equivalent straight line perpendicular to the base line instead of along the arc produced by the pen is $L\Theta^3/6$. This error is usually negligible. If the length of the straight line is D cm and the distance difference between the arc and the straight line with respect to the base line produces a timing error of $D^2/(2Ls)$ seconds where s is the paper speed in cm/s.

4.3 ELECTROCARDIOGRAPHY

The Electro Cardio Graphy (ECG) deals with the study of the electrical activity of the heart muscles. The potentials originated in the individual fibers of heart muscle are added to produce the ECG wave form. *Electro cardiogram* is the recorded ECG wave pattern. ECG sometimes called EKG which is derived from the German electrokardiogram. The electrocardiogram reflects the rhythemic electrical depolarisation and repolarisation of the myocardium (heart muscle) associated with the contractions of the atria and ventricles. The shape, time interval and amplitude of the ECG give the details of the state of the heart. Any form of arrhythmia (disturbances in the heart rhythm) can be easily diagnosed using electrocardiogram. But the valvular defects can be identified by phonocardiography which will be dealt later.

4.3.1 Origin of Cardiac Action Potential

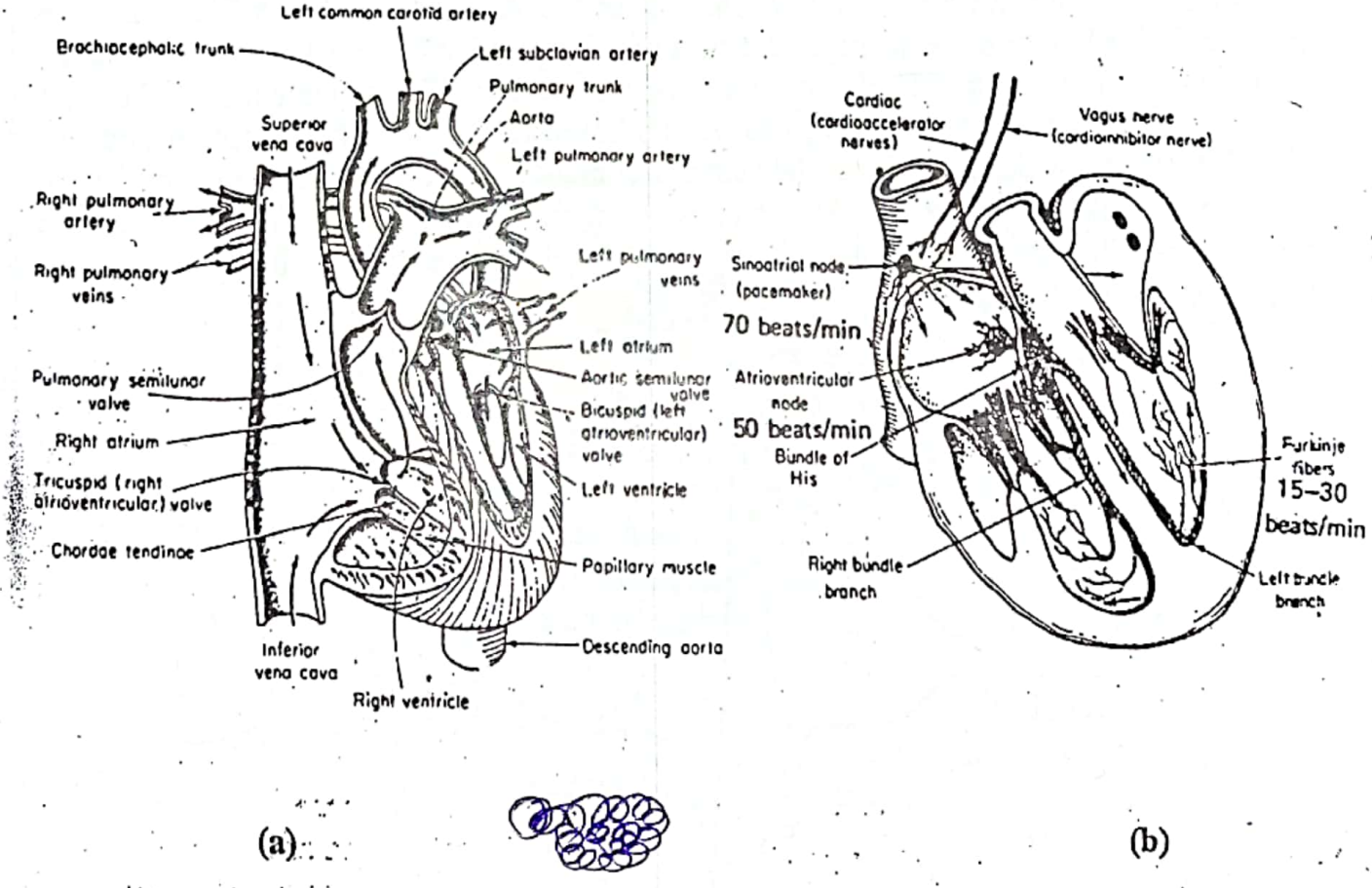


Fig.4.2. (a) Anatomy and (b) Conducting system of heart

Figure 4.2 shows the cross section of the interior of the heart. We know that the heart is divided into four chambers. The top two champers are atria and lower two chambers are ventricles. The right atrium receives blood from the veins and pumps it into right ventricle. The right ventricle pumps the blood into the lungs where it is purified and oxygenated. The oxygen enriched blood enters the left atrium from which it is pumped into the left ventricle. Then the left ventricle pumps the blood into arteries through Aortic valve for circulation throughout the body. For circulation, blood requires proper pressure. Sufficient pressure is delivered by the ventricular muscle's contraction which is achieved through the cardiac action potential.

Figure 4.2(b) shows the electrical conducting system of heart. Each action potential in the heart originates at the ***sinoatrial (SA) node*** which is situated in the wall of the right atrium and near the entry of the Vena Cava. It is also called ***cardiac pacemaker*** and generates impulses at the normal rate of the heart, about 70 beats per minute at rest. The rate is governed by the autonomic nervous system, being increased by the sympathetic nerves and decreased by the parasympathetic nerves. These are connected with brain through the spinal cord. The action potential contracts the atrial muscle and the impulse spreads through the atrial wall during a period of about 0.04 second to the ***atrio-ventricular (AV) node***. The node is located in the lower part of the wall between the two atria. The AV node delays the spread of excitation for about 0.11 second. Thus the AV node acts as a "delay line" to provide timing between the action of the atria and the ventricles. Then a special conduction system carries the action potential to the ventricular muscles. This system consists of a short common part (***the bundle of His***), two bundle branches on each of the septum and fine ***Purkinjie fibers*** which arborize in the ventricular muscle. Thus the atria and ventricles are functionally linked only by the AV node and the conduction system. The A-V delay is provided so that the atrial contraction can complete the ventricular filling before the contraction of ventricles.

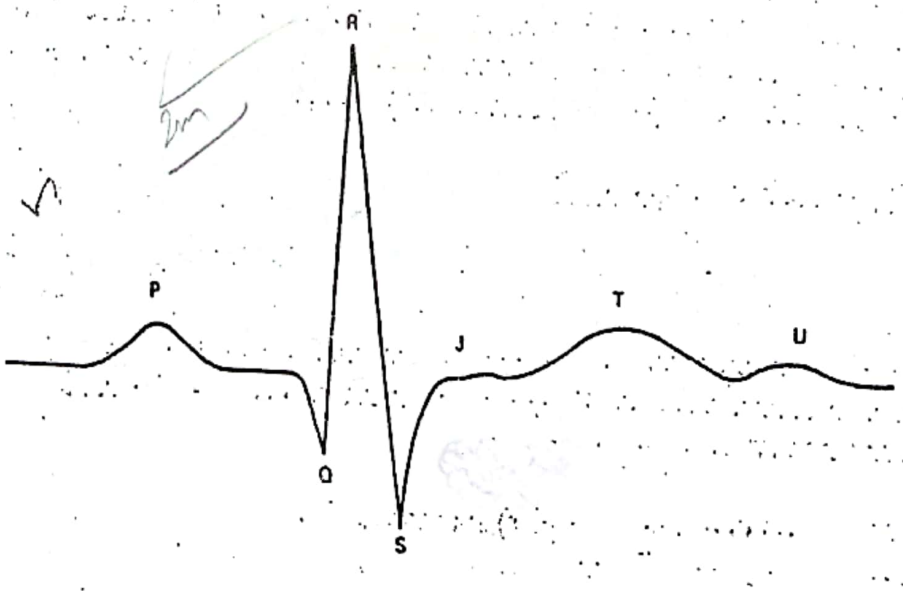


Fig.4.3. Electrocardiogram

Figure 4.3 shows the typical ECG wave. It consists of P wave, QRS complex and T wave. The origin, amplitude and duration of the different waves in the electrocardiogram are given in the Table 4.1.

Table 4.1. Physiological Nature of ECG Waveform

	Origin	Amplitude mV	Duration sec.
P Wave	Atrial depolarisation or contraction	0.25	0.12 to 0.22 (P-R interval)
R Wave (QRS complex)	Repolarisation of the atria and the depolarisation of the ventricles	1.60	0.07 to 0.1
T Wave	Ventricular repolarisation (Relaxation of myocardium)	0.1 to 0.5	0.05 to 0.15 (S-T interval)
S-T interval	Ventricular contraction		
U Wave	Slow repolarisation of the intraventricular (Purkinje fibers) system	< 0.1	0.2 (T-U interval)

The complete waveform is called electrocardiogram with lebels PQRSTU indicating important diagnostic features. For example if the PR interval is more than 0.22 sec., the AV Block (First degree - heart attack) occurs. When the QRS complex duration is more than 0.1 second the bundle block (severe heart attack) occurs.

4.3.2 ECG Lead Configurations

Usually surface electrodes are used with jelly as electrolyte between skin and electrodes. The potentials generated in the heart are conducted to the body surface. The potential distribution changes in a regular and complex manner during each cardiac cycle. Therefore to record electrocardiograms, we must choose standardised electrode positions. There are three types of electrode systems:

1) Bipolar limb leads (or) standard leads
2) Augmented unipolar limb leads

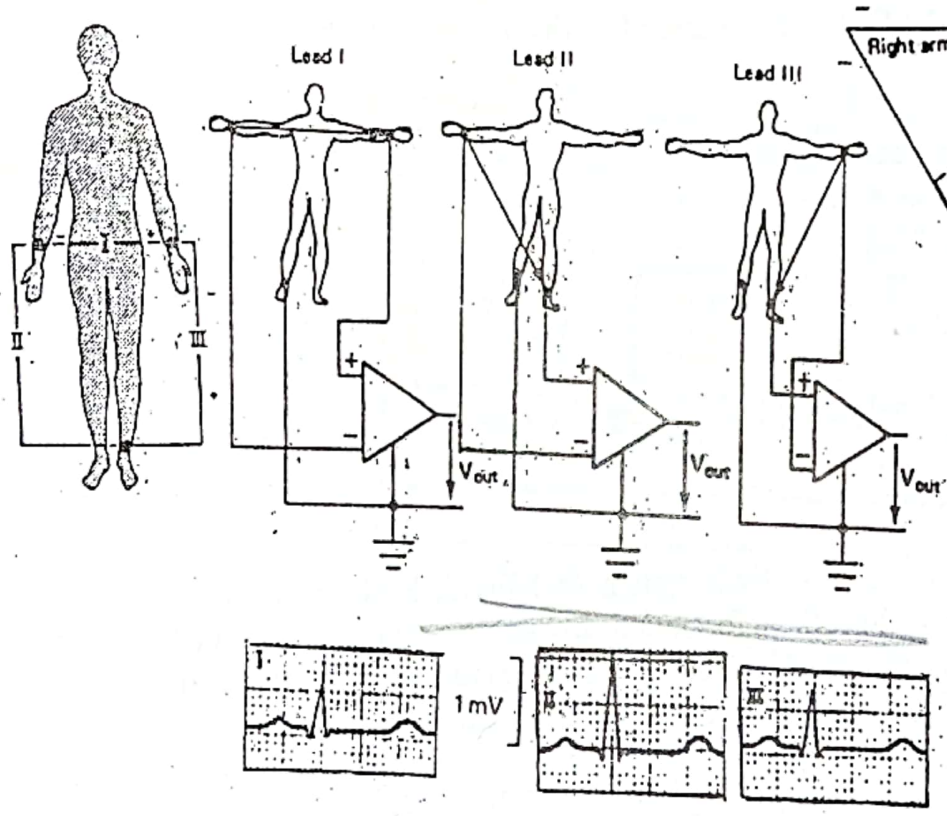
3) Chest leads (or) precordial leads
4) Frank lead system (or) corrected orthogonal leads

Among these four systems, the first three are widely used.

Bipolar limb leads - standard leads I, II and III

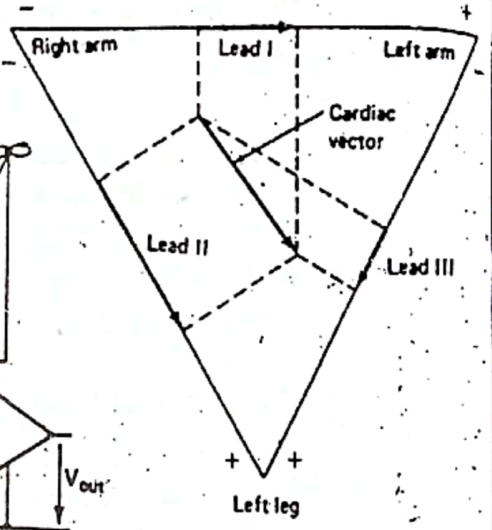
In standard leads, the potentials are tapped from four locations of our body. They are (i) right arm, (ii) left arm, (iii) right leg and (iv) left leg. Usually the right leg electrode is acting as ground reference electrode.

Figure 4.4(a) shows the standard bipolar limb leads positions and the corresponding wave patterns.



