Contents

Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya
Department of Electronics and Communication Engineering
Syllabus for Full Time BE, Regulations 2018
(Applicable for students admitted from 2018-19 onwards
PRE-REQUISTIE:
Basic Knowledge in Electronic Devices and Circuits
OBJECTIVES:

- To learn the electrical and non-electrical physiological measurements
- To understand the function of bio amplifiers.
- To know the configuration of various electrodes

UNIT I BIO POTENTIAL ELECTRODES (9 Hrs)

Origin of bio potential and its propagation, Electrode-electrolyte interface, electrode–skin interface, half cell potential, impedance, polarization effects of electrode – non polarisable electrodes. Types of electrodes - surface, needle and micro electrodes and their equivalent circuits, Recording problems - measurement with two electrodes

UNIT II ELECTRODE CONFIGURATIONS (9 Hrs)

Bio signals characteristics – frequency and amplitude ranges. ECG – Einthoven's triangle, standard 12 lead system. EEG – 10-20 electrode system, unipolar, bipolar and average mode, EMG– unipolar and bipolar mode

UNIT III BIO AMPLIFIER (9 Hrs)

Need for bio-amplifier - single ended bio-amplifier, differential bio-amplifier – right leg driven ECG amplifier. Band pass filtering, isolation amplifiers – transformer and optical isolation - isolated DC amplifier and AC carrier amplifier. Chopper amplifier, Power line interference

UNIT IV MEASUREMENT OF NON-ELECTRICAL PARAMETERS (9 Hrs)

= 30 + 2(T1,T2)= 32 classes)

JNIT IV MEASUREMENT OF NON-ELECTRICAL PARAMETERS (9 Hrs)

Temperature, respiration rate and pulse rate measurements. Blood Pressure: indirect methods - auscultatory method, oscillometric method, direct methods: electronic manometer, Pressure amplifiers

- systolic, diastolic, mean detector circuit. Blood flow and cardiac output measurement: ndicator

dilution, thermal dilution and dye dilution method, Electromagnetic and ultrasound blood flow measurement.

JNIT V BIO-CHEMICAL MEASUREMENT (9 Hrs)

Biochemical sensors - pH, pO2 and pCO2, Ion selective Field effect Transistor (ISFET), mmunologically sensitive FET (IMFET), Blood glucose sensors - Blood gas analyzers, colorimeter, flame photometer, spectrophotometer, blood cell counter, auto analyzer (simplified schematic description).

OUTCOMES: Total: 45 Hrs

At the end of the course, the student should be able to:

- Perform electrical and non-electrical physiological measurements
- Explain the function of bio amplifiers.

TEXT BOOKS:

1. John G. Webster, "Medical Instrumentation Application and Design", John Wiley and sons, 2004.

2. Khandpur R.S, "Handbook of Biomedical Instrumentation", Tata McGraw-Hill, 2003.

REFERENCES:

1. Leslie Cromwell, "Biomedical Instrumentation and measurement", PHI, 2007.

Points to ponder upon*

*What is the goal of Biomedical systems?

To make diagnosis of a disease easy.

*What are the commonly used biomed. Instruments in our home?
Thermometer,BP,/pulse-oximeters, gluco-Meter.

*What are advantages of modern bio medical electronics?
Ability to produce Reports understandable by patient as well as doctor, in the f
of X-Ray or CT Scan etc.

below are few of **the important landmarks** in the history of development of various medical equipment:

1816 - Stethoscope invented

1851 - Ophthalmoscope invented

1895 - Use of X-rays in medical imaging

1896 - Sphygmomanometer (mercury based blood pressure meter)

1901 - First Electrocardiograph (ECG or EKG) Machine

1924 - First human electroencephalogram (EEG) performed

1927 - First practical modern respirator ("iron lung") invented

1943 - First electron linear accelerator designed for radiation therapy developed

the important landmarks in the history of development of various medical equipment: (contd.)

1945 - First practical human haemodialysis machine developed
1953 - Heart/lung bypass machine first used in surgery on humans
1955 - Ultrasound first used on pregnant women
1958 - First cardiac pacemaker implanted.
1965 - First portable defibrillator installed
1972 - Computed axial tomography(CAT) scan for brain
1973 - First whole-body CAT scan
1975 - First positron emission tomography (PET) image
1977 - First whole-body magnetic resonance imaging (MRI) scanner.
First cochlear implant surgery
1982 - First permanent artificial heart implant
1985 - Implantable cardioverter defibrillator (ICD)
1987 - First laser surgery on a human cornea
2004 - 64-slice CT scanner

Essential biomed. Instruments at your home.

- Thermo-meter
- Heart rate meter
- Oximeter
- Blood pressure meter
- Gluco- meter

PEC5 **BIO-MEDICAL ELECTRONICS VII SEMESTER**

(Applicable for students admitted from 2018-19 onwards

PRE-REQUISTIE:

Basic Knowledge in Electronic Devices and Circuits

OBJECTIVES:

- To learn the electrical and non-electrical physiological measurements
- To understand the function of bio amplifiers.
- To know the configuration of various electrodes

UNIT I- BIO POTENTIAL ELECTRODES (9 Hrs)

Origin of bio potential and its propagation, Electrode-electrolyte interface, electrode–skin interface,half cell potential, impedance, polarization effects of electrode – non polarisable electrodes.

Types of electrodes - surface, needle and micro electrodes and their equivalent circuits, Recording problems -measurement with two electrodes

Q1) Origin of bio potential and its propagation

1.1 What is the relation of bio potential to the body/ organ status?

Q2)Explain the interface between a)Electrode-electrolyte

b)electrode–skin regions.

Q3) Explain the concept of **half cell potential, skin impedance**, **polarization** effects of electrode – **non polarisable electrodes.**

Q4) What are the various types of electrodes ?

Q5) Bio- electrodes & its electrical equivalents.

Q6) What is the function of electrode jelly in bio-signal recording?

Q7) What the various types of pasteless electrodes used for bio-signal recording

Q8) Where do we use microelectrodes? What are the types of microelectrodes

Q9)what are the recording problems in bio-med.instruments?

Q10) mention the need for eq. circuits in biomed.instrument design.

Q1.1)Human body is made of massive Parallel & series Cellular network ,that aids in generation & transmission/reception of voltages.

Bio potential reveals the current status of the organ you are probing.

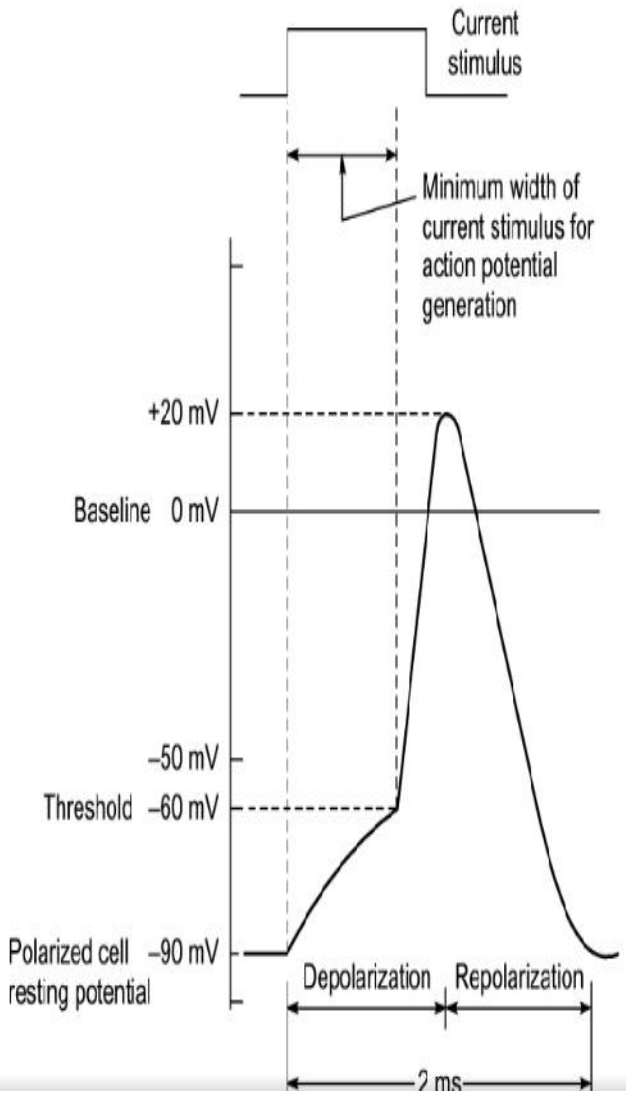
Q8.1 What is the size of human cell?100 microns

Q8.2 What is the typical tip size of a Micro- electrode?

0.5 to 5microns

Q9)To reduce errors and improve accuracy.

discharging and recharging of the cell produces the voltage waveforms which can be recorded by suitable methods using microelectrodes. A typical cell potential waveform so recorded is shown in Fig. 2.1.



An equation relating the potential across the membrane and the two concentrations
of the ion is called the Nernst equation and can be stated as follows:
follows:

$$E = -\frac{RT}{nF} \ln \frac{C_1 f_1}{C_2 f_2}$$

where R = gas constant (8.315 x 10' ergs/mole/degree Kelvin)
T = absolute temperature, degrees Kelvin
n = valence of the ion (the number of electrons added or removed to ionize the atom)
F = Faraday constant (96,500 coulombs)
C1,C2 = two concentrations of the ion on the two sides of the membrane
f1f2 = respective activity coefficients of the ion on the two sides of
the membrane

Resting state
(polarized)
Stimulation
Repolarization
completed
Excited
Unexcited
Depolarization
started
Repolarization
Depolarization completed

Q1) Origin of bio potential

The association of electricity with medical science dates back to the 18th century when Galvani demonstrated that most of the physiological processes were accompanied with electrical changes.This discovery formed the basis of the explanation of the action of living tissues in terms of bioelectric potentials. It is now well established that the human body, which is composed **of living tissues, can be considered as a power station generating multiple electrical signals with two internal sources, namely muscles and nerves.**

Bioelectric potentials are generated at a cellular level and the source of these potentials is ionic in nature. A cell consists of an ionic conductor separated from the outside environment by a semipermeable membrane which acts as a selective ionic filter to the ions. This means that some ions can pass through the membrane freely whereas others cannot do so.

The principal ions involved with the phenomena of producing cell potentials are sodium (Na+), potassium (K+) and chloride (Cl–). The membrane of excitable cells readily permits the entry of K+ and Cl– but impedes the flow of Na+ even though there may be a very high concentration gradient of sodium across the cell membrane.

Q1) Origin of bio potential and its propagation

The distribution of positively charged ions on the outer surface and negatively charged ions inside the cell membrane results in the difference of potential across it and the cell becomes,in effect, a tiny biological battery. Experiments have shown that the internal resting potential within a cell is approximately –90 mV with reference to the outside of the cell.

The wave of excitation while propagating in the muscle causes its contraction. The contraction wave always follows the excitation wave because of its lower velocity. This phenomenon is found with the skeletal muscles, the heart muscle and the smooth muscles. In its turn, every contraction (movement) of a muscle results in the production of an electric voltage

Q2)Explain the interface between a)Electrode-electrolyte
b)electrode–skin regions.

Table 2.3 Potential between Electrodes in Electrolytes (Geddes and Baker, 1975)

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

Q3) electrode–skin interface,half cell potential, impedance, polarization effects of electrode – non polarisable electrodes.

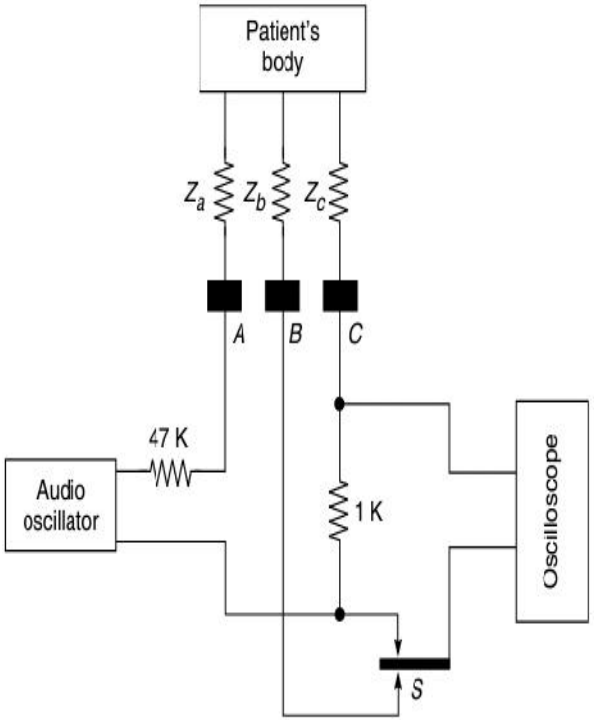
The impedance at the **electrode-skin junction** comes in the overall circuitry of the recording machine and, therefore, has significant effect on the final record. Skinelectrode impedance is known as the contact impedance and is of a value much greater than the electrical impedance of the body tissue as measured beneath the skin. The outer horny layer of the skin is responsible for the bulk of the skin contact impedance and, therefore, a careful skin preparation is essential in order to obtain best results.

Principle of skin impedance measurement.The three electrodes, A, B and C, have contact impedance respectively of Za, Zb and Zc. An oscillator provides a constant current in the frequency range of 0.1–100 Hz through the 47 kW series resistor. By suitably positioning the switch, a sensitive oscilloscope can be used to monitor either the voltage dropped across the 1 kW resistor or the voltage dropped across Zb. The voltage drop across Zb can be neglected since the input impedance of the oscilloscope used with an input probe is usually high. From the voltage dropped across the 1 kW resistor it is possible to calculate the circuit current and thus to obtain a value for Zc. Using this technique, the skin contact impedance of the following types of electrodes were measured by Hill and Khandpur (1969).

– non polarisable electrodes.

preparation is essential in order to obtain best results.

Measurement of Skin Contact Impedance: A convenient method to measure the contact impedance at any individual electrode is shown in Fig. 2.10. This method has been suggested by Miller



➤ Fig. 2.10 *Arrangement for measurement of electrode skin-contact impedance for surface electrodes*

Q3) Contd.

Non-polarizing electrodes on the other hand, are designed to rapidly dissipate any charge imbalance induced by powerful electrical discharges such as a defibrillation procedure. Rapid depolarization enables the immediate reappearance of bioelectric signals on the monitor after defibrillation. For this reason, non-polarizing electrodes have become the electrodes of choice for monitoring in the intensive care units and stress testing procedures. Historically, these electrodes employ a conducting metal with a silver/silver-chloride (Ag/AgCl) surface in contact with the conducting gel.

alf-cell potential

ıe metal electrolyte interface

ppears to consist of a voltage source in series with a parallel combination of a apacitance and reaction resistance. The voltage developed is called the half-cell otential.

To a first-order approximation, the half-cell potential is equal to the electrode otentialof the metal, if the electrodes were used in a chemical measuring application. ll electrodepotentials are measured with respect to a reference electrode, usually that f hydrogen absorbed on platinum black. This is an inconvenient electrode to make and, ıerefore, other alternative electrodes which may have fairly stable and repeatable otential (e.g. calomel electrode) are employed. Electrode potentials of some of the ɔmmonly used metals in the electrochemical series with respect to hydrogen are given ı Table 2.2.

• Table 2.2 *Electrode Potentials of Some Metals with Respect to Hydrogen*

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

may or may not take place. In some metal/liquid interfaces, the electrical double layer gets temporarily disturbed by the externally applied voltage, and therefore, a very small currentflows after the first surge, thus indicating a high resistance. This type of electrode will not
permit the measurement of steady or slowly varying potentials in the tissues. They are said to, be polarized or nonreversible. Thus, the phenomenon of polarization affects the electro-chemical double layer on the electrode surface and manifests itself in changing the value of the impedance and voltage source representing the transition layer.

Parsons (1964) stated that electrodes in
which no net transfer of charge takes place across the metal-electrolyte interface can be termed as perfectly polarized.

Those in which unhindered exchange of charge is possible are called
non-polarizable or reversible electrodes

Q4) What are the various types of electrodes ?

BIOPOTENTIAL ELECTRODES

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

1 **. Microelectrodes**: Electrodes used to measure bioelectric potentials near or within a single cell.

2. Skin **surface electrodes**: Electrodes used to measure ECG, EEG, and EMG potentials from the surface of the skin.

3. **Needle electrodes**: Electrodes used to penetrate the skin to record EEG potentials from a local region of the brain or EMG potentials from a specific group of muscles.

Q5) Bio- electrodes & its electrical equivalents.

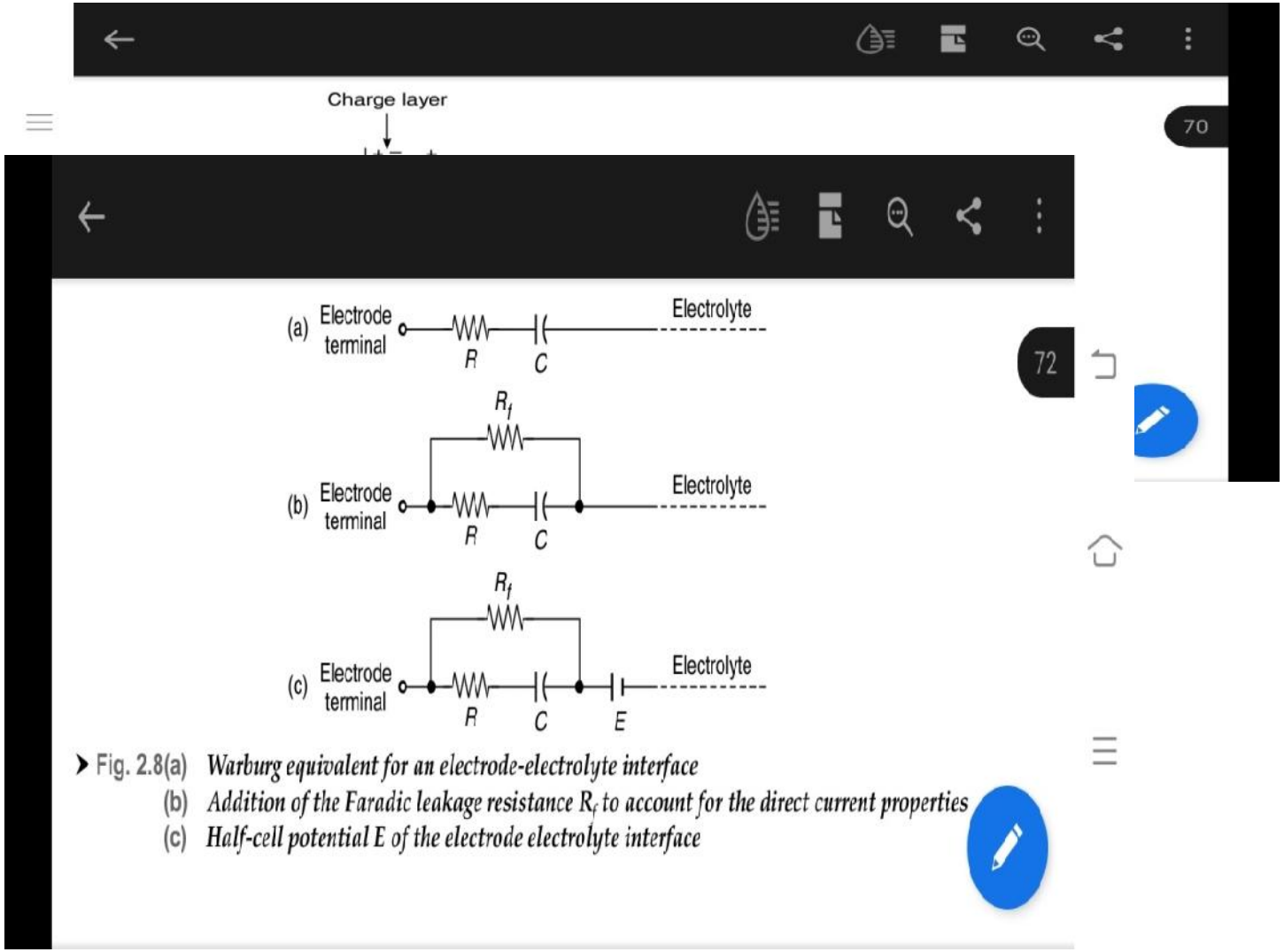
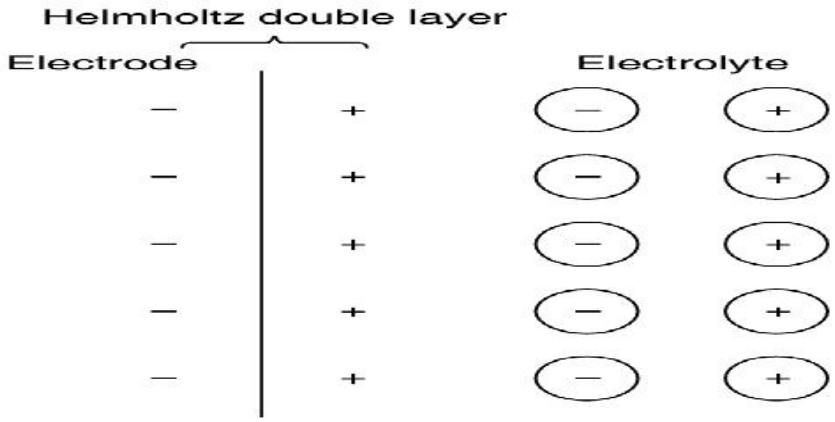


Fig. 2.8(a) *Warburg equivalent for an electrode-electrolyte interface*
(b) *Addition of the Faradic leakage resistance R_f to account for the direct current properties*
(c) *Half-cell potential E of the electrode electrolyte interface*



➤ **Fig. 2.7(b)** ***The electrode tissue interface circuit involves transfer of electrons from the metal phase to an ionic carrier in the electrolyte, a charge double layer (capacitance) forms at the interface***

ectric. Therefore, the metal electrolyte interface
vith a parallel combination of a capacitance and
lled the *half-cell potential*.
l potential is equal to the electrode potential
chemical measuring application. All electrode
ıce electrode, usually that of hydrogen absorbed
trode to make and, therefore, other alte
epeatable potential (e.g. calomel electro
cor nly used metals in the electrochemical

Q6) What is the function of electrode jelly in bio-signal recording?

