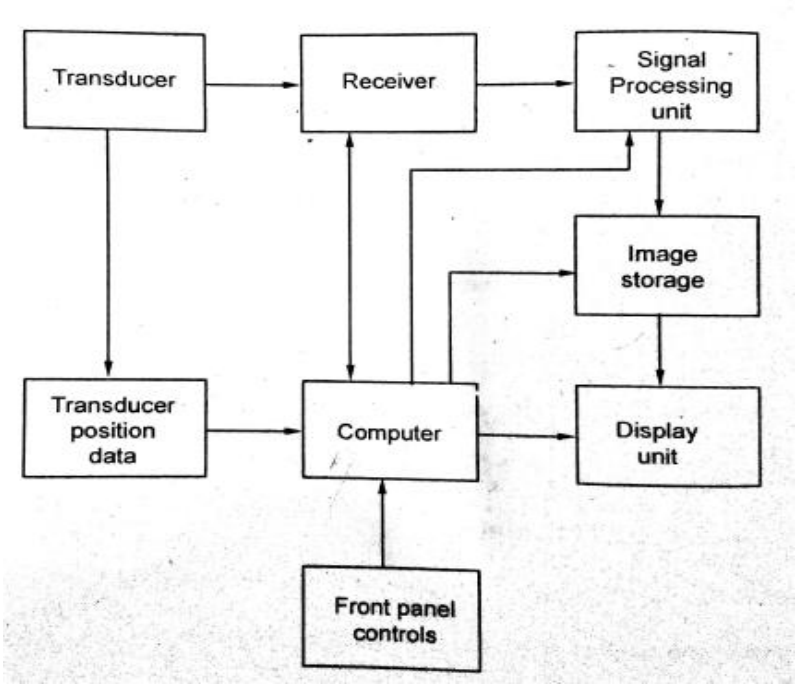

Fig 8.1 Block diagram of a computer controlled ultrasonic image forming system

- The ultrasonic image forming system consist of so many peripheral sub-units such as (transducer data, receiver panel controls, display unit, image storage and signal processing unit) which are controlled by a computer through control buses.
- Computer is the heart of the system.
- Signal processing unit receives information from transducer data through computer and also receiver transducer signal from receiver.
- Receiver sensitivity is controlled by control bus.
- Proper depth gain compensation is calculated by computer and given to signal processing unit.
- Like ultrasonic velocity is calculated and displayed using display unit.

- Past and current status of patient are stored and displayed for detailed examination using ultrasonic imaging technology and the functions are controlled by microcomputer.
- But it is difficult to carry out direct real time image processing.
- Therefore, an ultra high speed analog to digital converter have enabled for straight digitization of high frequency signals.
- Thus, the digital real time scanners are used for displaying ultrasound images.

8.5 Digital Real Time Scanner

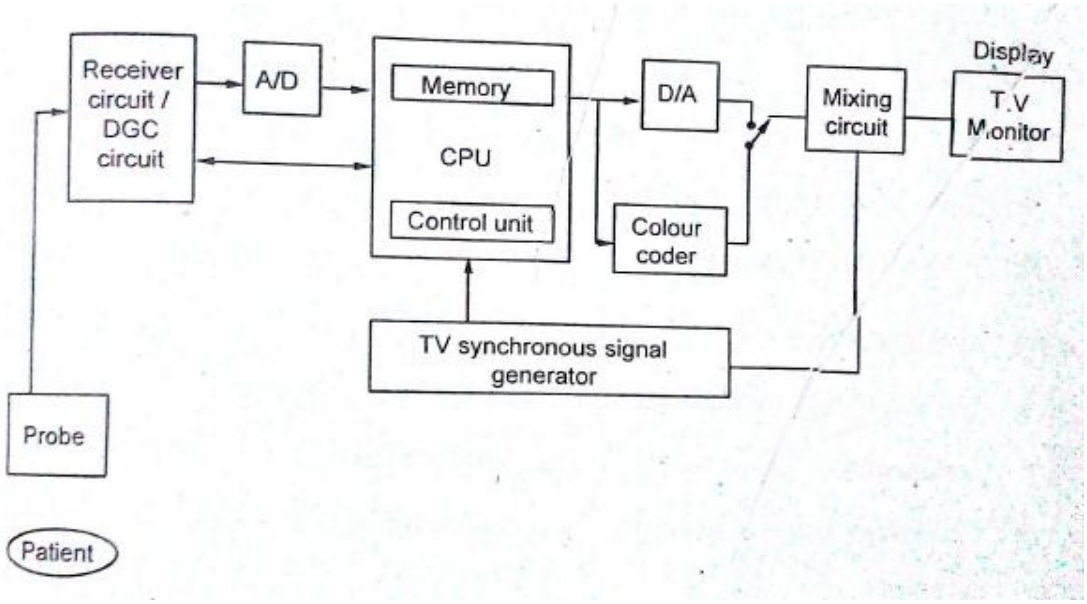

Fig 8.2 Block diagram of real time scanner

- The above block diagram of digital real time scanner consist of receiver / DGC circuit which is used to provide proper depth gain compensation signal and echoes from patient body surface are collected through probe by the receiver unit.
- The received signals are converted into digital signals by using A/D converter and stored in memory.
- Received signals of transducer position, TV synchronous pulses and generated X and Y information about patients which fed in memory are controlled by scan converter.
- The stored digital image signals are processed and colour coded and then given to digital to analog converter.
- Finally, the analog signal is displayed by the TV monitor with higher accuracy.

8.6 Display

The reflected echoes are displayed on the screen as a useful image by the following various modes of display.

- A-mode (Amplitude modulation)
- B-mode (Brightness modulation)
- T-M-mode (Time motion modulation)

8.7 Applications

- Used to find any brain tumor
- Ophthalmology is used to find foreign objects in eye.
- Cardiology is used to determine the cross-section of the heart and to determine heart rate.
- Gynecology is used to monitor the fetus growth and to indicate the presence of twins.

8.8 Limitations

- Bone injury, lung injury and intra-luminal injury of the GI tract cannot be evaluated.
- Ultrasound cannot penetrate gas and bones due to acoustic impedance mismatch at soft tissue (or) soft tissue gas interface.

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UNIT - IV

PHYSICAL MEDICINE AND BIOTELEMETRY

Diathermies – Shortwave, Ultrasonic and microwave type and their applications, Surgical Diathermy, Biotelemetry

1. DIATHERMY

Explain the working principle of a diathermy unit with a neat block diagram. [Nov/Dec 2016][April/May 2016][May/June 2006][April/May 2008][Nov/Dec 2016]

1.1 Introduction

- When heat is applied to the particular area of the body, the temperature of the tissue increases.
- Due to dilation of blood vessels, the flow of blood increases at that area.
- Various methods are used to raise the tissue temperature.
- One of them is called as external method or conductive heating.
- The main disadvantage of this method is, it increases the skin temperature but the heat does not penetrate very deeply into the body.
- The devices used for the purpose of external heating are hot compressors, infra-red lamp, etc.
- The externally used heat sources like hot towels, heat lamps, and heating pads often produce inconvenience and discomfort to the patient.
- This results in the burning of skin before the penetration of adequate heat to the deeper tissues.
- Hence to overcome such demerits, diathermy technique is adopted.
- In this method the patient's body becomes a part of electrical circuit, hence heat is produced within the body instead of transferring through the skin.
- Diathermy is the treatment process by which cutting, coagulation of tissues are obtained.

1.2 Advantages of Diathermy

The advantages of diathermy technique are as follows,

- The treatment can be controlled easily.
- Use of appropriate electrodes permits the heat to be localized only in the region to be treated.
- Amount of heat that is to be delivered can be adjusted accurately.
- Inter lying tissues, muscles, bones, internal organs, etc., can be provided with heat by using high frequency energy.

1.3 Types of Diathermy:

The types of diathermy techniques used are as follows:

- Short-wave diathermy
- Microwave diathermy
- Ultrasonic diathermy

- Surgical diathermy

The short-wave and microwave diathermy involves electromagnetic effects and the ultrasonic diathermy uses mechanical effect.

1.3.1 Short-wave Diathermy

Draw the block diagram of short wave and microwave diathermy and explain in detail. [April/May 2019][May/June 2016][April/May 2018][Nov/Dec 2017][April/May 2017][Nov/Dec 2016]

- Short-wave diathermy involves high frequency of 27.12 MHz and wavelength of 11m.
- Since high frequency currents are used, the motor and sensory nerves are not stimulated and there is no muscle contraction.
- This method has no discomfort to the patient.
- The basic operation of the short-wave diathermy unit can be explained with the help of block diagram as shown below.

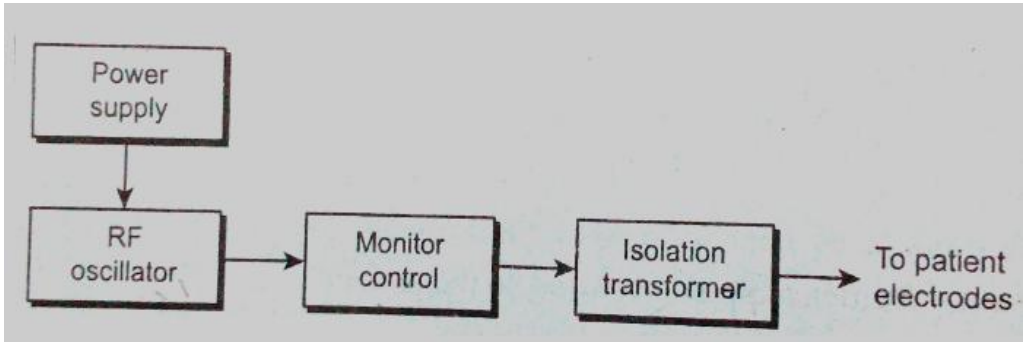

Fig 1.1 Short-wave diathermy unit – Block diagram

- The output of RF oscillator is given to the patient electrodes.
- The RF energy heats the tissues and helps in heating of injured tissues.
- The power delivered by the unit is about 500 W.
- The intensity of the current used can be regulated and adjusted.
- The electrodes are not directly in contact with the skin.
- Usually layers of towels are interposed between the metal and surface of the body.
- There are two methods of short-wave diathermy, they are:
  - (i) Capacitive method
  - (ii) Inductive method

Capacitive method

- Here, the patient electrode pads form a capacitor plates and the body tissues between the pads act as a dielectric.
- Thus the whole arrangement forms a capacitor.
- When the RF current is applied to the electrodes, the capacitor produces heat in the interlying tissues.
- This technique is called as capacitive method.

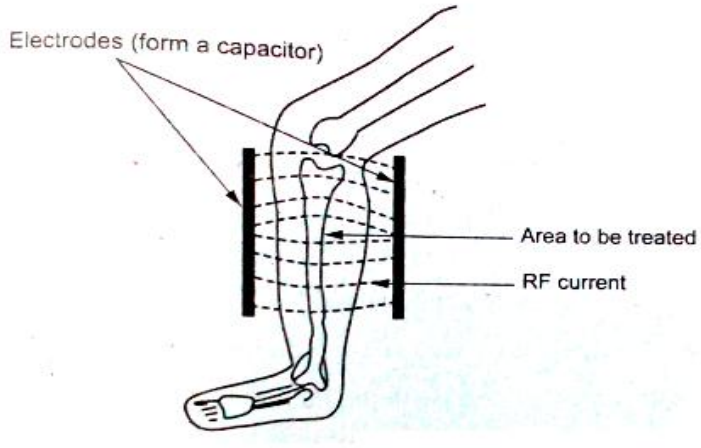

Fig 1.2 Capacitive method

Inductive method (Inductothermy)

- In the inductive method a flexible cable is coiled around the arm or knee or any other portion of the body which is to be treated.
- This is used where the plate electrodes are inconvenient to use.
- When the electrostatic field set up is given between the ends of the cable, deep heating of the tissue occurs.
- The superficial tissues are heated by the eddy currents that are produced due to the magnetic field around the cable. This technique is also called as ***Inductothermy.***

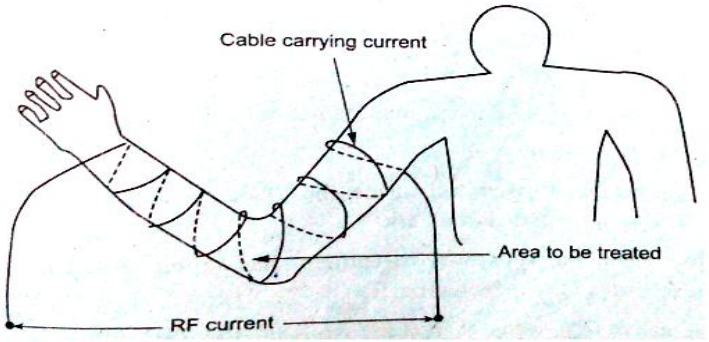

Fig 1.3 Inductive method

- Then instead of using continuous RF waves, RF pulses are used.
- This technique is called Diapulse short-wave diathermy.

Advantages:

- Heating rate of tissue is increased.
- Depth of penetration of RF waves can be easily adjusted.
- There is no danger of burns or irritation and the patient has no discomfort.

1.3.2 Microwave Diathermy

- In this method the tissues are heated by the absorption of microwave energy.
- The frequency used is about 2450MHz with a corresponding wavelength of 12.55 cm.

- Better results are obtained by the microwave method and it is more advantageous than the short wave method.
- Here, there is no usage of pad electrodes and flexible cable.
- Microwave is transmitted into body and treats directly from the direction of the unit.
- Usually microwaves are produced with the help of magnetron.
- A time period of 3 to 4 minutes is required for heating of magnetron.
- A lamp light arrangement is provided to indicate that the magnetron is ready to deliver its output.
- Proper cooling arrangements are made for the purpose of cooling the magnetron.

Precautions

- Necessary precautions should be taken during this method of treatment.
- Excessive dosage causes skin burns and the skin should be dry as the waves are rapidly absorbed by water.

Disadvantages

- Patients with implanted pacemaker should not undergo this treatment.
- There are possibilities of overheating.
- Care should be taken while the treatment is made near the eyes.