(a)

Fig.4.4(a). Standard biopolar limb leads and the corresponding ECG



(b)

Fig.4.4(b). The Einthoven triangle

Lead I Position - gives voltage V_I, the voltage drop from the left arm (LA) to the right arm (RA)

Lead II Position - gives voltage V_{II}, the voltage drop from the left leg (LL) to the right arm (RA)

Lead III Position - gives voltage V_{III}, the voltage drop from the left leg (LL) to the left arm (LA)

The closed path RA to LA to LL and back to RA is called the ***Einthoven triangle.*** According to Einthoven, in the frontal plane of the body the cardiac electric field vector is a two dimensional one. The ECG measured from any one of the three limb leads is a time variant single dimensional component of that vector. Along the sides of this triangle the three projections of ECG vector are measured as shown in figure 4.4(b). Further the vector sum of the projections on all the three sides is equal to zero. Thus following Kirchoff's law, the R wave amplitude of lead II is equal to the sum of the R wave amplitudes of leads I and III. For example the R wave nominal voltage from different leads is given below:

	Lead I	Lead II	Lead III
	V_I mV	V_{II} mV	V_{III} mV
R wave amplitude	0.53 (0.07 to 1.13)	0.71 (0.18 to 1.68)	0.38 (0.03 to 1.31)

The voltages given in brackets indicate the range of the measured voltage. Thus

$$V_{II} \approx V_I + V_{III}$$

Augmented unipolar limb leads

In the augmented unipolar limb leads system, which is introduced by Wilson, the electrocardiogram is recorded between a single ***exploratory electrode*** and the ***central terminal*** which has a potential corresponding to the center of the body. Thus two equal and large resistors are connected to a pair of limb electrodes and the center of this resistive network acts as central terminal and the remaining limb electrode acts as the exploratory electrode. By means of augmented ECG lead connections, a small increase in the ECG voltage can be realized. The augmented lead connections are augmented voltage Right arm (aVR), augmented voltage Left arm (aVL) and augmented voltage Foot (aVF) as shown in figure 4.5(a).

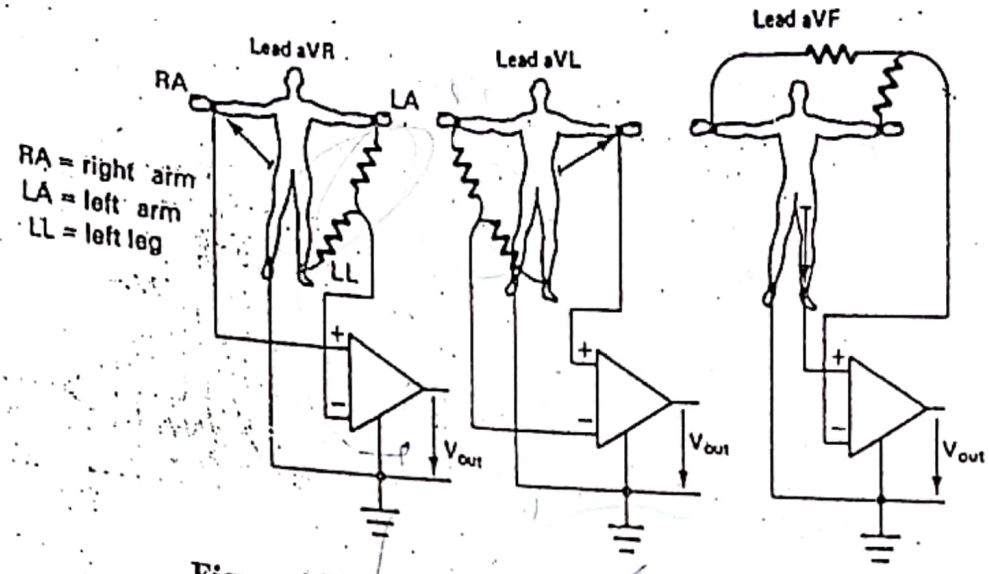


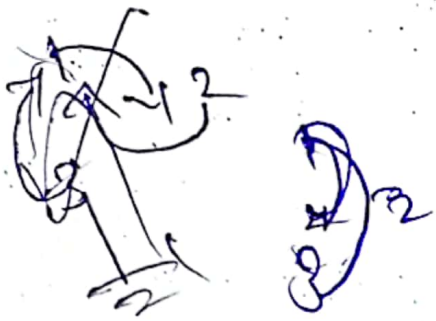
Figure 4.5(a). Augmented unipolar limb leads

Eventhough the resistors in these limb leads have large value, their values are smaller when we compare with the input resistance of the preamplifier. By Kirchoff's law, the augmented voltages can be written as in terms of standard leads voltage:

$$aVR = -V_I - \frac{V_{III}}{2}$$

$$aVL = V_I - \frac{V_{II}}{2}$$

$$aVF = V_{II} - \frac{V_I}{2}$$



Unipolar chest leads

In the case of unipolar chest leads, the exploratory electrode is obtained from one of the chest electrodes. The chest electrodes are placed on the six different points on the chest closed to the heart as shown in figure 4.5(b). By connecting three equal large resistances to the left arm, right arm and left leg a reference electrode or central terminal is obtained. This lead system is known as Wilson system. Thus the electrocardiograms are recorded from these 12 lead selections such that 3 standard bipolar leads, 3 augmented unipolar leads and 6 chest leads.

V_1 Fourth intercostal space, at right sternal margin.

V_2 Fourth intercostal space, at left sternal margin.

V_3 Midway between V_2 and V_4.

V_4 Fifth intercostal space, at mid-clavicular line.

V_5 Same level as V_4, on anterior axillary line.

V_6 Same level as V_4, on mid-axillary line.

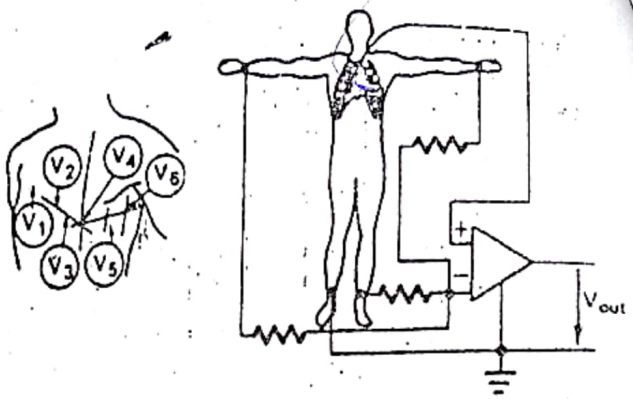


Fig.4.5(b). Unipolar chest leads

The ECG potentials are measured with colc - coded leads according to th convention:

White - right arm
Black - left arm
Green - right leg
Red - left leg
Brown - chest.

This is internationally adopted for easy reference.

Frank lead system

The corrected orthogonal leads system (or) Frank lead system is used in vector cardiography. Here one can get the informations from above said 12 leads. Further using this lead system, the heart's dipole field is resolved into three mutually perpendicular components and hence the state of the heart is studied three dimensionally.

4.3.3 ECG Recording set up

The important parts of ECG recorder are shown in figure 4.6.

1. Patient cable and Defibrillator Protection Circuit

The patient cable connects the different leads from the limbs and chest to the defibrillator protection circuit. It consists of buffer amplifiers and over voltage protection circuit. The leads are connected with the buffer amplifiers such that one buffer amplifier for

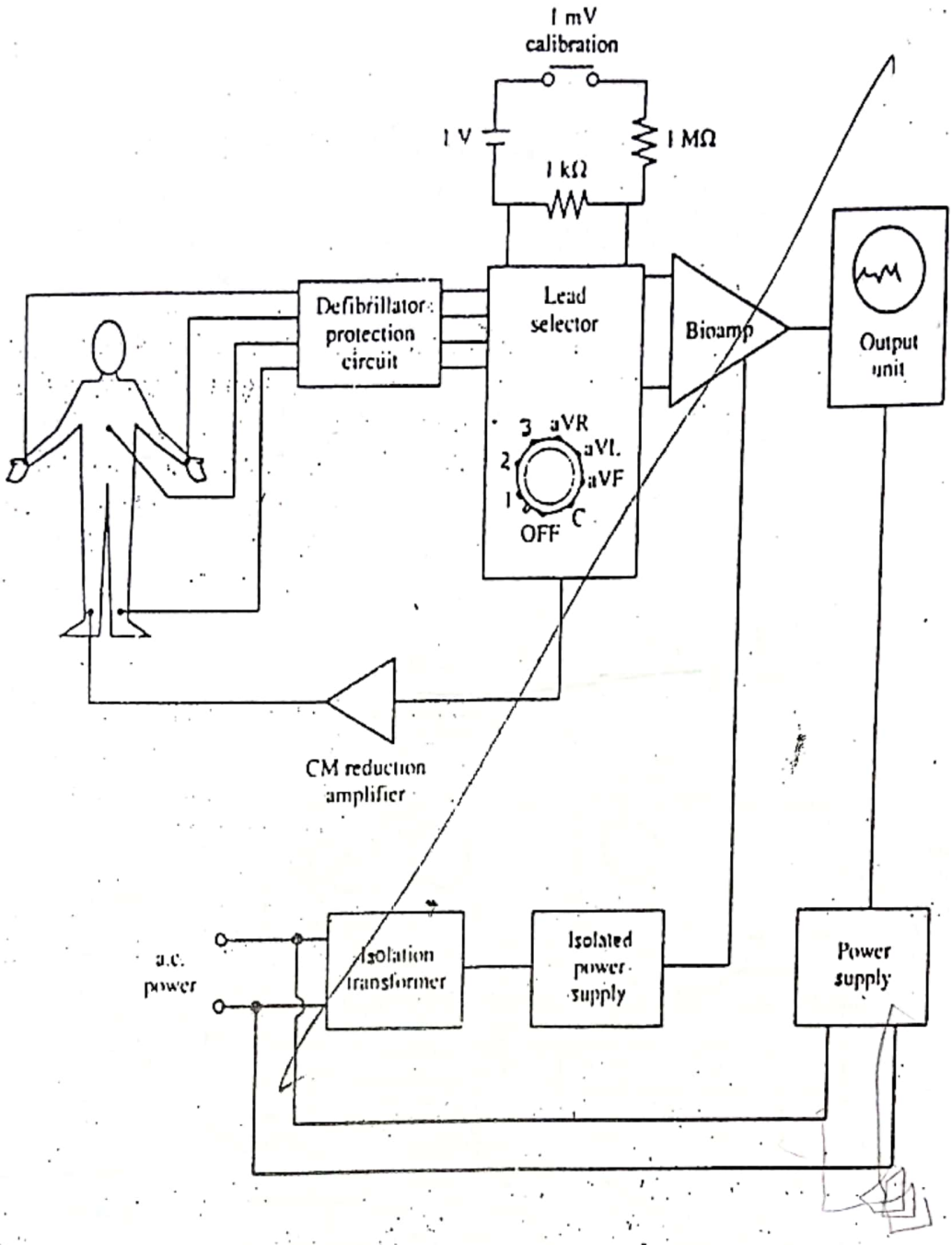


Fig.4.6. ECG Recording set up

each patient lead. By this means the input impedance is increased and the effects arising from the variations in the electrode impedance are reduced. Further the over voltage protection circuit is necessary to avoid any damage to the bioamplifiers in the recorder. The over voltage of the order of 1000 V may occur when the electrocardiograph is used during surgery in conjunction with radiofrequency diathermy units for cutting and coagulation or during the treatment of ventricular fibrillation using defibrillators. This over voltage protection circuit consists of a network of resistors and neon lamps which fire when a pulse from a defibrillator is present. During firing of the neon lamp, there is no input to the preamplifier of the recorder.

2. Lead selector switch

After the defibrillator protection circuit, there is lead selector switch which is used to feed the input voltage from the appropriate electrode to the preamplifier.

3. Calibrator

A push button allows the insertion of a standardization voltage of 1 mV to the preamplifier. This enables the technician to observe the output on the display unit and adjust the scale so that a known deflection corresponds to a 1 mV input signal. Changing the setting of the lead selector switch introduces an artifact on the recorded trace. But by means of a special contact on the lead selector switch the amplifier is momentarily turned off during the change of setting of the lead selector switch and after the passage of the artifact the amplifier is turned on. From the lead selector switch the ECG signal goes to bio-amplifier.

4. Bio-amplifier

The bio-amplifier consists of a preamplifier and power amplifier. Already the preamplifier, as a differential amplifier with high gain and high CMRR is discussed in the last chapter. The sensitivity or the gain of the amplifier can be varied. Followed by the preamplifier, there is a power amplifier which is used to drive the recorder. Pen motors in the recorder requires sufficient electrical power to activate the recording or display. Therefore power amplifiers are required with high power gain. Generally transistor circuits are favourable because a relatively large surface area is necessary to dissipate the heat generated in the circuit due to passage of high current.

Figure 4.7 shows a power amplifier circuit used to drive ECG chart recorder stylus. It is a push pull type. Further it is provided with crossover distortion compensation and offset control. It consists of two silicon power transistors such that the emitters of the transistors are joined together and connected with a load resistor, R_L. When V_B is sufficiently positive, transistor Q_1 is forward biased and conducts, while Q_2 is reverse biased and remains off.

Output Power, $P_{out} = V^2_{out}/R_L$

The amplifier efficiency, $\eta = P_{out}/(P_{out} + P_{loss})$

To avoid the crossover distortion in a push pull amplifier, an ideal noninverting amplifier is inserted at the input. Since the input impedance of noninverting amplifier approaches infinity, the power gain also approaches infinity. The crossover distortion is eliminated because the feedback resistance, R_f is so large and hence it raises the gain in a linear manner and in turn raises the output voltage. The offset control is provided by the resistance R_2 and is used to position the output stylus pen. Gain adjustment is provided with the resistance R_0.