Ideally, gels should possess the following properties:

-* Adequate moisture in the Gel during shelf life.

-*Prevent micro-organism & mould growth .

-* Provide low electolyte-skin impedance

-*No skin infection.

Q7) What the various types of pasteless electrodes used for bio-signal recording

Capacitive Electrodes: A metal plate electrode in direct contact with the skin though makes a very high resistive contact and has a considerable capacitive contact too with the skin (Stevens, 1963). By using a very high input impedance amplifier, it is possible to record a signal through the tissue electrode capacitance. Lopez and Richardson (1969) describe the construction of electrodes which can be capacitively coupled to the

The electrode consists of an aluminium plate which is anodized on the surface to be placed in contact with the skin. The ohmic resistance of the anodized electrode is about 1 to 30 GW (1000–30,000 MW). Two such electrodes are applied to the subject without any preparation of the skin and the output of the source followers is connected to a conventional electrocardiograph. Wolfson and Neuman (1969) also designed a capacitively coupling electrode and used a high input impedance amplifier having a MOSFET in the input stage arranged in a source-follower configuration. The capacitances encountered in such type of electrodes range from about 5000 to 20,000 pf/cm2 of the electrode area (Geddes, 1972).

Q8) Where do we use microelectrodes?

microelectrodes have tip dimensions ranging from 0.5 to 5 microns. The tips of these electrodes have to be sufficiently strong to be introduced through layers of tissues without breaking. To study the electrical activity of individual cells, microelectrodes are employed. This type of electrode is small enough with respect to the size of the cell in which it is inserted so that penetration by the electrode does not damage the cell. The size of an intracellular microelectrode is dictated by the size of the cell and the ability of its enveloping membrane to tolerate penetration by the microelectrode tip. Single-living cells are rarely larger than 0.1mm (100 microns) and are usually less than one-tenth of this size. Typical micro electrodes have tip dimensions ranging from 0.5 to 5 microns. The tips of these electrodes have to be sufficiently strong to be introduced through layers of tissues without breaking.

Recording problems

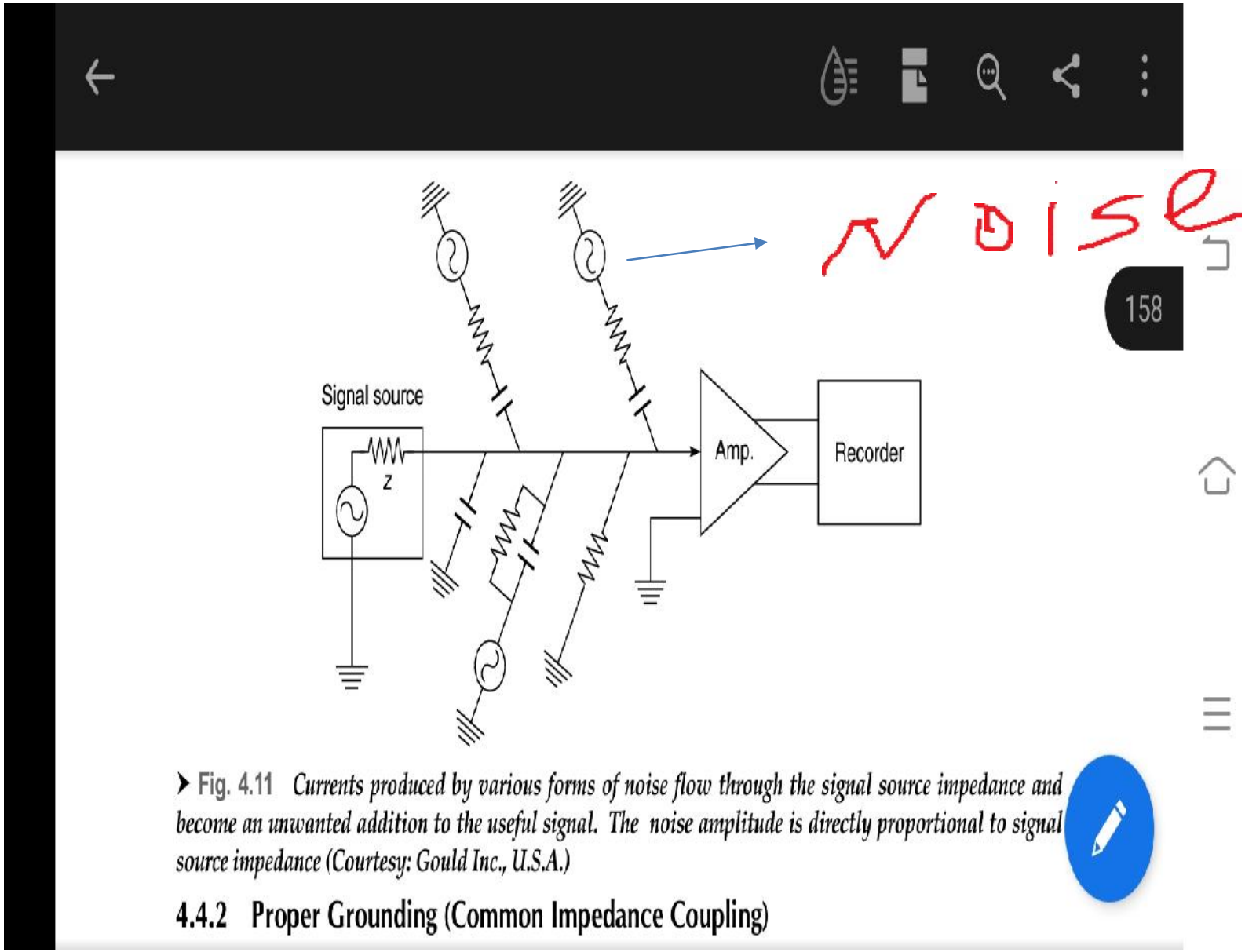
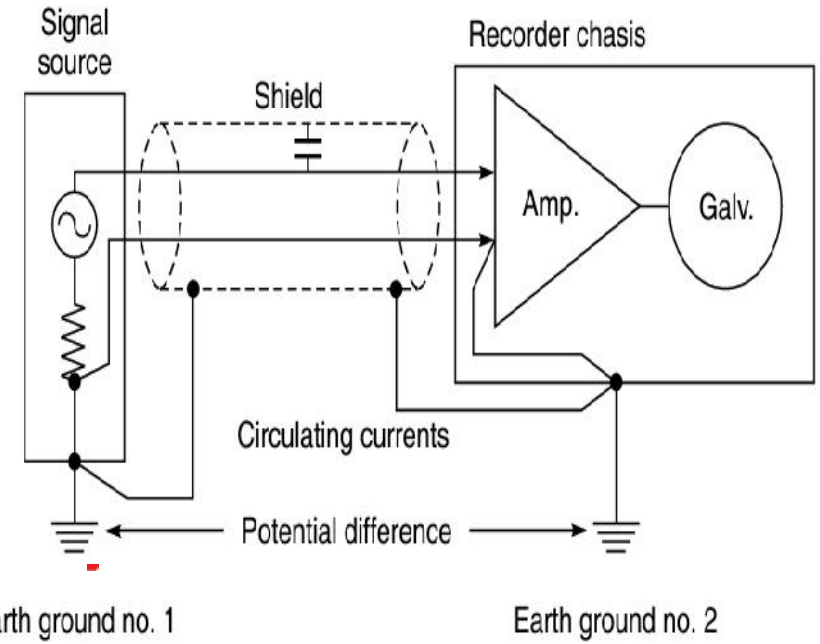


Fig. 4.11 *Currents produced by various forms of noise flow through the signal source impedance and become an unwanted addition to the useful signal. The noise amplitude is directly proportional to signal source impedance (Courtesy: Gould Inc., U.S.A.)*

4.4.2 Proper Grounding (Common Impedance Coupling)



➤ Fig. 4.12 *Ground loop created by more than one ground on a signal circuit. The potential difference between earth ground no. 1 and earth ground no. 2 causes current to circulate in the signal cable shield and also in the lower signal conductor, producing two separate ground loops*

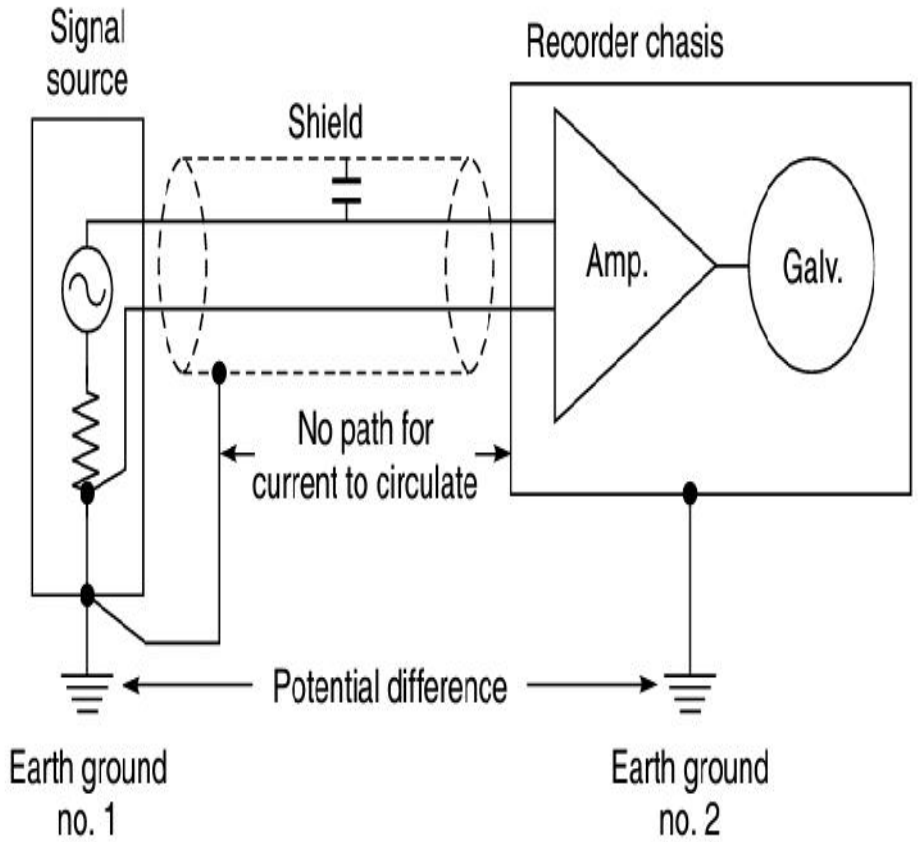


Fig. 4.13 *Eliminating multiple grounds. The ground loop in the lower signal lead h removing the jumper wire to earth ground no. 2. The ground loop in the cable shield h removing its connection to earth ground no. 2 (Courtesy: Gould Inc. U.S.A.)*

4.5 BIOMEDICAL SIGNAL ANALYSIS AND PROCEESING TECH

Q9)Recording problems in electrodes& the solutions.

- All parts of the electrode must be of same potential
- Dissimilar metals must be avoided interconnections/ joints.
- While using more than one electrode , same Material has to be used for all electrodes. (for avoiding errors)
- No tension in leadwires
- Amplifiers near the electrode must have higher input impedance than source impedance.

UNIT I- BIO POTENTIAL ELECTRODES(MODEL QUESTIONS)

1. Describe the origin of bioelectric signals. Draw a typical cell potential waveform, label it properly and explain the phenomena of depolarization and repolarization.
2. Explain the origin of electrical activity of the heart with the help of a diagram. Draw a typical ECG waveform and label it.
3. Draw a typical Electroencephalogram (EEG) waveform. Give frequency range of various bands for purpose of EEG analysis. What is an evoked potential?
4. Illustrate with the help of a diagram the origin of electromyogram signal and give its characteristic values in terms of amplitude and frequency.
5. Draw the diagram for electrode-tissue interface for surface electrodes used with electrode jelly. Explain metal-electrolyte and electrolyte skin interface.
6. Define contact potential. What are the factors on which contact potential depends? How we can reduce the contact potential?
7. Explain the 'polarization' phenomenon as applicable to bio-electric electrodes. Give example of a non-polarizing electrode used for ECG recording.
8. What is skin-contact impedance and what is its significance? Draw a diagram showing general relationship between skin-contact impedance and signal frequency.
9. Define motion artefact and explain its origin. What is the common method for reducing motion artefact?
10. Why are silver-silver chloride electrodes preferred for bioelectric signal recordings?
11. What are the various types of electrodes used for recording of ECG signal? Give a brief description of at least 3 types of electrodes.
12. Describe the construction of pre-gelled disposable electrodes. Why they are preferred for long term recording of bioelectric signals?
13. What the various types of pasteless electrodes used for bio-signal recording? What are their limitations and advantages?
14. What is difference between ECG, EEG and EMG electrodes in terms of skin contact impedance?
15. What is the function of electrode jelly in bio-signal recording? Draw a graph showing variation of contact impedance with electrolyte concentration in jelly and time.
16. Where do we use microelectrodes? What are the types of microelectrodes? Desc

UNIT II ELECTRODE CONFIGURATIONS (9 Hrs)

Bio signals characteristics – frequency and amplitude ranges.

ECG – Einthoven's triangle, standard 12lead system.

EEG – 10-20 electrode system, unipolar, bipolar and average mode,

EMG– unipolar and bipolar mode

Q0)Draw the Configuration of electrodes used for ECG

Q0)Draw the Configuration of electrodes used for EEG

Q0)Draw the Configuration of electrodes used for EMG.

Q0a)What is the importance of electrodes in ecg/eeg measurement?

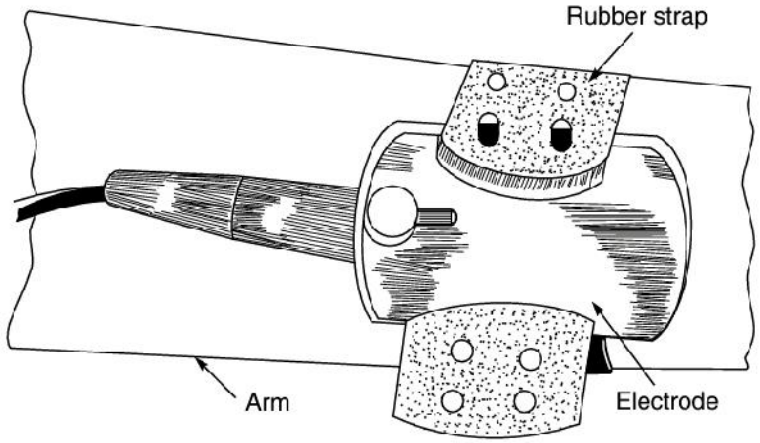
Q1) Mention the amplitude,freq. range of ECG,EEG,EMG signals.

Q2) Explain unipolar and bipolar leads with reference to ECG system.

Q3)Explain ECG with block diagram.

Q4)Explain EEG with block diagram.

Q5)Explain EMG with block diagram.



➤ **Fig. 2.12** *ECG plate electrode. The electrode is usually fastened to the arm or leg with a perforated rubber strap which keeps it in position during ECG recording*

generated by the activity of the limb muscles makes them unsuitable for use when monitoring conscious and semi-conscious patients.

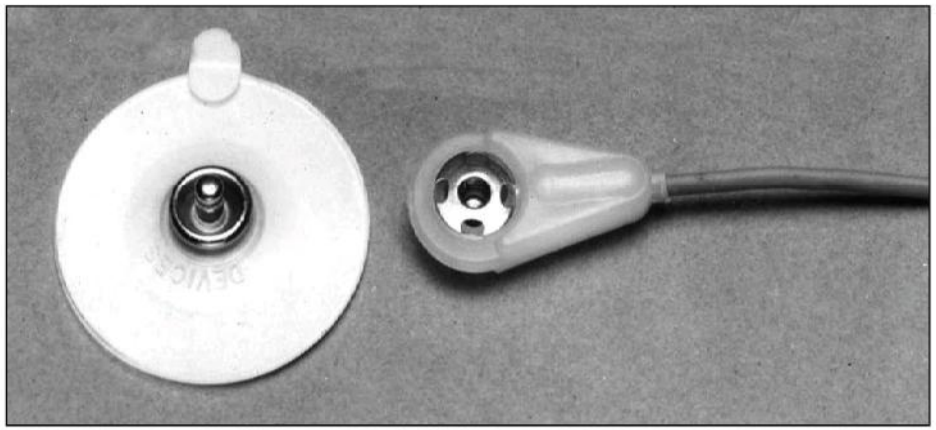


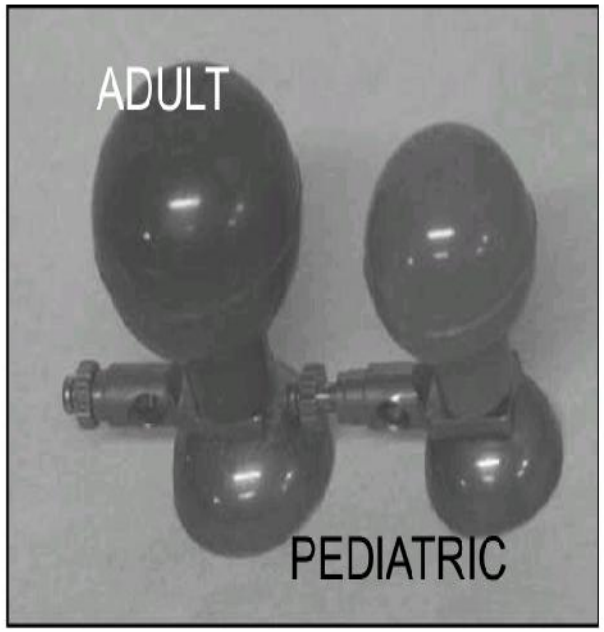
Fig. 2.14 *Light-weight floating electrode with press stud for long term monitoring of ECG*

Completely flexible ECG electrodes for the long-term monitoring of ECG during space flight

generated by the activity of the limb muscles makes them unsuitable for use when monitoring conscious and semi-conscious patients.

Welsh Cup Electrode

Welsh Cup Electrode or suction electrode (Fig. 2.13) is a metallic cup shaped electrode which is used for recording ECG from various positions on the chest. It is commonly used to record the unipolar chest leads. It has a high contact impedance as only the rim of the electrode is in contact with the skin. The electrode is popular for its practicality, being easily attachable to fleshy parts of the body. Electrode jelly forms the vacuum seal. However, they are now being gradually replaced with disposal electrodes, as they are liable to infection due to inadequate cleaning procedures.