1.3.3 Ultrasonic Diathermy

- Ultrasonic diathermy is used for curing the diseases of peripheral nervous system, skeletal muscle system and skin ulcers.
- It is adopted when the short-wave treatment has failed and it helps to achieve the localization of heat to the affected part.
- The heating effect is produced in the tissues by the absorption of ultrasonic energy.
- The absorption effect is similar to that of a micro massage.
- Ultrasonic massage is better than the manual massage because the micro massage provides a greater depth of massage without causing any pain to the patient.

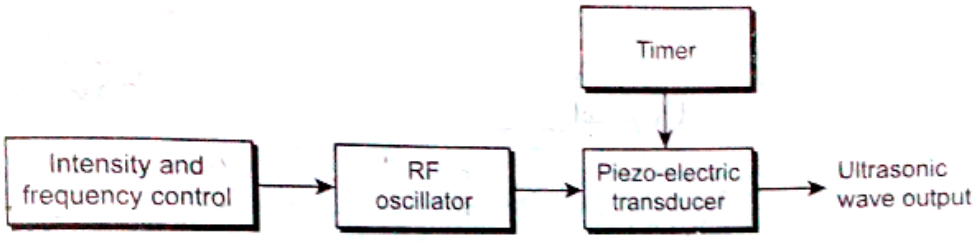

Fig 1.4 Block diagram of ultrasonic diathermy

- The piezo-electric transducer is excited by the high frequency alternating current produced by the RF oscillator.
- The ultrasonic output waveform from the piezo electric transducer is used for the purpose of treatment.

- The ultrasonic waves can be applied in continuous mode or pulse mode.
- Micro massage is obtained without any thermal heating in the pulsed mode.
- The metal face plate in the crystal is made to vibrate due to the oscillations of the crystal and ultrasonic waves are emitted from this plate.
- The frequency range of 800 KHz to 1 MHz is suitable for the ultrasonic method of treatment.
- The timer is an electrically operated contact which can be set upto 15 minutes and gets switched off after the preset time.
- The transducer probe is in direct contact with the patient and it can be moved up and down or circularly around the treatment area for uniform distribution of ultrasonic energy.

1.3.4 Surgical Diathermy

Write short notes on Surgical Diathermy. ***[May/June 2016]***

Explain the working principle of surgical diathermy unit with a neat block diagram. ***[Nov/Dec 2018]***

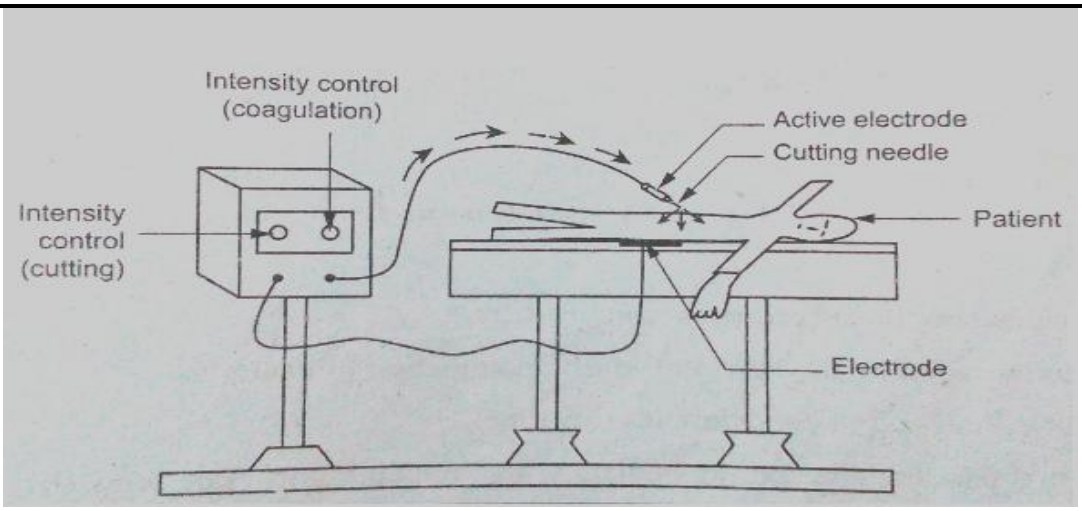

Fig 1.5 Surgical diathermy machine

- Apart from the thermal and therapeutical applications, the high-frequency currents are also used for surgical purposes like cutting and coagulation.
- The frequency of current used here is 1 to 3 MHz (low-frequency currents are not suitable for this method).

Cutting

- When a high frequency current flows through sharp edge of a wire or the point of a needle into the tissue, there is a high concentration of current at this point.
- The tissues get heated and as a result the cells immediately under the electrode are torn apart by the boiling of cell fluid.
- The other electrode called indifferent electrode has large area of contact with the patient and the RF current passed through it induces only a very little heat at the electrode.
- This type of tissue separation is called as electrosurgical cutting.

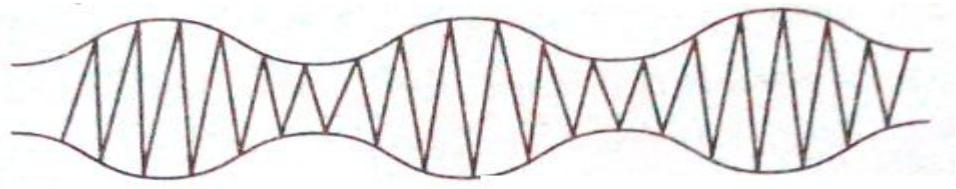

Fig 1.6 Cutting RF waveform

Coagulation

- The coagulation process is achieved by the high frequency current flowing through the tissue and results in heating and coagulation.
- The process of coagulation is accompanied by a grayish-white discoloration of the tissue at the edge of electrode.
- Better coagulation is achieved by high frequency currents as this does not cause burning.
- The continuous radio-frequency current is used for cutting and burst wave radio-frequency is used for coagulation.
- The electrode melts through the tissues and seals capillaries and other vessels. Even if the high-frequency surgery is not used, the method of electro-coagulation can be used.

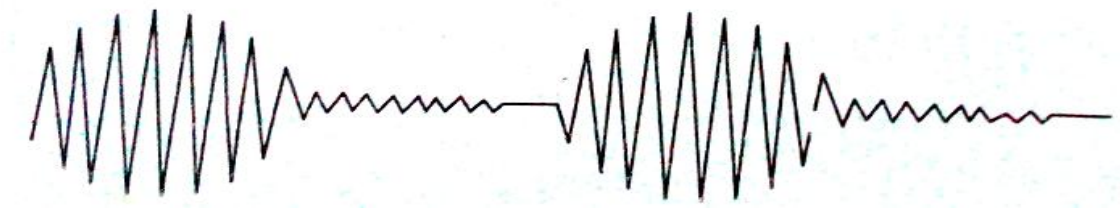

Fig 1.7 Coagulation waveform

Advantages

- It provides simple and effortless surgery.
- This coagulation method prevents the contamination of bacteria.
- Simplified method of coagulation saves time.
- Bleeding can be arrested immediately by touching the spot with the coagulation electrode.

1.3.4.1 Electrosurgical diathermy

- Center logic board is used to produce the waveform for cutting, coagulation, etc.
- Astable multivibrator is used to generate the required pulses.
- 250 KHz frequency signal is used for cutting.
- The generated frequency is given to the power amplifier.
- Here, push pull amplifier is used.
- The transformer is used at the output of the push-pull amplifier.
- So, stepping up and stepping down is possible.
- Class B – push pull amplifier is shown in the figure.
- Audio tone generator is used to heat the 1 KHz signal which is used for coagulation.

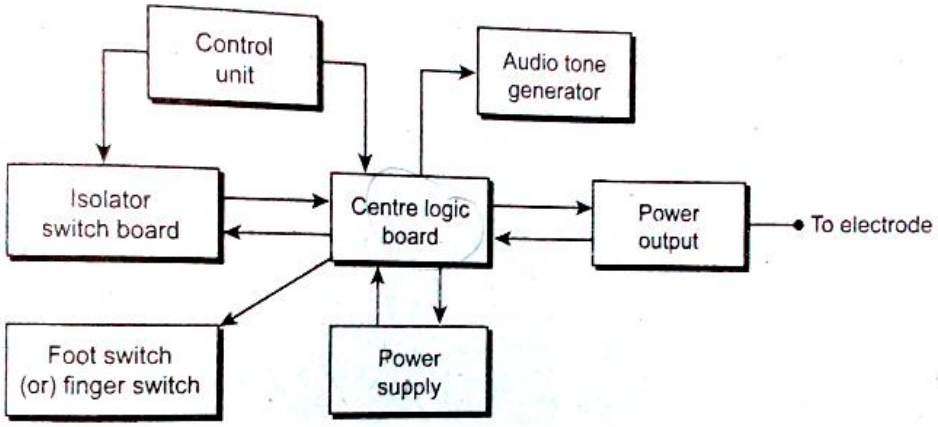

Fig 1.8 Block diagram of electrosurgical diathermy

- Isolation switch board is used to provide the isolation between main supply and the diathermy blocks.
- Foot switch is used to avoid the explosion formed by the existence of anesthesia gas used for the patient near the electrical contact.
- Now, finger switch is mostly used, because, in emergency, the persons in the operating room can press the foot switch without the proper preparation.
- So, the operator gets the supply by using Finger switch only.

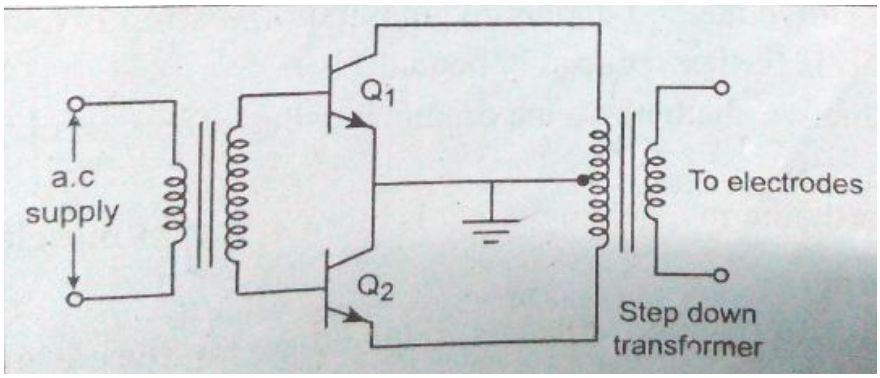

Fig 1.9 Class-B push-pull amplifier

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2. Bio Telemetry

What is bio telemetry? Explain the working of single channel and multi channel ECG telemetry system. ***[May/June 2016][Nov/Dec 2007][May/June 2006]***

What are the components of biotelemetry system? Briefly discuss about biotelemetry. [April/May 2019]

Describe the working of biotelemetry system. [Nov/Dec 2018]

- Bio-telemetry is the measurement of biological parameters over long distances.
- For conveying biological information from a living organism and its environment to a different location where this can be recorded.
- This involves radio frequency signal as a carrier for modulation, referred to as radio-telemetry.

2.1 Elements of Biotelemetry

The essential blocks of a bio-telemetry system are shown below.

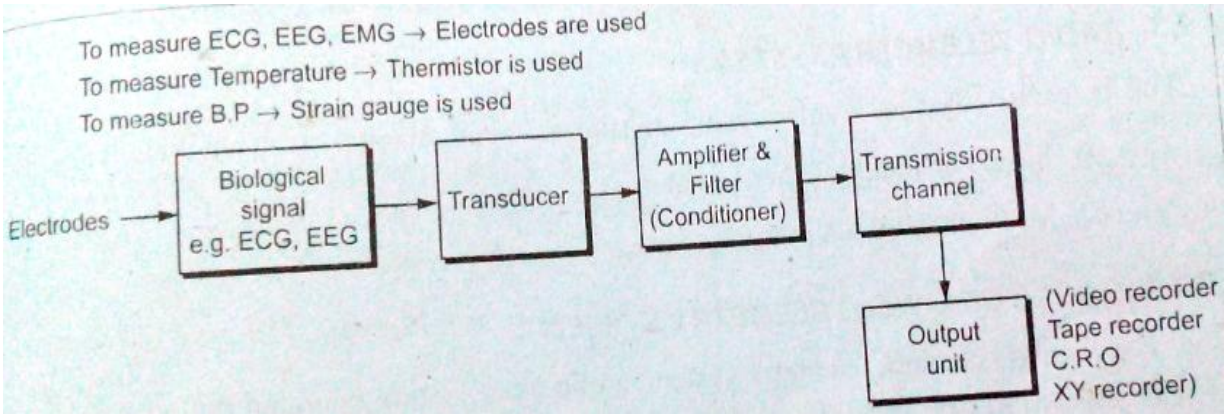

Fig 2.1 Block diagram of a bio-telemetry system

- The biological signal may be ECG, EEG, and EMG.
- The biological information is converted into corresponding electrical signal by using transducer.
- It converts one form of energy into another form.
    - For measuring ECG, EEG, EMG → Electrodes act as transducer
    - For measuring temperatures → Thermistor is used as transducer
    - For measuring blood pressure → Strain gauge is used as transducer
    - For measuring stomach pH → Glass electrode is used as transducer
- The signal (electrical) is not sufficient for transmission because they are weak in nature.
- So sufficient amplification and condition is needed.
- For that purpose conditioner element is provided.
- The transmission link provides a link between the transmitter and receiver. i.e, it changes the electrical signal sufficient for transmission.
- It modulates the signal as frequency modulated and allow for transmission.
- The read out devices are used to read the received signal.
- Some of the read out devices are video recorder, tape recorder, cathode ray oscilloscope, x-y recorder.

2.2 Design of Biotelemetry

- The telemetry system should be selected to transmit the bio-electric signal with maximum fidelity and simplicity.
- The system should not affect the living system by any interference.
- Smaller in size and light in weight.
- It should have more stability and reliability.
- The power consumption at the transmitter and the receiver should be small.
- The system should reject common mode interference rejection i.e., High CMRR can be provided to the system by using differential amplifier.

- The miniature radio telemetry system should be used to reduce noise.

2.3 Radio Telemetry Systems

With suitable diagram, explain how the ECG signal can be transmitted using single channel telemetry systems. ***[Nov/Dec 2016][April/May 2017][April/May 2018]***

The telemetry system involves radio transmission and reception of biosignals. They are:

(i) Single channel telemetry system

(ii) Multi channel telemetry system

2.3.1 Single channel telemetry system

- For a single channel telemetry system, a miniature battery operated radio transmitter is connected to the electrodes of the patients.
- The transmitter broadcasts the biopotential to a remote place in which the receiver detects the radio signal and recovers signal for further processing.
- The receiving system can even be located in a room separately from the patients.
- The only risk is shock to the patient.
- It is due to the battery powered transmitter itself.
- Since it is kept low, there is negligible risk to the patient.