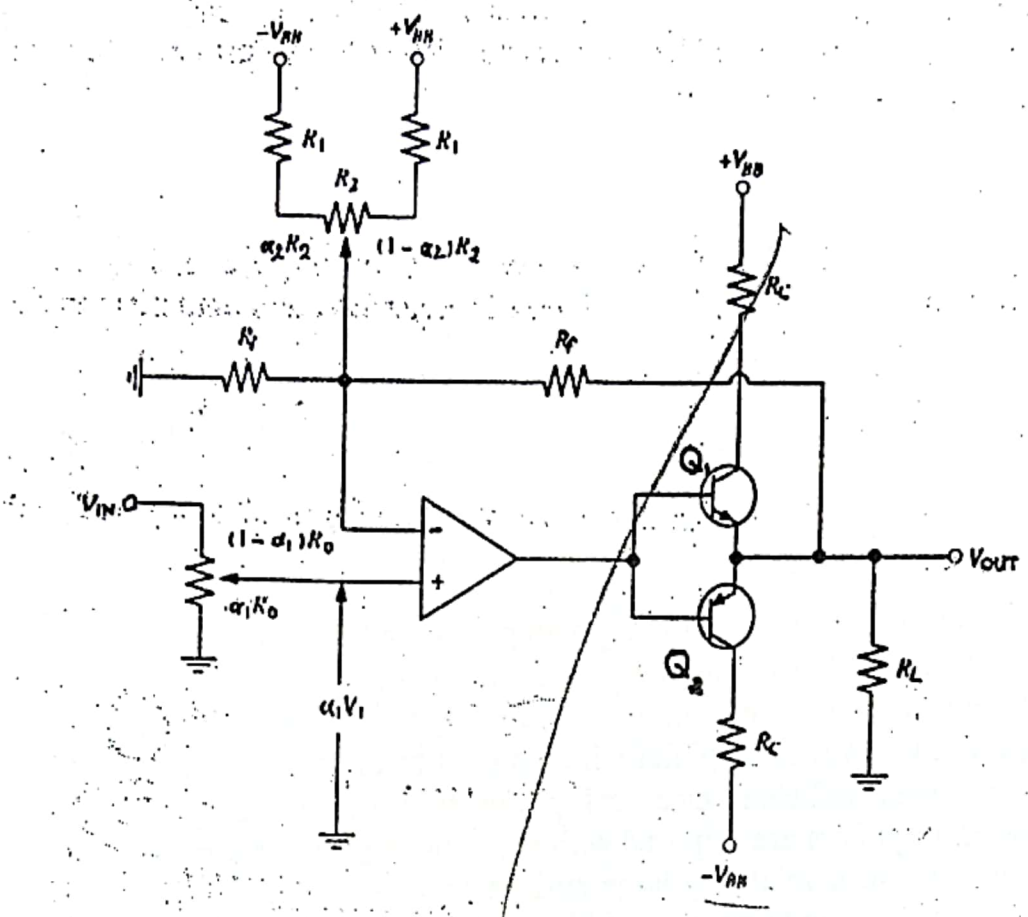


Fig.4.7. Push-pull power amplifier with crossover compensation and offset control

The output voltage of this amplifier circuit is given by

$$V_{out} = (\alpha_1 V_1)\,(1 + (R_f/R_i)) + R_f \left[\left[\frac{\alpha_1 V_1 + V_{BB}}{\alpha_2 R_2 + R_1} \right] + \left[\frac{\alpha_1 V_1 - V_{BB}}{(1-\alpha_2)\,R_2 + R_1} \right] \right]$$

5. Auxiliary amplifier

Since the electrode impedances are not equal, a differential amplifier does not completely reject the common mode signals. The common mode signals can be reduced to a minimum level by means of adding an auxiliary amplifier between the driven right leg lead and the ECG unit. By this way, the right leg is not connected to ground but it is connected to the output of the auxiliary amplifier. If the body common mode voltage is different from zero, a summing network produces the sum of all common mode voltages from all other electrodes and feeds that sum of the voltages as input to inverting terminal of the auxiliary

amplifier. Meanwhile its noninverting terminal is grounded. The output of the [illegible] amplifier is connected to the right leg. Therefore it drives the body to zero common voltage. Thus the common mode rejection ratio of the overall system is increased. Further in the right leg electrode the current flow is reduced.

6. Isolated Power Supply

The isolated power supply is used to give power to the bio-amplifier and by means of that the electrical safety for the patient is increased. (Refer isolation amplifiers in the Chapter III).

7. Output Unit

The output unit is a cathode ray oscilloscope as shown in figure 4.7 or a paper chart recorder as shown in figure 4.8.

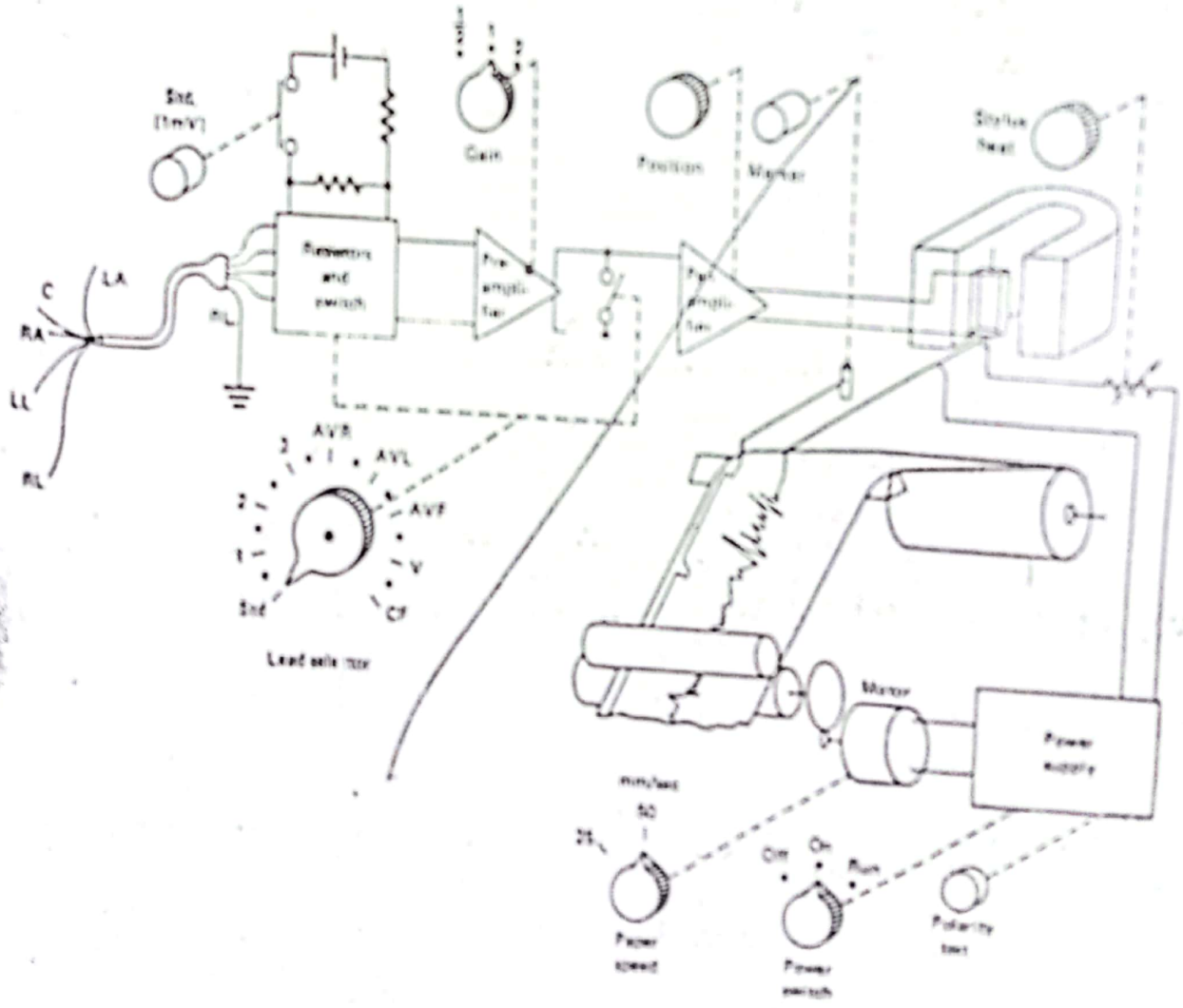


Fig.4.8. Paper chart recorder using pen as writer

In the case of paper chart recorder the power amplifier or pen amplifier supplies the required power to drive ***pen motor*** that records the ECG trace on the wax coated heat sensitive paper. A position control on the pen amplifier is used to position the pen at the center on the recording paper. The ***stylus pen*** is heated electrically and the temperature of the stylus pen can be adjusted with a stylus heat control. There is a marker stylus which is actuated by a push button and allows the technician to mark a coded indication of the lead being recorded. The paper speed is about 25 mm/s (U.S. paper speed) or 50 mm/s (European paper speed). The faster speed of 50 mm/s is provided to allow better resolution of the QRS complex at very high heart rates.

8. Power Switch

The power switch of the recorder has three positions. In the ON position the power to the amplifier is turned on; but the paper drive is not running. In order to start the paper drive the switch must be placed in the RUN position. In OFF position, the ECG unit is in switched off condition.

4.3.4 Practical considerations for ECG recording

Several practical aspects must be observed in order to obtain diagnostically useful electrocardiogram.

I. Artifacts

Since the ECG unit is a sensitive device, it can pick up unwanted electrical signals which may modify the actual ECG signals. Eventhough AC interference is reduced by increasing the CMRR of the bioamplifier, the operator before recording EEG, should check the following things:

i) Be sure that the patient does not touch or make contact with any metal object such as bed rail, bed stand or furniture.

ii) Remove or unplug any other electrical appliances such as clocks, radios, lamps, etc in the vicinity of patient.

iii) If adder ECG machines are used, make sure that the polarity test has been performed before connecting the cable to the patient.

iv) Be sure that all electrodes have been applied with right amount of paste or jelly and that all electrode straps are tight enough.

v) Be sure that the patient is in comfortable and relaxed condition. If the patient is not completely relaxed, the unsteady trace may be produced.

II. Wandering of Base line

The wandering of base line results from the gross movements of patients or from mechanical strain on the electrode wires. If there is no proper application of jelly between the electrode and the skin, during that time also the wandering of base line occurs.

III. Solid Base line

An indistinct trace or solid base line appears due to improper adjustment of stylus temperature or by buildup of waxy residue on heated stylus.

IV. Frequency Response

Generally the upper frequency limit of the bioamplifier is about 100 Hz. But the pen inertia limits the ECG unit response to about 50 Hz. This lowers the fidelity of QRS complex. The lower frequency limit of the bioamplifier is about 0.05 Hz.

$$\therefore \quad \text{The time constant of the amplifier} = \frac{1}{2\pi \times 0.05}$$

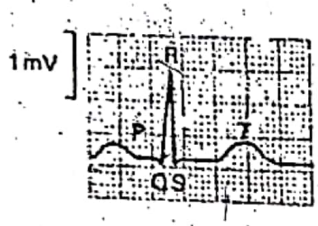
$$= 3 \text{ seconds}$$

If the time constant is less than 3 seconds, there is a distortion in the P and T waves. If the time constant is more than 3 seconds, the recovery time of the amplifier is so large. Thus it would not record properly when we go from one lead to another lead.

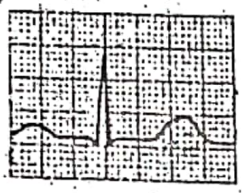
V. Other Specifications of the Ordinary ECG Recorder

Sensitivity (max.)	:	20 mm/mV
Input impedance	:	5 Mega ohms
Output impedance	:	Less than 100 ohms
Standardisation signal	:	1 mV
CMRR	:	10000:1
Recording techniques	:	Heated stylus and heat sensitive paper
Paper speed	:	25 mm/s or 50 mm/s
Frequency response	:	0.1 to 60 Hz

4.3.5 Analysis of Recorded ECG Signals

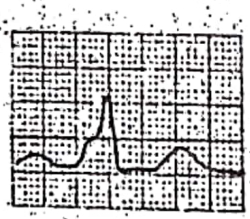


→ Normal ECG curve



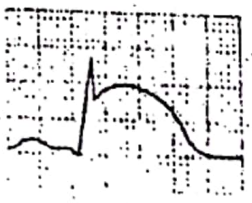
→ Here PQ segment has prolonged conduction time i.e. greater than 0.22 second

Result: First degree AV block



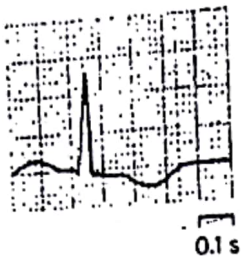
→ Here QRS complex is widened i.e. QRS interval is greater than 0.1 second.

Result: Bundle block



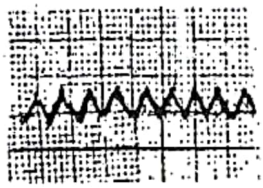
→ Here ST segment is elevated.

Result: Myocardial infarction.



→ Here ST segment is depressed and negative T wave is persent.

Result: Coronary insufficiency.



→ Here there is a train of pulses instead of PQRST waves.

Result: Ventricular fibrillation which may lead to death if it is not properly corrected by defibrillator.

Fig.4.9. Analysis of ECG signals

Figure 4.9 shows the analysis of different ECG signals. If the normal conduction system is disturbed, then the beat rate will be slower than the normal rate. This state is called ***heart block***. There are different types of heart block:

1st degree AV block	:	Due to prolonged conduction time.
2nd degree AV block	:	Due to conduction of few pulses instead of all from atrium.
3rd degree AV block	:	Due to asynchronous action of atrium and ventricle.
Adams - Stokes attack	:	Due to sudden attack of total block (this can be treated by fixing electronic pacemaker)
Bundle block	:	Due to improper conduction of the stimulus to the ventricle.

Atrial fibrillation : Due to fast beating rate (300-500 beats/min) of the atrium. Here ventricles beat very slowly.

Ventricular fibrillation : Due to fast beating rate of the ventricles. No pumping of the blood to different parts of the body.

Thus the electrocardiography can diagnose any form of arrhythmia or disturbance in heart rhythm. The ***Computer analysis of ECG*** is discussed in the Chapter on Advances in Biomedical Engineering.