➤ **Fig. 2.13** *Suction cup electrode*

2.4.2 Floating Electrodes

Limb electrodes generally suffer from what is known as motion artefacts caused due to the

ding on several factors. Some of these factors
e interface layer (such as skin preparation,
ss, hair, etc.), area of electrode's surface, and
rature of the electrolyte.

other types of electrode for EEG (electroen-
ogram) recording is the chlorided silver disc
.23) having approximately 6–8 mm diameter.
ct with the scalp is made via an electrolytic
through a washer of soft felt. They have ac
nce varying from 3–20 kΩ. Small needle elec-
are sometimes used for carrying out special
tudies when they are inserted subcutane-
Silver ball or pellet electrodes covered with
l cloth pad are useful when electrical activity
e recorded from the exposed cortex, but they
igh dc resistances.

other type of EEG electrode is dry electrode
.24). This type of electrode does not need
set-up time and it is convenient for long-

Fig. 2.22 *EEG cables with disc electrodes*

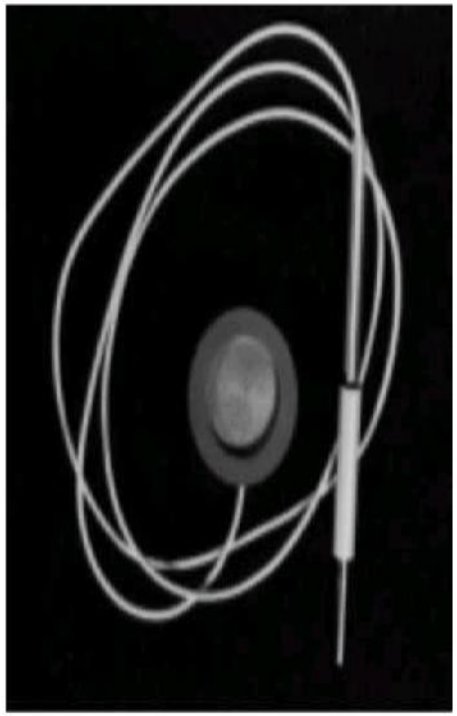
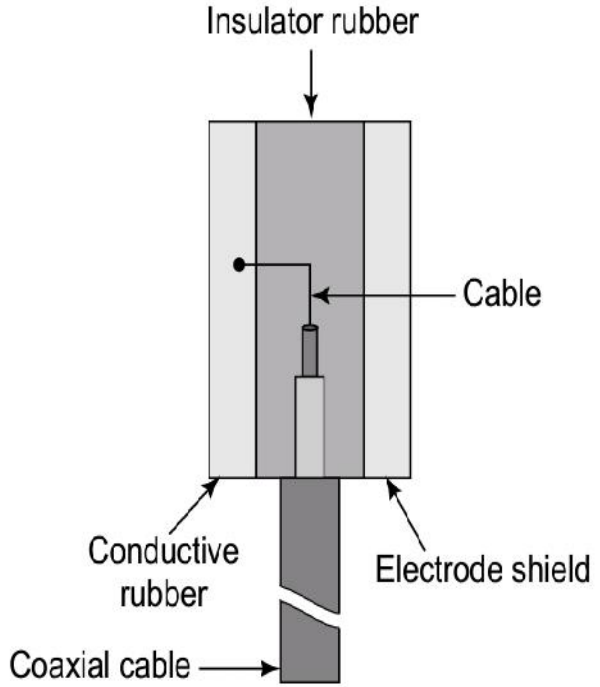


Fig. 2.23 *EEG electrode which can be applied to the surface of the skin by an adhesive tape (Courtesy: In Vivo Metrics, U.S.A.)*

Another type of EEG electrode is dry electrode
ig. 2.24). This type of electrode does not need
long set-up time and it is convenient for long-
rm recordings. These properties are specially
lvantageous for neurofeedback applications.
ıe electrode consists of 1.5 mm thick silicone
nductive rubber-shaped discs of 8 mm diameter.
ıe active side of the electrode is capacitive and
upled through a layer of insulating silicon rubber
ith a metal shield wired to the active guard shield.
ıe impedance of the realized electrodes at 100 Hz
greater than 20 M with a parasitic capacitance
ıaller than 2 pF (Gargiulo, 2008).

The EEG electrodes can be classified as disposable,
usable disc and cup shaped, subdermal needles
ngle-use needles that are placed under the skin),
d implanted electrodes. Needles are available
ith permanently attached wire leads, where the whole assembly is discarded. They are made

applied to the surface of the skin by an adhesive tape (Courtesy: In Vivo Metrics, U.S.A.)



➤ **Fig. 2.24** *Construction of EEG dry electrode*

motor unit territory.

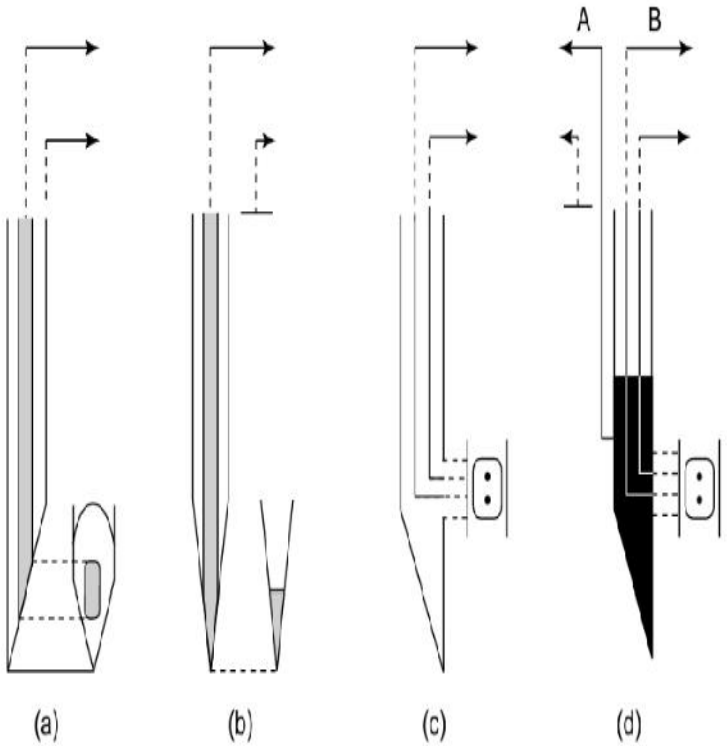


Fig. 2.25 *Four common types of needle EMG electrodes.*

(a) *Concentric needle electrode. The recording wire is represented by the stippled area, running the length of a hypodermic needle.*

(b) *A monopolar needle electrode that is simply a wire insulated all around except at the tip.*

(c) *Single-fiber electrode.*

(d) *Macro-EMG electrode. The setup on the right side (4B) is identical to that of the single-fiber electrode. At the tip of the needle is a very large recording surface (the area in black measuring 1.5 cm in length) for detecting the action potentials generated by all the constituent muscle fibers within the motor unit territory (A). (Adapted from Stalberg, 1986)*

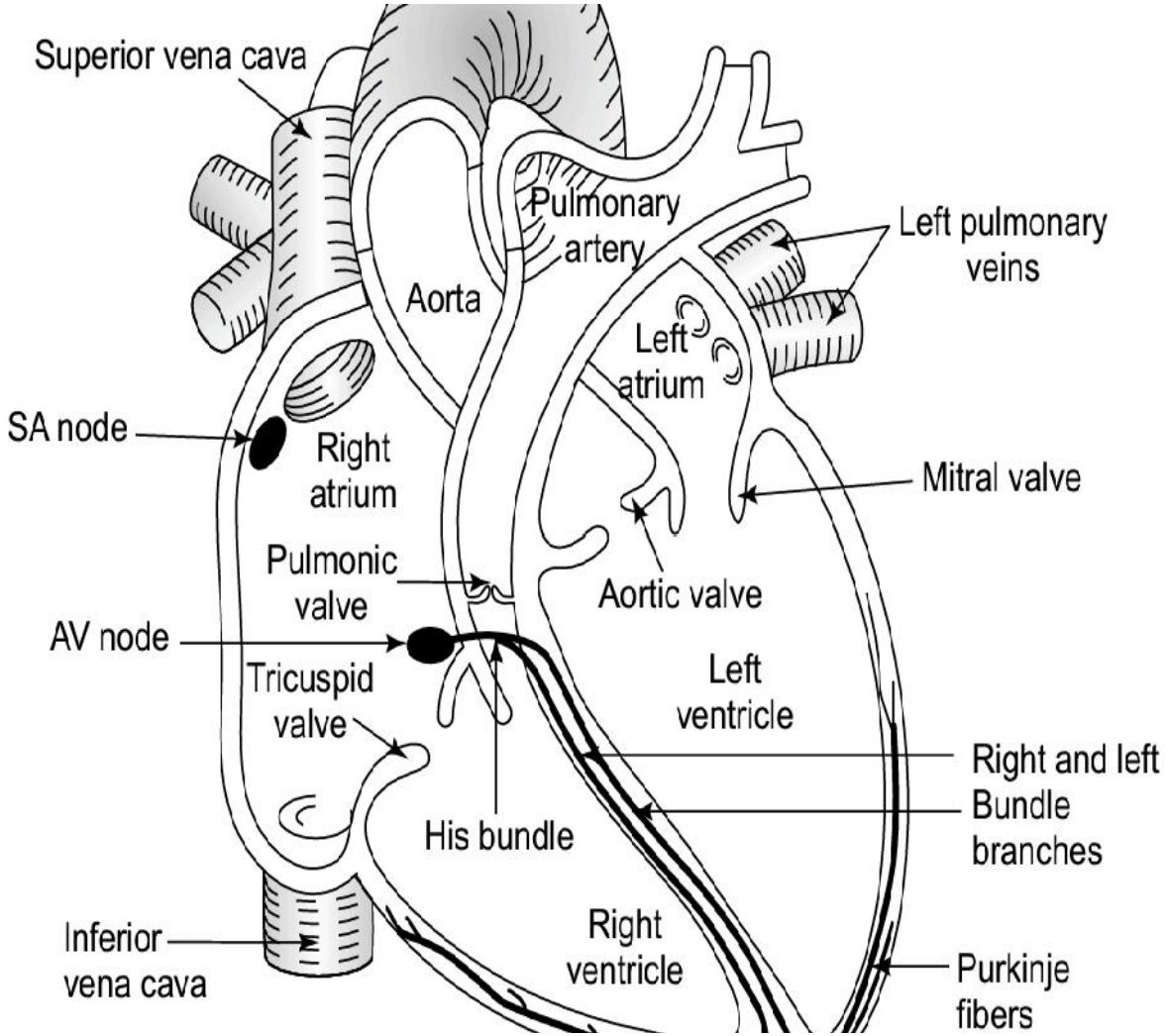
Bio signals characteristics

1)Which is the most important bio electric signal?
2)Which bio electric signal has higher range of freq.s?
3)What is the normal heart rate range? 60-80 bps.
4)What is arrhythmia?
Slower heart rate is called bradycardia (slow heart) and a higher rate, tachycardia (fast heart). He would then see if the cycles are evenly spaced. If not, an arrhythmia irregular-heart beat.
5]Differentiate between electrical & Anatomical axis.
6)What is the meaning of Lead in an ECG instrument?
7) How many Lead configurations are there in an ECG instrument?
8)What is the advantage of unipolar over bipolar lead system?
9)What are the 5 freq. bands in an EEG signal?Explain them.
10)Draw the ECG,EEG,EMG signals marking important activitiies.

Bio signal characteristics

• Table 2.1 *Bioelectric Signals*

Parameter	*Primary signal characteristics*	*Transducer required*
Electrocardiography (ECG)	Frequency range: 0.05 to 120 Hz Signal amplitude: 0.1 – 5 mV Typical signal: 1 mV	Surface electrodes
Electroencephalograph (EEG)	Frequency range: 0.1 to 50 Hz Signal amplitude: 2 – 200 μV Typical signal: 50 μV	Scalp electrodes
Electromyography (EMG)	Frequency range: 5 to 2000 Hz Signal amplitude: 0.05 to 5 mV	Needle electrodes


Superior vena cava
Pulmonary artery
Left pulmonary veins
Aorta
Left atrium
SA node
Right atrium
Mitral valve
Pulmonic valve
Aortic valve
AV node
Tricuspid valve
Left ventricle
Right and left Bundle branches
His bundle
Inferior vena cava
Right ventricle
Purkinje fibers

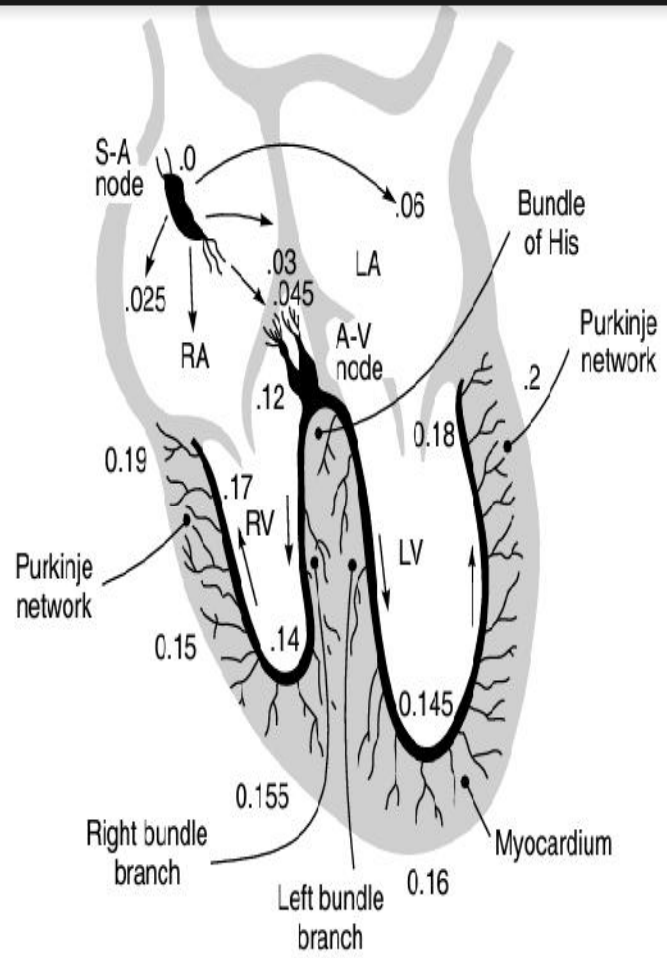
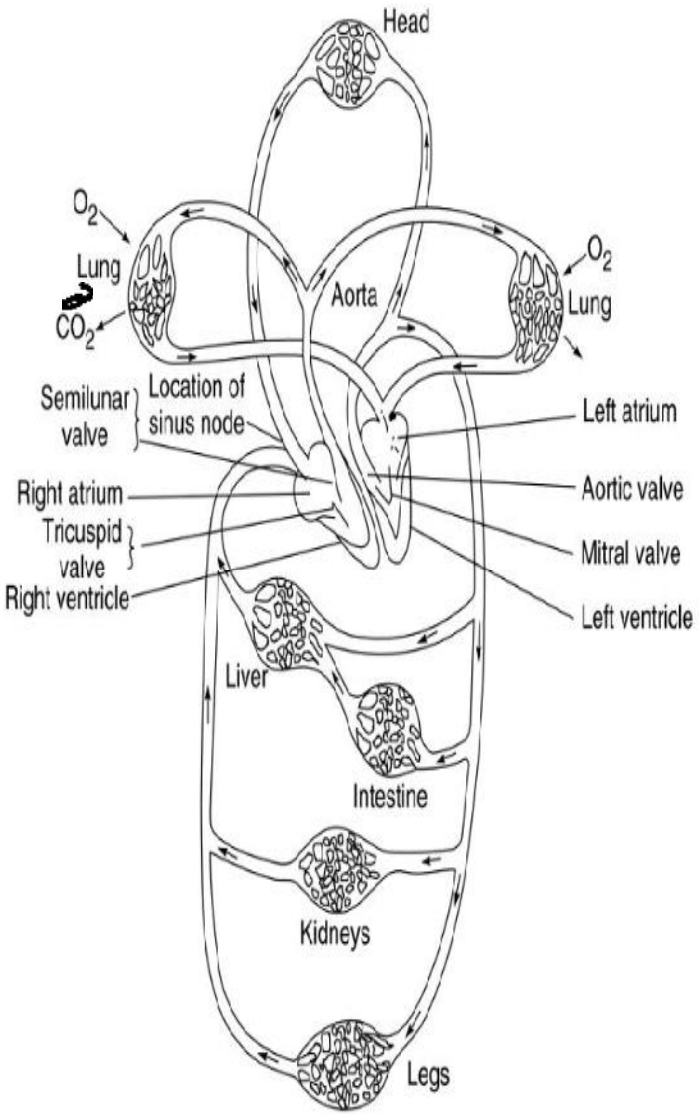
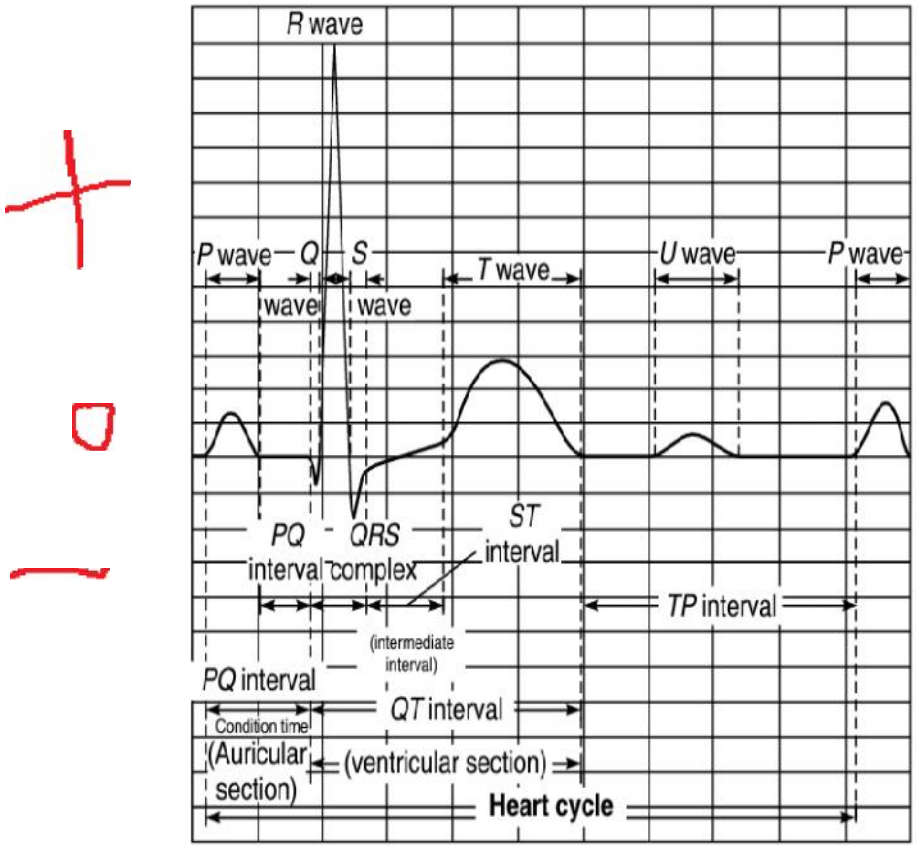


Fig. 2.3 *The position of the Sino-atrial node in the heart from where the impulse responsible for the electrical activity of the heart originates. The arrow shows the path of the impulse.*

Note: The numbers like 0.18, 0.145, 0.15, 0.2... etc. indicate the time taken in seconds for the impulse to travel from S-A node to various parts of the body


Head
O_2
Lung
CO_2
Aorta
O_2
Lung
Semilunar valve
Location of sinus node
Left atrium
Right atrium
Aortic valve
Tricuspid valve
Mitral valve
Right ventricle
Left ventricle
Liver
Intestine
Kidneys
Legs

A Typical ECG Signal



What is PR waveform?

What do P QRS and T waves represent?

The P wave in an ECG complex indicates atrial depolarization. The QRS is responsible for ventricular depolarization and **the T wave is ventricular repolarization**. If a P wave is absent there is a lack of atrial depolarization.

The electrocardiogram (ECG or EKG) is a graphic recording or display of the time-variant voltages produced by myocardium during the
cardiac cycle. Figure shows the basic waveform of the normal electrocardiogram. The P, QRS, and T waves refl the rhythmic electrical depolarization and repolarization of the myocardium associated with the
contractions of the atria and ventricles. The electrocardiogram is used clinically in diagnosing various diseases conditions associated with the
heart. It also serves as a timing reference for other measurements.serves as a timing reference for other measurements.
parameters are as follows:

Amplitude: P wave 0.25 mV
R wave 1.60 mV
Q wave 25<Vo of R wave
T wave 0.1 to 0.5 mV
Duration: P-R interval 0.12 to 0.20 sec
Q-T interval 0.35 to 0.44 sec
S-T segment 0.05 to 0.15 sec
P wave interval 0.11 sec
QRS interval 0.09 sec

For his diagnosis, a cardiologist would typically look first at the heart rate. The normal value lies in the range of 60 to 100 beats per minute. A slower rate than this is called bradycardia (slow heart) and a higher rate, tachycardia (fast heart). He would then see if the cycles are evenly spaced not, an arrhythmia may be indicated. If the P-R interval is greater than 0.2 second, it can suggest blockage of the AV node. If one or more of the ba features of the ECG should be missing, a heart block of some sort might be somewhere.

Anatomical axis is centered along spinal a
Chord with 3 axes of rotation.

The electrical axis (which parallels the anatomical axis) is defined as the one along which the greatest electromotive force is developed at a given instant during the cardiac cycle. The electrical axis shifts continually through a repeatable pattern during every cardiac cycle.

Under pathological conditions, several changes may occur in the ECG. These include (1) altered paths of excitation in the heart, (2) changed origin of waves (ectopic beats), (3) altered relationships (sequences) of features, (4) changed magnitudes of one or more features, and (5) differing durations of waves or intervals.

to zero.