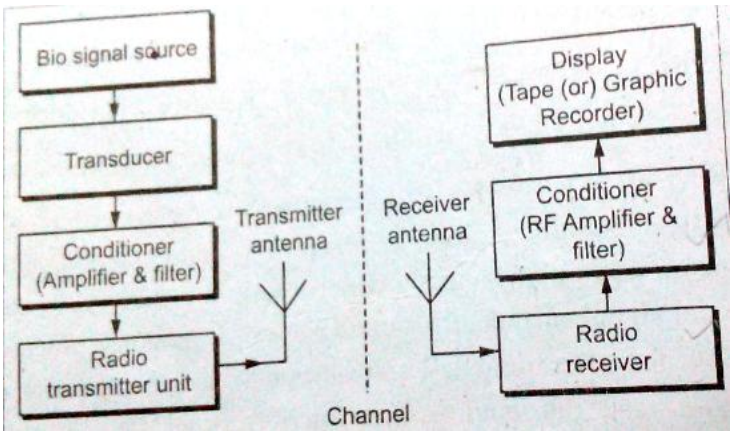

Fig 2.2 Block diagram of a typical single channel telemetry system

- Biosignal from the patient is converted into electrical signals by the transducer.
- Then they are amplified and filtered at the conditioner.
- Further they are frequency modulated or pulse modulated.
- Frequency modulation provides the high noise interference rejection and high stability.
- Amplitude modulation is not adopted because when relative motion occurs between transmitter and receiver, the signal amplitude will be varied and thus introduces serious error.
- The biosignals are amplified to radio frequency range of few hundred KHz to about 300 KHz and then they are transmitted by transmitter antenna.
- At radio receiver the corresponding frequency are received and then they are demodulated, amplified and displayed.

Transmission of Bioelectric variables – Various methods

(i) Active measurements: Bioelectric variables like ECG, EMG and EEG are measured directly without using any excitation voltage.

(ii) Passive measurements: The physiological variables like blood pressure, temperature, blood flow are measured indirectly by using this method. The bridge unbalance voltage obtained from the variations of these variables is measured.

1. Tunnel Diode FM Transmitter (For transmitting ECG, EEG, EMG, and Respiration Rate)

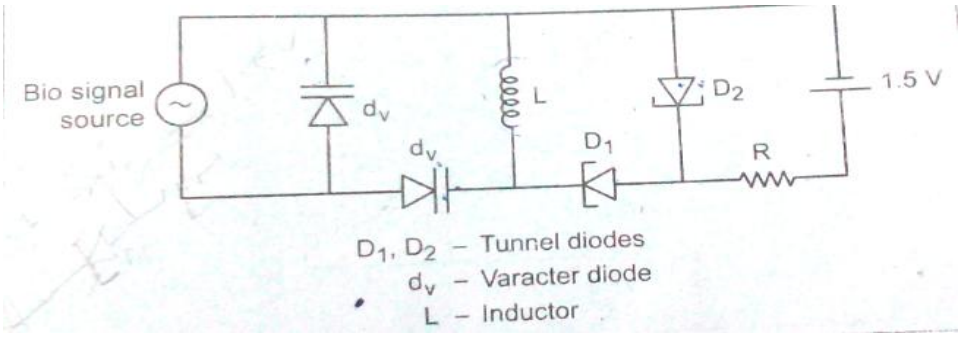

Fig 2.3 Single channel FM transmitter

- The tunnel diodes exhibit a specific characteristic known as negative resistance.
- They have extremely low values of inductance and capacitance.
- It is used for the transmission of EMG, ECG, respiration rate, etc.
- In this type, tunnel diodes are used as active devices and this circuit has higher fidelity and sensitivity.
- Total weight is 1.44 gm with battery and the size is small.
- These are the advantageous factors of this circuit. Some specifications are given below.
  - (a) Radio frequency used is 100 to 250 MHz
  - (b) Frequency range is 0.01 Hz to 20 KHz
  - (c) Input impedance is 300 KΩ to Mega Ωs
  - (d) Temperature stability of carrier frequency is 0.05% / ^{o}C
- Varactor diode is basically a reverse biased PN junction which utilizes the inherent capacitance of depletion layer.
- Varactor diodes (d_V) are voltage capacitors used for frequency modulation.
- The other names of varactor diode are varicap, voltcap, tuning diode.
- The signal is transmitted through the inductor 'L' of the tank circuit of RF oscillator.

Advantages

- All the signal can be transmitted by using this circuit
- No shielded room is needed.
- Interference is much reduced.

2. Hartley type FM transmitter

- It consists of two stages, first stage is known driver amplifier stage and second stage is known as oscillator circuit stage.
- R_4, R_5, R_1, R_2, R_3 are used as Biasing Resistors.
- The capacitor C and inductor L form the tank circuit component of Hartley oscillator.
- The capacitor C_1 is coupling capacitor.
- Q_1 is the driver amplifier transistor and it drives the next stage.

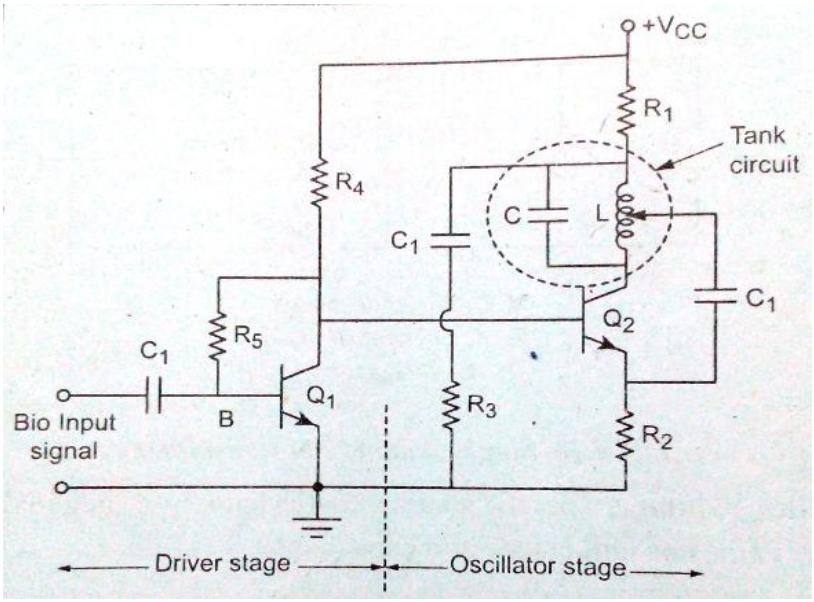

Fig 2.4 Hartley type transmitter

- Q_2 transistor is used in oscillator circuit.
- By using LC tank circuit, the specified frequency can be designed.
- The capacitance between the emitter and base of transistor (V_{BE}) is voltage sensitive and is used to modulate the carrier frequency.
- Amplitude of input signal may vary from 10 μV to several millivolts.
- The distance between T_X and R_X is varied from few meters to 30 meters.
- Bandwidth of the signal is varied from 100 Hz to 1 KHz.

3. Pulsed Hartley Oscillator (Transmission of Temperature Signals)

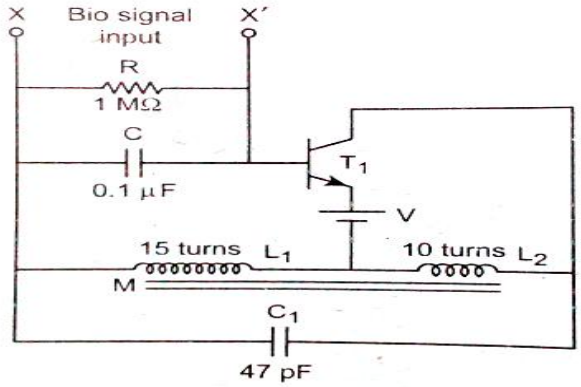

Fig 2.5 Pulsed Hartley oscillator

- It is used for transmission of temperature signals.
- L1, L2, C1 forms the tank circuit of Hartley oscillator.
- To measure temperature, a thermistor is placed in the place of R.
- To measure pressure, the pressure changes should be given to move the core 'M'.
- To measure pH or any voltage, suitable electrodes are connected in the input side.
- The transducer and conditioner are integrated into the components of the oscillator-transmitter.
- Continuous wave operation can be obtained by reducing the value of resistor R.

Advantages

- The circuit is simple.
- It consumes low power (from 5 μW to 10 μW)

Disadvantages

- Error can be produced by the power supply voltage variations.
- Interference can be generated over wide frequency band (due to self blocking pulsed carrier mode operation).

Radio Telemetry with Sub-carrier system

Explain the working of a biotelemetry system with sub-carrier. ***[Nov/Dec 2017]***

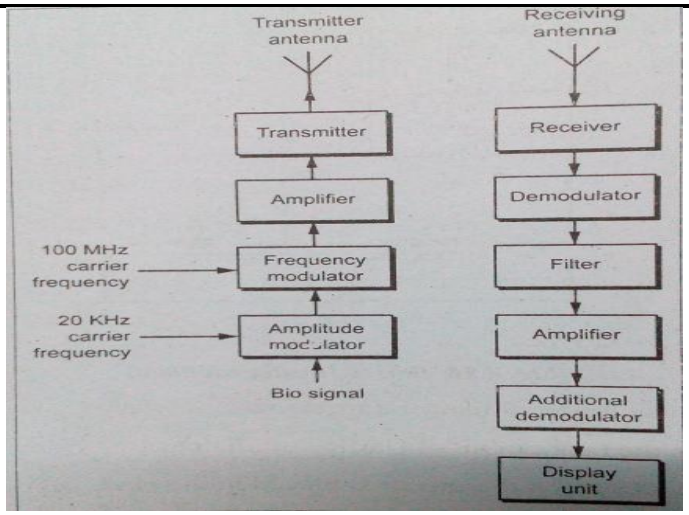

Fig 2.6 Bio-telemetry using sub-carrier system

This system is used for continuous measurement.

Need of Sub-carrier System

At the transmitter side:

- When the position of transmitter to the body or other conduction object change, the carrier frequency and amplitude will change, due to the loading change of the carrier frequency resonant circuit.
- If the signal has a frequency different from the loading effect, they can be separated by filters.
- Otherwise the real signal will be distorted by loading effect.
- To avoid this loading effect the sub-carrier system is needed.

- The signal is modulated on a sub-carrier to convert the signal frequency to the neighborhood of the sub-carrier frequency.
- Then the R.F carrier is modulated by this sub-carrier carrying the signal.
- The 20 KHz sub-carrier signal is given to amplitude modulator.
- It is then given to frequency modulator circuit to frequency modulate the 100 MHz R.F carrier.
- The signals are amplified and forwarded to the transmitter.

At the receiver side:

- At the receiver end, the receiver detects the R.F and recovers the sub-carrier carrying the signal.
- At the receiver side, the signals are passed to demodulator, demodulated signal is filtered, amplified by amplifier and then they are given to additional demodulator.
- It is used to convert the signal from the modulated subcarrier and to get the original signal.
- Finally this signal is displayed.

2.3.2 Multi Channel Telemetry system

******Write short notes on frequency selection for telemetry applications.*** ***[April/May 2016]***

Need

- For most biomedical applications, simultaneous recording of bio signals are required for correlation study.
- Each signal is in need of one channel.
- When the number of channels is more than the two or three, the simultaneous operation of the several single channels is difficult.
- At that time multiple channel (multiplex) telemetry system is adopted.
- Two types of multiplexing are used.

  (i) FDM

  (ii) TDM

(i) Frequency Division Multiplex system (FDM)

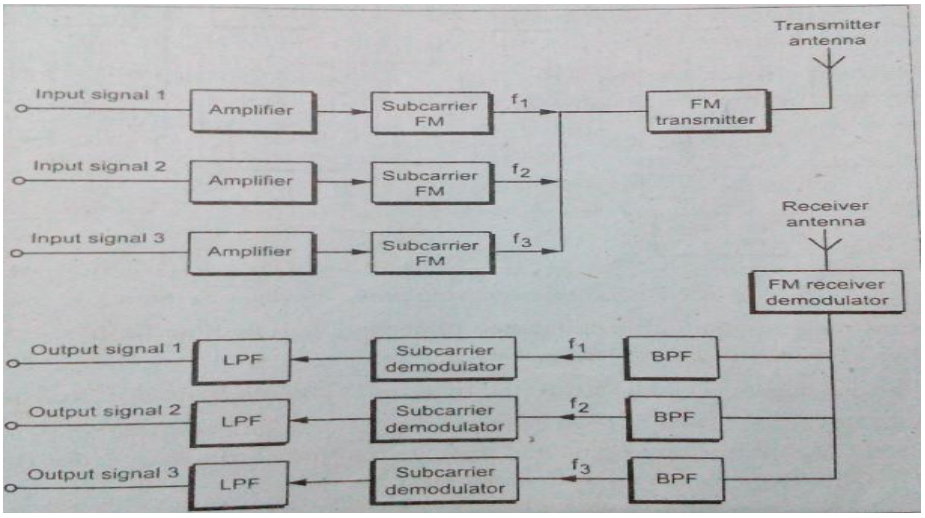

Fig 2.7 Frequency Division Multiplex System

- Each signal is frequency modulated on a sub-carrier frequency.
- Then these modulated sub-carrier frequencies are combined to modulate the R.F carrier.
- Then they are transmitted by using the FM transmitter and antenna.
- At the receiver side the modulated sub-carrier can be separated by the proper band pass filter.
- Then the each signal is demodulated by using specified frequency.
- The frequency of the sub-carrier has to be carefully selected to avoid interference.
- The low pass filter is used to extract the signals without any noise.
- Finally, the output unit displays the original signal.