4.3.6 Vectorcardiography

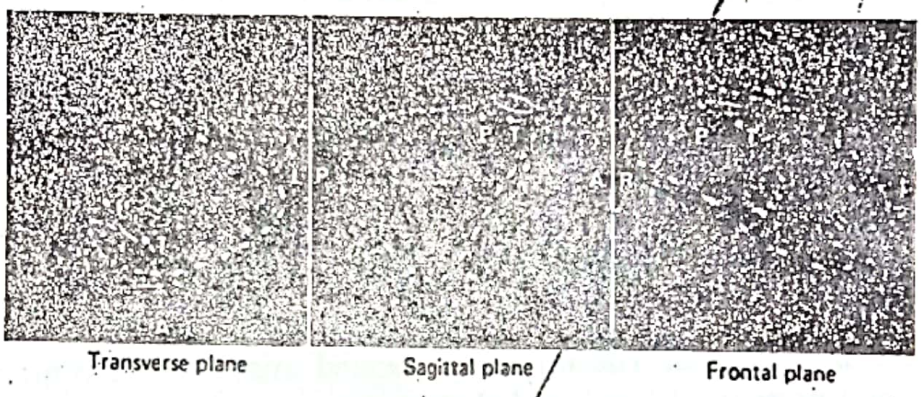


Fig.4.10. Vectorcardiogram. Here R - Right, L - Left, P-Posterior, A - Anterior, S - Superior, I - Inferior

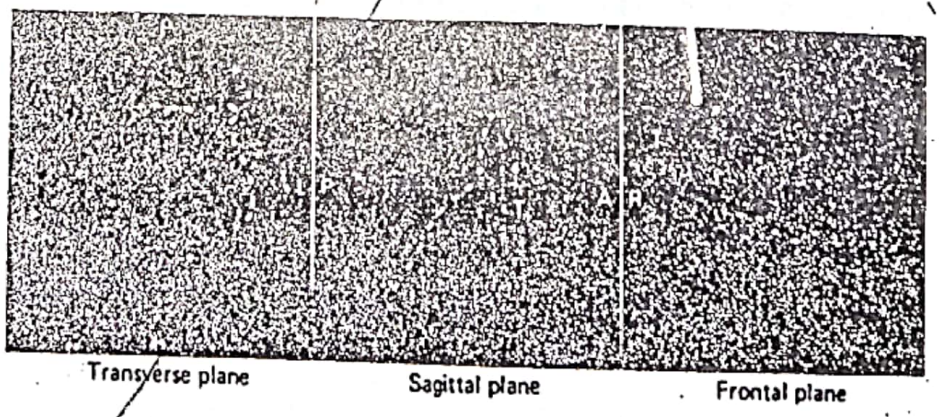


Fig.4.11. Vectorcardiogram in the case of myocardial infarction

In the case of electrocardiography only the voltage generated by the electrical activity of the heart is recorded. But in vectorcardiography, the cardiac vector is displayed along with its magnitude and spatial orientation. Eventhough the cardiac vector is a three dimensional, its projections on orthogonal planes converts it into two dimensional vector. By means of orthogonal lead system, the spatial relations of the cardiac dipole vector is usually displayed on a cathode ray oscilloscope. This is accomplished by resolving the signal into three images, corresponding to the frontal, sagittal and transverse planes. The vectorcardiogram appears as loops in each plane as shown in figure 4.10. There are three loops corresponding to P, QRS and T waves. Among these the QRS complex loop is a dominating one. The iso-electric line in the standard lead system is represented by the endpoint of the vectors in the vectorcardiogram. A polaroid camera photographs the oscilloscope screen to provide a permanent record. In the case of any diseased heart, like myocardial infarction, the loops are altered in a characteristic fashion as shown in figure 4.11. With the modern computer facilities, the vectorcardiography may be clinically used in an extensive manner, eventhough it is not widely used clinically now.

4.3.7 Phonocardiography (2) 10m

The graphic record of the heart sounds is called "phonogram". Because the sound is from the heart, it is called ***phonocardiogram***. The instrument used to measure the heart sounds is called ***phonocardiograph***. This instrument uses a phonocatheter, a device similar to a conventional catheter, with a microphone at the tip. The basic aim of phonocardiograph is to pick up the different heart sounds, filter out the heart sounds and to display them (or) record them. Heart sounds are acoustic phenomena resulting from the vibrations of the cardiac structures. Acoustic events of the heart can be divided into two categories (i.e.) ***heart sounds*** and ***murmurs***. Heart sounds have a transient character and are of short duration. Heart murmurs have a noisy characteristic and last for a longer time. But in general the hearts sounds are due to the closing and opening of the valves, whereas the murmurs are due to the turbulent flow of blood in the heart and large vessels.

Heart sounds

Heart sounds are classified into four group on the basis of their mechanism of origin; they are

1) Valve closure sounds
2) Ventricular filling sounds
3) Valve opening sounds and
4) Extra cardiac sounds

1) **Valve Closure Sounds:** These sounds occur at the beginning of systole (first heart sound) and the beginning of a diastole (second heart sound). The first heart sound is due to the closure of mitral and tricuspid valves. The second heart sound is due to closure of the aortic and pulmonary valves. The two sounds are normally present in an individual.

2) **Ventricular filling sounds:** These sounds occur either at the period of rapid filling of the ventricles (third heart sound) (or) during the terminal phase of ventricular filling (i.e.) atrial contraction and are believed to be caused by sudden distention of the ventricular wall. These sounds are normally inaudible.

3) **Valve opening sounds:** These sounds occur at the time of opening of the atrio-ventricular valves and semilunar valves.

4) **Extra cardiac sounds:** These sounds occur in mid (or) late systole (or) early diastole and are believed to be caused by thickened pericardium which limits ventricular distensibility.

Physical characteristics of the sound

Heart sounds and murmurs are usually characterised by three physical properties. They are

i. Frequency ii. Amplitude and iii. Quality

Frequency

Practically all heart sounds and murmurs are made up of frequencies between ***10 and 1000 Hz***. Within this range they are arbitrarily divided into low, medium and high-pitch categories depending upon which frequency predominates. The ***low range is 10-60 Hz*** and it is represented by the third and the fourth heart sounds. The ***medium range is 60-150 Hz*** and is represented by the first and second heart sounds. The ***high range is 150-1000 Hz*** and is represented by snaps, clicks and diastolic murmurs of aortic and pulmonary insufficiency.

Amplitudes of heart sounds and murmurs may differ by a factor of more than 1000. Usually low-frequency, heart sounds have the biggest amplitude while the high frequency murmurs have small amplitudes.

Quality depends upon the overtones (or) harmonics accompanying the fundamental frequency and applies to tones.

Origin of the heart sounds: There are four basic separate heart sounds that occur during the sequence of one complete cardiac cycle.

1) **First heart sound:** The first heart sound is produced by a sudden closure of the mitral and tricuspid valves associated with myocardial contraction.

   a) **Timing:** The low frequency vibrations occur approximately 0.05 second after the onset of the 'QRS' complex of the ECG.

b) **Duration:** The first heart sound lasts for 0.1 to 0.12 second

c) **Frequency:** The first heart sound ranges from 30-50 Hz.

d) **Asculatory Area:** The first heart sound is best heard at the apex of the mid pericardium.

2) **Second heart sound:** The second heart sound is due to the vibration set up by the closure of semilunar valves (i.e.) the closure of aortic and pulmonary valves

a) **Timing:** The second heart sound starts approximately 0.03 - 0.05 second after the end of 'T' wave of the ECG.

b) **Duration:** This lasts for 0.08 - 0.14 second.

c) **Frequency:** The frequency is upto 250 Hz.

d) **Asculatory Area:** The second sound is best heard in the aortic and pulmonary areas.

3) **Third heart sound:** The third heart sound arises as the ventricles relax and the internal pressure drops well below the pressure in atrium, Meanwhile the atrio-ventricular valves open and the blood has a rapid movement into the relaxed ventricular chambers.

a) **Timing:** The third heart sound starts at 0.12 - 0.18 second after the onset of the second heart sound.

b) **Duration:** The third heart sound lasts approximately 0.04 - 0.08 second.

c) **Frequency:** The frequency is approximately 10 - 100 Hz.

d) **Ausculatory Area:** The third sound is usually best heard at the apex and left lateral position after lifting the legs.

4) **Fourth heart sound:** The fourth heart sound also called an atrial sound is caused by an accelerated flow of blood into the ventricles (or) due to atrial contraction. This occurs immediately before the first heart sound.

a) **Timing:** The fourth heart sound starts approximately 0.12 - 0.18 second after the onset of the P-wave.

b) **Duration:** The sound lasts for 0.03 - 0.06 second.

c) **Frequency:** 10 - 50 Hz

d) **Ausculatory Area:** Because of its extremely low frequency it is usually inaudible.

Heart Murmurs: Murmurs are sounds related to non-laminar flow of blood in the heart and the great vessels. They are distinguished from the basic heart sounds such that,

1. they have noisy character,
2. they have a longer duration and
3. they are high frequency components upto 1000 Hz.

Typical conditions in the cardiovascular system which cause turbulence in Blood flow:

1. Local obstructions to the blood flow.
2. Abrupt changes in the diameter of the blood stream.
3. Pathalogic communication in the cardiovascular system.
4. Ruptured cardiac structures.
5. Valve insufficiency.

Transduction of heart sound: The sounds and murmurs which originate from the heart can be picked up from the chest using a stethoscope (or) by transduction of the sound into electrical signals.

The heart sound are well conducted from the heart to the surface of the chest when the myocardial tissue lies in the close proximity to the chest wall.

Recording set-up: A block diagram for the recording set up is shown in figure 4.12. The heart sounds are converted into electrical signals by means of a heart microphone fastened to the chest wall by an adhesive strip. The pick up is successively located at different areas mentioned in figure 4.13. The electrical signals from microphone are amplified by a phonocardiographic preamplifier followed by suitable filters and recorder. Further the electrodes are also placed on the limbs to pickup the electrical activity of the heart and these signals are amplified and recorded. This recorded ECG is used as a reference for PCG.

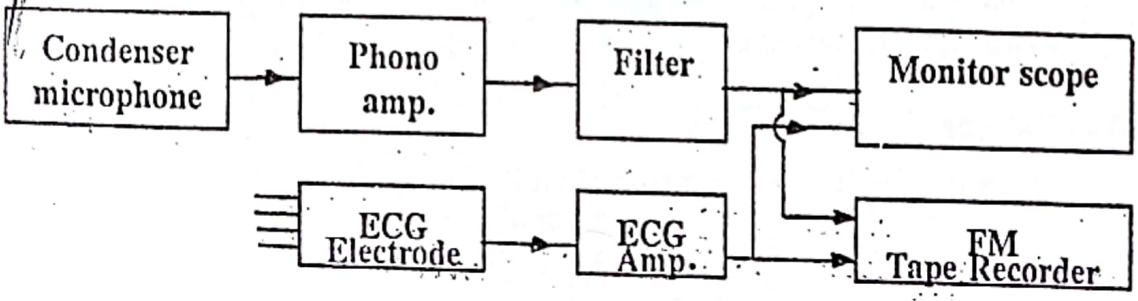


Fig.4.12. Block diagram of recording set up

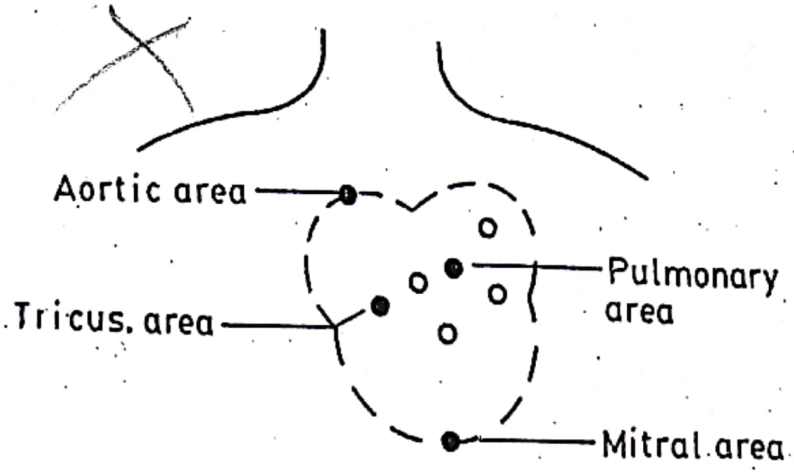


Fig.4.13. Placement of microphone on different areas of the chest for recording PCG

Heart sound Microphone: The conversion of the heart sounds into electrical signals can be done using a variety of transducers *viz.*, condenser microphone, moving coil microphone, piezoelectric crystal, carbon microphone, etc. There are two main categories of microphones used in phonocardiography:

1. The air coupled microphone and
2. The contact microphone

In the former case, the movement of the chest is transferred (via) an air cushion and presents a low mechanical impedance to the chest. But the second one is directly coupled to the chest wall and presents a higher impedance, high sensitivity, low noise and light weight. Therefore the second one is more suitable.

A typical condenser microphone is shown in figure 4.14.