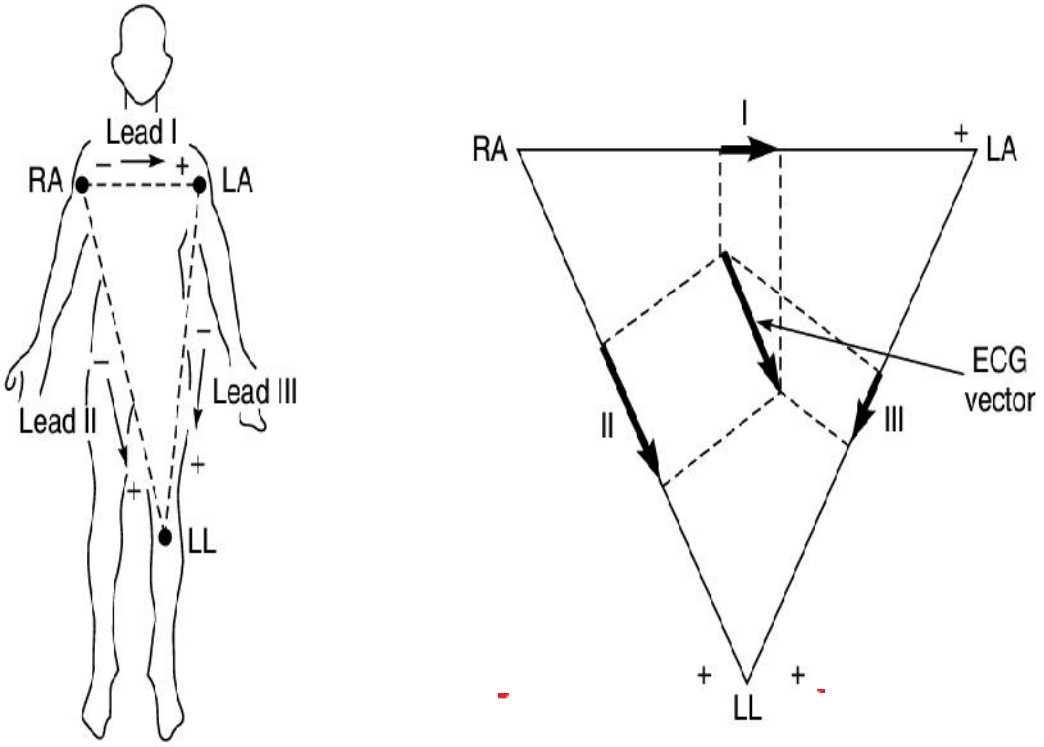
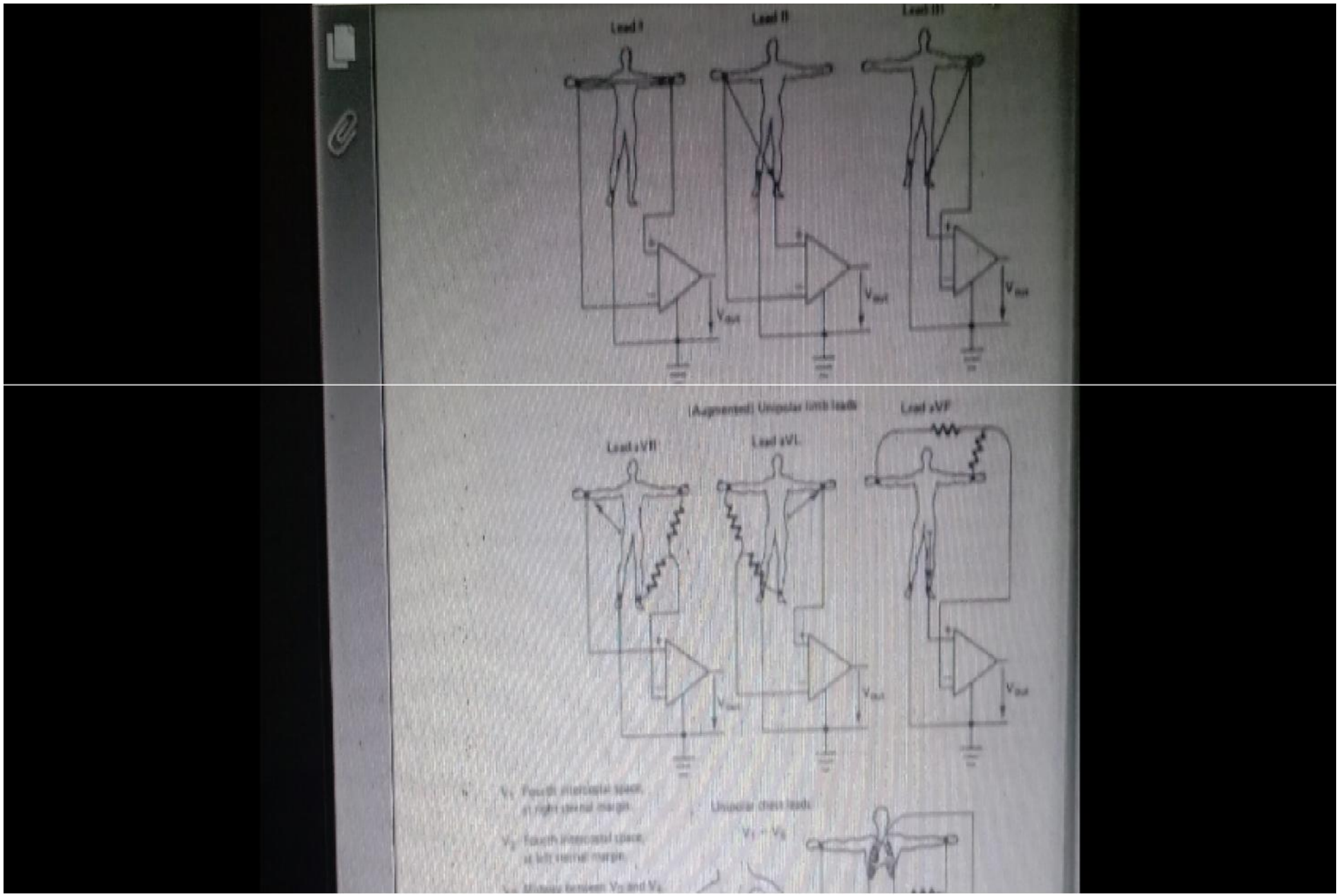


Fig. 5.5 *The Einthoven triangle for defining ECG leads*

*For his diagnosis, a cardiologist would typically look first at the heart rate. The normal value lies in the range of 60 to 100 beats per minute. A
slower rate than this is called bradycardia (slow heart) and a higher rate, tachycardia (fast heart). He would then see if the cycles are evenly spaced. If not, an arrhythmia may be indicated. If the P-R interval is greater than 0.2 second, it can suggest blockage of the AV node. If one or more of the basic features of the ECG should be missing, a heart block of some sort might be
Indicated.

The early electrocardiograph machines thus employed
three electrodes, of which only two were used at one time. With the introduction of the electronic amplifier, an additional connection to the body was needed as a ground reference.
The three bipolar limb lead selections first introduced
by Einthoven, shown in the top row of the figure, are as follows:
Lead I: Left Arm (LA) and Right Arm (RA)
Lead II: Left Leg (LL) and Right Arm (RA)
Lead III: Left Leg (LL) and Left Arm (LA)
These three leads are called bipolar because for each lead the electrocardiogram
is recorded from two electrodes and the third electrode is not connected

ECG-12-lead system

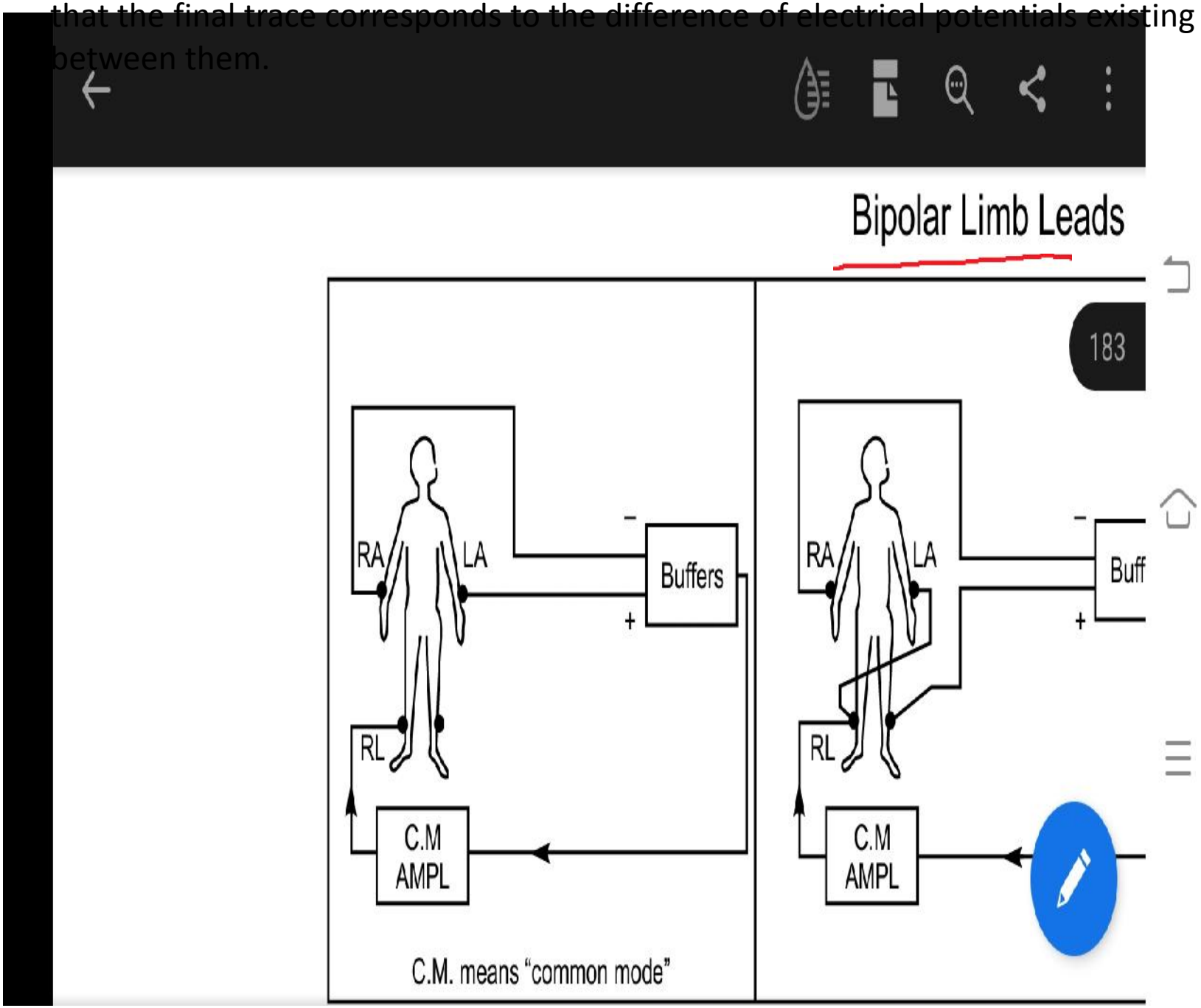


The early electrocadiograph machines thus employed three electrodes, of which only two were used at one time. With the introduction of the electronic amplifier, an additional connection to the body was needed as a ground reference.

Although an electrode could have been positioned almost anywhere on the body for this purpose, it became a convention to use the **free'' right leg.
Chest or precordial electrodes were introduced later.

To avoid this ambiguity,
the term lead will be used only to indicate a particular group of electrodes and the way in which they are connected to the amplifier. For the individual lead wire, as well as the physical connection to the body of the patient, the term electrode will be used. The reader,
however, should be aware of the double meaning that the term **lead'' can have in normal usage.
The voltage generated by the pumping action of the heart is actually a vector whose magnitude, as well as spatial orientation, changes with time.
Because the ECG signal is measured from electrodes applied to the surface of the body, the waveform of this signal is very much dependent on the placement of the electrodes.
Figure 6.1 shows a typical ECG waveform. Some of the segments of this trace may, however, almost disappear for certain electrode placements, whereas others may show up clearly on the recording.
For this reason, in a normal electrocardiographic examination, the electrocardiogram is recorded from a number of different leads, usually 12, to ensure that no important detail of the waveform is missed.
Placement of electrodes and names and configurations of the leads have become standardized and are used the same way throughout the world.

Bipolar Leads: In bipolar leads, ECG is recorded by using two electrodes such that the final trace corresponds to the difference of electrical potentials existing between them.



Two types of unipolar leads are employed which are: (i) limb leads, and (ii) precordial leads.
(i) Limb leads In unipolar limb leads [Fig. 5.4(b)], two of the limb leads are tied togetherand recorded with respect to the third limb. In the lead identified as AVR, the right arm is recorded with respect to a reference established by joining the left arm and left legelectrodes. In the AVL lead, the left arm is recorded with respect to the common junction of the right arm and left leg. In the AVF lead, the left leg is recorded with respect to the
two arm electrodes tied together.

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

tied together at one point. Two types of unipolar leads are employed which are: (i) limb leads, and (ii) precordial leads.

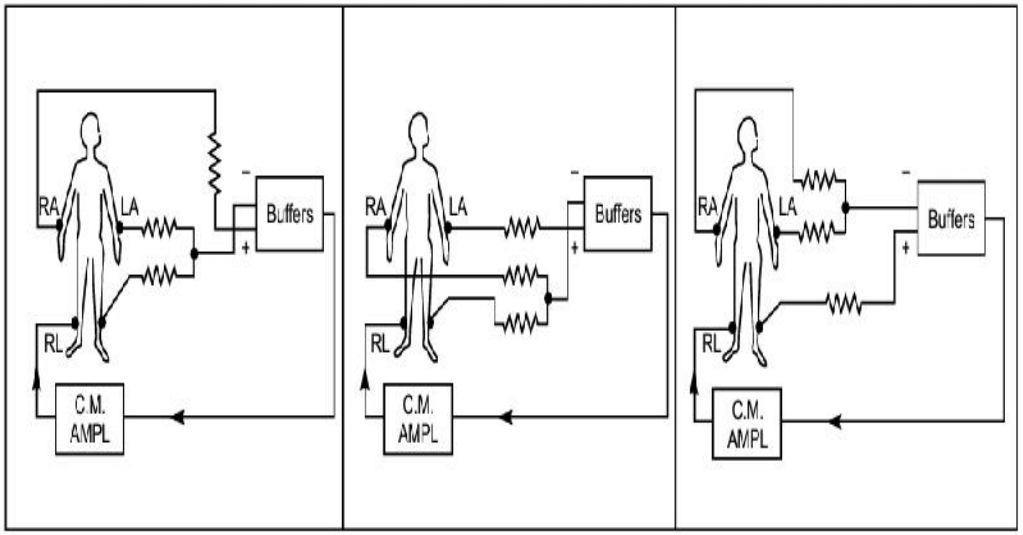
(i) *Limb leads* In unipolar limb leads [Fig. 5.4(b)], two of the limb leads are tied together and recorded with respect to the third limb. In the lead identified as AVR, the right arm is recorded with respect to a reference established by joining the left arm and left leg electrodes. In the AVL lead, the left arm is recorded with respect to the common junction of the right arm and left leg. In the AVF lead, the left leg is recorded with respect to the two arm electrodes tied together.

They are also called augmented leads or 'averaging leads'. The resistances inserted between the electrodes-machine connections are known as 'averaging resistances'.

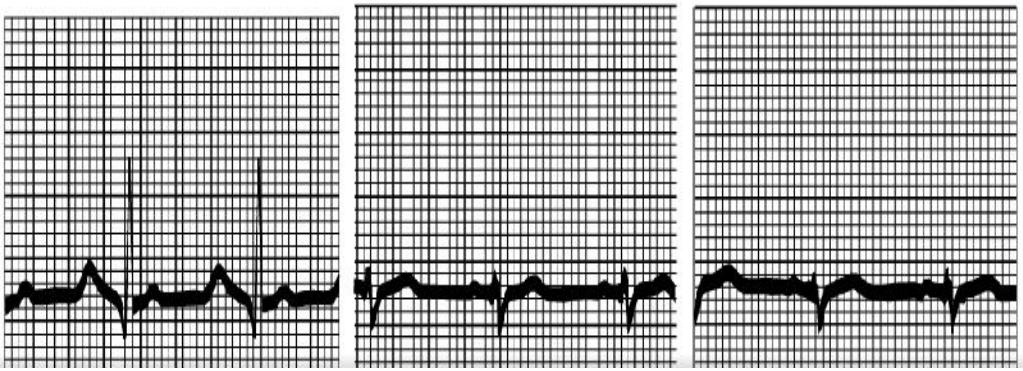
(ii) *Precordial leads* The second type of unipolar lead is a precordial lead. It employs an exploring electrode to record the potential of the heart action on the chest at six different positions. These leads are designated by the capital letter 'V' followed by a subscript numeral, which represents the position of the electrode on the pericardium. The positions of the chest leads are shown in Fig. 5.4(c).

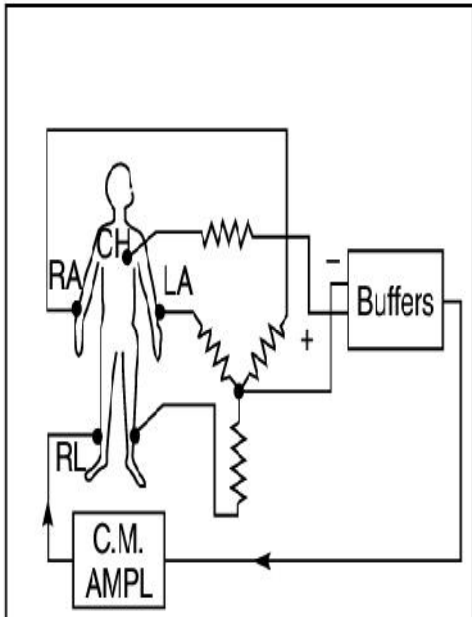
5.1.3 Effects of Artefacts on ECG Recordings

Unipolar Limb Leads

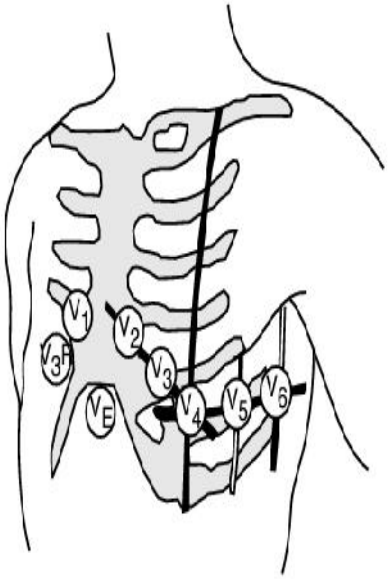


Lead AVR** Lead AVL** Lead AVF**





Lead V **



CH positions

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-calvicular line.

V_5 Same level as V_4, on anterior axillary line.

V_6 Same level as V_4, on mid axillary line.

E Ensiform, base of sternum.