2. Time Division Multiplex Telemetry System

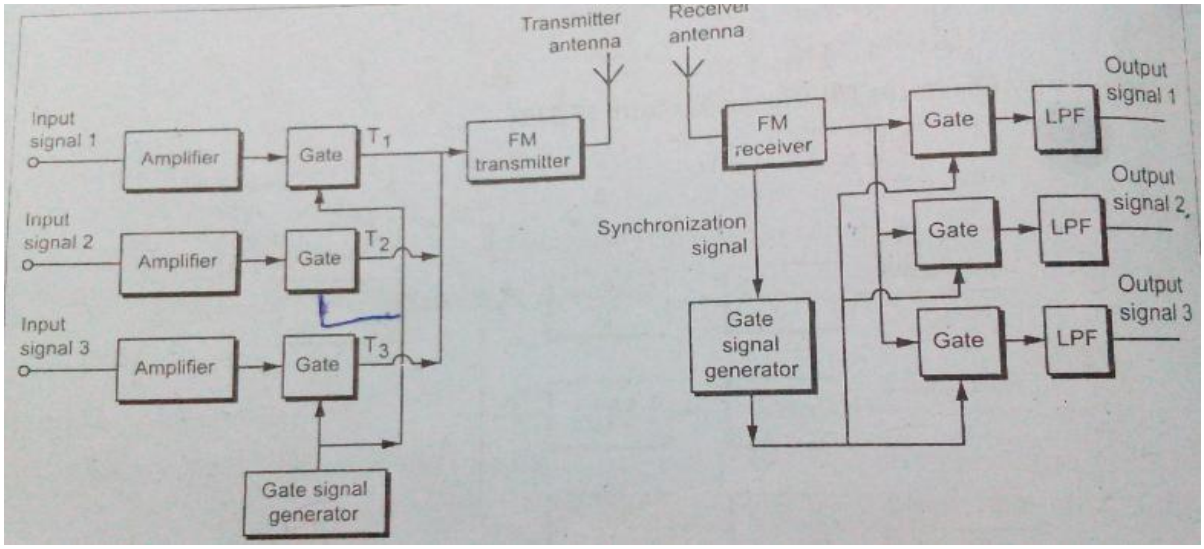

Fig 2.8 Time Division Multiplex Telemetry System

- Since most biomedical signals have low frequency bandwidth requirement, we can use time division multiplex system by time sharing scheme.
- The transmission channel is connected to each signal channel input for a short time to sample and transmit that signal.
- Then the transmitter is switched to the next input signal channel in a definite sequence.
- When all the channels have been scanned once, a cycle is completed and the next cycle will start.
- Scanning follows an 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.
- If the number of scanning cycles per second is large and if the transmitter and the receiver are synchronized, the signal in each channel at the receiver side can be recovered.
- But the scanning frequency has to satisfy the following condition.

$$f_{scan} > 2\ f_{max}$$

Scanning frequency > 2 x Maximum signal frequency

- The maximum number of channels, $n = \frac{T_n}{t_n} = \frac{\text{Scanning period}}{\text{Sampling time of each channel}}$
- The number of channels practically allowed is smaller than the calculated value of 'n' to avoid the interference between channels.

Problems in Implant Telemetry

- For long term telemetry, implant telemetry is very useful.
- The full electronic circuit is packed as a capsule and then implanted deep in the body to be closer to the signal source and to avoid the mechanical difficulties of surface mounted units for long-term observation.
- The size and weight limitations are much more serious and the reliability requirement is more critical.
- Reliability means the life time of a specified circuit. It should be good.
- **Body Reaction:** Size, weight, surface condition and shape of the implant system will be affected by the body reaction.
- The medical grade metals used as enclosures causes little foreign body reaction on tissues.
- The various coating materials used in electronic circuits is silicon, rubber, epoxy, plastics, paraffin, glass and metal.
- They are used to protect them from body fluid.
- At the time of scaling, the temperature should not be high because the electronic components may be affected by the temperature.
- **Power Supply:** Two special power supplies are used for long term implant telemetry units.
- They are:
  - ***Environmental power supply:*** Radio induction has been applied to transmit milliwatt of power to the implanted telemetry unit for months.
  - ***Microwatt power supply*** circuits using Piezo electric crystals placed on any blood vessel or aorta.

Advantages of Biotelemetry

- It is used to record the biosignals over long periods and while the patient is engaged in his normal activities.
- The medical attendant or computers can easily diagnose the nature of disease by seeing the telemetered biosignals without attending patient room.
- Patient is not disturbed during recording.
- For future reference or to study the treatment effect, the biotelemetry is the essential one.
- For recording on animals, particularly for research, the biotelemetry is greatly used.
- For monitoring the persons who are in action, the biotelemetry is an ideal one.
- Biotelemetry is extended for monitoring patients in a hospital from a remote location.

- Now, Tamilnadu government had taken great effort to implement this Bio Telemetry system.
- For monitoring astronauts in space, for monitoring patients who are on the job or at home and carrying implanted pacemakers or other stimulators.
- It is used to monitor the athletes running a race.

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3. Telemetry

What is telemetry? Mention the application of telemetry. [Apr/May 2007, Apr/May 2008, Nov/Dec 2006]

- **Telemetry** is a technology that allows remote measurement and reporting of information.
- The word is derived from Greek roots *tele* = remote, and *metron* = measure.
- Systems that need external instructions and data to operate require the counterpart of telemetry, telecommand.
- Although the term commonly refers to wireless data transfer mechanisms (e.g. using radio or infrared systems), it also encompasses data transferred over other media, such as a telephone or computer network, optical link or other wired communications.
- Many modern telemetry systems take advantage of the low cost and ubiquity of GSM networks by using SMS to receive and transmit telemetry data.

3.1 Applications

Motor racing

- Telemetry is a key factor in modern motor racing.
- It allows race engineers to interpret the vast amount of data collected during a test or race, and use that to properly tune the car for optimum performance.
- Systems used in some series, namely Formula One, have become advanced to the point where the potential lap time of the car can be calculated and this is what the driver is expected to meet.
- Some examples of useful measurements on a race car include accelerations (G forces) in 3 axis, temperature readings, wheel speed, and the displacement of the suspension.

Agriculture

- Most activities related to healthy crops and good yields depend on timely availability of weather and soil data.
- Therefore, wireless weather stations play a major role in disease prevention and precision irrigation.
- These stations transmit major parameters needed for good decisions to a base station: air temperature and relative humidity, precipitation and leaf wetness (for disease prediction models), solar radiation and wind speed (to calculate evapotranspiration), water deficit stress (WDS) leaf sensors and soil moisture, crucial to understand the progress of water into soil and roots for irrigation decisions.

Water management

- Telemetry has become indispensable for water management applications, including water quality and stream gauging functions.
- Major applications include AMR (automatic meter reading), groundwater monitoring, leak detection in distribution pipelines and equipment surveillance.

Defense, space and resource exploration systems

- Telemetry is an enabling technology for large complex systems such as missiles, RPVs, spacecraft, oil rigs and chemical plants because it allows automatic monitoring, alerting, and record-keeping necessary for safe, efficient operations.
- Space agencies such as NASA, ESA, and other agencies use telemetry/telecommand systems to collect data from operating spacecraft and satellites.
- Telemetry is vital in the development phase of missiles, satellites and aircraft
- Without telemetry, these data would often be unavailable.

Rocketry

- In rocketry, telemetry equipment forms an integral part of the rocket range assets used to monitor the progress of a rocket launch.
- Some special problems are the extreme environment (temperature, accelerations, vibration), the energy supply, the precise alignment of the antenna and (at long distances, e.g. in spaceflight) the signal travel time.

Flight test

- Flight test programs typically telemeter data collected from on-board flight test instrumentation over a PCM/RF link.
- This data is analyzed in real-time for safety reasons and to provide feedback to the test pilot.
- Particular challenges for telemetering this data includes fading, multipath propagation and the Doppler Effect.
- The bandwidth of the telemetry link is often insufficient to transfer all the data acquired and therefore only a limited set is sent to the ground for real-time processing

Enemy intelligence

- Telemetry was a vital source of intelligence for the US and UK when Soviet missiles were tested.
- For this purpose, the US operated a listening post in Iran.
- Eventually, the Russians discovered this kind of US intelligence gathering and encrypted their telemetry signals of missile tests.
- Telemetry was a vital source for the Soviets who would operate listening ships in Cardigan Bay to eavesdrop on the UK missile tests carried out there.

Energy monitoring

- In factories, buildings, and houses, energy consumption of systems such as HVAC are monitored at multiple locations, together with the related parameters (e.g. temperature) via wireless telemetry to one central location.
- The information is collected and processed enabling intelligent decisions regarding the most efficient use of energy to be implemented.
- Such systems also facilitate predictive maintenance.

Resource distribution

- Many resources need to be distributed over wide areas.
- Telemetry is essential in these cases, since it allows the system to channel resources to where they are needed.

Medicine

- Telemetry also is used for patients (biotelemetry) who are at risk of abnormal heart activity, generally in a coronary care unit.
- Such patients are outfitted with measuring, recording and transmitting devices.
- A data log can be useful in diagnosis of the patient's condition by doctors.
- An alerting function can alert nurses if the patient is suffering from an acute or dangerous condition.
- Also a system that is available in medical-surgical nursing to monitor a condition where heart condition may be ruled out.

Fisheries and wildlife research and management

- Telemetry is now being used to study wildlife, and has been particularly useful for monitoring threatened species at the individual level.
- Animals under study may be fitted with instrumentation ranging from simple tags to cameras, GPS packages and transceivers to provide position and other basic information to scientists and stewards.
- Telemetry is used in hydro acoustic assessments for fish which have traditionally employed mobile surveys from boats to evaluate fish biomass and spatial distributions.
- Conversely, fixed-location techniques use stationary transducers to monitor passing fish.

Electrical energy providers

- In some countries telemetry is used to assess the amount of electrical energy users have consumed.
- The electricity meter communicates with a concentrator and the latter sends that information through GPRS or GSM to the electrical energy provider's server.

Falconry

- In falconry, "telemetry" means a small radio transmitter carried by a falconry bird to let the bird's owner track it when it is out of sight.

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4. Electrical safety

Explain the physiological effects of current at 50 Hz. [Nov/Dec 2006][Nov/Dec 2010][May/June 2016]

State the influence of leakage current in cardiac patients and explain in detail about the preventive method. [Nov/Dec 2018]

What is the need of electrical safety in hospital? Discuss the various physiological effects of electricity. [April/May 2018]

4.1 Physiological Effects due to 50 Hz Current passage

- Patients and hospital equipment users are susceptible to shock, because they must make physical contact with the hardware.
- The physiological effects of shock range from discomfort to injury to death.
- An electrical shock is a physiological response to current i.e. electrical shock cause an unwanted cellular depolarization and its associated muscular contraction, or it may cause cell vaporization and tissue injury.

4.2 Physiological Effects of current at 50 Hz (Macro shocks, they are distributed over large areas)

Type of current	Current Range	Physiological Effect
Threshold	1 – 5	Tingling sensation
Pain	5 – 8	Intense or painful sensation
Let-go	8 – 20	Threshold of involuntary muscle contraction
Paralysis	> 20	Respiratory paralysis and pain
Fibrillation	80 – 1000	Ventricular and heart fibrillation
Defibrillation	1000 – 10,000	Sustained myocardial contraction, temporary respiratory paralysis and possible tissue burns

- Let-go current is the minimum current to produce muscular contraction.
  [For men → About 16 mA, for women → About 10.5 mA]
- Between 5 Hz to 200 Hz, value of let-go current is so low.
- Above 200 Hz, let-go current is directly proportional to the logarithm of frequency.

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5. Macro shock and Micro shock

Discuss briefly on macroshock and microshock. [Nov/Dec 2010][May/June 2006][April/May 2017]

Define leakage current. Explain the impact of leakage in cardiac patient and discuss about the prevention methods. [Nov/Dec 2017]

5.1 Macro Shock

- A physiological response to a current ***applied to the surface of the body*** that produces unnecessary stimulation like muscle contractions or tissue injury is called macro shock.

- The hospital patients and medical attendants are exposed to macro shocks from defective electrical devices and biomedical equipment.

5.2 Micro Shock

- A physiological response to a current ***applied to the surface of the heart*** that results in unwanted stimulation like muscle contractions or tissue injury is called micro shock.
- Micro shock occurs when currents in excess of 10 μA flow through an insulated catheter to the heart.

Macro shock to Micro shock

Current		Current lever
1000	:	1

- Macro shock can cause heart fibrillation, results in patient's death i.e. current applied directly to the heart.
- Shock is defined in terms of current, because the voltages that produce the currents are highly variable.
- The variance in voltage is caused by wide variation in skin resistance among individuals and among different clinical situation.
    1. Dry skin
    2. Electrode gel on skin
    3. Penetrated skin

5.3 Micro Shock Hazards

- Many devices have a metal basis and cabinet that can be touched by the medical attendants and patients.
- If they are not grounded, then an insulation failure or short circuit results and lead to macroshock or microshock.
- Hence the patients must be isolated or insulated from the electrical circuit.

5.4 Factors

(a) Leakage current: The leakage current is due to:

(i) Ungrounded equipment

(ii) Broken ground wire

(iii) Unequal around potentials

- Leakage current is an extraneous current flowing along a path other than those intended.
- It could be due to resistive, inductive or capacitive couplings with the mains or some electric equipment.

(b) Static Electricity

- Static electricity may be dangerous to people and sensitive equipment having integrated circuits.

- Sparks from static electricity could ignite flammable gases causing an explosion.
- Shocks from static electricity could cause cardiac arrest, if applied to a pacing patient.
- Floor carpeting is common source for static electricity charge build up.

(c) Interruption of power

- Interruption of electrical power to life support equipment can also be dangerous.
- If a delay occurs before emergency power is brought into operation, the failure of a respirator monitor, defibrillator, pacemaker or other life support equipment can be fatal.
- The possibility of a power failure must be considered in the planning of a power distribution system.

Macro shock Hazards

- It occurs with two-wire systems than with three-wire systems. Hot H, Neutral N, Patient P leads. (Proper ground connection)

5.5 Devices to protect against electrical hazards (Macro to micro shock)

******Explain the working of a ground fault interrupter.*** ***[Nov/Dec 2016]***

The devices used to protect against electrical hazards are,

- Ground fault interrupter
- Isolation transformer

5.5.1 Ground Fault Interrupter (GFI)

- It protects against the shock that occurs if a person touches the hot lead with one hand and the ground with the other.
- It consists of a magnetic coil on which hot lead and neutral lead be wound with same number of turns, but in opposite directions.
- When system is normal, $I_N = I_H$, magnetic flux ϕ in the coil due to these current cancels.
- Hence in the sensing coil, no voltage is induced.
- When hot leads faults, the fault current I_F is shunted to ground.

$$I_N = I_H - I_F \; [I_N \neq I_H, \text{hence flux are unequal, induces an voltage}]$$

- If I_F exceeds 2 mA for 0.2 second, relay opens the line and prevents a macro shock from injuring the person, as well as preventing further damage to the equipment.