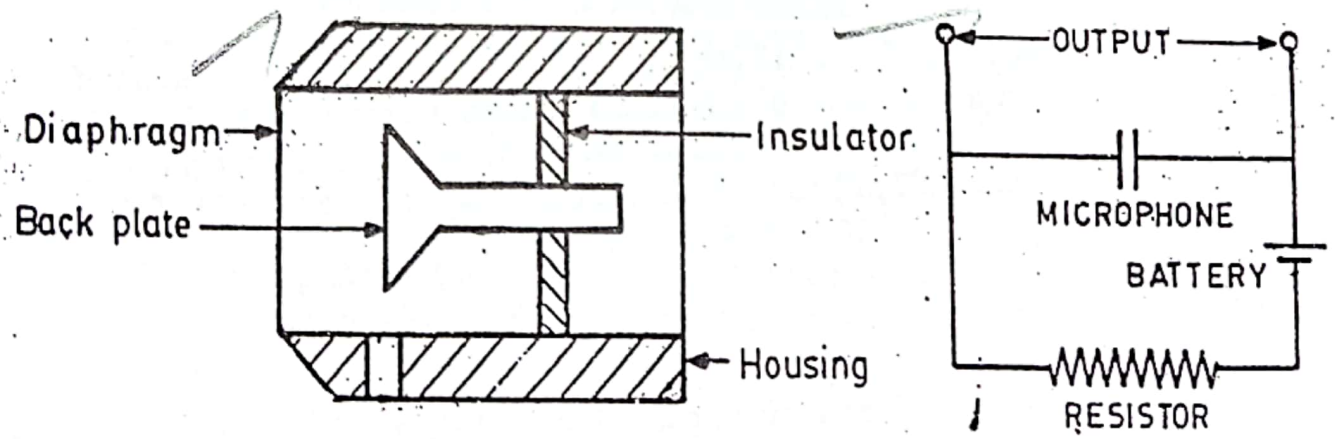


Fig.4.14. Condenser microphone along with its circuit

It consist of a diaphragm which acts as the "rotor" and the back plate as "stator" of a variable capacitor. The two electrodes are spaced very close to each other. When a well regulated d-c voltage is applied through a high resistance across the two electrodes, a constant charge is maintained by the electrodes as per the formula,

$$C = \frac{Q}{V} \text{ (constant)}$$

The vibrations produced by the chest wall change the position of the diaphragm of the condenser; which results in the change in voltage across the electrode. The developed a.c. voltage is only of the order of few millivolts.

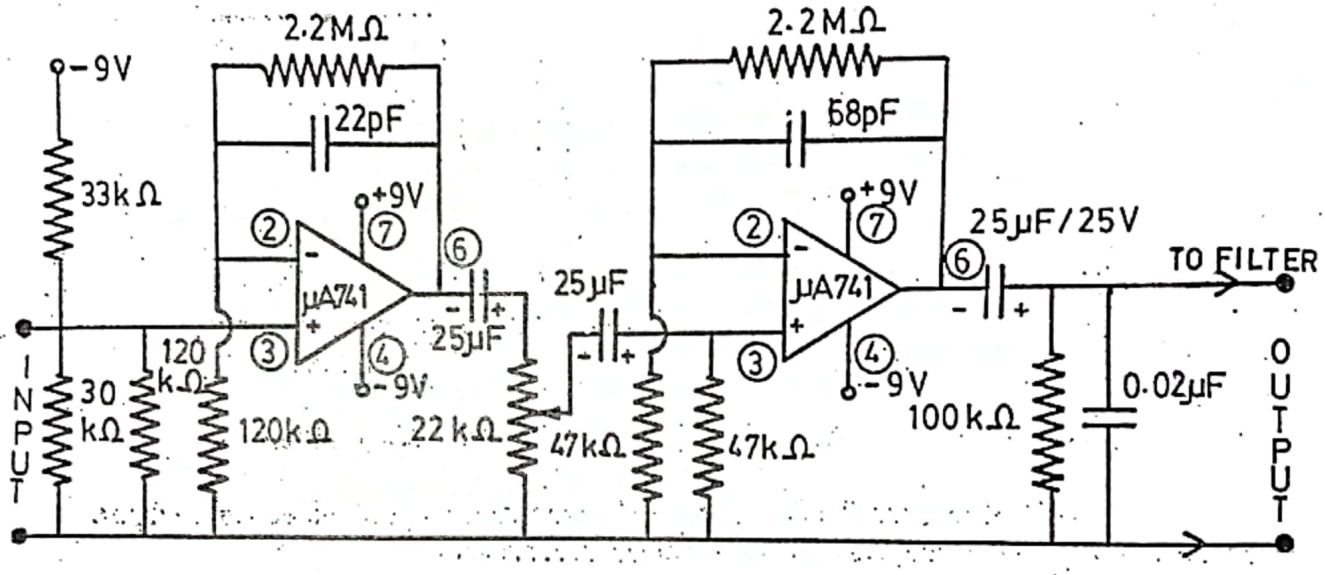


Fig.4.15. Phonocardiograph preamplifier

The preamplifier shown in figure 4.15 has two stages. First stage has amplification of about 20. Second stage has amplification of about 50. Therefore the expected total gain is about 1000. Continuous variation of gain can be achieved through a 22 kilo-ohm potentiometer. The shunt capacitance (0.02 μF) and the feedback loop capacitance (68 pF) of the second stage limit the response from 10 Hz to 1000 Hz.

Filters for phonocardiogram

Generally high pass filters having a gradual slope of attenuation are needed since the band pass filters and filters with sharp cut off produce transients and mask the splitting of heart sounds. In the case of murmurs, where greater selectivity is required, high pass filters

with sharper slopes are required. Figure 4.16 shows a high pass filter with increasing slopes of attenuation for frequencies below 1000 Hz.

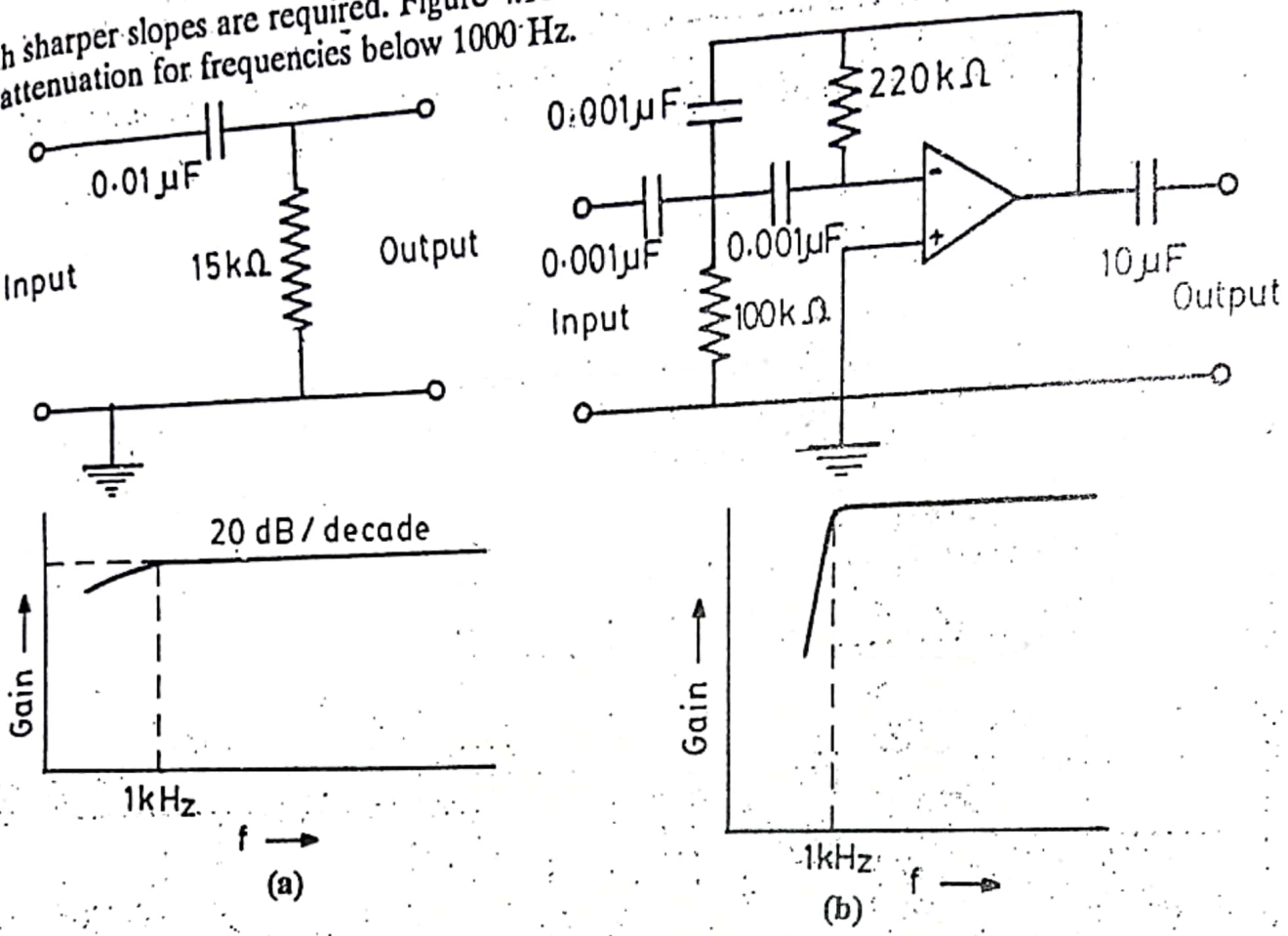


Fig.4.16(a). R - C Filter **(b) Active Filter**

Figure 4.16 (a) shows the R-C filter where the gradual slope is obtained and in figure 4.16(b) shows the active filter where a sharp cut off is achieved.

Relationship between the heart sounds and function of the cardiovascular system

Figure 4.17 shows the relationship before the blood pressure, heart sounds and ECG in the normal case, pictorially. During the opening of aortic valve and closing of mitral valve, the first heart sound is developed. Similarly during the opening of mitral valve and closing of aortic valve the second heart sound is developed and so on.

Medical Applications

Rheumatic Valvular Lesions: The greatest number of valvular lesions results from rheumatic fever. Rheumatic fever is an autoimmune (or) allergic disease in which the heart valves are likely to be damaged or destroyed. This can be detected by phonocardiograph. The valvular lesions cause the abnormal heart sounds as given below: Figure 4.18(a) shows the normal heart sounds.

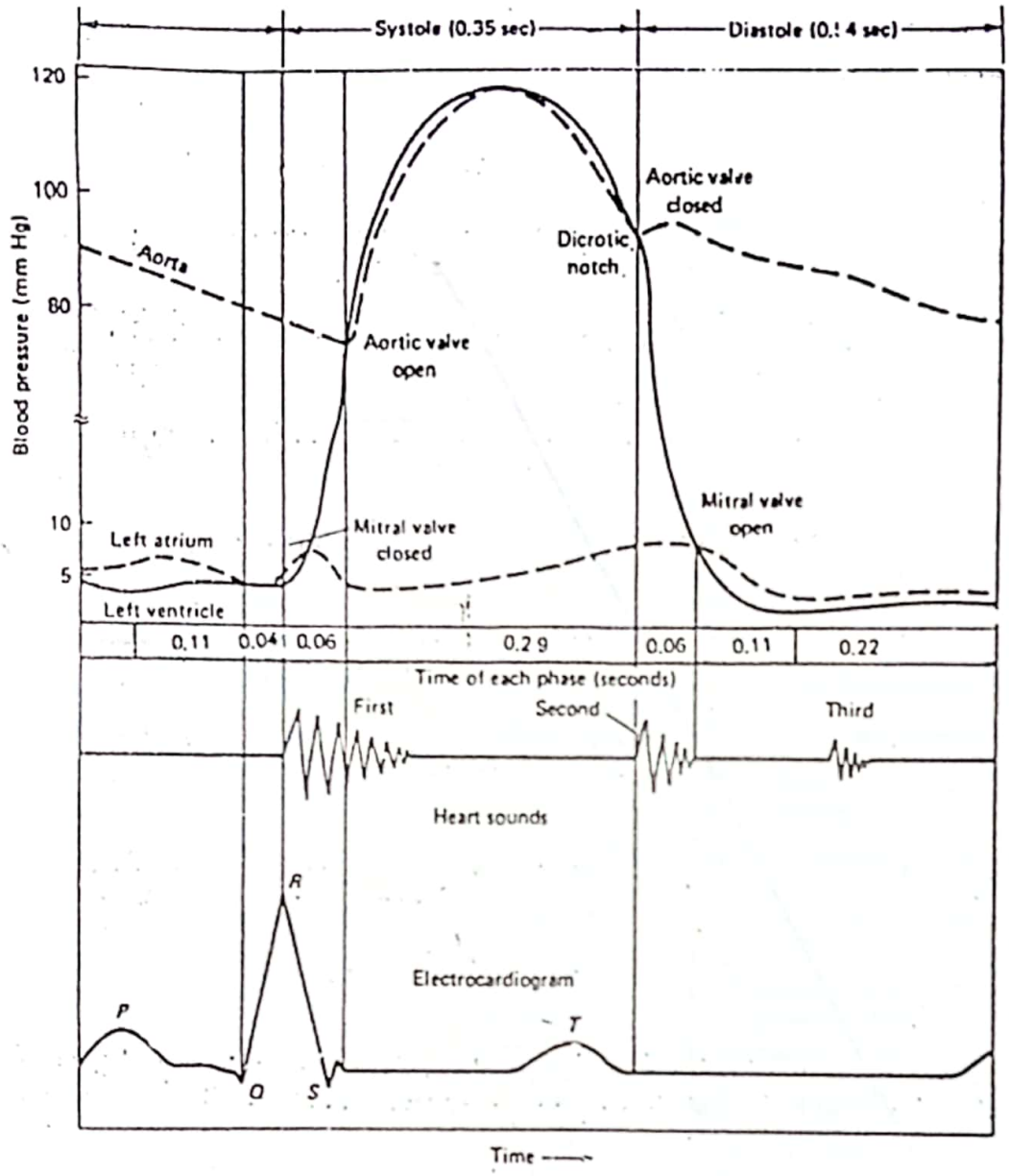


Fig.4.17. Blood pressure, heart sounds and ECG on the time scale

i) **The murmur of Aortic Steonosis:** In aortic stenosis (figure 4.18(b)) the blood is ejected from the left ventricle through a small opening of the aortic valve. Because of the resistance to ejection, the pressure in the left ventricle rises sometimes to as high as 350 mm of Hg. This causes turbulent blood flow. This turbulent blood impinging the aortic valve causes intense vibration, it produces loud murmur. This sound can be heard several feet away from the patient.

ii) **The murmur of aortic regurgitation:** In aortic regurgitation (figure 4.18(c)) no sound is heard during systole, but during diastole blood flows backward from the aorta into the left ventricles, causing a "blowing" murmur, the sound is not as high that of aortic stenosis. This is produced during the valves are damaged.

[**Regurgitation:** Backward flow of blood through a defective heart valve].