CH positions

(c) Unipolar chest leads

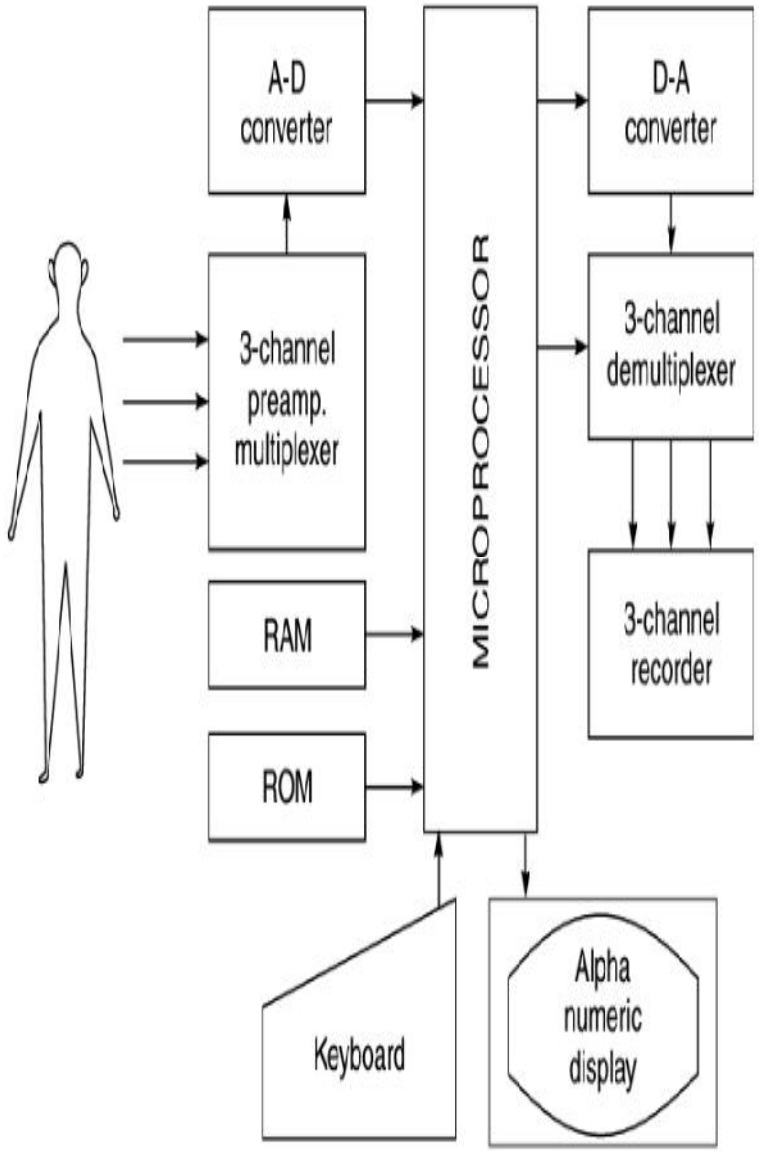


Fig. 5.10 *Block diagram of microprocessor based three channel ECG machine*

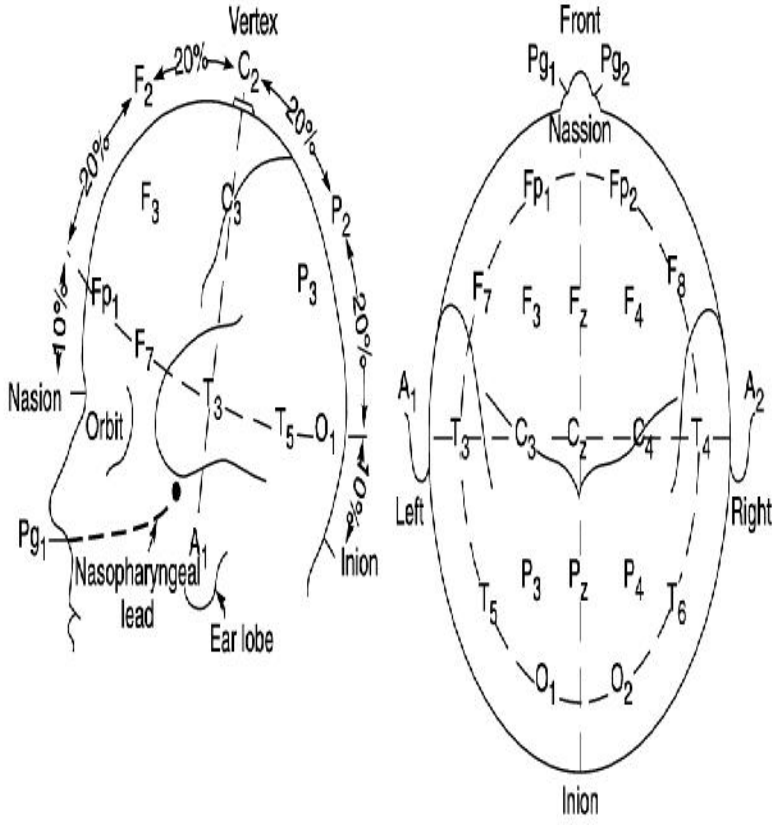
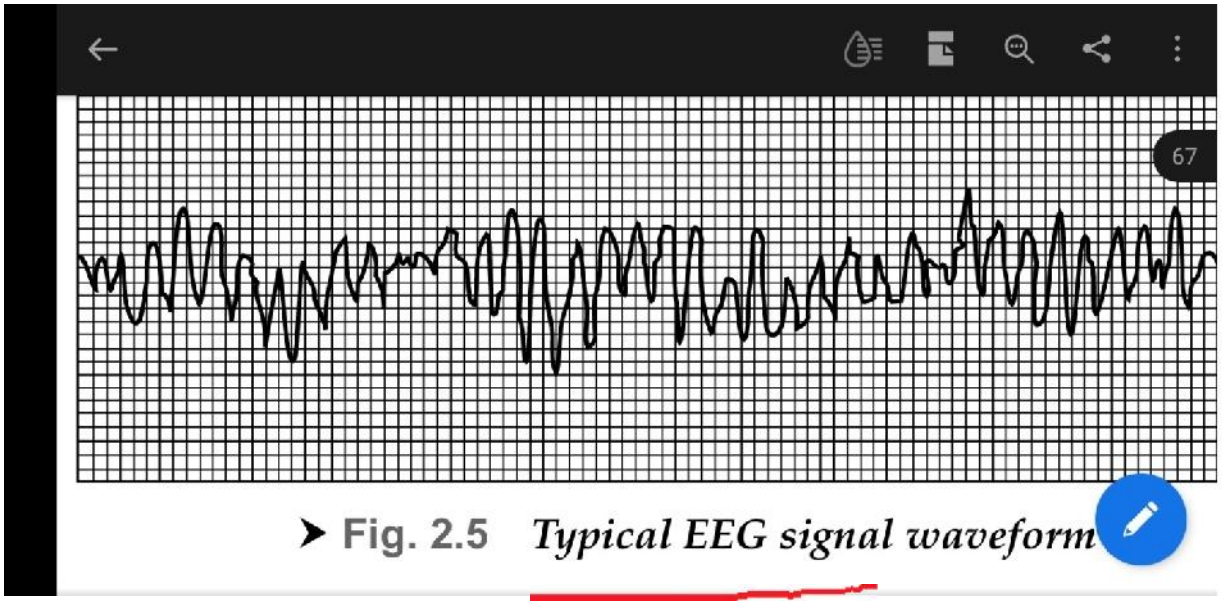


Fig. 5.18 *10-20 System of placement of electrodes*

50 Hz



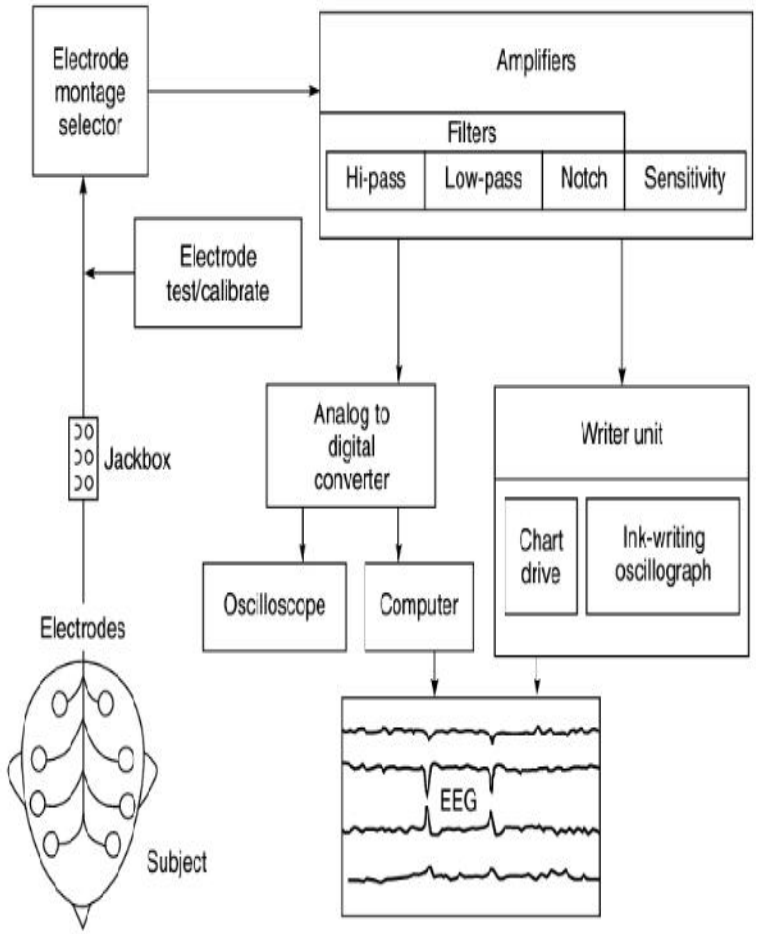
➤ Fig. 2.5 *Typical EEG signal waveform*

The variations in EEG signals both in terms of amplitude and frequency are of diagnostic value. Frequency information is particularly significant since the basic frequency of the EEG range is classified into the following five bands for purposes of EEG analysis:

Delta (δ)	0.5-4 Hz
Theta (θ)	4-8 Hz
Alpha (α)	8-13 Hz
Beta (β)	13-22 Hz
Gamma (γ)	22-30 Hz

The alpha rhythm is one of the principal components of the EEG and is an indicator of the state of 'alertness' of the brain. It serves as an indicator of the depth of anaesthesia in the operating room. The frequency of the EEG seems to be affected by the mental activity of a person. The wide variation among individuals and the lack of repeatability in a given person from one occasion to another makes the analysis a difficult proposition. However, certain characteristic EEG waveforms can be conveniently related to gross abnormalities like epileptic seizures and sleep disorders.

Besides the importance of the frequency content of the EEG pattern, phase relationships between similar EEG patterns from different parts of the brain are also being studied with great interest in order to obtain additional knowledge regarding the functioning of the brain. Another important measurement is the recording of 'evoked response', which indicates the disturbance in the EEG pattern resulting from external stimuli. The stimuli could be a flash of light or a click of sound. Since the responses to the stimuli are repeatable, the evoked response can be distinguished from the rest of the EEG activity by averaging techniques to obtain useful information about the functioning of particular parts of the brain.



▶ Fig. 5.17 *Schematic diagram of EEG machine (after Isley et al., 1998)*

Traditionally, there are 21 electrode locations in the 10/20 system. This system involves placement of electrodes at distances of 10% and 20% of measured coronal, sagittal and

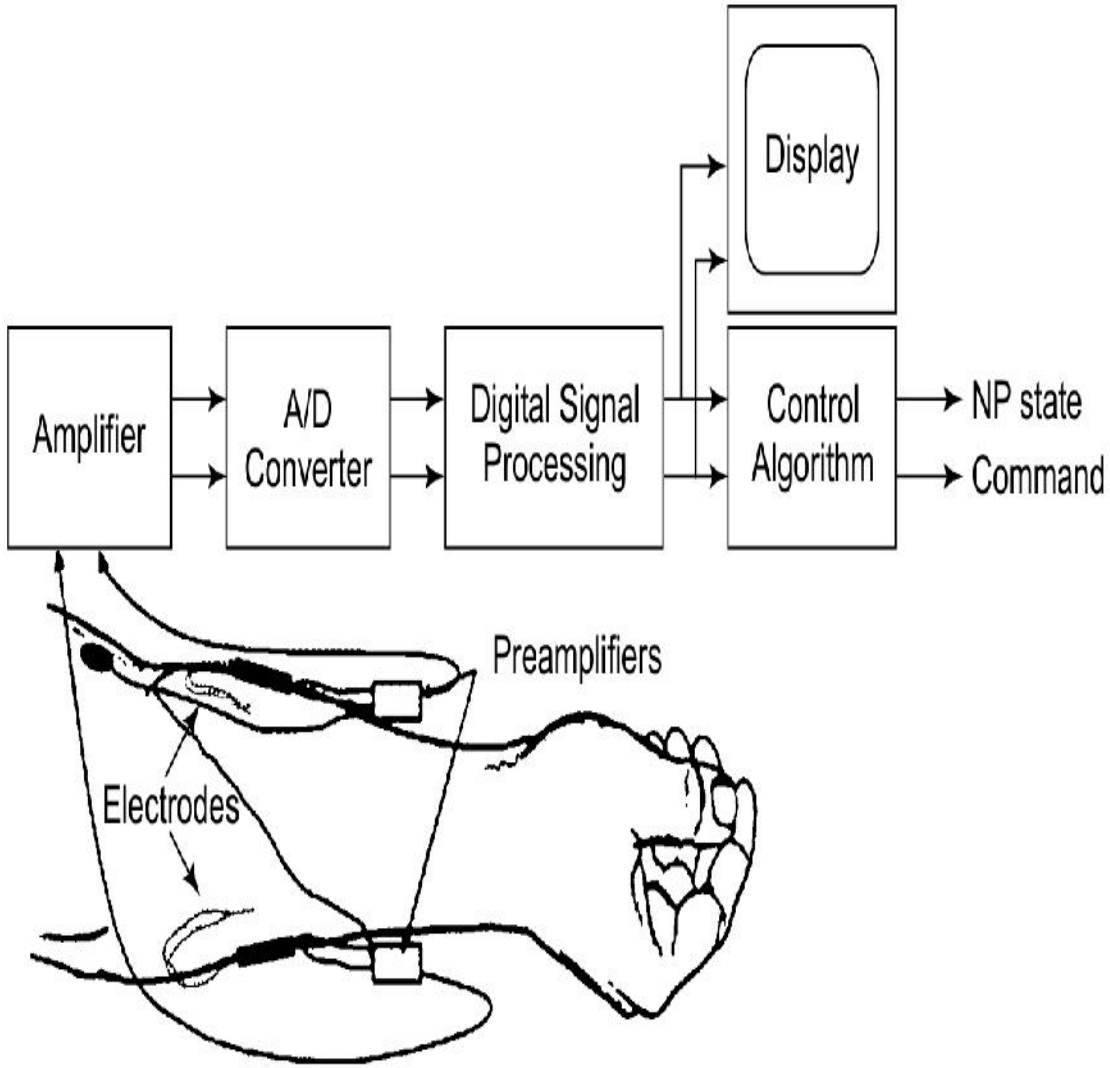


Fig. 5.20 *Block diagram of a typical set-up for EMG recording*

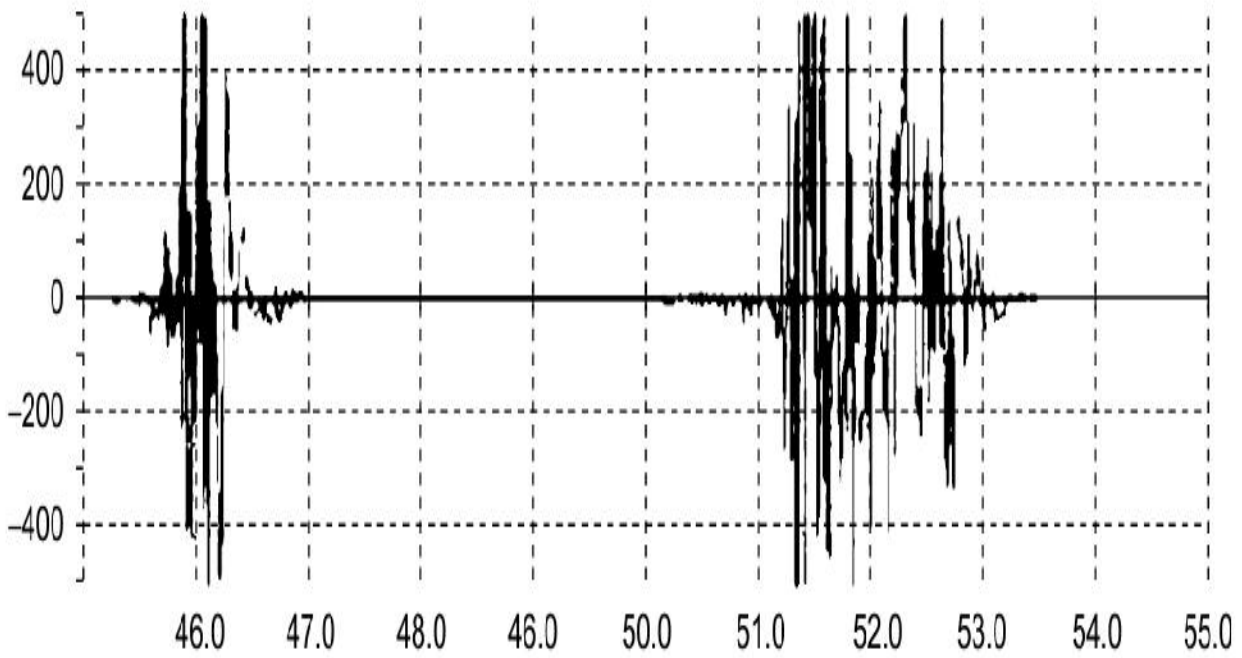


Fig. 2.6 *Waveshape of a typical EMG signal*

2.1.3 Electromyogram (EMG)

The contraction of the skeletal muscle results in the generation of action potentials in the individual muscle fibres, a record of which is known as electromyogram. The activity is similar to that observed in the cardiac muscle, but in the skeletal muscle, repolarization takes place much more rapidly, the action potential lasting only a few milliseconds. Since most EMG measurements are made to obtain an indication of the amount of activity of a given muscle, or a group of muscles, rather than of an individual muscle fibre, the EMG pattern is usually a summation of the individual action potentials from the fibres constituting the muscle or muscles being studied. The electrical activity of the underlying muscle mass can be observed by means of surface electrodes on the skin. However, it is usually preferred to record the action potentials from individual motor units for better diagnostic information using needle electrodes.

In voluntary contraction of the skeletal muscle, the muscle potentials range from 50 [illegible] mV a[illegible]he duration from 2 to 15 ms. The values vary with the anatomic position of the [illegible]scle and t[illegible]ize and location of the electrode. In a relaxed muscle, there are normally no action

UNIT III BIO AMPLIFIER (9 Hrs)

Need for bio-amplifier - single ended bio-amplifier, differential bio-amplifier – right leg driven ECG amplifier. Band pass filtering, isolation amplifiers – transformer and optical isolation - isolated DC amplifier an AC carrier amplifier. Chopper amplifier, Power line interference

Q1) Explain Need for bio-amplifier –

Q2)Mention the draw backs of single ended traditional bio-amplifier.-

poor noise resistance

Q3)Explain the advantages of differential bio-amplifier.

Q4) Mention the properties of isolation amplifiers. –

Q5) Mention the types of isolation amplifiers. transformer and optical isolation –

Q6) Mention the properties of AC carrier amplifier

Q7) Mention the properties of Chopper amplifier,

Q8)Explain the Power line interference and its effects

Bio-Signal Amplification: The signals available from the transducers are often very small in magnitude. Amplifiers boost the level of the input signal to match the requirements of the recording/ display system or to match the range of the analog-to-digital convertor, thus increasing the resolution and sensitivity of the measurement.

Bioelectric measurements are basically low-level measurements, which involve amplifying and recording of signals often at microvolt levels. The problem of electrical noise makes these measurements a difficult proposition and calls for both expert technical knowledge and skillful handling of the signal in the circuit design

Using signal conditioners located closer to the signal source, or transducer, improves the signal-to-noise ratio of the measurement by boosting the signal level before it is affected by the environmental noise

Q3)the use of differential amplifiers.

. Its excellence lies in its ability to reject common-mode interference signals which are
invariably picked up by electrodes from the body along with the useful bioelectric signals.
Also, as a direct coupled amplifier, it has good stability and versatility

. High stability is achieved because it can be insensitive to temperature changes which are often the source of excessive drift in other configurations.

Useful in applications requiring floating inputs and outputs or for applications where grounded inputs and/or outputs are desirable.

Carrier amplifiers

are used with transducers which require an external source of excitation.They are characterized by high gain, negligible drift, extremely low noise and the ability to operate with resistive, inductive or capacitive type transducers. They essentially contain a carrier oscillator, a bridge balance and calibration circuit, a high gain ac amplifier, a phasesensitivedetector and a dc output amplifier.

Chopper input dc amplifiers are preferred for low level inputs to instrumentation systemsbecause of their high sensitivity, negligible drift and excellent common mode rejection capability.Their high frequency response is limited to about one half of the input chopper frequency.

Chopper-stabilized dc amplifiers are used for low level but preferably wideband applications such as oscilloscopes, tape recorders and light beam oscilloscope recorders. These are complex amplifiers having three amplifiers incorporated in the module. This includes an ac amplifier for signals above about 20 Hz, a dc chopper input amplifier for signals from about 20 Hz down to dc plus a wideband feedback stabilized dc amplifier.

Isolation amplifiers

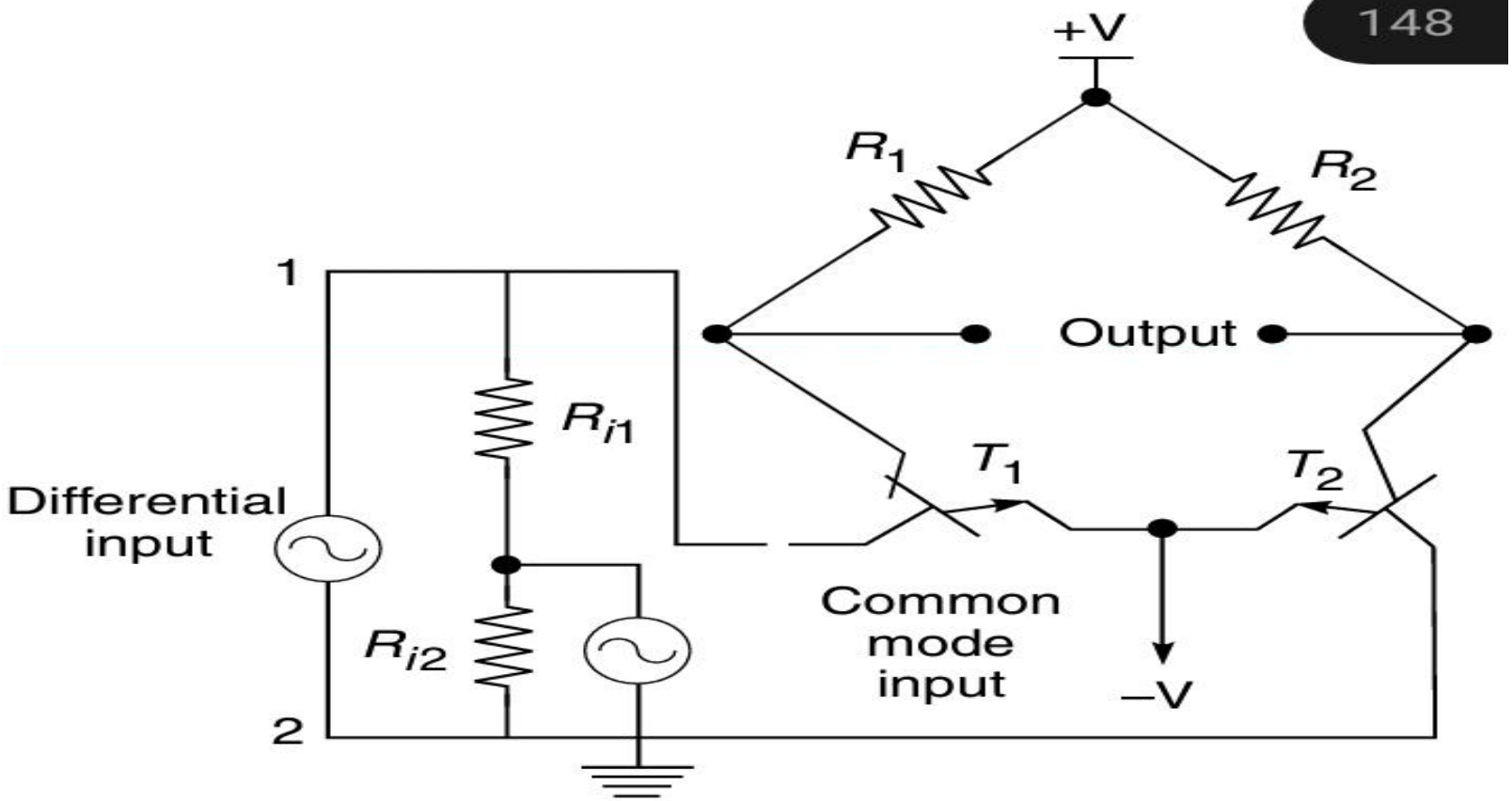
are commonly used for providing protection against leakage currents in biomedical recorders such as ECG machine. They break the ohmic continuity of electric signals between the input and output of the amplifier. The isolation includes different supply voltage sources and different grounds on each side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

Power line interference

The distributed capacitance between the signal conductors and from the signal conductors to the ground provides a low impedance ac path, resulting in signal contamination from external sources like power lines and transformers.