Receptacle:

- The power delivery point in the hospital room consists of the outlets in the vicinity of the patient.
- The outlets should have 3-prong wall receptacles that meet the ground retention force requirements as per the relevant medical standards.
- These force requirements are very important to ensure that plugs on the medical devices do not fall out of the receptacle.
- Receptacle is to be tested for proper wiring, low ground resistance and mechanical tension.

- The tension in the receptacle should not be so high.
- Otherwise it will destroy the plug cable.

5.5.2 Isolation transformer

- It protects against a H-lead to G-lead macro shock.
- It also prevents sparks when H-lead touches ground.
- Important protection in an explosive or flammable environment, such as user flammable anesthetics or excessive oxygen is present.
- This reduces the isolation from either secondary lead to ground and then to the other secondary lead. (ECG isolation amplifier circuit)

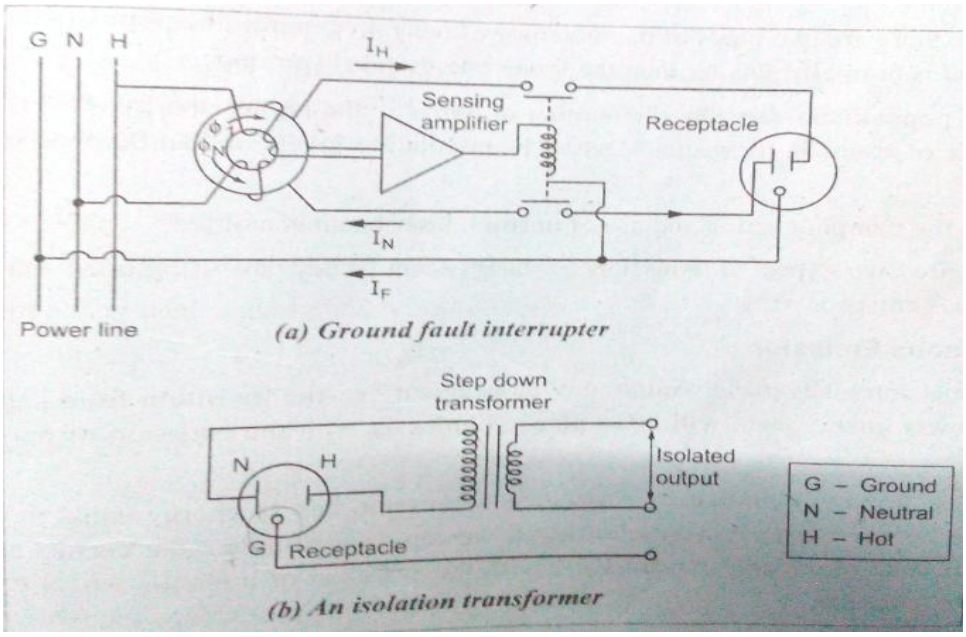

Fig 5.1

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UNIT – V

RECENT TRENDS IN MEDICAL INSTRUMENTATION

Telemedicine, Insulin pumps, Radio pill, Endomicroscopy, Brain machine interface, Lab on a chip.

1. Telemedicine

Explain in detail on telemedicine.

1.1 Telemedicine

- Telemedicine is the application of telecommunications and computer technology to deliver health care from one location to another.
- Telemedicine technology includes hardware, software, medical equipment and communication links.

1.2 Applications of Telemedicine

Telemedicine are widely used in various applications such as teleradiology, telepathology, telecardiology, teleeducation, teleconsultation etc.

- ***Teleradiology:*** Radiological images such as X-ray, CT or MRI images can be transferred from one location to another location for expert consultation. The process involves image acquisition and digitization.
- ***Telepathology:*** To obtain an expert opinion on the microscopic images of pathology slides and biopsy reports.
- ***Telecardiology:*** Refers to the transmission of ECG, echo cardiography, colour Doppler, etc.
- ***Teleeducation:*** Delivery of medical education programmes to the physicians and the paramedics located at smaller towns that are isolated from major medical centres.
- ***Teleconsultation:*** Specialist doctor can be consulted either by a patient directly or by the local medical staff through telemedicine technology.

1.3 Telemedicine Concepts

- Store and forward concept
- Real time telemedicine

1.3.1 Store and forward concept:

- It involves compilation and storing of information relating to audio, video images and clips, ECG.
- The stored information in the digital form is sent to the expert for review.
- The expert's opinion can be transmitted back.

1.3.2 Real time Telemedicine:

- Real time exchange of information between the two centers simultaneously and communicating interactively.
- It may include video conferencing, interviewing and examining the patients, transmission of images of various anatomic sites, auscultation of the heart and lung sounds and a continuous review of various images.

1.4 Essential parameters for telemedicine

For telemedicine, a detailed electronic patient record can be created.

1. Primary patient data: Name, age, occupation, sex, address, telephone number, registration number, etc.

2. Patient history: Personal and family history and diagnostic reports

3. Clinical information: Signs and symptoms are interpretation of data obtained from direct and indirect patient observations.

- ***Direct observations:*** Data obtained from senses (sigh, touch, sound, smell, etc.) and through mental and physical interaction with patient.
- ***Indirect observations:*** Data obtained from diagnostic instruments such as temperature, pulse rate, blood pressure.

4. Investigations: Complete analysis reports of haemotology and biochemistry tests, urine examination.

5. Data and reports: Radiographs, MRI, CT, ultrasound and nuclear medicine images and reports, pathology slides, electrocardiogram, spirogram.

6. Video conferencing facility for online consultations.

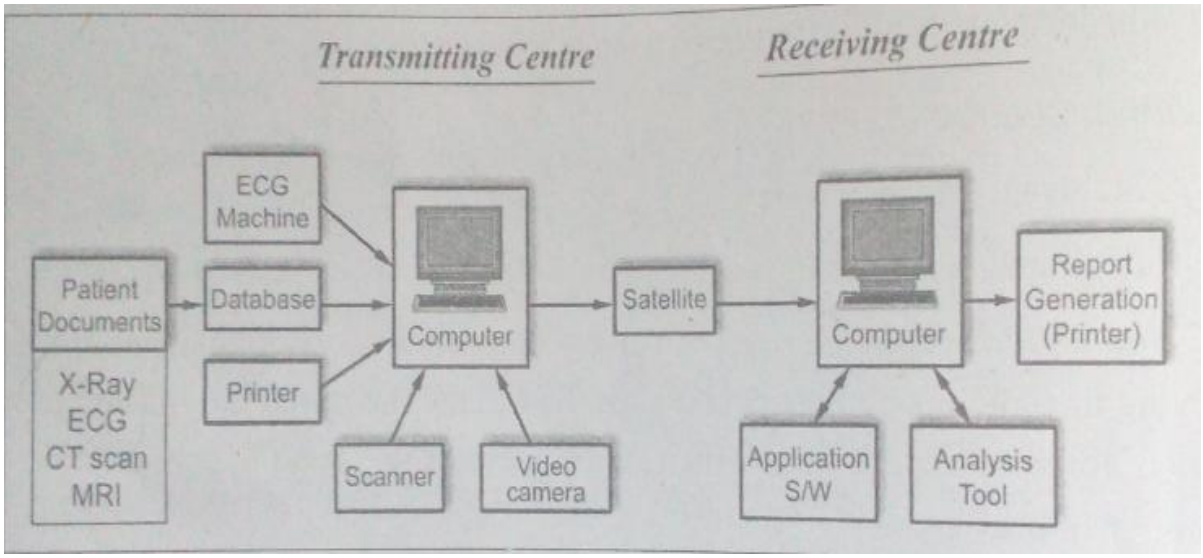

Fig 1.1 Block diagram of a typical telemedicine system

1.5 Telemedicine technology

(a) Transmission of medical images:

- One of the main aspects of telemedicine is the acquisition and transmission of medical images such as X-ray, CT, MRI, Histopathology slides, etc.
- These images are converted into digital form.

(b) Transmission of video images: Video clips, moving images, video conferencing, audio messages.

(c) Video conferencing: One of the essential components in a telemedicine system is the video conferencing facility, which permits transmission of both audio and video information.

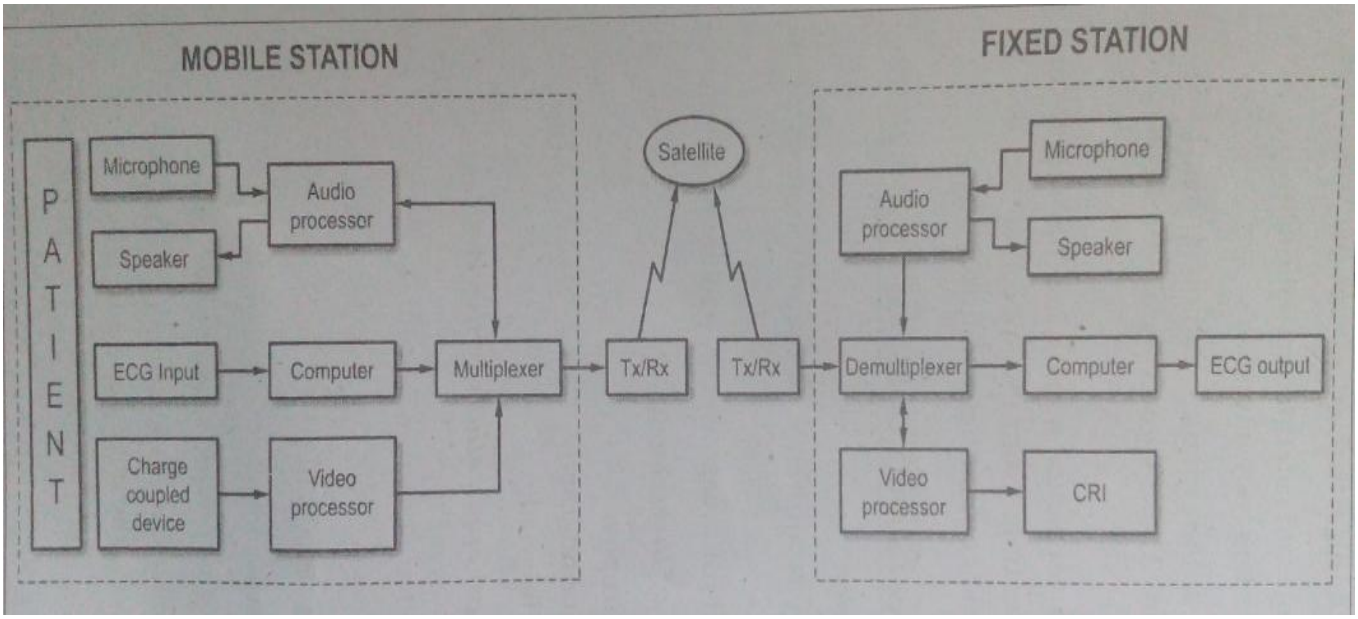

Fig 1.2 Principle of telemedicine using mobile satellite communication

Telemedicine using mobile communication

- Mobile communication and satellite communication made new possibilities for mobile telemedicine in emergency situation.
- In a moving vehicle, colour images, audio signals, ECG and blood pressure are obtained from the patient.
- These signals are multiplexed and transmitted to a fixed station.
- In fixed station, the received signals are demultiplexed and presented to a medical specialist.
- Instructions from the specialist are then transmitted back to the mobile station through the communication link.

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2. Insulin pumps

Briefly discuss the operation of insulin pumps.

2.1 What is Diabetes?

- Diabetes is a condition where the body is unable to regulate levels of glucose (a sugar) in the blood, resulting in excess glucose being present in the blood.
- Glucose is the main sugar digested from our foods.
- Blood glucose levels are regulated by insulin.

2.1 Insulin

- Insulin is a hormone produced in the pancreas that regulates blood glucose levels.
- Insulin enables the body to use Glucose.
- First discovered in 1921.
- Before the discovery children with diabetes were expected to live for under a year.
- Diabetics can’t produce insulin so it must be given to their body.

2.3 Types of Insulin Delivery

Insulin pens

- Needle that injects insulin units into blood stream
- Easy to use

Inhaled insulin

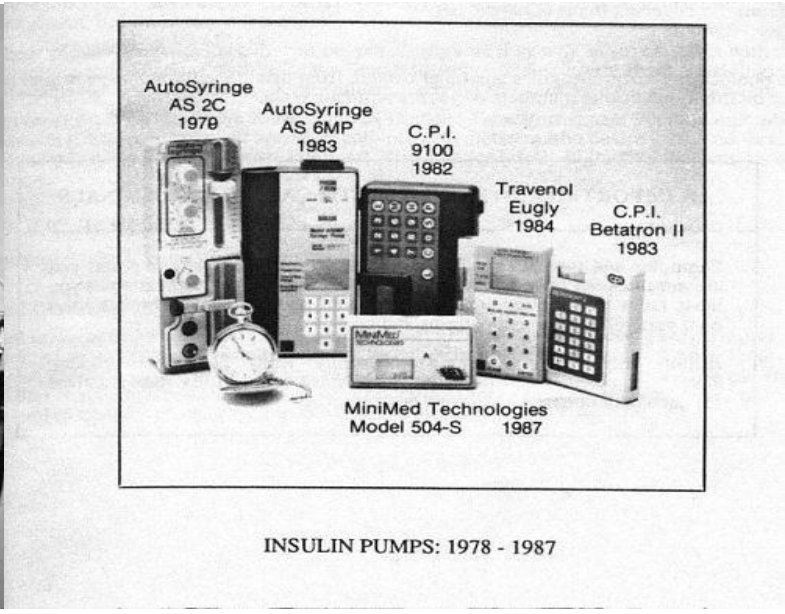
- Similar to an asthma inhaler where the insulin is inhaled and then absorbed into the bloodstream.

Insulin pumps

- Devices that deliver insulin through a flexible tube that ends in a needle attached at the abdomen.