Analysis of phonocardiograms

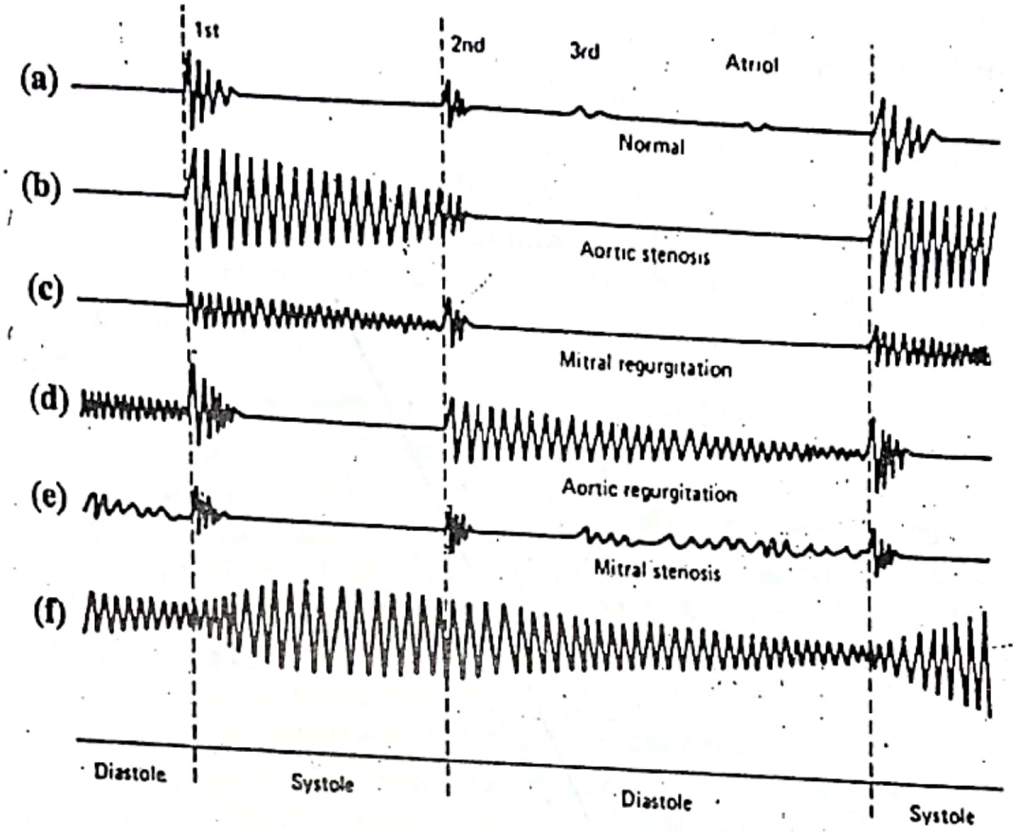


Fig.4.18. Analysis of heart sounds

iii) **The murmur of mitral regurgitation:** In the mitral regurgitation (figure 4.18(d)) blood flows backward through the mitral valve during systole. This produces sound during systole.

iv) **The murmur of mitral stenosis:** In mitral stenosis (figure 4.18(e)) blood passes with difficulty from the left atrium into the left ventricle due to the pressure difference. It produces murmur, which is very weak.

Special applications of phonocardiogram

1) **Fetal Phonocardiogram:** A sthethoscopic microphone with a large chest piece is applied over that part of the maternal abdomen where ausculation reveals fetal heart tones. Simultaneously with the fetal sound tracing, maternal ECG is recorded for comparison.

2) **Esophageal Phonocardiogram:** Basis of interest in the method lies in the fact that the heart sounds are collected from inside the chest. In general, sounds and murmurs have lower frequencies than when recorded by conventional techniques. The heart sounds are with shorter duration.

3) **Tracheal Phonocardiogram:** Tracheal Phonocardiograms have been recorded in patients by means of a tracheal cannula. The technique consists of connecting the outer end of the cannula with a microphone by means of short piece of rubber tube. The heart sounds are with shorter duration and have vibrations of a lower frequency than when recorded from outside the chest.

4.3.8 Echocardiography

Echocardiography is also an useful technique for diagnosis of heart diseases. Echocardiogram displays the time versus motion information about the intra-cardiac structures on slow speeds. Particularly for detection of mitral stenosis and for preliminary screening test related to heart diseases, echocardiography is the test one among all. The piezoelectric transducer is placed between the third and the fourth ribs on the outer chest wall where there is no lung between the skin and the heart. From this transducer, an ultrasonic beam of frequency 2.25 MHz is directed towards the heart and the reflected signals, called ***echoes*** from the heart muscle are collected by the same transducer. Thus a single piezoelectric transducer acts as a transmitter and a receiver alternatively. By changing the position of the transducer we can get reflections from the desired areas on the heart. An aqueous gel is used to couple the transducer to the skin and the beam from the transducer to a depth of 5 to 10 cm. There is a time compensated signal amplifier so as to collect the deeper low amplitude signals with the same signal to noise ratio. Then these amplified signals are given to the cathode ray tube display unit.

A-mode display

In amplitude mode or A-mode display, the echoes produce vertical displacements of a horizontal trace on the screen such that the amount of vertical displacement is proportional to the strength of the echo and the distance along the horizontal trace represents the time taken by the ultrasound to travel through the tissue. Since the heart is moving, the echoes dance up and down during the cardiac cycle.

B-mode display

In brightness mode or B-mode display, the echoes are rotated through 90° towards the observer and so the echoes are presented as dots of light. The distance between dots represents the tissue depth. When the echoes are from the moving structure, the dots of light move back and forth.

M-mode display

In the time-motion mode or M-mode display, the B-mode echo signal is recorded either by sweeping the oscilloscope screen or photographing the oscilloscope face on moving paper. Thus the conventional M-mode display is widely used in echocardiography such that

	M-mode	2 dimensional
Axial dimension	excellent	good
Axial motion	excellent	good
Lateral dimensions	impossible	good
Lateral motion	poor	good
Shape	poor	good

4.4 ELECTROENCEPHALOGRAPHY (EEG)

Electroencephalography deals with the recording and study of electrical activity of the brain. By means of electrodes attached to the skull of a patient, the brain waves can be picked up and recorded. The brain waves are the summation of neural depolarisations in the brain due to stimuli from the five senses as well as from the thought processes. On the surface of the brain, these voltages are about 10 mV; Due to propagation through skull bone, they are attenuated to levels from 1 to 100 μV which are picked up by EEG electrodes. They are in the frequency range from 0.5 to 3000 Hz. These potentials vary with respect to position of the electrode on the surface of skull. Therefore during recording, the electrodes are placed around the frontal, parietal, temporal and occipital lobes of the brain. Electroencephalogram is the record of the brain waves made by an electroencelphalograph.

4.4.1 Origin of EEG

Initially it was thought that brainwaves represent a summation of the action potentials of the neurons in the brain. Now it is believed that the electrical patterns obtained on the surface of the skull are the result of the graded potentials on the dendrites of neurons in the cerebral cortex and other parts of the brain, as they are influenced by the firing of other neurons that impinge on these dendrites. *Graded potentials* are variations around the average value of the resting potential. Thus the EEG potentials originate within the dendrite potentials. Electric charges are transferred between one nerve fiber and the other through a dendrite of a post synaptic neuron during the release of *acetylcholine*. A great number of these potentials are then summed to produce EEG rhythms.

The discharge of a single neuron or single nerve fiber in the brain cannot be recorded from the surface of the head. Instead, for an electrical potential to be recorded all the way through the skull, large portions of nervous tissue must emit electrical current simultaneously. There are two ways by which this can occur. First, tremendous numbers of nerve fibers can discharge in synchronous with each other, thereby generating very strong electrical currents. Secondly, large numbers of neurons can partially discharge, though not emit action potentials. Furthermore, these partially discharged neurons can give periods of current flow which is undulate with changing degrees of excitability of the neurons. Simultaneous electrical

measurements within the brain while recording brain waves from the scalp indicate that it is the second of these that causes the brain waves.

To be more specific, the surface of the cerebral cortex is composed almost entirely of a mat of dendrites extending to the surface from neuron cells in the lower layers of the cortex. When signals impinge on these dendrites, the dendrites become partially discharged. This partially discharged state makes the neurons of the cortex highly excitable - that is, facilitates them and the negative potential is simultaneously recorded from the surface of the scalp, indicating this high degree of excitability.

One of the important sources of signals to excite the other dendritic layer of the cerebral cortex is the ascending reticular activating system. Therefore, brain wave intensity is closely related to the degree of activity in either the brain stem (or) the thalamic portions of the reticular activating system.

Action potentials of the brain

Progressive transient disturbance of the resting potential along a nerve fiber is used to transmit information from one end to the other. This action potential is caused by a very rapid change of membrane permeability to sodium ions followed by a recovery period. When the propagated action potential reaches the cell, the cell fires and thus a spike wave is produced. This firing spreads throughout the dendritic branches and causes the release of transmitter substances where the dendritic synapses terminate on other cell bodies.

If the transmitter substance is inhibitory, 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 an ***Inhibitory Post Synaptic Potential (IPSP)***. If the transmitter substance is excitatory, the receptor membrane potential increases in a positive direction; So that the receptor neuron is more likely to discharge and produces a spike potential. This induced change is called an ***Excitatory Post Synaptic Potential (EPSP)***. We know that the neuronal system is acting in a synchronised manner such that the receptor neuron discharges by the simultaneous emission of excitatory transmitter substances coming from adjacent neurons. Thus if EPSPs occur simultaneously at A and B, then C will become excitatory and it is more likely to discharge. If IPSPs occur simultaneously at A and B, then C will become less active. These action potentials can be as large as 30 mV and cause external currents to flow between the upper and lower layers of cortex.

Evoked potentials

Evoked potentials are the potentials developed in the brain as the responses to external stimuli like light, sound etc. The external stimuli are detected by the sense organs which cause changes in the electrical activity of the brain. Now-a-days the term ***'event related potential'*** has been used instead of evoked potential. This is because there are some

changes that are evoked by an external stimulus but are related to an event. The studies on evoked potentials are more prone to contamination by artifact than the clinical EEG. The artifact is synchronised with the stimulus and eventually appear with the evoked potential. Therefore good recording techniques are to be used for evoked potential studies.

Anatomy of the brain

The brain (encephalon) consists of three parts such as cerebrum, cerebellum and the brain stem as shown in figure 4.20. Cerebrum consists of two hemispheres separated by a deep fissure. The hemispheres are divided into frontal lobe, parietal lobe, occipital lobe and temporal lobe. The outer layer is called as cerebral cortex which is the center of intellectual functions (figure 4.21). The frontal lobe is for intelligence. The upper side of the temporal lobe consists of hearing center. In the posterior part of the occipital lobe, the vision center is situated. In the anterior part of the parietal lobe, there are sensory center and motor center. The temporal lobes are for the storage process in the long term memory.

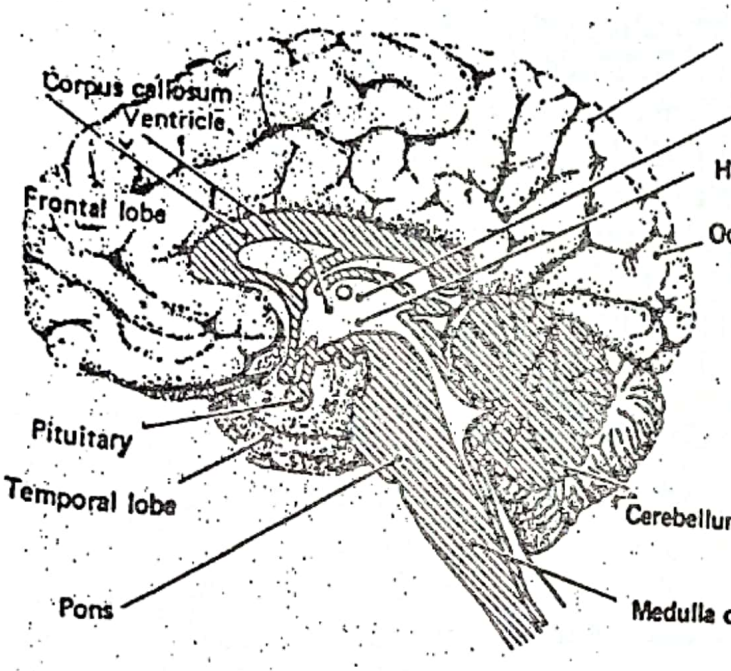


Fig.4.20. Median sagittal section of the brain

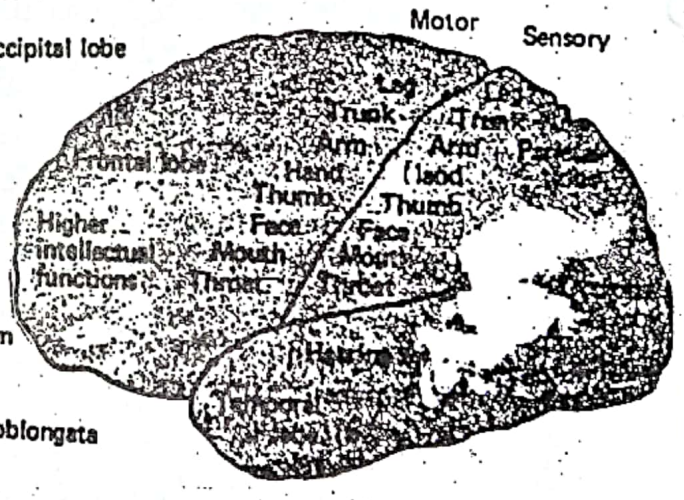


Fig.4.21. Cerebral cortex

4.4.2 Brain waves

Electrical recordings from the surface of the brain (or) from the outer surface of the head demonstrate continuous electrical activity in the brain. Both the intensity and patterns of this electrical activity are determined to a great extent by the overall level of excitation of the brain resulting, from functions in the reticular activating system i.e. awakening from

sleep. The undulations in the recorded electrical potentials, shown in the figure 4.22 are called ***brain waves.***

The intensities of the brain waves on the surface of the scalp range from 0-300 μV and their frequencies range from once in every few seconds to 50 or more per second.