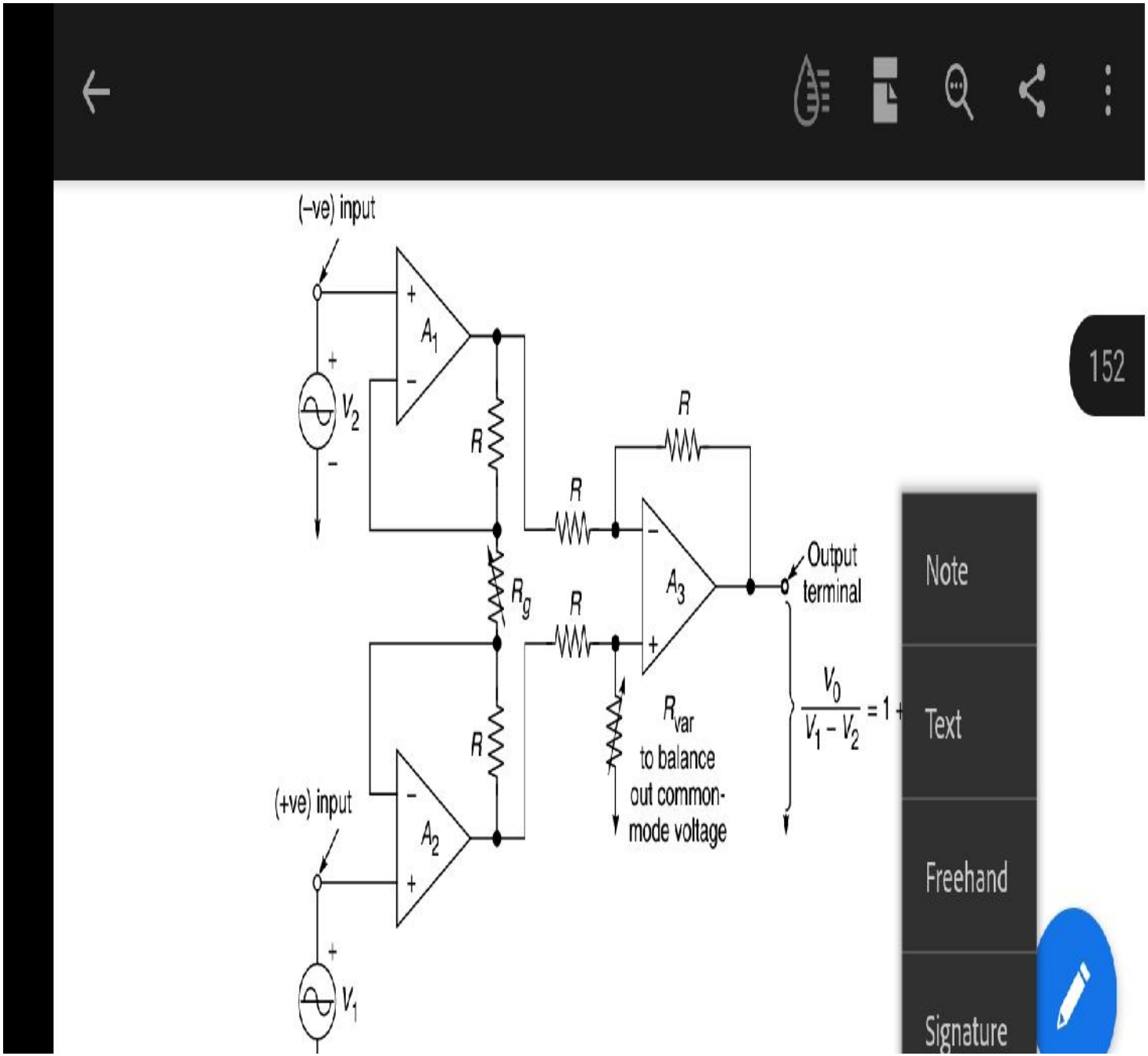
Similarly, the alternating magnetic flux from the adjacent power line wires induces a voltage in the signal loop which is proportional to the rate of change of the disturbing current, the magnitude of the disturbing current and the area enclosed by the signal loop. It is inversely proportional to the distance from the disturbing wir to the signal circuit. Unequal distances of the two signal carrying conductors from the disturbi current wire result in unequal mutual inductances, which cause the magnetic field to produce a noise voltage across the amplifier input terminals.

different patterns. Heart-generated voltages
d legs, and brain-generated voltages picked
ples of signals whose measurement requires

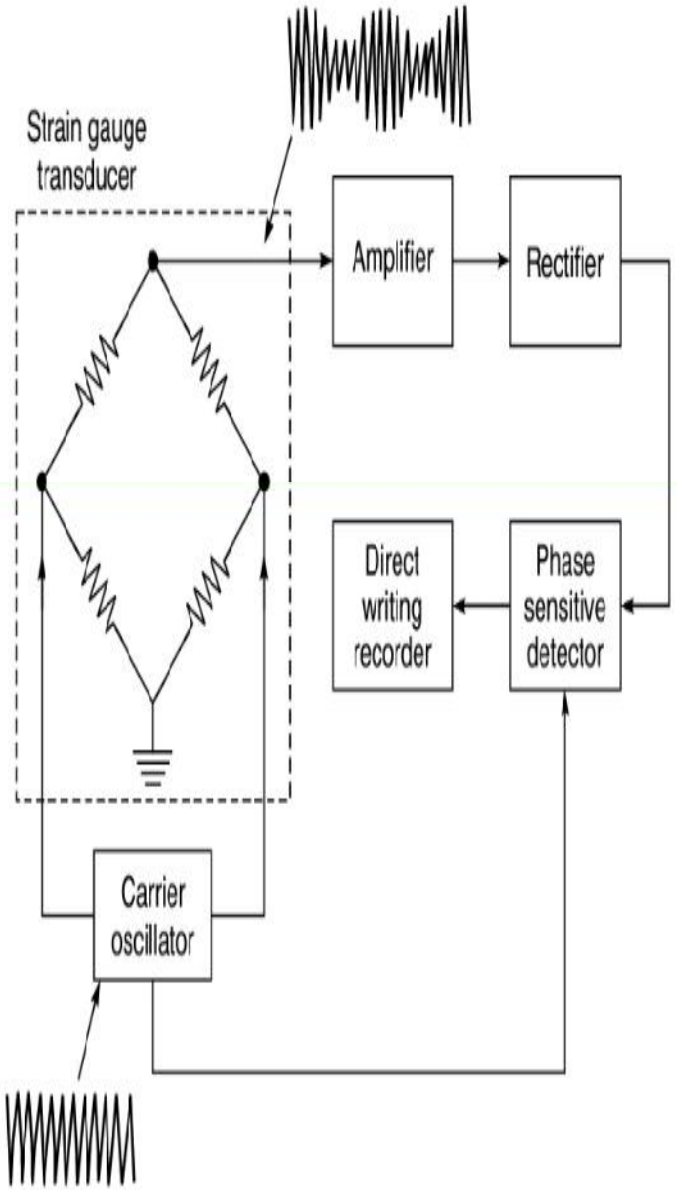


➤ **Fig. 4.2** ***Typical differential amplifier configuration***

A Differential Amplifier



demodulator can then be applied to the driver stage of the writing system.



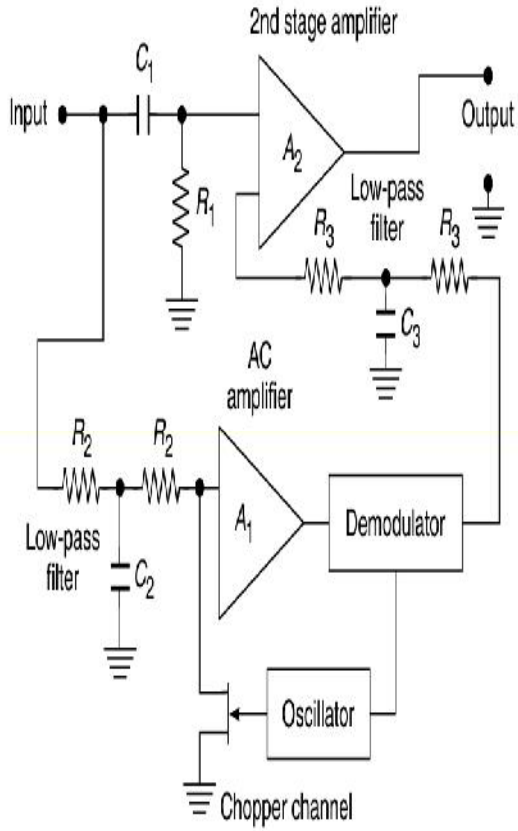


Fig. 4.7 *Simplified block diagram of a single-ended chopper-stabilized operational amplifier.*

Due to the extremely low dc offset and dc drift associated with the chopper-stabilized amplifier, the signal resolution is limited only by the noise present in the circuit. Thus, it is

It uses an internal dc-to-dc converter comprising a 20 kHz oscillator, transformer, rectifier and filter to supply isolated power.

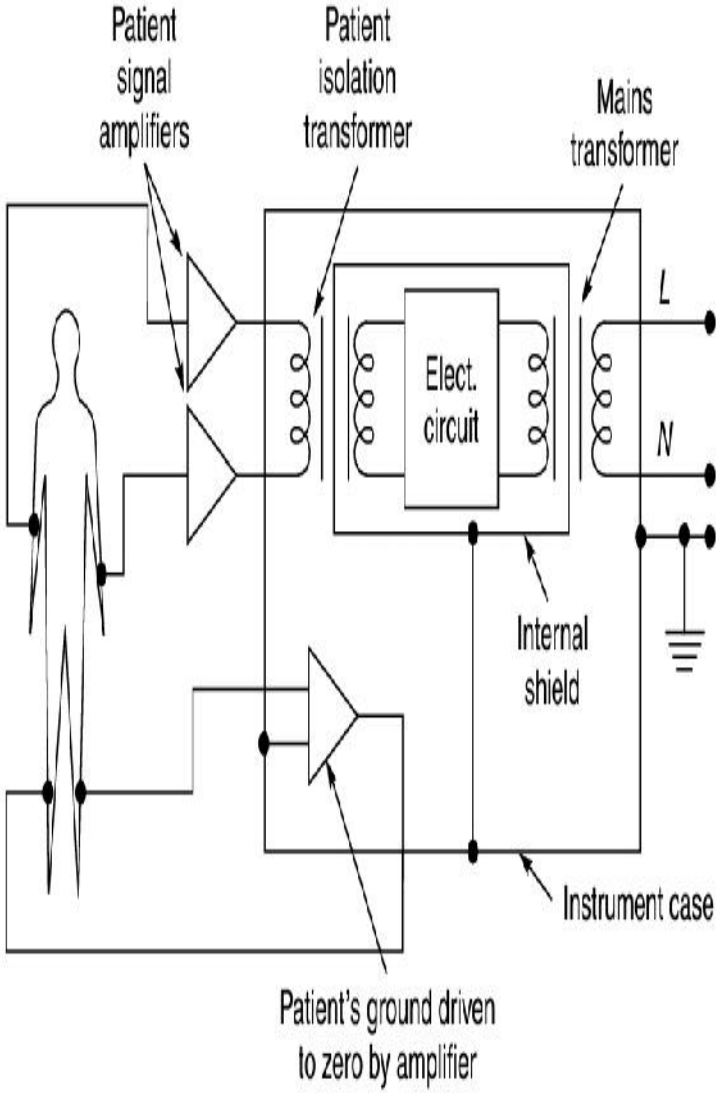


Fig. 4.8 *Isolation amplifier (transformer type)*

It uses an internal dc-to-dc converter comprising a 20 kHz oscillator, transformer, rectifier and filter to supply isolated power.

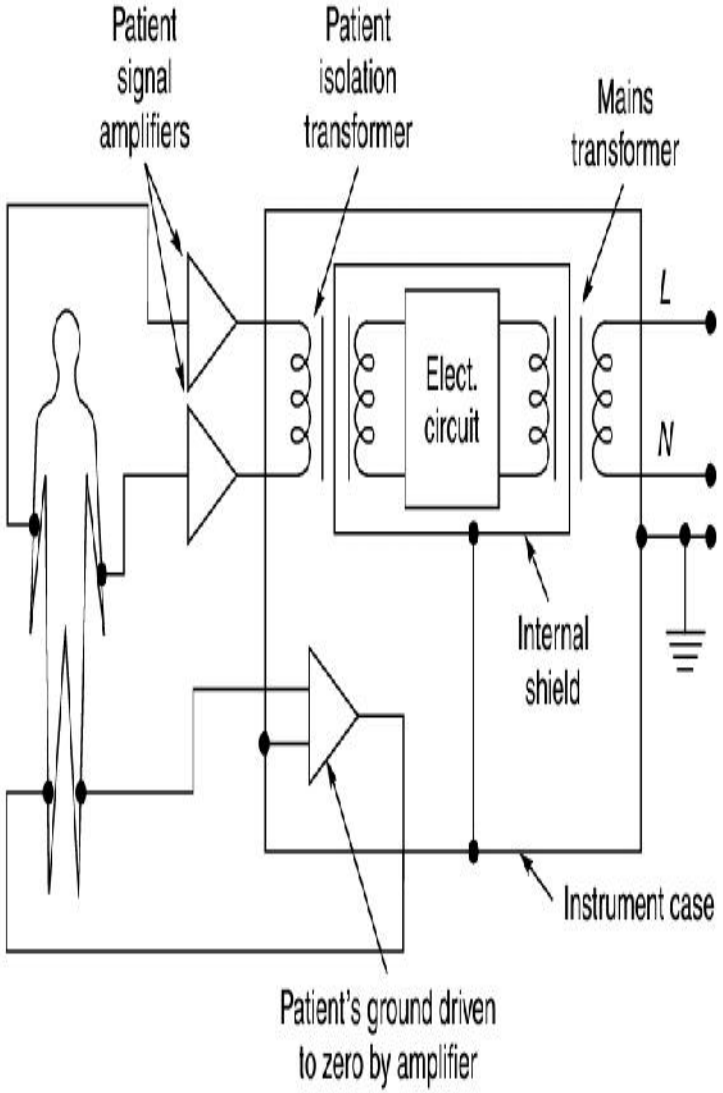


Fig. 4.8 *Isolation amplifier (transformer type)*

modulator/demodulator is needed because the signal is transmitted optically all the way.

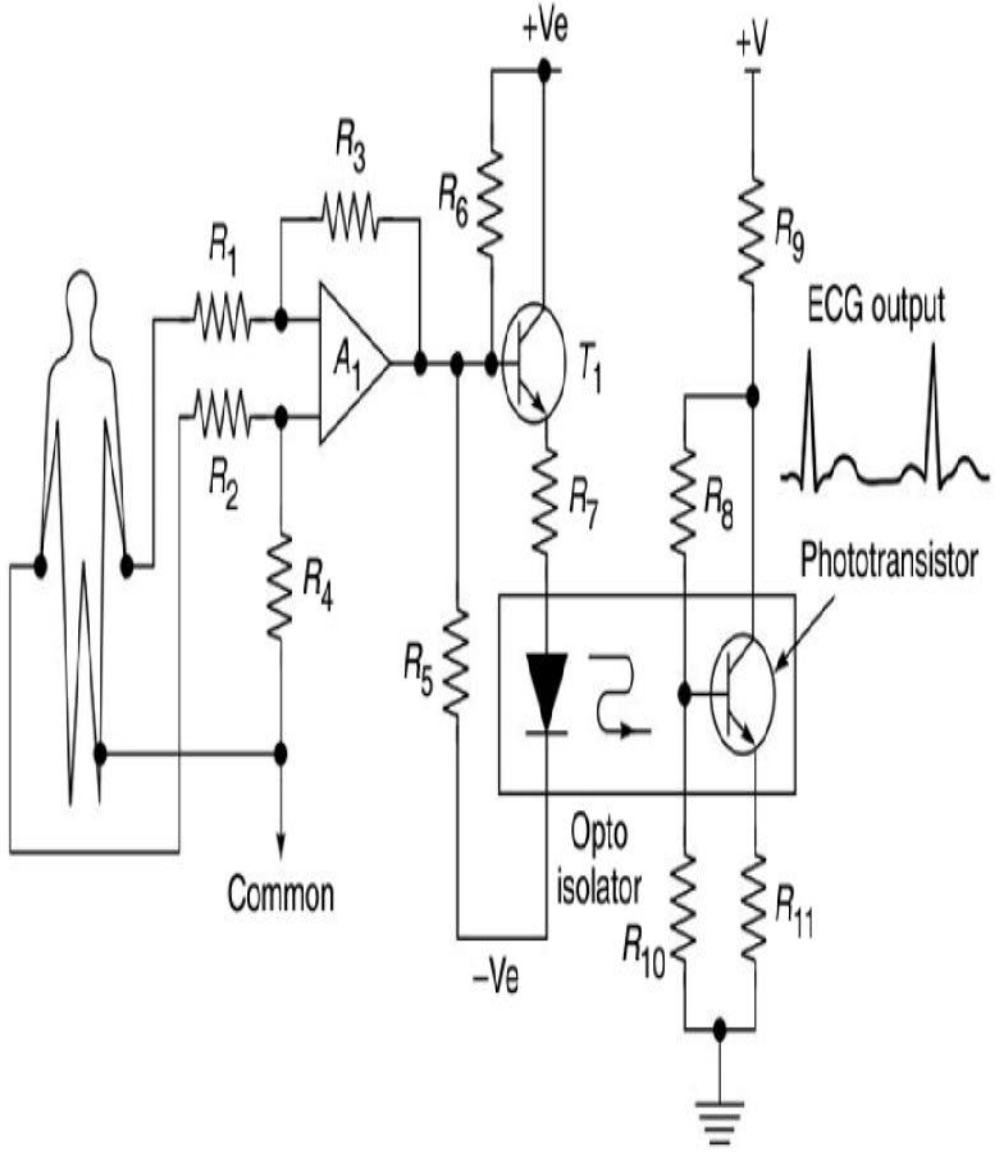


Fig. 4.9 Optically isolated isolation amplifier

Power line Interference

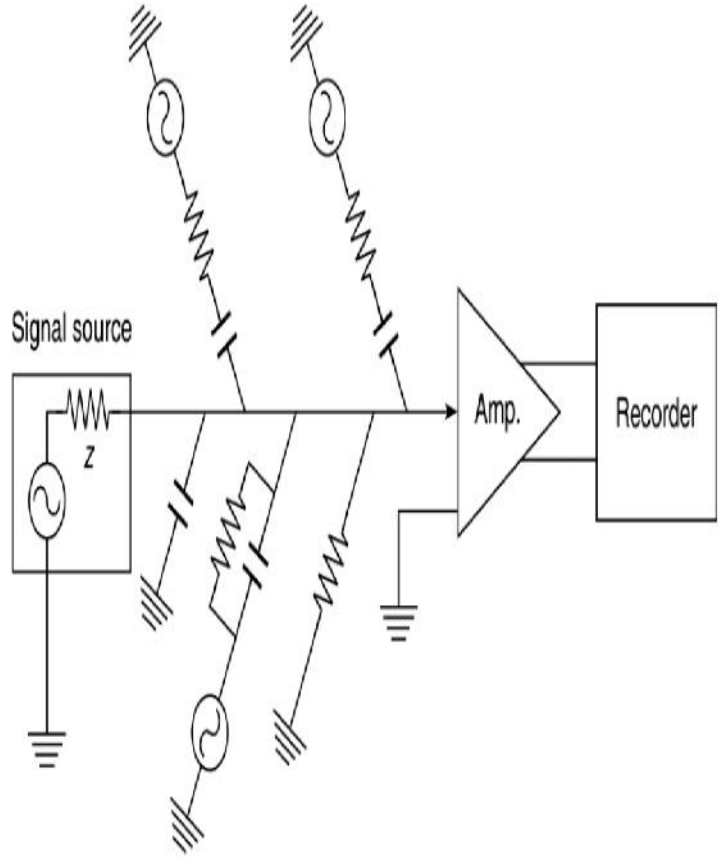


Fig. 4.11 *Currents produced by various forms of noise flow through the signal source impedance and become an unwanted addition to the useful signal. The noise amplitude is directly proportional to signal source impedance (Courtesy: Gould Inc., U.S.A.)*

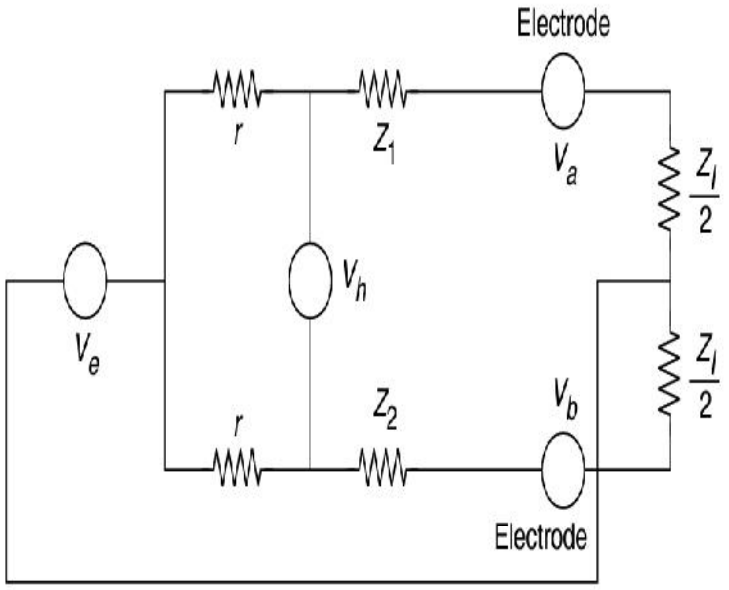


Fig. 4.3 *Equivalent circuit for the input of an ECG amplifier*

$$\frac{Z_2 - Z_1}{Z_1 / 2} . V_e$$

UNIT IV MEASUREMENT OF NON-ELECTRICAL PARAMETERS (9 Hrs)

Temperature, respiration rate and pulse rate measurements.