2.4 History of the Insulin pump

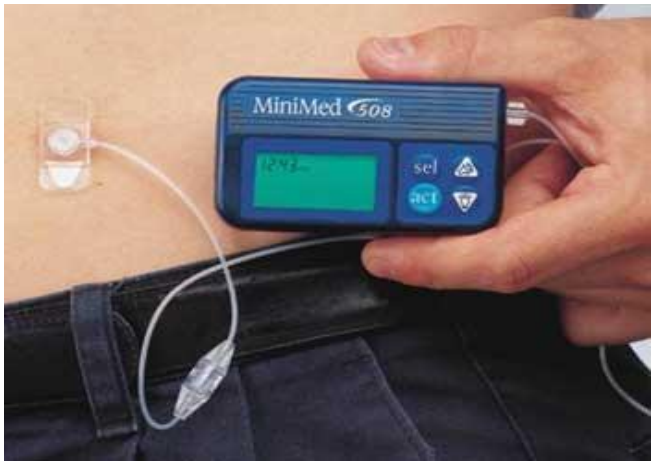
- The first insulin pump was developed in 1963 by Dr. Arnold Kadish.
- 1976 Dean Kamen invented the first wearable insulin pump.
- 1980's insulin pumps start to enter the market.
    - Minimed and Disetronic
- MiniMed 502 first popular insulin pump.
- 2003 MiniMed 512 first insulin pump to monitor glucose levels.



INSULIN PUMPS: 1978 - 1987

2.5 Using an Insulin Pump

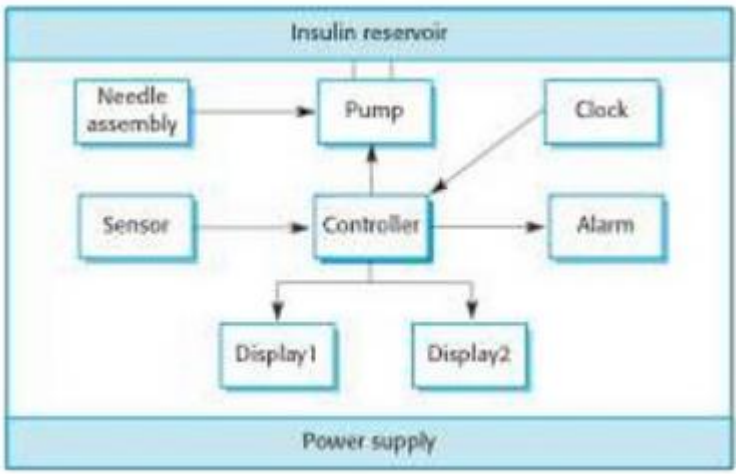
- Insert needle anywhere into body typically the abdomen.
- Three programmable ways to deliver insulin
    - Basal rates
    - Bolus doses
    - Correctional doses
- Then press ok



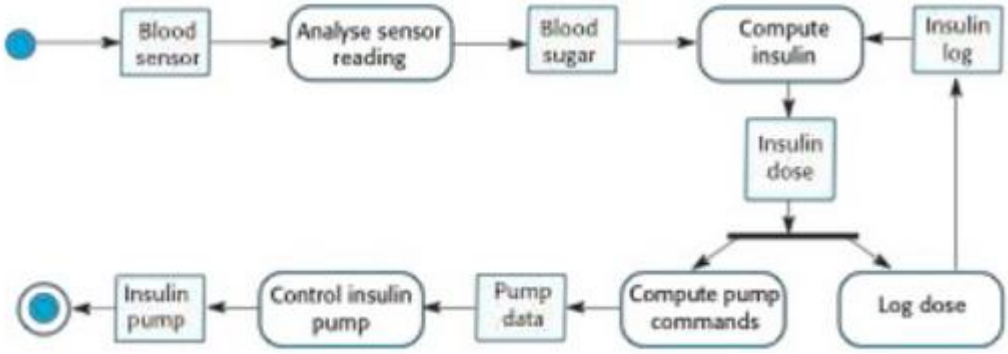
2.6 How Do Insulin Pumps Work?

- Insulin pumps are small, computerized devices.
- The human pancreas works by delivering small doses of short acting insulin continuously (basal rate).
- The device also is used to deliver variable amounts of insulin when a meal is eaten (bolus).
- The basal insulin rates are usually set up in your pump with doctor.
- Can have one or multiple basal settings programmed in the pump, based on their needs.
- They program the amount of insulin for the mealtime bolus directly on the pump.
- Most pumps come with built-in bolus calculators.
- It helps to figure out how much insulin is needed at mealtime based on the glucose levels and the amount of carbohydrates eating.
- The pump, which is about the size of a smart phone or deck of cards, is worn on the outside of body.
- It delivers insulin through a tube (catheter), connected to a thin cannula.
- It is placed into the layer of fat under your skin, typically around your stomach area.
- The pump can be worn around your waist in a pump case or attached to a belt, in a pocket, or on an armband.
- There are a variety of custom-made accessories available so they can carry your insulin pump with style.
- To use an insulin pump, hands-on training from the diabetes care team is needed.
- They will teach how to fill a pump reservoir, prime tubing, select an infusion site, change an infusion set, disconnect the device, calculate and program basal and bolus doses, troubleshoot potential problems, create backup plans in case of pump failure, and prevent diabetic ketoacidosis.

Insulin pump hardware schematic



Activity model of the personal insulin pump



2.7 Types of Pumps

A variety of insulin pumps are available, and diabetes care team can help to choose the best pump.

In general, there are two types of pump devices:

1. **Traditional Insulin pumps** have an insulin reservoir (or container) and pumping mechanism, and attach to the body with tubing and an infusion set. The pump body contains buttons that allow you to program insulin delivery for meals, specific types of basal rates, or suspend the insulin infusion, if necessary.
2. **Insulin patch pumps** are worn directly on the body and have a reservoir, pumping mechanism, and infusion set inside a small case. Patch pumps are controlled wirelessly by a separate device that allows programming of insulin delivery for meals from the patch.

2.8 What Are the Parts of an Insulin Pump?

Traditional insulin pumps contain three main parts:

2.8.1 Pump:

- Traditional insulin pumps are battery powered and contain an insulin reservoir (or container), pumping mechanism, and buttons or touch screen to program insulin delivery.
- Pumps send insulin through tubing into an infusion set that delivers the insulin to your body.

2.8.2 Tubing:

- A thin plastic tube (catheter) is connected to the insulin reservoir and insulin flows into the subcutaneous tissue through the infusion set.
- There are several length sizes of tubing length.
- They are chosen based on how you wear the insulin pump.
- For example, longer tubing may be good for people who wear their pump far from the infusion set.

2.8.3 Infusion set:

- Infusions sets are made of Teflon or steel and attach to your skin with an adhesive patch.
- On the underside of the infusion set is a short thin tube (cannula) that is inserted in your skin with a small needle that is housed within the cannula to deliver insulin into a layer of fatty tissue.
- The needle is necessary to puncture the skin and insert the set.
- After insertion, the needle is removed and the thin cannula stays under the skin.
- The set is usually implanted around your stomach area, but can be placed on the thigh, hips, upper arms.

Infusion sets fall into ***two*** categories:

Angled sets:

- These are inserted at a 30- to 45-degree angle to the surface of the skin.
- In general, these have longer cannulas.
- Athletes, thin or muscular people, pregnant women and active children may prefer these types of angled sets.
- Angled sets also allow for view of the cannula at the insertion site, monitor for signs of redness and for potential infections at the insertion site.

Straight sets*:*

- These are inserted at a 90-degree angle to the surface of the skin.
- They have shorter needles, and may be preferred by people when they insert the set on the arms, or in hard to reach areas.
- Also, people who are afraid of needles can use this type of set with an insertion device that hides the needle.

- People who are active or sweat a lot may need to use tape (such as Hy-Tape, IV3000, Micropore, Polyskin, Tegaderm, and Transpore) or stronger adhesive products (such as Mastisol) to keep the infusion set in place.
- Diabetes care team can provide sources for where to order different types of tape.

2.8.4 Patch pumps

Patch pumps contain three main parts:

- The three main parts of a patch pump include an insulin reservoir, pumping mechanism and cannula.
- But unlike traditional pumps, the parts are contained in one case without tubing, and the device is worn directly on the body, attaching with a self-adhesive.
- The cannula is inserted automatically after attaching the patch on the skin by programming the activation of the patch from a remote device.
- The patch pumps are usually replaced every three days.

2.9 Insulin Treatment for Diabetes

- People with ***type 1 diabetes*** cannot make insulin because the beta cells in their pancreas are damaged or destroyed.
- Therefore, these people will need insulin injections to allow their body to process glucose and avoid complications from hyperglycemia.
- People with ***type 2 diabetes*** do not respond well or are resistant to insulin.
- They may need insulin shots to help them better process sugar and to prevent long-term complications from this disease.
- Persons with type 2 diabetes may first be treated with oral medications, along with diet and exercise.
- Since type 2 diabetes is a progressive condition, the longer someone has it, the more likely they will require insulin to maintain blood sugar levels.

Various ***types of insulin*** are used to treat diabetes and include:

- **Rapid-acting insulin**: It starts working approximately 15 minutes after injection and peaks at approximately 1 hour but continues to work for two to four hours. This is usually taken before a meal and in addition to long-acting insulin.
- **Short-acting insulin:** It starts working approximately 30 minutes after injection and peaks at approximately 2 to 3 hours but will continue to work for three to six hours. It is usually given before a meal and in addition to a long-acting insulin.
- **Intermediate-acting insulin:** It starts working approximately 2 to 4 hours after injection and peaks approximately 4 to 12 hours later and continues to work for 12-18 hours. It is usually taken twice a day and in addition to a rapid- or short-acting insulin.

- **Long-acting insulin:** It starts working after several hours after injection and works for approximately 24 hours. If necessary, it is often used in combination with rapid- or short-acting insulin.

Insulin can be given by a syringe, injection pen, or an insulin pump that delivers a continuous flow of insulin.

Advantages

- Eliminates individual insulin injections.
- Deliver insulin more accurately and regularly.
- Allows for exercise without having to eat a lot of carbs.
- Makes diabetes management easier.
- Better control.

Disadvantages

- Can cause weight gain.
- Needle can fall out leading to no insulin.
- Expensive.
- Requires training.
- Constantly need to be attached to pump.

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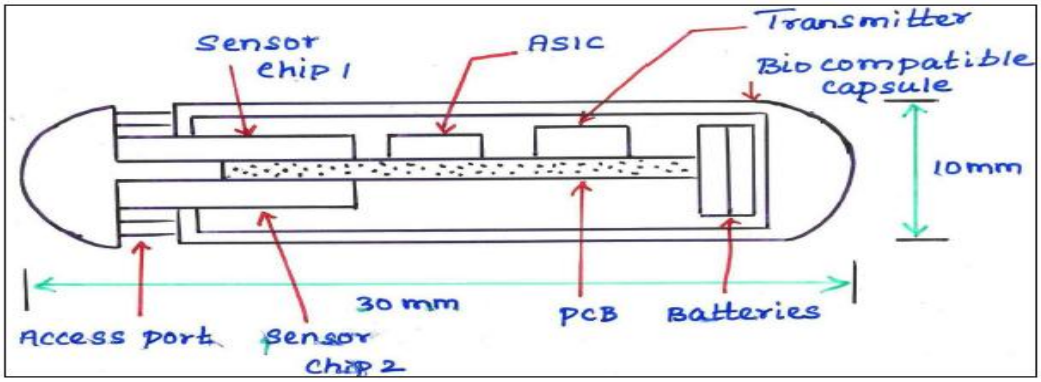
3. Radio pill

Explain briefly on radiopill. ***[April/May 2011]***

- ❖ Radio pill when swallowed, will travel the GI tract (Gastrointestinal tract) and simultaneously perform multi parameter in physiological analysis.
- ❖ After completing its mission it will come out of the human body by normal bowel movement.
- ❖ The pill is 10mm in diameter and 30mm long weighing around 5gm.
- ❖ It records parameters like temperature, pH, conductivity and dissolved oxygen in real time.
- ❖ The pill comprises an outer biocompatible capsule encasing micro sensors, a control chip, radio transmitter and two silver-oxide cells.

3.1 Inside the capsule:

- ❖ The schematic diagram of the microelectronic pill is as shown in figure below.
- ❖ The outer casing of the pill is made by machining chemically resistant polyetheterketone, which is biocompatible.
- ❖ It is made up of two halves, which are joined together by screwing.
- ❖ The pill houses a PCB chip carrier that acts as a common platform for attachment of,
    1. Sensors,
    2. Application- Specific Integrated Circuit (ASIC)
    3. Radio transmitter
    4. Batteries.



3.2 Task of the sensors:

- The device is provided with four micro sensors, namely
    1. A silicon diode,
    2. An ion-selective field effect transistor (ISFET),
    3. A pair of direct- -contact gold electrodes and
    4. A 3-electrode electrochemical cell.

3.2.1 Silicon diode:

- The silicon diode is used to measure the body core temperature.
- It also identifies local changes associated with tissue inflammation and ulcers.

3.2.2 ISFET:

- It is used to measure pH.
- It is used to determine the presence of pathological conditions associated with abnormal pH levels, particularly associated with pancreatic disease, hypertension, inflammatory bowel disease, the activity of fermenting bacteria, the level of acid excretion, reflux to the oesophagus and the effect of GI-specific drugs on target organs.

3.2.3 Gold electrodes:

- A pair of direct contact gold electrode is used to measure conductivity.
- The conductivity sensor is used to monitor the contents of the GI tract by measuring water and salt absorption, bile secretion and the breakdown of organic components into charged colloids.