Much of the time, the brain waves are irregular and no general pattern can be discerned in the EEG. However, at other times, distinct patterns do appear. Some of these characteristic of specific abnormalities of the brain occur during epilepsy, which is discussed later and others occur even in normal persons and can be classified into alpha, beta, theta and delta waves.

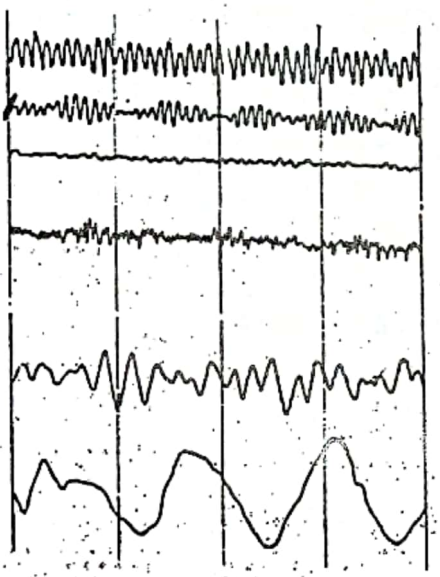


Fig.4.22. Brain Waves

Alpha waves

Frequency : 8 - 13 Hz

Occurrence : They found in normal persons when they are awake in a quiet, resting state. They occur normally occupital region. During sleep, these disappear. These have amplitude of 20-200 μV with mean of 50 μV.

Beta waves

Frequency : 13 - 30 Hz
(at intense mental activity, the frequency increases upto 50 Hz)

Occurrence : These are recorded from the parietal and frontal regions of the scalp. These are divided into two types as beta I which is inhibited by the cerebral activity and beta II which is excited by the mental activity; like tension.

Theta waves

Frequency : 4 - 8 Hz

Occurrence : These are recorded from the parietal and temporal regions of the scalp of children. These also occur during emotional stress in some adults particularly during disappointment and frustration.

Delta waves

Frequency : 0.5 - 4 Hz

Occurrence : These occur only once in every 2 or 3 seconds. These occur in deep sleep, in premature babies and in very serious organic brain diseases. These can occur strictly in the cortex independently by the activities in the lower regions of the brain.

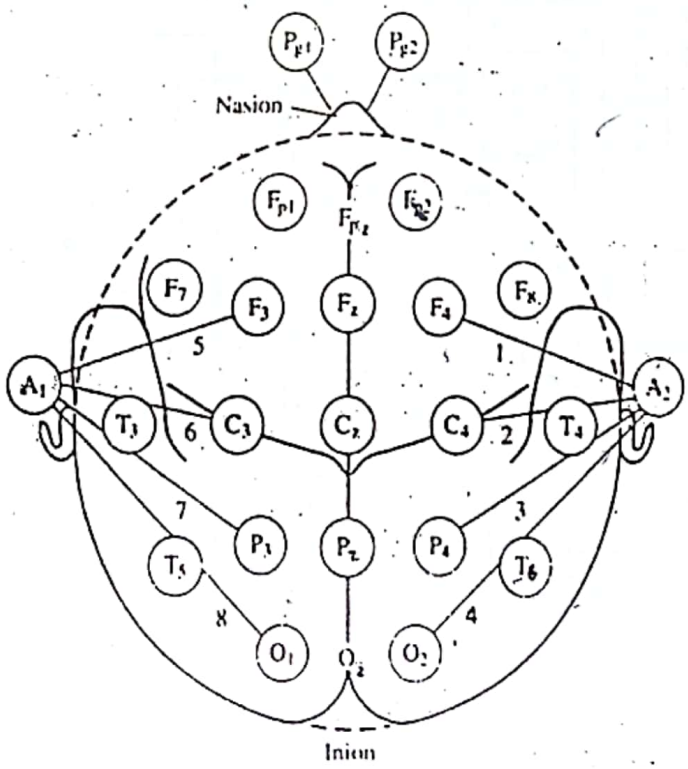


Fig.4.23. Placement of electrodes on the scalp for EEG recording

4.4.3. Placement of electrodes

In EEG, electrodes are placed in standard positions on the skull in an arrangement called 10 - 20 system, a placement scheme devised by the International Federation of Societies of EEG. The electrodes in this arrangement are placed as follows:

i. Draw a line on the skull from the ***nasion***, the root of the nose, to the ***inion***, ossification center (bump) on the occipital lobe.

ii. Draw a similar line from the left preauricular (ear) point to the right preauricular point.

iii. Mark the intersection of these two lines as C_Z which is the mid point of the distance between the nasion and inion (or) the distance between the auricular points.

iv. Mark points at 10, 20, 20, 20 and 10% of the total nasion - inion distance. These points are F_{pz}, F_z, C_z, P_z and O_z.

v. Mark points at 10, 20, 20, 20, 20 and 10% of the total distance between the preauricular points.

These points are T_3, C_3, C_z, C_4 and T_4. In these odd numbered points T_3 and C_3 are on the left and even numbered points C_4 and T_4 are on the right.

vi. Measure the distance between F_{pz} and O_z along the great circle passing through T_3 and mark points at 10, 20, 20, 20, 20 and 10% of this distance. These are the positions of F_{p1}, F_7, T_3, T_5 and O_1.

vii. Repeat this procedure on the right side and mark the positions of F_{p2}, F_8, T_4, T_6 and O_2.

viii. Measure the distance between F_{p1} and O_1 along the great circle passing through C_3 and mark points at 25% intervals. These points give the positions of F_3, C_3 and P_3.
The ground reference electrode is a metal clip on the earlobe.

ix. Repeat this procedure on the right side and mark the positions of F_4, C_4 and P_4.

x. Check that F_7, F_3, F_z, F_4 and F_8 are equidistant along the transverse circle passing through F_7, F_z and F_8 and check that T_5, P_3, P_z, P_4 and T_6 are equidistant along the transverse circle passing through T_5, P_z and T_6. In the

figure 4.23 the positions of the scalp electrodes are indicated. Further there are nasopharyngeal electrodes P_{g1} and P_{g2} and ear electrodes A_1 and A_2.

Before placing the electrodes, the scalp is cleaned, lightly abraded and electrode paste is applied between the electrode and the skin. By means of this application of electrode paste, the contact impedance is less than 10 kΩ. Generally disc like surface electrodes are used. In some cases, needle electrodes are inserted in the scalp to pick up EEG.

Both bipolar and unipolar (monopolar) electrode systems are used to facilitate the location of foci, that is cortical areas from which abnormal waves spread. The phase relationship of the waves indicates the position of the focus and in some cases, it enables the velocity at which the waves spread to be calculated. In ***bipolar technique*** the difference in potential between two adjacent electrodes is measured. In the ***monopolar technique*** the potential of each electrode is measured with respect to a reference electrode attached to ear lobe or nostrils. In the ***Wilson technique*** (or) average mode recording techniques the potential is measured between one of the electrodes (exploring electrode) and the central terminal which is formed by connecting all electrodes through high, equal resistors to a commonpoint. Multichannel electroencephalographs having as many as the channels permit simultaneous recording from several pairs of electrodes, reducing the total time required to complete the recordings. Eight channel recorders are very popular.

4.4.4 Recording Setup

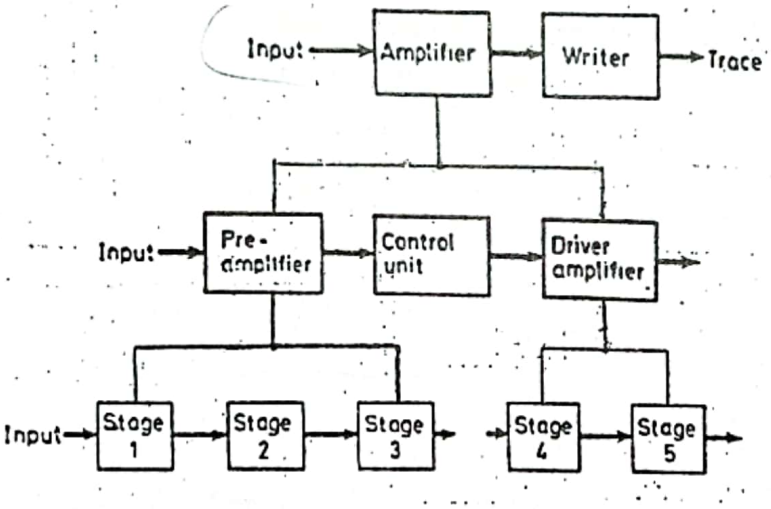


Fig.4.24 Simple block diagram of EEG recording set up

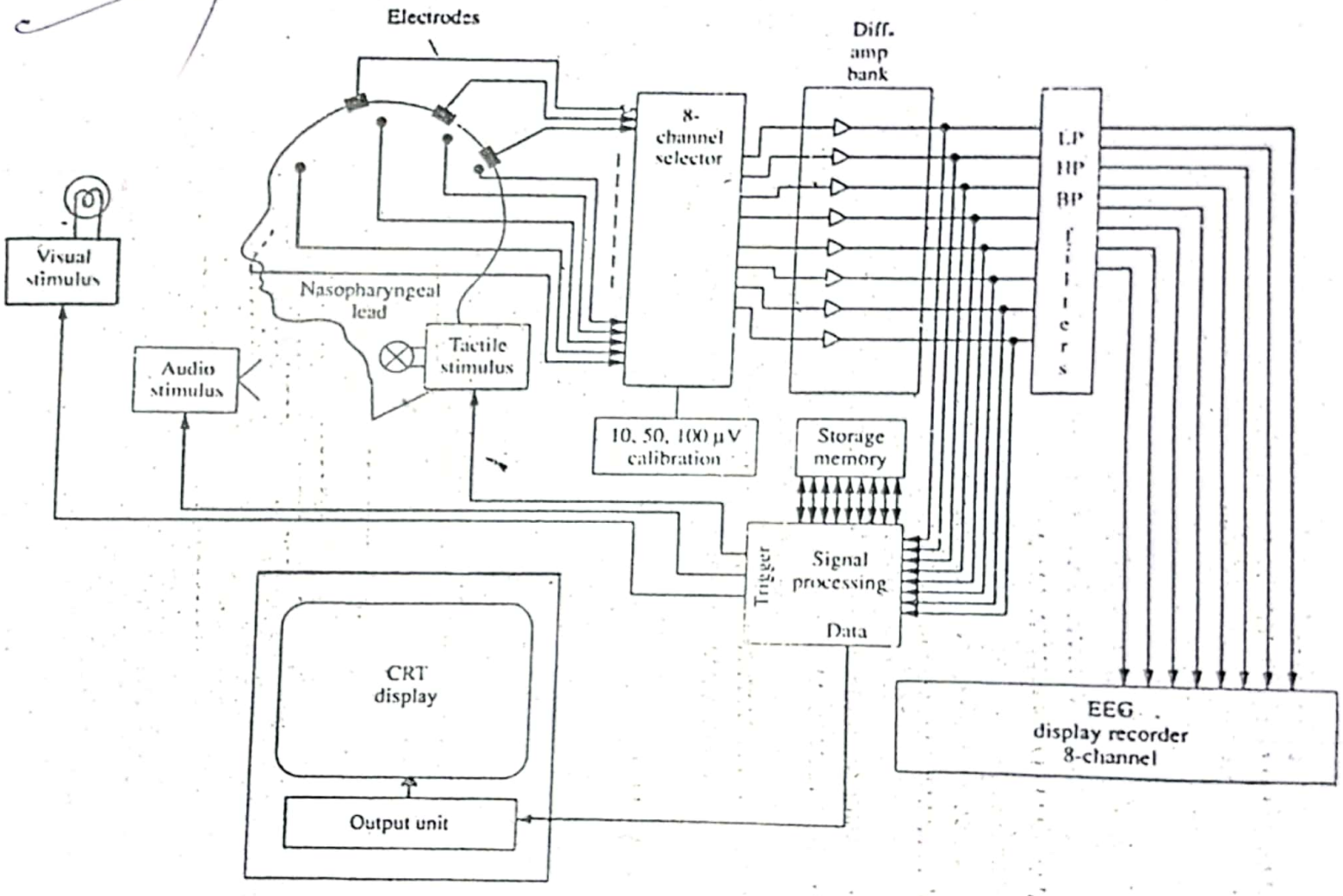


Fig.4.25. Modern EEG Unit

Figure 4.24 shows the simple block diagram of EEG recording setup. In this there are pre and driver amplifiers whose gains are increased by cascading several stages of amplification.

Figure 4.25 shows the modern 8 channel EEG recorder. The patient cable consists of 21 electrodes and is connected to the eight channel selector. The electrodes are attached to the channel selector in groups of eight called a ***montage*** of electrodes. A representative montage is shown in Figure 4.23 as numbers from 1 to 8. In that case, the right ear electrode acts as reference electrode for the right brain electrodes and the left ear electrode acts as reference electrode for the left brain electrodes. The 50 Hz interference is reduced by employing differential amplifiers as preamplifiers with more than 80 dB CMRR and by use of 50 Hz notch filters. The effect of notch filter on signal distortion is not so much because important EEG signals have frequencies below 30 Hz. Further if the room, in which EEG unit is placed, is covered with ferrous metal screen, 50 Hz a.c. interference is greatly reduced. Because the source of brain wave has high internal impedance, the input impedance of the preamplifier should be more than 10 MΩ to prevent reduction of signal amplitude. Further by cascading, the gain of the amplifier is increased to 10^6 so as to drive the recorder or imaging CRT without any difficulty. The output voltage from the amplifier may either be applied directly to the eight channel display through the filter bank or it may be stored as data on a tape recorder or in a computer memory for further processing. The filter bank consists of appropriate filters to select different types of brain waves. There are other acilities are available to record evoked potentials from sensory parts of the brain such that there are external stimuli like visual stimulus, audio stimulus and tactile (touch) stimulus. The time delay between the stimulus and response can also be measured in the signal processing unit. In the eight channel pen recorder there are 8 pens such that a pen for each channel. The normal paper chart speed is 30 mm/second. There are also 60 mm/second for higher frequency recording and 15 mm/second to conserve paper during setup time.