Blood Pressure: indirect methods -

auscultatory method, oscillometric method, direct methods: electronic manometer, Pressure amplifiers ,systolic, diastolic, mean detector circuit.

-Blood flow and cardiac output measurement: Indicator

dilution, thermal dilution and dye dilution method, Electromagnetic and ultrasound blood flow

measurement.

MODEL QUESTIONS

1. Explain the principle of an electromagnetic flowmeter with the help of a diagram highlighting the various design considerations of flow transducers.
2. Describe the working of an electromagnetic flowmeter with the help of a block diagram. Explain the working of each sub-system.
3. Illustrate the principle of ultrasonic Doppler-shift flow-velocity meter. Explain the working of Doppler-shift blood flowmeter with the help of a block diagram.
4. Name the various methods for measurement of blood flow and explain one of them in detail.
5. Explain with the help of building blocks the working of range-gated pulsed Doppler flowmeter.
6. Describe the principle of NMR blood flowmeter. What are their limitations?
7. Draw a block diagram of a laser Doppler system for blood flow measurement in skin, and explain function of each block. What are the disadvantages of using laser based blood flowmeters?
8. Define cardiac output and stroke volume and what are their average values.
9. What is the principle of 'Indicator Dilution Method' for measurement of cardiac output? Explain

Temperature measurement-

The most popular method of measuring temperature is by using a mercury-in-glass thermometer.However, they are slow, difficult to read and susceptible to contamination.

In many of the circumstances of lowered body temperature, continuous or frequentsampling of temperature is desirable, as in the operating theatre, post-operative recovery room and intensive care unit, and during forced diuresis, massive blood transfusion, and accidental
hypothermia.

The continuous reading facility of electronic thermometers obviously lends itself to accurate in practice than mercury-in-glass thermometers for medical applications. They mostly use probes incorporating a thermistor or thermocouple sensor which have rapid response characteristics. The probes are generally reusable and their covers are disposable.

Small thermistor probes may be used for oesophageal, rectal, intramuscular and intravenous measurements and in cardiac catheters.

Thermocouples are normally used for measurement of surface skin temperature, but rectal thermocouple probes are also available.

Resistance thermometers are usually used for rectal and body temperature measurement. The resistance thermometer and thermistor measure absolute temperature, whereas thermocouples generally measure relative temperature.

6.9.1 Displacement Method

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

Changes in the chest circumference can also be detected by a rubber tube filled with mercury. The tube is fastened firmly around the chest. With the expansion of the chest during an inspiratory phase, the rubber tube increases in length and thus the resistance of the mercury from one end of through it and by measuring the changes in voltage developed with the respiratory cycle.

6.9.2 Thermistor Method

Since air is warmed during its passage through the lungs and the respiratory tract, there is a detectable difference of temperature between inspired and expired air. This difference of temperature can be best sensed by using a thermistor placed in front of the nostrils by means of a suitable holding device. In case the difference in temperature of the outside air and that of the expired air is small, the thermistor can even be initially heated to an appropriate temperature and the variation of its resistance in synchronism with the respiration rate, as a result of the cooling effect of the air stream, can be detected. This can be achieved with thermistor dissipations of about 5 to 25 mW. Excessive thermistor heating may cause discomfort to the subject. The thermistor is placed as part of a voltage dividing circuit or in a bridge circuit whose unbalance signal can be amplified to obtain the respiratory activity. The method is simple and works well except in the

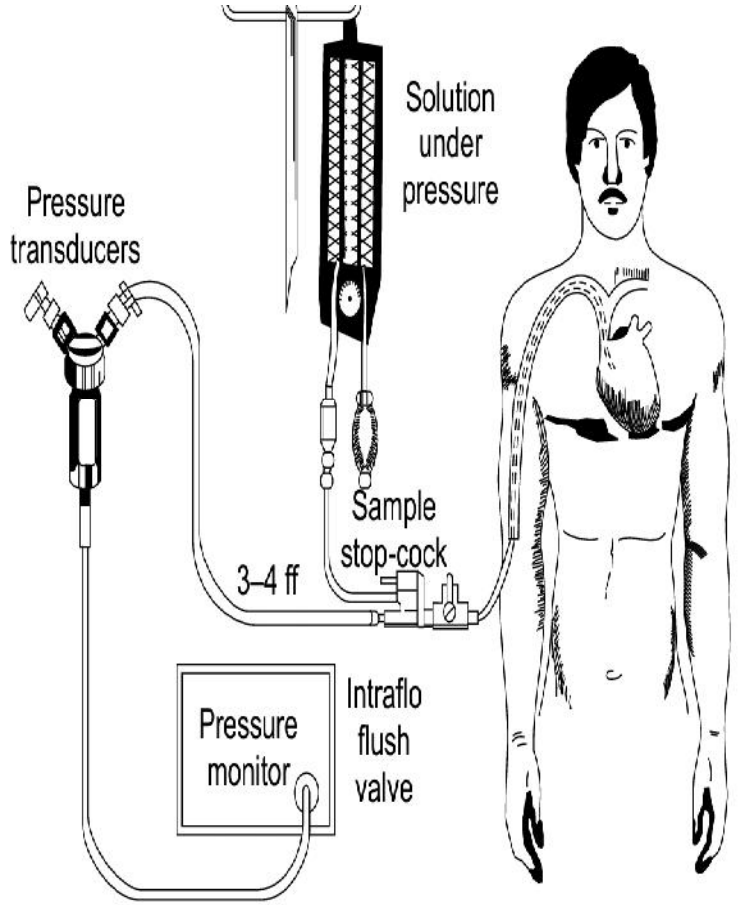
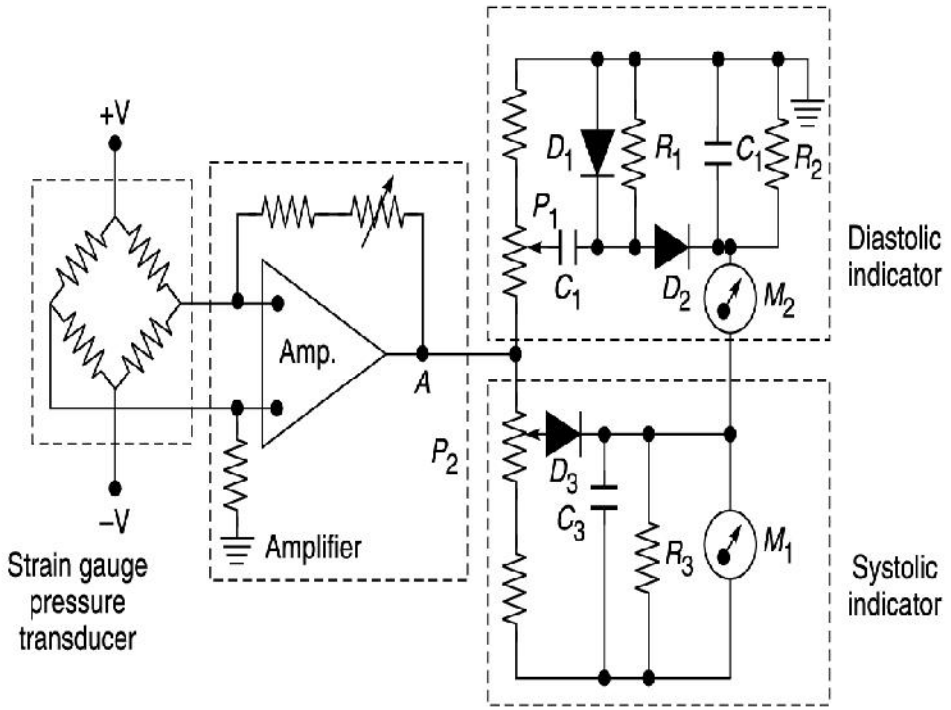
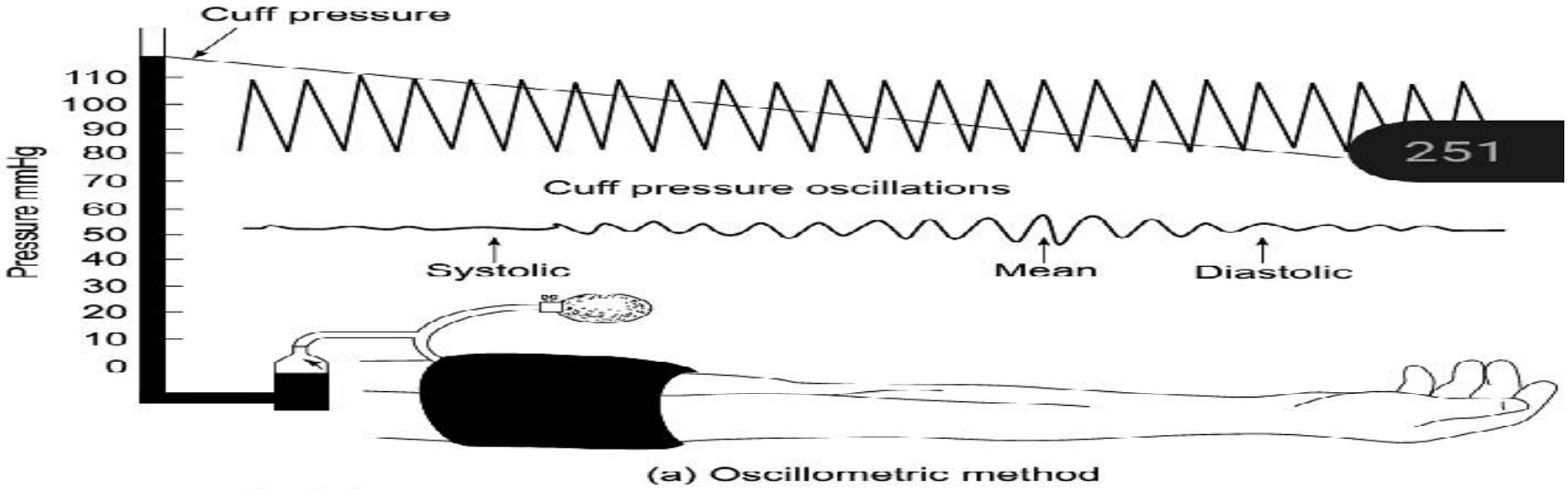


Fig. 6.22 *Typical set up of a pressure measuring system by direct method*

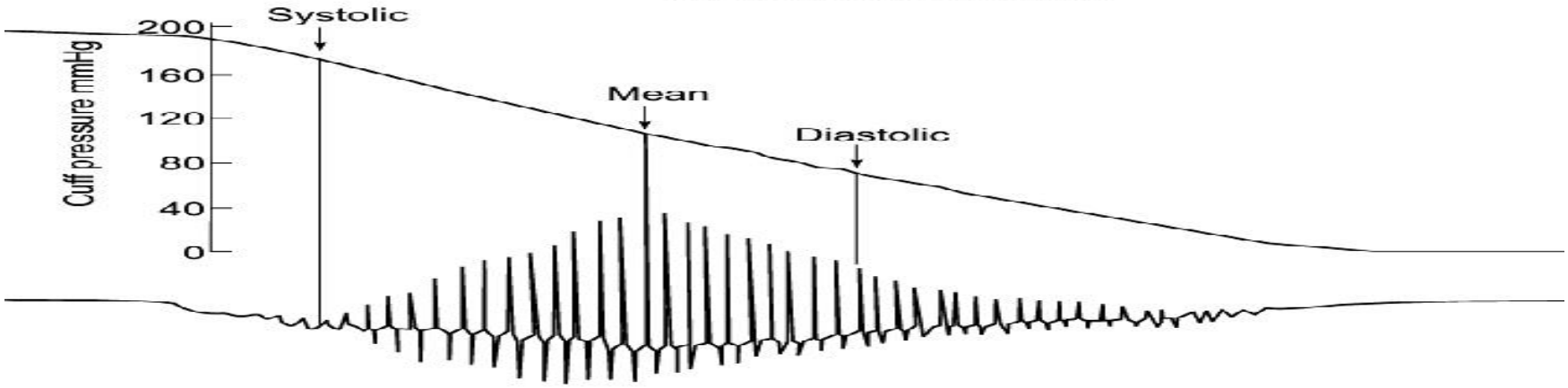


➤ Fig. 6.23 *Circuit diagram for measurement of systolic and diastolic blood pressure*

rived and proven empirically but are not yet well explained by any
ctual determination of blood pressure by an oscillometric device is p
algorithm developed by the manufacturer of the device.



(a) Oscillometric method

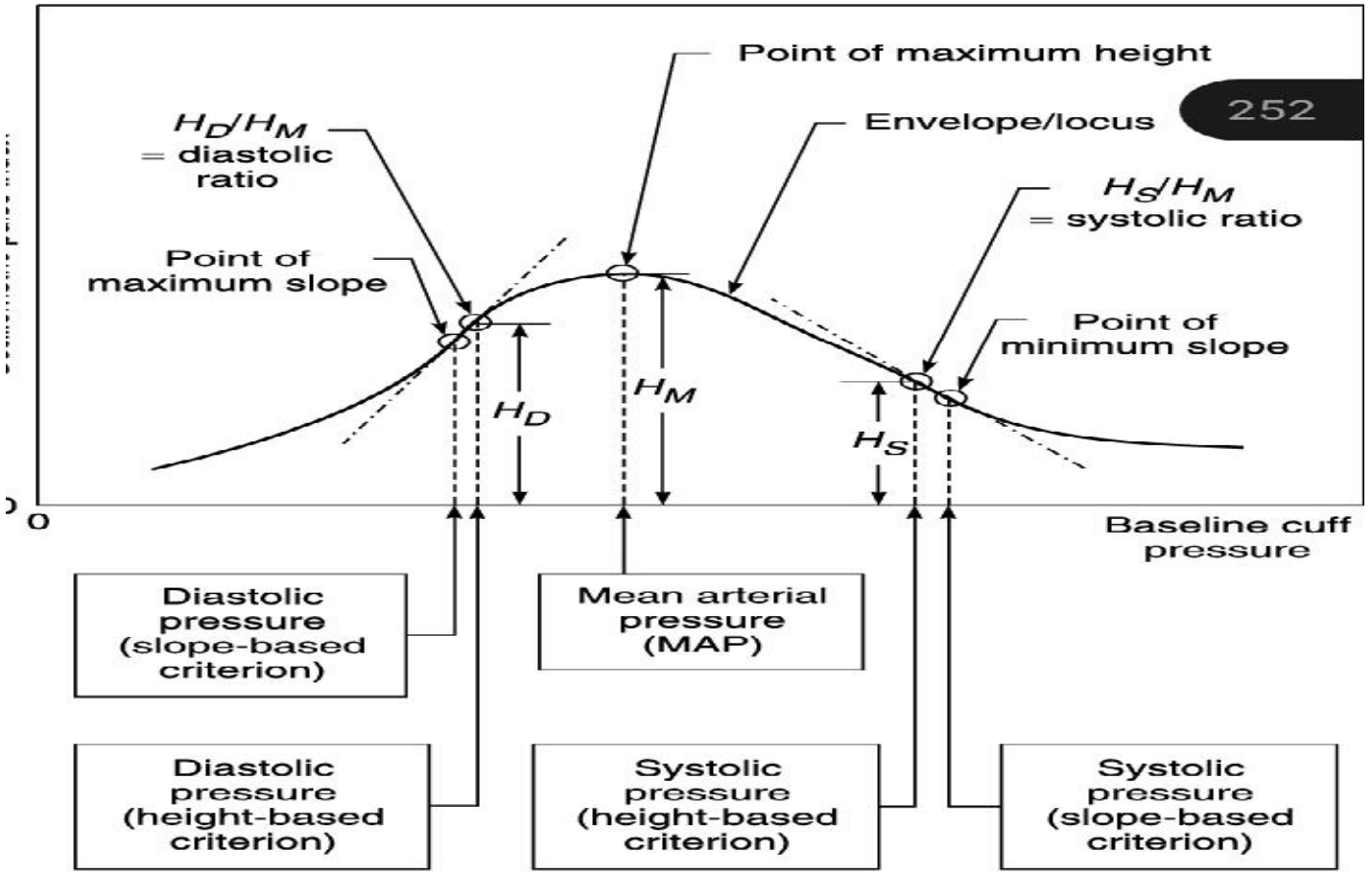


(b) Oscillations in cuff pressure

Fig. 6.35 *Illustration of oscillometric method of blood pressure measurem*

ometric method is based on oscillometric pulses (pressu

cuff pressure at which the envelope peaks (maximum h
P (mean arterial pressure). Height-based and slope-based
ystolic and diastolic pressures.



ig. 6.36 *Criteria for oscillometric blood pressure determinati*

te measurements taken are those of systoli ea
urements being more susceptible to operator ty.
ted to systolic pressure and MAP using the following fo