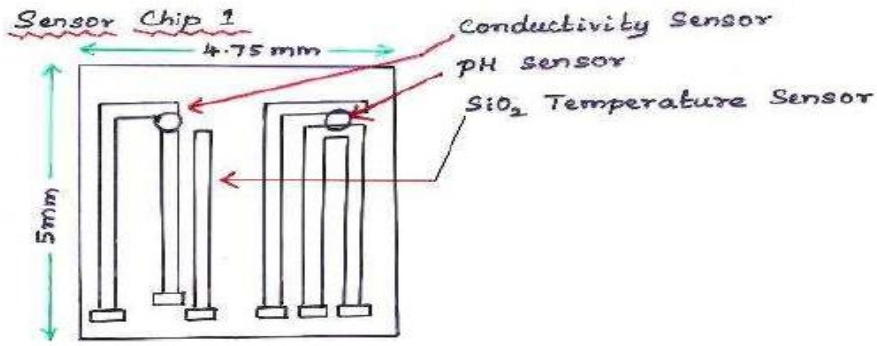
3.2.4 3- Electrode electrochemical cell:

- The 3-electrode electrochemical cell is used to detect the level of dissolved oxygen in solution.
- The oxygen sensor measures the oxygen gradient from the proximal to the distal GI tract.
- This enables a variety of syndromes to be investigated including the growth of aerobic bacteria or bacterial infection.
- The implementation of a generic oxygen sensor will also enable the development of a first generation enzyme linked amperometric biosensors.
- It extends the range of future applications to include (eg.) glucose and lactate sensing, as well as immuno sensing protocols.
- The microelectronic sensors are attached to the PCB chip carrier by a 10 pin, 0.5mm pitch polyimide ribbon connector.

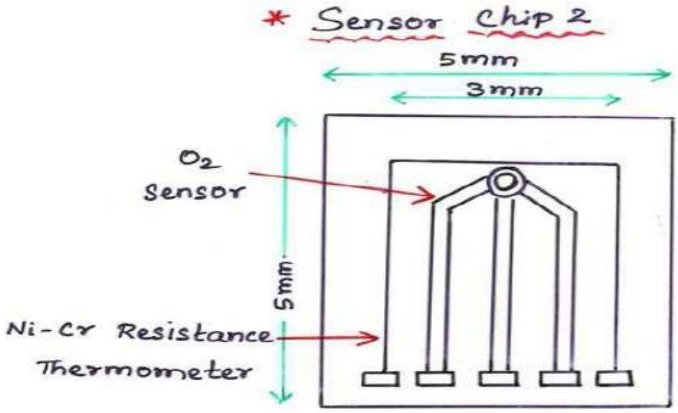
- The PCB carrier is made from 1.6mm thick fiberglass board.
- The transmitter and the ASIC are also integrated on the board.
- The integrated radio transmitter sends the signal to a local receiver prior to data acquisition on a computer.
- The unit is powered by two standard 1.55V silver-oxide cells with a capacity of 175mAh.
- The batteries are connected in series and provide an operating time of 40 hours at the rated power consumption of 12.1mW.
- The sensor chips are provided at the front end of the pill and are exposed to the ambient environment through access ports.
- They are scaled by two sets of stainless-steel clamps incorporating an 0.8mm thick sheet of fluoroelastomer seal.
- The 3mm diameter access channel in the center of each steel clamp exposes the sensing region of the chips to the ambient environment.

3.3 Sensors:

- The schematic diagram of sensor chips is as shown below.
- The sensors are fabricated on two silicon chips located at the front end of the capsule.
- Chip1, measuring 4.75 x 5mm2, comprises the silicon diode temperature sensor, the pH ISFET sensor and the two-electrode 5x $10^{-4}$$mm^2$ conductivity sensor.
- Predefined n-channels in the p-type bulk silicon form the basis for the diode and the ISFET.
- The 15x600mm floating gate of the ISFET is precovered with a 50nm thick proton sensitive layer of Si3N4 for pH detection.
- The pH sensor consists of the integrated 3x 10-2mm2 Ag/Agcl reference electrodes, a 500mm diameter and 10-nL electrolyte chamber and 15x600mm floating gate of the ISFET sensor.



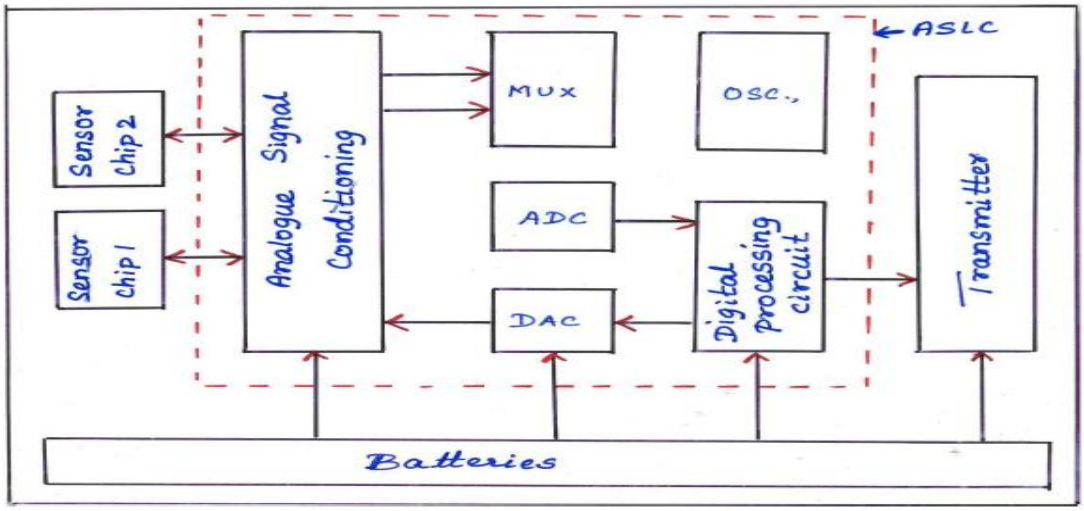
- Chip2, measuring 5 x 5mm2, comprises the electrochemical oxygen sensor and a NiCr resistance thermometer.
- The oxygen sensor is embedded in the electrolyte chamber.
- The 3-electrode electrochemical cell of the oxygen sensor comprises the 1x10-1 mm2 counter electrode made of gold, a microelectrode array of 57x10mm diameter working gold electrodes and an integrated 1.5x 10-2mm2 Ag/Agcl reference electrodes.



- The microelectrode array has an inter-electrode spacing of 25mm and a combined area of 4.5x 10-3mm2.
- It promotes electrode polarization and reduces response time by enhancing transport to the electrode surface.
- The NiCr resistance thermometer is made from a 100nm thick layer of NiCr and is 5mm wide and 11mm long.
- The 500nm thick layer of thermally evaporated silver is used to fabricate the reference electrode. It is then oxidized to Ag/Agcl by chrono potentiometry.

3.4 Control chip:

- The ASIC is the control unit that connects together other components of the microsystem as shown in the figure below.
- It contains an analogue signal conditioning module operating the sensors, 10-bit ADC and DAC converters and a digital data processing module. An oscillator provides the clock signal.
- The temperature circuitry biases the diode at constant current so a change in temperature reflects a corresponding change in diode voltage.
- The pH ISFET sensor is biased as a simple source and drain follower at constant current with the drain-source voltage changing with the threshold voltage and pH.



- The conductivity circuit operates at direct current, measuring the resistance across the electrode pair as an inverse function of solution conductivity.

- ❖ An incorporated potentiostat circuit operates the amperometric oxygen sensor with a 10-bit DAC controlling the working electrode potential with respect to the reference.
- ❖ The analogue signals have a full-scale dynamic range of 2.8V with the resolution determined by the ADC.
- ❖ These are sequenced through a multiplexer prior of being digitized by the ADC.
- ❖ The bandwidth for each channel is limited by the sampling interval of 0.2msec.
- ❖ The digital data processing module processes the digitized signals through the use of a serial bit stream data compression algorithm, which decides when transmission is required by comparing the most recent sample with the previous sampled data.
- ❖ The digital module is clocked at 32 KHz and employs a sleep mode to conserve power from the analogue module.

3.5 Radio transmitter:

- ❖ The size of the transmitter is 8x5x3mm. The transmission range is one meter and the modulation scheme frequency shift keying has a data rate of 1 kbps.
- ❖ The transmitter is designed to operate at a transmission frequency of 40.01 MHz at 20°C generating a signal of 10 KHz bandwidth.

3.6 Power consumption:

- ❖ Two SR44 Ag2O batteries are used, which provide an operating time of more than 40 hours of the microsystem.
- ❖ The power consumption of the system is around 12.1mW and current consumption is around 3.9mA at 3.1V supply.
- ❖ The ASIC and sensor consume 5.3mW corresponding to 1.7mA of current and the free running radio transmitter consumes 6.8mW at 2.2mA of current.

3.7 Range of measurement:

The microsystem can measure,

- ❖ Temperature from 0 to 70°C,
- ❖ pH from 1 to 13,
- ❖ Dissolved oxygen up to 8.2mg/litre
- ❖ Conductivity from 0.05 to 10 ms.cm-1(s=Siemens).

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4. Endomicroscopy

What is an endomicroscopy? Discuss the working of an endoscopic unit.

4.1 Introduction

- **Endomicroscopy** is a technique for obtaining histology-like images from inside the human body in real-time, a process known as ‘optical biopsy’.
- It generally refers to fluorescence confocal microscopy.

- Multi-photon microscopy and optical coherence tomography have also been adapted for endoscopic use.
- Commercially available clinical and pre-clinical endomicroscopes can achieve a resolution on the order of a micrometer.
- They have a field-of-view of several hundred µm, and are compatible with fluorophores which are excitable using 488 nm laser light.
- The main clinical applications are currently in imaging of the tumour margins of the brain and gastro-intestinal tract, particularly for the diagnosis and characterization of Barrett's Esophagus, pancreatic cysts and colorectal lesions.
- A number of pre-clinical and transnational applications have been developed for endomicroscopy as it enables researchers to perform live animal imaging.
- Major pre-clinical applications are in gastro-intestinal tract, tumors margin detection, uterine complications, ischaemia, live imaging of cartilage and tendon, organoid imaging etc.

4.2 Principles

- Conventional, wide field microscopy is generally unsuitable for imaging thick tissue because the images are corrupted by a blurred, out-of-focus background signal.
- Endomicroscopes achieve optical sectioning (removal of the background intensity) using the confocal principle - each image frame is assembled in a point-by-point fashion by scanning a laser spot rapidly over the tissue.
- In table-top confocal microscopes the scanning is usually performed using bulky galvanometer or resonant scanning mirrors.
- Endomicroscopes either have a miniaturised scanning head at the distal tip of the imaging probe, or perform the scanning outside of the patient and use an imaging fibre bundle to transfer the scan pattern to the tissue.

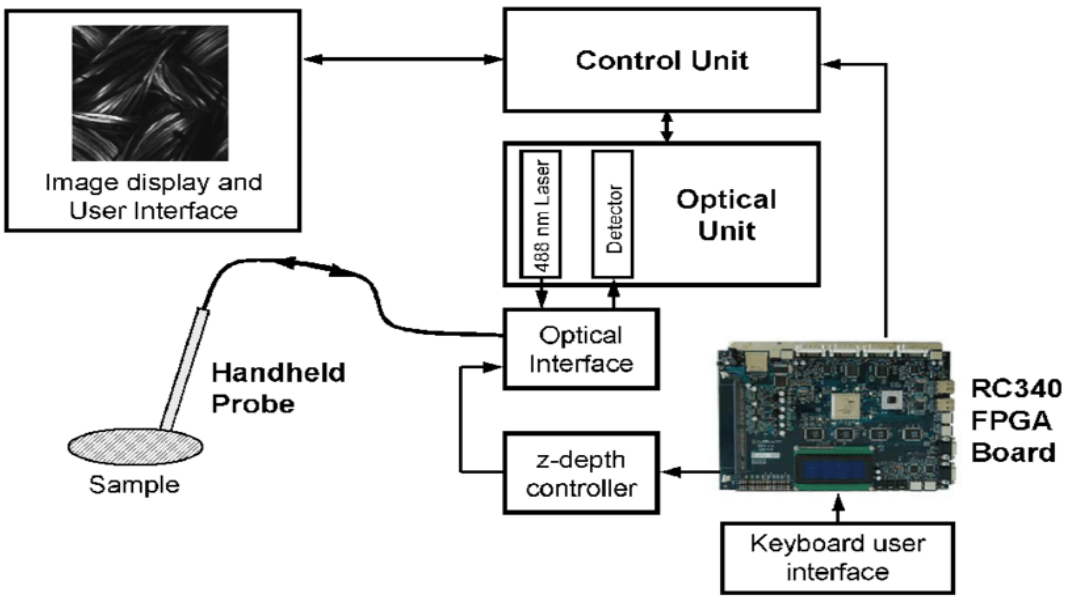

Fig 4.1 Block diagram of endomicroscope interfaced with a FPGA

4.3 Single Fibre Endomicroscopes

- Single fibre confocal endomicroscopes use the tip of an optical fibre as a spatial filter, enabling miniaturisation of the microscope.
- 488nm blue laser passes from the source through an optical fibre to a flexible hand-held probe.
- Optics in the probe focuses the laser to a spot in the tissue, exciting fluorescence.
- Emitted light is captured into the optical fibre and passed through an optical filter to a detector.
- An image is generated by scanning the focused spot throughout the image plane and compiling the point intensity measurements.
- The image plane can be translated up and down in the sample, allowing generation of 3D image stacks.
- Single fibre endomicroscopes have similar resolution of a conventional confocal microscope.

4.4 Fibre Bundle Endomicroscopes

- Fibre bundles were originally developed for use in flexible endoscopes.
- It has been adapted for use in endomicroscopy.
- They consist of a large number (up to tens of thousands) of fiber cores inside a single shared cladding.
- They are flexible, and have diameters on the order of a millimeter.
- In a coherent fiber bundle the relative positions of the cores are maintained along the fibre, meaning that an image projected onto one end of the bundle will be transferred to the other end without scrambling.
- Therefore, if one end of the bundle is placed at the focus of a table-top confocal microscope, the bundle will act as a flexible extension and allow endoscopic operation.
- Since only the cores, and not the cladding, transmit light, image processing must be applied to remove the resulting honeycomb-like appearance of the images.
- Each core essentially acts as an image pixel, and so the spacing between fibre cores limits the resolution.
- The addition of micro-optics at the distal tip of the bundle allows for magnification and hence higher resolution imaging, but at the cost of reducing the field-of-view.

4.5 Distal Scanning Endomicroscopes

- Distal scanning endomicroscopes incorporate a miniature 2D scanning apparatus into the imaging probe.
- The laser excitation and returning fluorescent emission are sent to and received from the scanning head using an optical fiber.
- Most experimental devices have either used MEMS scanning mirrors, or direct translation of the fiber using electromagnetic actuation.