4.4.5 Analysis of EEG

EEG helps physicians to diagnose the level of consciousness, sleep disorders, brain death, brain tumors, epilepsy and multiple sclerosis.

(i) Level of consciousness

EEG changes with the level of consciousness. Diminished mental activity usually results in a lower frequency and large amplitude EEG wave. EEG has made valuable contribution to the study of sleep physiology. Figure 4.26 shows the variation of EEG with respect to sleep or the level of consciousness. In that figure, REM means rapid eye movement. REM sleep coincides with the periods of dreaming.

EEG displays characteristic features during the application of anaesthesia. As the anaesthesia is applied, the brain wave frequency decreases and the amplitude increases. Thus,

theta and delta waves appear. In the case of cerebral death (brain death), EEG shows a permanent absence of brain wave eventhough respiration and circulation are maintained.

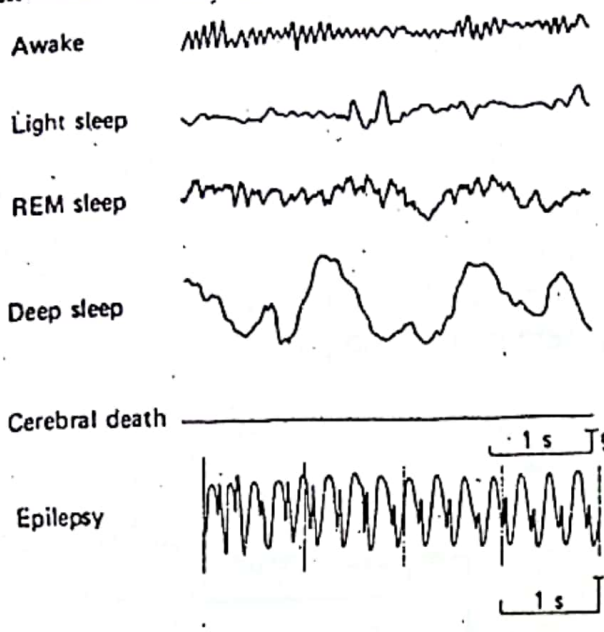


Fig.4.26. EEG waves for different level of consciousness

Brain Tumors

If the tumor displaces the cortex and if it is large enough, the electrical activity will be absent in that part of hemisphere, since no electric potentials originate in the tumor itself. Thus an extinguished or damped EEG over a certain part of cortex can thus be a sign of a tumor.

Epilepsy

Epilepsy is a symptom for brain damage. This may due to defects in the birth delivery or head injury during accident or boxing. It may also be due to brain tumor. Epilepsy is a disease and is characterised by synchronous discharge of large groups of neurons, often including the whole brain. Epilepsy is divided into two types, ***grandmal*** and ***peritmal***. Before grandmal attack, the patient recognizes a set of symptoms such that he sees a flash of light if the grandmal arises from visual center or he hears a noise if it arises from acoustic center. The grandmal seizure extends from few seconds to several minutes. In the peritmal attack spike type waves are produced with a frequency 3 Hz. and its seizure lasts for 1-20 seconds.

4.5 ELECTROMYOGRAPHY (EMG)

Electromyography is the science of recording and interpreting the electrical activity of muscle's action potentials. Meanwhile the recording of the peripheral nerve's action potentials is called ***electroneurography***. The electrical activity of the underlying muscle can

be measured by placing surface electrodes on the skin. To record the action potentials of individual motor units, the needle electrode is inserted into the muscle. Thus EMG indicates the amount of activity of a given muscle or a group of muscles and not an individual nerve fiber.

The action potentials occur both positive and negative polarities at a given pair of electrodes; so they may add or cancel each other. Thus EMG appears, very much like a random noise wave form. The contraction of a muscle produces action potentials. When there is stimulation to a nerve fiber, all the muscle fibers contract simultaneously developing action potentials. In a relaxed muscle, there is no action potential.

4.5.1 Recording setup

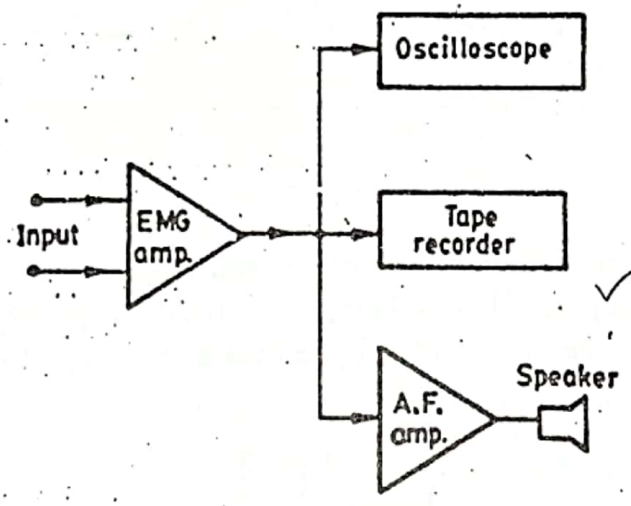


Fig.4.27 Block diagram for EMG recording set up

Figure 4.27 shown the typical setup for EMG recording. The surface electrodes or needle electrodes pickup the potentials produced by the contracting muscle fibers. The surface electrodes are from Ag-AgCl and are in disc shape. The surface of the skin is cleaned and electrode paste is applied. The electrodes are kept in place by means of elastic bands. By that way, the contact impedance is reduced below 10 kΩ. There are two types of conventional electrodes: bipolar and unipolar type electrodes. In the case of ***bipolar electrode***, the potential difference between two surface electrodes resting on the skin is measured. In the case of ***unipolar electrode*** the reference surface electrode is placed on the skin and the needle electrode, which acts as active electrode, is inserted into the muscle. Because of the small contact area, these unipolar electrodes have high impedances ranging from 0.5 to 100 MΩ. With needle electrodes, it is possible to pickup action potentials from selected nerves or muscles and individual motor units. In the case of ***coaxial electrode*** which consists of an insulated wire threaded through a hyperdermic needle with an oblique tip for

easy penetration, the surrounding steel jacket acts as reference and the metallic wire acts exploring electrode. The needle is inserted into the muscle. Further to record the act potentials from a single nerve, microelectrodes are used.

The amplitude of the EMG signals depends upon the type and placement electrodes used and the degree of muscular exertions. That is, the surface electrode picks many overlapping spikes and produces an average voltage from various muscles and mo units. The needle electrode picks up the voltage from a single muscle fiber. Generally EM signals range from 0.1 to 0.5 mV. They may contain frequency components from 20 Hz 10 k Hz. which are in the audio range. But using low pass filter, the electromyograph restricts this frequency range from 20 Hz to 200 Hz for clinical purposes. The norm frequency of EMG is about 60 Hz. Therefore the slow speed strip chart recorders are n useful and the signals are displayed on a cathode ray oscilloscope and photograph recordings are made. Normally there are two cathode ray tubes, one for viewing and oth one for recording. A light sensitive paper moves over the recording cathode ray tube and tl image is produced on that paper. After developing it, one can see the visible image. Fo continuous recording, the paper speed is about 5 to 25 cm/second. For short duration it about 50 to 400 cm/second. The paper width is about 10 cm.

The amplifier should have uniform frequency response in the frequency range fro 10 Hz to 1 kHz with high CMRR (100 dB) and input impedance greater than 10 MΩ. Th signal is also recorded in the tape recorder for future reference. Further the myographer ca listen the sounds from the loud speaker and from that he can diagnose the neuromuscula disorders.

Thus EMG is very useful for studying the neuromuscular function, neuromuscula condition, reflex responses and extent of nerve lesion and diagnosing the muscular disease like myasthenia gravis which can produce a highly damped impulses during contraction of th muscles due to too rapid fatigue of the neuromuscular synapses.

4.5.2 Determination of conduction velocities in motor nerves

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

Figure 4.28 illustrates the measurement procedure. The EMG electrode and the stimulating electrode are placed at two points on the skin, separated by a known distance l_1. A brief electrical pulse is applied through the stimulating electrode. When the excitation reaches the muscle, this contracts with a short twitch. Since all the nerve fibers are stimulated

at the same time and the conduction velocity is normally the same in all nerve fibers, there is synchronous activation of the muscle fiber. This action potential of the muscle is picked up by the EMG electrode and is displayed on the oscilloscope along with the stimulating impulse. The elapsed time 't_1' (latency) between the stimulating impulse and muscle's action potential is measured. Now the two electrodes are repositioned with the distance of separation as l_2 metres. Among the distances l_1 and l_2, $l_2 < l_1$. The latency is now measured as 't_2' seconds.

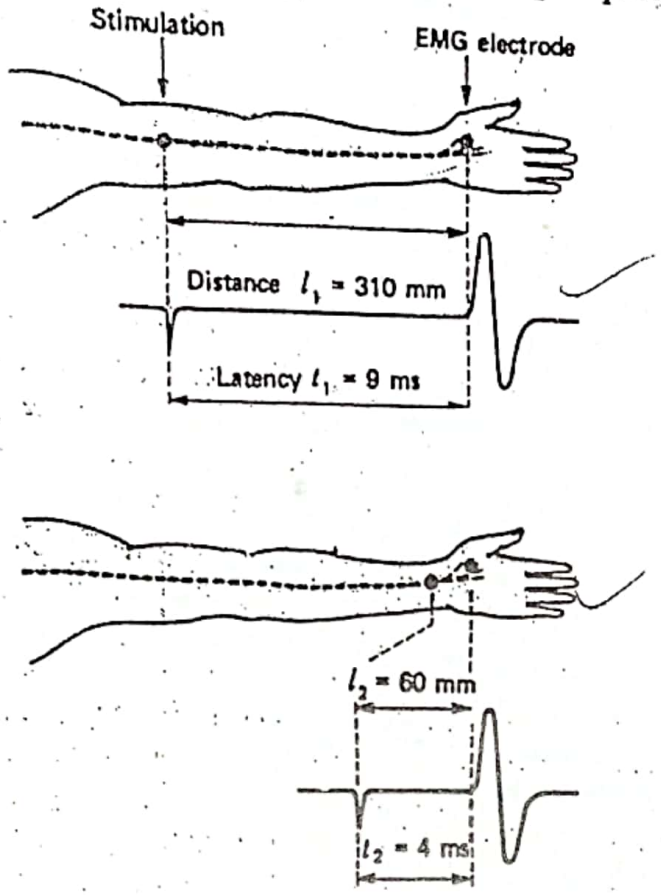


Fig.4.28. Determination of conduction velocity in a motor nerve

$$\text{The conduction velocity, } v = \frac{l_1 - l_2}{t_1 - t_2}$$

The conduction velocity in peripheral nerves is normally 50 m/s. When we have it below 40 m/s, there is some disorder in that nerve conduction.

4.6 ELECTRORETINOGRAPHY (ERG) AND ELECTROOCULOGRAPHY (EOG)

The recording and interpreting the electrical activity of eye is called electroretinography. All sense organs are connected to the brain but the eye has a special

relationship as the retina is an extension of the cerebral cortex. Potentials within the eye may be recorded relatively easily because of its exposed position. The cornea is about 20 mV positive relative to the fundus of the eye. The fundus is the back of the interior of the eye ball. If the illumination of the retina is changed, the potential changes slightly in a complex manner. The recording of these changes is called the ***electroretinogram***. A silver - silver chloride electrode on a contact lens and a distant electrode on the cheek are used to record the eye potential changes. The largest variations are usually slightly less than 1 mV. This technique is not used very much clinically but is of great value in research on vision.

Electrode Placement

A bipolar recording technique is used. The exploring electrode is placed on a saline filled contact lens. The contact lens is tightly attached to the eye. During eye movement there is no slip of contact lens by using negative pressure (between the corneal cavity and the cornea) attachment techniques. The common contact lenses used for corrections or cosmetic purposes ride on a tear film over the cornea, do not follow eye movements well and are unsuitable for recording purposes. Therefore specially made contact lenses are used to record the action potentials of eye during flash of light incident on eye.

Recording Techniques

When light falls on the retina, the absorption of photons by photopigments localized in the outer segment of the retina's photoreceptors is taking place. This causes the breakdown or bleaching of photopigments which results in the liberation of ions that cause a change in the membrane potential. This in turn results in the development of action potential that is transmitted down the optic nerve. This action potential is picked up the electrodes and are fed to the bioamplifier and then to the recorder. The recording set up is similar to the ECG recorder.

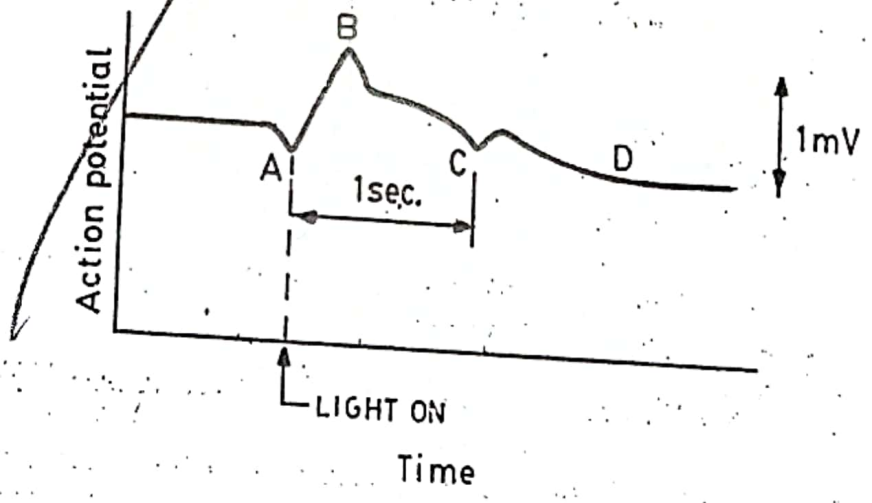


Fig.4.29 Electroretinogram