4.6 Non-Confocal Endomicroscopes

- Wide field endomicroscopes (i.e. non-depth sectioning microscopes) have been developed for select applications, including the imaging of cells *ex vivo*.
- Optical coherence tomography and multi-photon microscopy have both been demonstrated endoscopically.
- Successful implementations have used distal scanning rather than fibre bundles due to problems with dispersion and light loss.

4.7 Commercial Products

- Four endomicroscope products have been developed:
  - ❖ The fluorescence in vivo endomicroscope - FIVE2 developed for pre-clinical research,
  - ❖ The neurosurgical device Convivo,
  - ❖ The Pentax ISC-1000/EC3870CIK endoscope, and
  - ❖ Cellvizio.
- The Pentax Medical device was packaged into an endoscope that used OptiScan's electromagnetic-controlled scanning of a single fibre to perform the confocal scanning at the distal tip of the device.
- This provides sub-micrometre resolution across a large field of view and up to a million pixels per frame.
- The original Pentax instrument had variable frame rate up to 1.6 fps and dynamic adjustment of working distance by the user over a depth range from surface to 250 μm.
- The second generation of OptiScan's scanner has an adjustable frame rate between 0.8fps to 3.5fps, field of view of 475μm and a depth range of surface to 400μm.
- Mauna Kea's Cellvizio device has an external laser scanning unit and offers a selection of fibre - bundle based probes with resolution, field of view and working distance optimised for different applications.
- These probes are compatible with standard endoscope instrument channels, and have a frame rate of 12 Hz.

4.8 Applications

- The majority of clinical trials have focused on applications in the gastro-intestinal (GI) tract, particularly the detection and characterization of pre-cancerous lesions.
- Research studies have suggested a large range of potential applications, including in the urinary tract, head and neck, ovaries, and lungs.

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5. Brain Machine interface

Write short notes on Brain machine interface.

5.1 Introduction

- A brain-machine interface (BMI) is a device that translates neuronal information into commands capable of controlling external software or hardware such as a computer or robotic arm.
- A brain computer interface (BCI), also referred to as a brain machine interface (BMI), is a hardware and software communications system.
- It enables humans to interact with their surroundings, without the involvement of peripheral nerves and muscles, by using control signals generated from ElectroEncephaloGraphic (EEG) activity.
- It is collaboration between a brain and a device.
- It enables signal from the brain to direct some external activity, such as control of a cursor or a prosthetic limb.
- The interface enables a direct communication pathway between the brain and the object to be controlled.
- In the case of cursor control, for example, the signal is transmitted directly from the brain to the mechanism directing the cursor, rather than taking the normal route through the body's neuromuscular system from the brain to the finger on a mouse.
- By reading signals from an array of neurons and using computer chips and programs to translate the signals into action.
- BCI can enable a person suffering from paralysis to write a book or control a motorized wheel chair or prosthetic limb through thought alone.
- To control a BCI, the user should produce various brain activity patterns which are captured in form of Electroencephalogram (EEG) and converted to commands by identifying the patterns by the system.

5.2 ElectroEncephalogram (EEG)

- EEG is an electrophysiological monitoring method to record electrical activity of the brain.
- It is typically non-invasive, with the electrodes placed along the scalp, although invasive electrodes are sometimes used such as in electrocorticography.
- EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain.
- In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a period of time as recorded from multiple electrodes placed on the scalp.

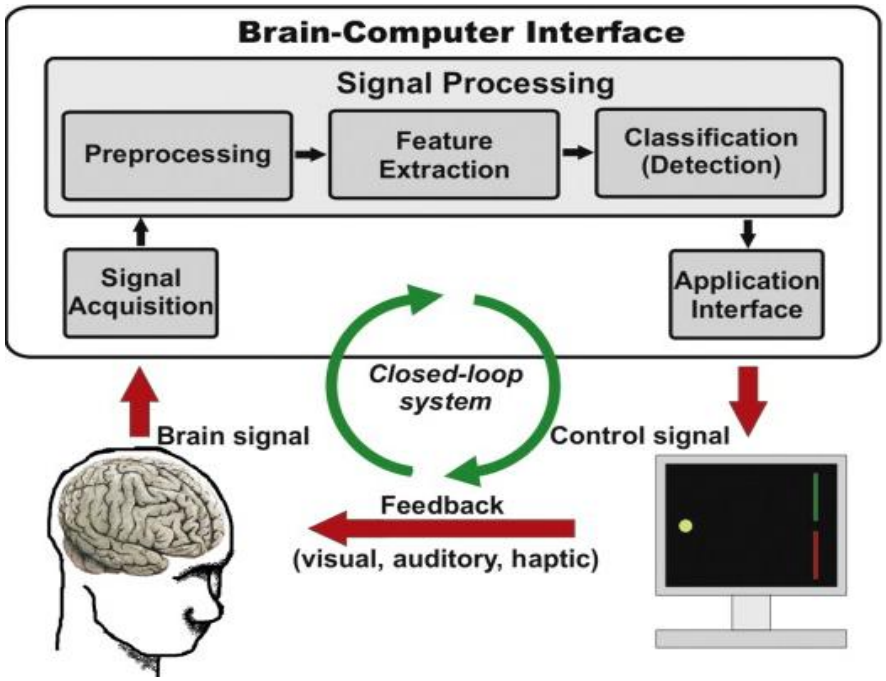

Fig 5.1 Schematic diagram of EEG based BCI

- The interface comprises EEG acquisition system, feature extraction through data processing software and pattern classification, and a system capable of transferring the command to external devices, providing feedback to operator.
- A BCI system whether it is invasive or non-invasive is composed of following phases i.e. Signal acquisition, signal pre-processing, feature extraction, signal classification and computer interaction.

5.3 Signal acquisition

- The ability of a signal acquisition system to measure different phenomena depends on the transducers to convert the physical phenomena into signals measureable by the signal acquisition hardware.
- It is the process of digitizing data from the world around us so it can be displayed, analyzed and stored in a computer.

5.4 Signal pre-processing

- Signal pre-processing is also called as signal enhancement.
- After data acquisition we first preprocess the data to extract the feature.
- It usually intensifies the signals and the upgrade signal to noise ratio (SNR).
- The general step in the preprocessing is band pass filtering which were designed to remove DC bias and high frequency noises.

5.5 Types of signal processing methods

- It may be used in the EEG signal generation according to the filtering types for preprocessing. Those are ***spatial filtering*** and ***frequency filtering***.

5.6 Feature extraction

- When the data is too large to be processed, the data will be transformed into a reduced representation set of features.

- The process of transforming the input data into the set of features is called feature extraction.
- The goal of feature extraction is selecting suitable data for the subsequent classification or detection of features needed to design.
- It is the process of collecting discriminative information from a set of samples.
- Transforming the input data into the set of features is called feature extraction.

5.7 Classification

- The central element in each BCI is the classification module which is also referred to as translation algorithm.
- It simply converts electrophysiological input from the user into output that controls external devices.
- The translation algorithm is an important stage in the signal processing module of the BCI system.
- It is responsible for translating the extracted signal features into device commands that performs the user's intent.
- Whatever the nature is, a translation algorithm changes signal features into device control commands.
- The first part of signal processing simply extracts specific signal features.
- The extracted signal features may be classified on both frequency and shape features based on linear methods or non-linear methods like the neural networks.

5.8 Application interface

- In computer programming, an application programming interface (API) is a set of subroutine definitions, communication protocols, and tools for building software.
- In general terms, it is a set of clearly defined methods of communication among various components.

5.9 Applications

- EEG based BCI systems
- ECoG based BCI systems
- Intracortical based BCI systems

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6. Lab On a Chip (LOC)

Explain briefly on Lab on a chip.

6.1 Introduction

- A **lab-on-a-chip** (**LOC**) is a device that integrates one or several laboratory functions on a single integrated circuit (commonly called a "chip") of only millimeters to a few square centimeters to achieve automation and high-throughput screening.
- LOCs can handle extremely small fluid volumes down to less than pico-liters.

- Lab-on-a-chip devices are a subset of microelectromechanical systems (MEMS) devices and sometimes called "micro total analysis systems" (μTAS).
- LOCs may use microfluidics, the physics, manipulation and study of minute amounts of fluids.
- However, strictly regarded "lab-on-a-chip" indicates generally the scaling of single or multiple lab processes down to chip-format.
- "μTAS" is dedicated to the integration of the total sequence of lab processes to perform chemical analysis.
- The term "lab-on-a-chip" was introduced when it turned out that μTAS technologies were applicable for more than only analysis purposes.

6.2 History

- After the invention of micro technology, these lithography-based technologies were soon applied in pressure sensor manufacturing (1966) as well.
- Due to further development of these usually CMOS-compatibility limited processes, a tool box became available to create micrometre or sub-micrometre sized mechanical structures in silicon wafers as well: the Micro Electro Mechanical Systems (MEMS) era had started.
- Next to pressure sensors, airbag sensors and other mechanically movable structures, fluid handling devices were developed.
- ***Examples*** are: channels (capillary connections), mixers, valves, pumps and dosing devices.
- The first LOC analysis system was a ***gas chromatograph***, developed in 1979 by S.C. Terry at Stanford University.
- However, only at the end of the 1980s and beginning of the 1990s did the LOC research start to seriously grow as a few research groups in Europe developed micropumps, flowsensors and the concepts for integrated fluid treatments for analysis systems.
- These μTAS concepts demonstrated that integration of pre-treatment steps, usually done at lab-scale, could extend the simple sensor functionality towards a complete laboratory analysis, including additional cleaning and separation steps.
- A big boost in research and commercial interest came in the mid 1990s, when μTAS technologies turned out to provide interesting tooling for genomics applications, like capillary electrophoresis and DNA microarrays.
- A big boost in research support also came from the military, especially from DARPA (Defense Advanced Research Projects Agency), for their interest in portable bio/chemical warfare agent detection systems.
- The added value was not only limited to integration of lab processes for analysis but also the characteristic possibilities of individual components and the application to other, non-analysis, lab processes.
- Hence the term "Lab-on-a-Chip" was introduced.

- Although the application of LOCs is still novel and modest, a growing interest of companies and applied research groups is observed in different fields such as analysis (e.g. chemical analysis, environmental monitoring, medical diagnostics and cellomics) but also in synthetic chemistry (e.g. rapid screening and microreactors for pharmaceutics).
- Besides further application developments, research in LOC systems is expected to extend towards downscaling of fluid handling structures as well, by using nanotechnology.
- Sub-micrometre and nano-sized channels, DNA labyrinths, single cell detection and analysis, and nano-sensors, might become feasible, allowing new ways of interaction with biological species and large molecules.

6.3 Chip materials and fabrication technologies

- The basis for most LOC fabrication processes is photolithography.
- Initially most processes were in silicon, as these well-developed technologies were directly derived from semiconductor fabrication.
- Because of demands for e.g. specific optical characteristics, bio- or chemical compatibility, lower production costs and faster prototyping, new processes have been developed such as glass, ceramics and metal etching, deposition and bonding, polydimethylsiloxane (PDMS) processing (e.g., soft lithography), Off-stoichiometry thiol-ene polymers (OSTEmer) processing, thick-film- and stereolithography as well as fast replication methods via electroplating, injection molding and embossing.
- The demand for cheap and easy LOC prototyping resulted in a simple methodology for the fabrication of PDMS microfluidic devices: ESCARGOT (Embedded SCAffold RemovinG Open Technology).
- This technique allows for the creation of microfluidic channels, in a single block of PDMS, via a dissolvable scaffold (made by e.g. 3D printing).
- Furthermore, the LOC field more and more exceeds the borders between lithography-based microsystem technology, nanotechnology and precision engineering.

6.4 Advantages

LOCs may provide advantages, which are specific to their application. Typical advantages are:

- Low fluid volumes consumption
- Faster analysis and response times due to short diffusion distances, fast heating, high surface to volume ratios, small heat capacities.
- Better process control because of a faster response of the system
- Compactness of the systems due to integration of much functionality and small volumes
- Massive parallelization due to compactness, which allows high-throughput analysis
- Lower fabrication costs, allowing cost-effective disposable chips, fabricated in mass production
- Part quality may be verified automatically

- Safer platform for chemical, radioactive or biological studies because of integration of functionality, smaller fluid volumes and stored energies

6.5 Disadvantages

The most prominent disadvantages of Labs-on-chip are:

- The micro-manufacturing process required to make them is complex and labor-intensive, requiring both expensive equipment and specialized personnel.
- It can be overcome by the recent technology advancement on low-cost 3D printing and laser engraving
- The complex fluidic actuation network requires multiple pumps and connectors, where fine control is difficult.
- It can be overcome by careful simulation, an intrinsic pump, such as air-bag embed chip, or by using a centrifugal force to replace the pumping, i.e. centrifugal micro-fluidic biochip
- Most LOCs are novel proof of concept application that is not yet fully developed for widespread use.
- More validations are needed before practical employment
- In the microliter scale that LOCs deal with, surface dependent effects like capillary forces, surface roughness or chemical interactions are more dominant.
- This can sometimes make replicating lab processes in LOCs quite challenging and more complex than in conventional lab equipment
- Detection principles may not always scale down in a positive way, leading to low signal-to-noise ratios

6.6 Applications

- Genomics and proteomics
- Environmental assays
- Medical diagnostics
- Drug discovery
- Chemical production
- Cellular analysis

6.7 Global health

- Lab-on-a-chip technology may soon become an important part of efforts to improve global health, particularly through the development of point-of-care testing devices.
- In countries with few healthcare resources, infectious diseases that would be treatable in a developed nation are often deadly.
- In some cases, poor healthcare clinics have the drugs to treat a certain illness but lack the diagnostic tools to identify patients who should receive the drugs.

- Many researchers believe that LOC technology may be the key to powerful new diagnostic instruments.
- The goal of these researchers is to create microfluidic chips that will allow healthcare providers in poorly equipped clinics to perform diagnostic tests such as immunoassays and nucleic acid assays with no laboratory support.

6.8 Global challenges

- For the chips to be used in areas with limited resources, many challenges must be overcome.
- In developed nations, the most highly valued traits for diagnostic tools include speed, sensitivity, and specificity; but in countries where the healthcare infrastructure is less well developed, attributes such as ease of use and shelf life must also be considered.
- The reagents that come with the chip, for example, must be designed so that they remain effective for months even if the chip is not kept in a climate controlled environment.
- Chip designers must also keep cost, scalability, and recyclability in mind as they choose what materials and fabrication techniques to use.

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