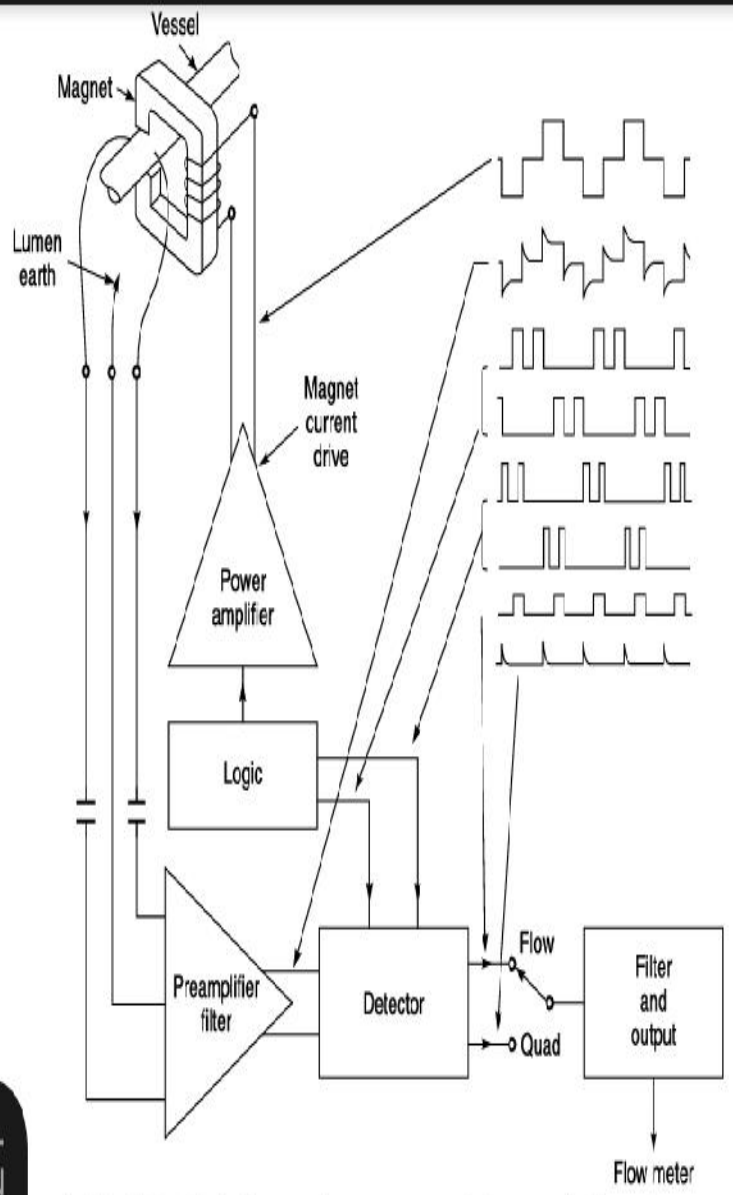
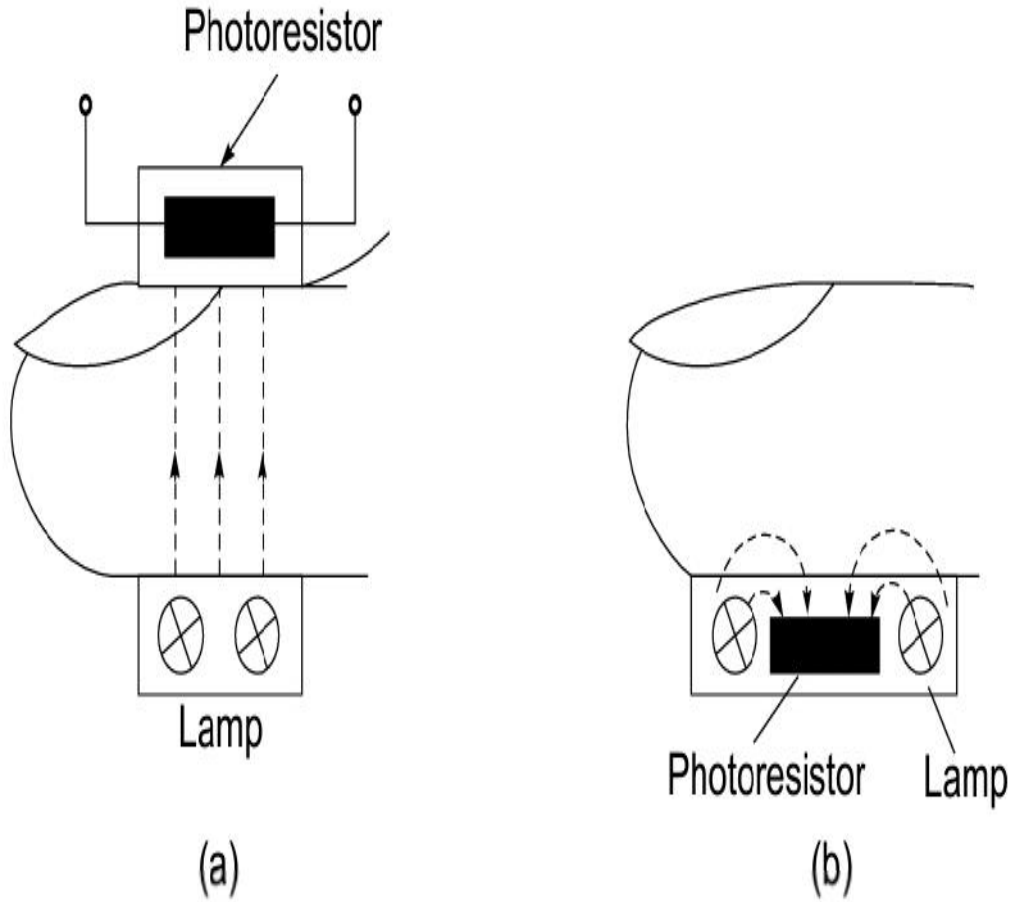


Fig. 10.3 *Block diagram of a square wave electromagnetic flowmeter*



g. 6.17 *Arrangement of photoresistor and lamp in a finger probe for pulse pick-up : (a) transm*
hod, (b) reflectance method

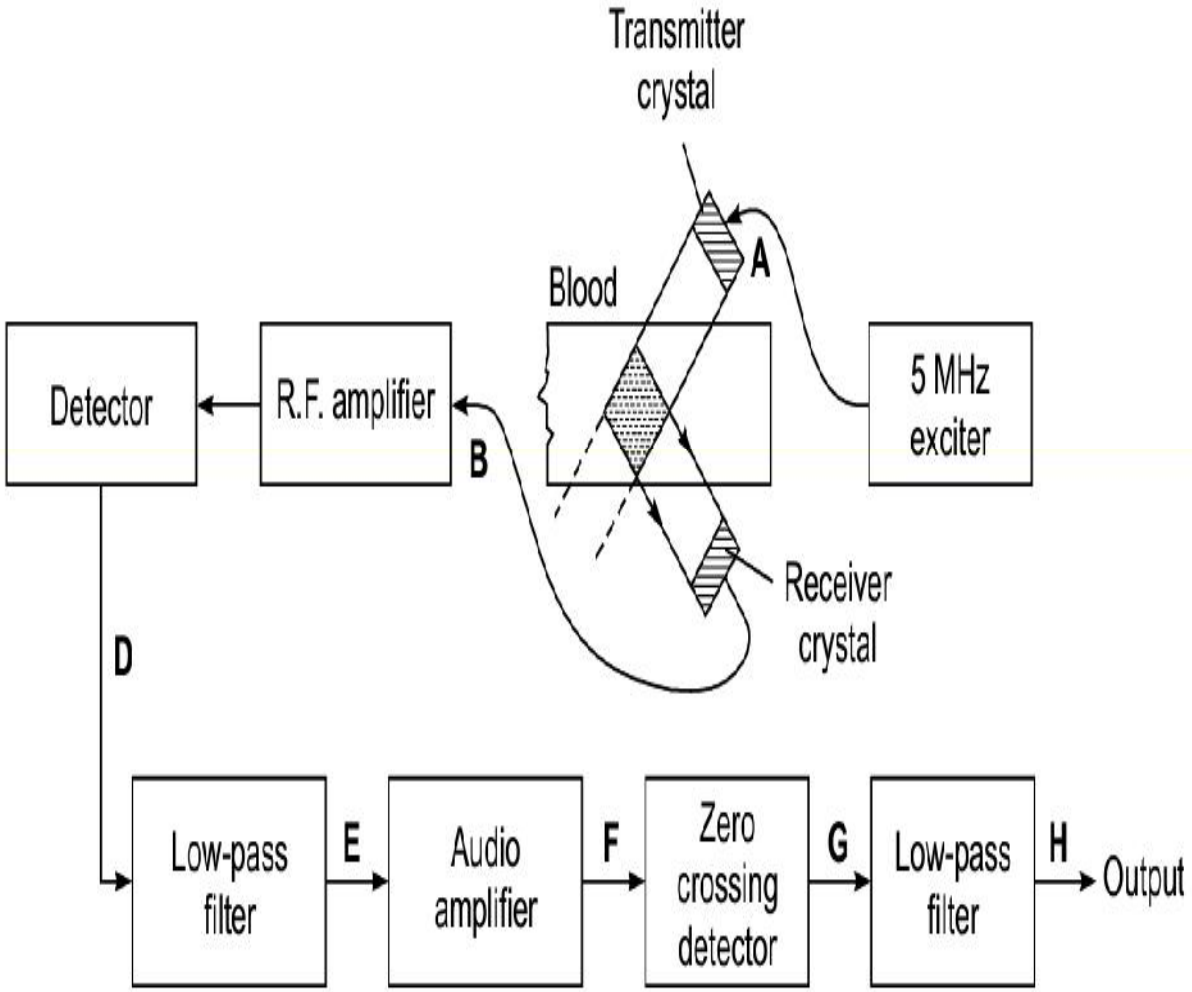


Fig. 10.5 *Block diagram of Doppler shift blood flowmeter (After Flax et al., 1973; by permission IEEE Trans. Biomed. Eng.)*

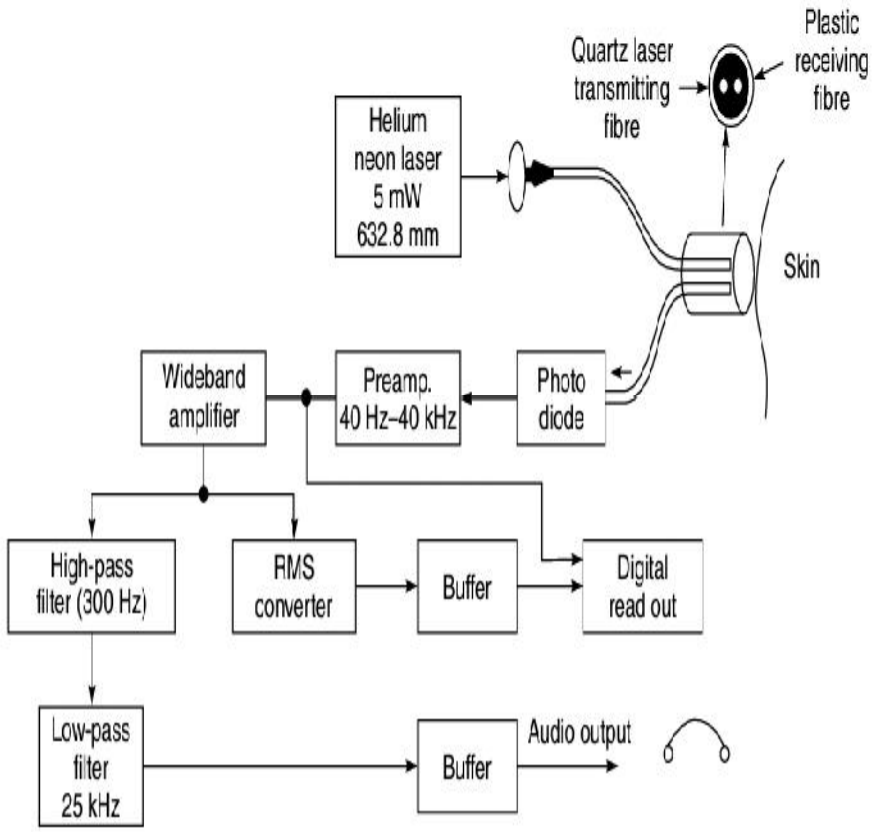


Fig. 10.11 *Block diagram of a laser Doppler system for blood flow measurement in skin (After Watkins and Holloway, 1978 by permission of IEEE Trans. Biomed. Eng.).*

Laser Doppler ...metry is a non-invasive technique and seems to offer several advantages like light reprod...y and sensitivity. However, its disadvantages like poor selectivity, base line instability a...riction in site of measurement are still limiting factors in its successful

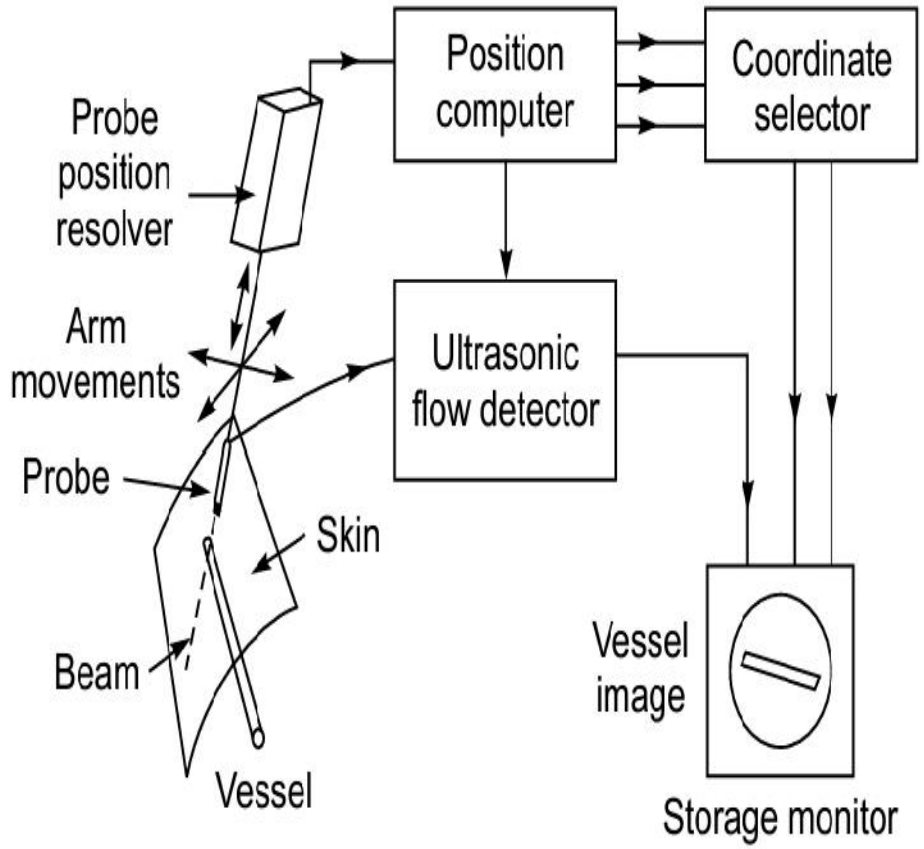


Fig. 10.7 *Doppler imaging system-block diagram (Redrawn after Fish, 1975)*

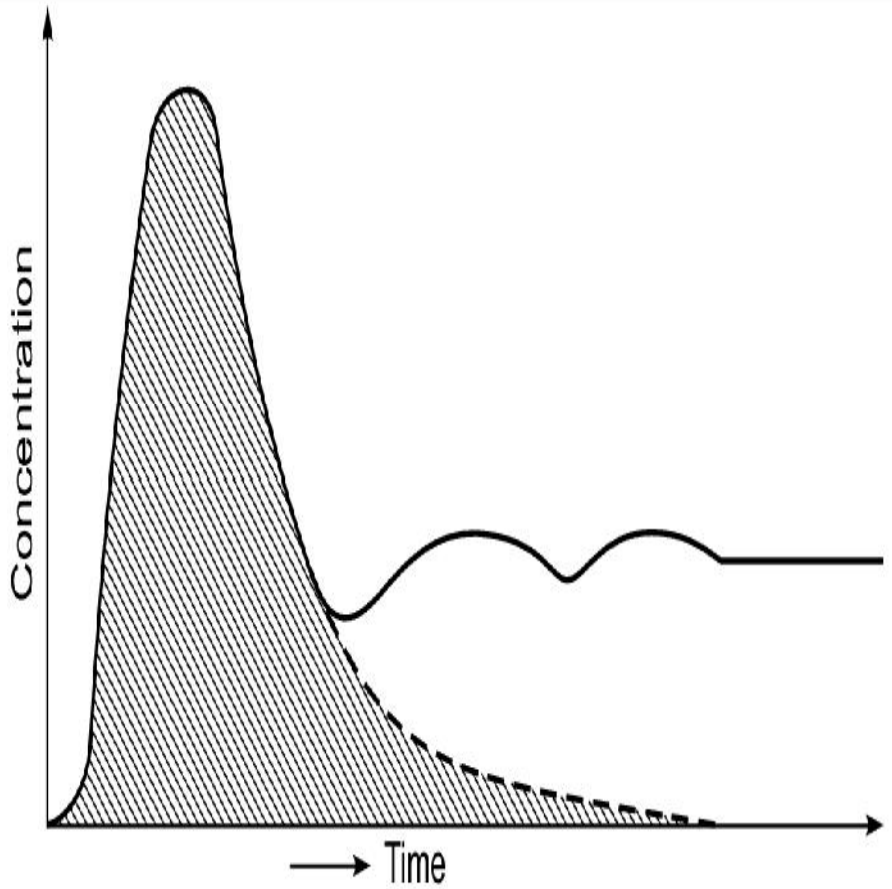


Fig. 10.13 *The run of the dilution curve*

The run of the dilution cu[illegible] is self-explanatory. During the first circulation [illegible]od,

the injected indicator would once again pass through the heart and enter the arterial circulation. A second peak would then appear. When the indicator is completely mixed up with blood, the curve becomes parallel with the time axis. The amplitude of this portion depends upon the quantity of the injected indicator and on the total quantity of the circulating blood.

For calculating the cardiac output from the dilution curve, assume that

M = quantity of the injected indicator in mg

Q = cardiac output

then

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

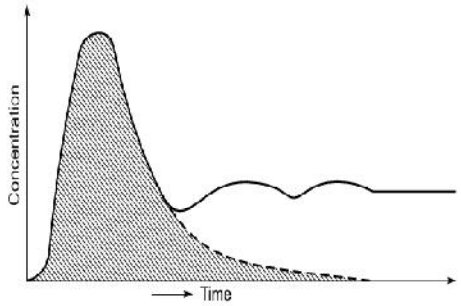
$$= \frac{M \times 60}{\text{area under the curve}} \text{ l/min}$$

Suppose that 10 mg of the indicator was injected and the average concentration as calculated from the curve was 5 mg/l for a curve duration of 20 s; then Q = 6 l/min.

The area under the primary curve obtained by the prolongation of the down slope exponential curve to cut the time axis, encloses an area showing the time concentration relationship of the indicator on its first passage round the circulation and does not include any of the subsequent re-circulations. It demands a considerable time to perform the exponential extrapolation for calculating the area. The evaluation of the dilution curve is simplified by replotting the curve on a semilogarithmic scale paper. The indicator concentration (Y-axis) is plotted on a logarithmic scale and the time (X-axis) on a linear scale. The decreasing exponential portion of the curve appears as a straight line, which is projected downwards to cut the time axis. The area under the replotted primary dilution curve is then measured either with a mechanical planimeter or by counting the square units under the curve. It can be approximated by summing the indicator concentration occurring at one second intervals from the start to the end of the curve.

10.2.2 Dye Dilution Method

small but known quantity of an indicator such as a dye or radioisotope is administered into the circulation. It is injected into a large vein or preferably into the right heart itself. After passing through the right heart, lungs and the left heart, the indicator appears in the arterial circulation. The presence of an indicator in the peripheral artery is detected by a suitable (photoelectric) transducer and is displayed on a chart recorder. This way we get the cardiac output curve shown in Fig. 10.13. This is also called the dilution curve.



➤ Fig. 10.13 *The run of the dilution curve*

The run of the dilution curve is self-explanatory. During the first circulation p indicator would mix up with the blood and will dilute just a bit. When passing b transducer, it would reveal a big and rapid change of concentration. This is shown by portion of the dilution curve. Had the circulation system been an open one, the r concentration would have been followed by an exponentially decreasing portion so as time axis as shown by the dotted line. The circulation system being a closed one, a f

10.2.3 Thermal Dilution Techniques

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

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

Although first reported by Fegler (1954), thermal dilution as a technique did not gain clinical acceptance until Branthwaite and Bradley (1968) published their work showing a good correlation between Fick and thermal measurement of cardiac output in man. However, the technique of cannulation of the internal jugular vein and the difficulty of floating small catheters into the pulmonary artery prevented a rapid clinical acceptance of the technique.

In 1972, a report appeared in the American Heart Journal describing a multi-lumen thermistor catheter, known today as the Swan-Ganz triple lumen balloon catheter (Ganz and Swan, 1972). 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

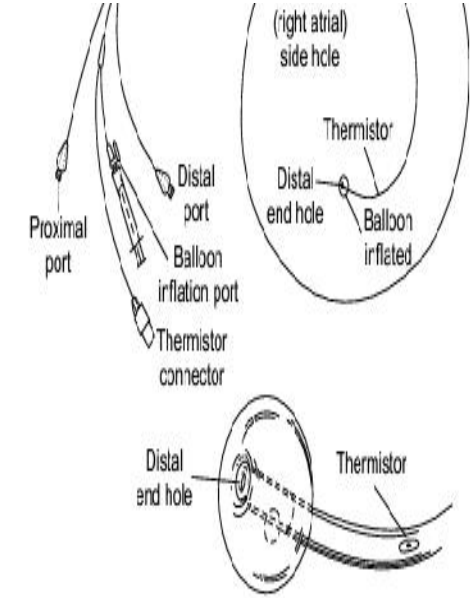
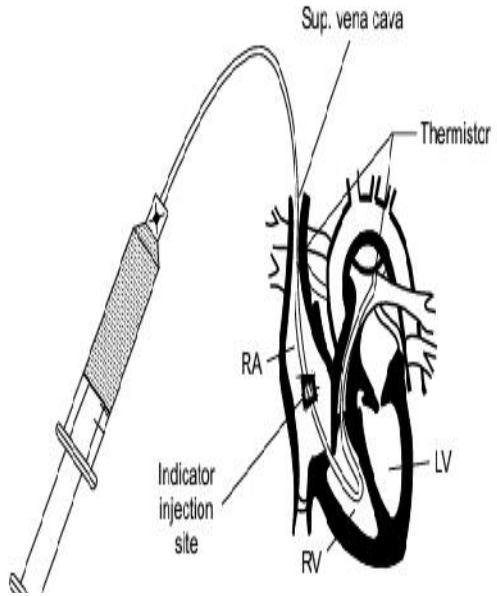


Fig. 10.15 *Swan-Ganz Catheter–A 4-lumen catheter Distal Lumen–connects to transducer system to monitor (i) pulmonary artery pressure (ii) Wedge pressure with balloon inflated. Inflation lumen - connects to balloon located approximately 1 mm from catheter-tip. Balloon inflates with 1 to 1.5 ml of air, proximal lumen–to monitor central venous pressure or right atrium pressure. Thermistor Lumen–connects with cable to cardiac output computer*



curve is determined by integration. The equation for determining the cardiac output by this method thus reduces to:

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

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

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

= 0.747 for 5 ml injectate at ice temperature

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

= 0.884 for 5 ml injectate at room temperature

V = volume of injectate (ml)

T_b = initial temperature of blood (°C)

T_i = initial temperature of injectate (°C)

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

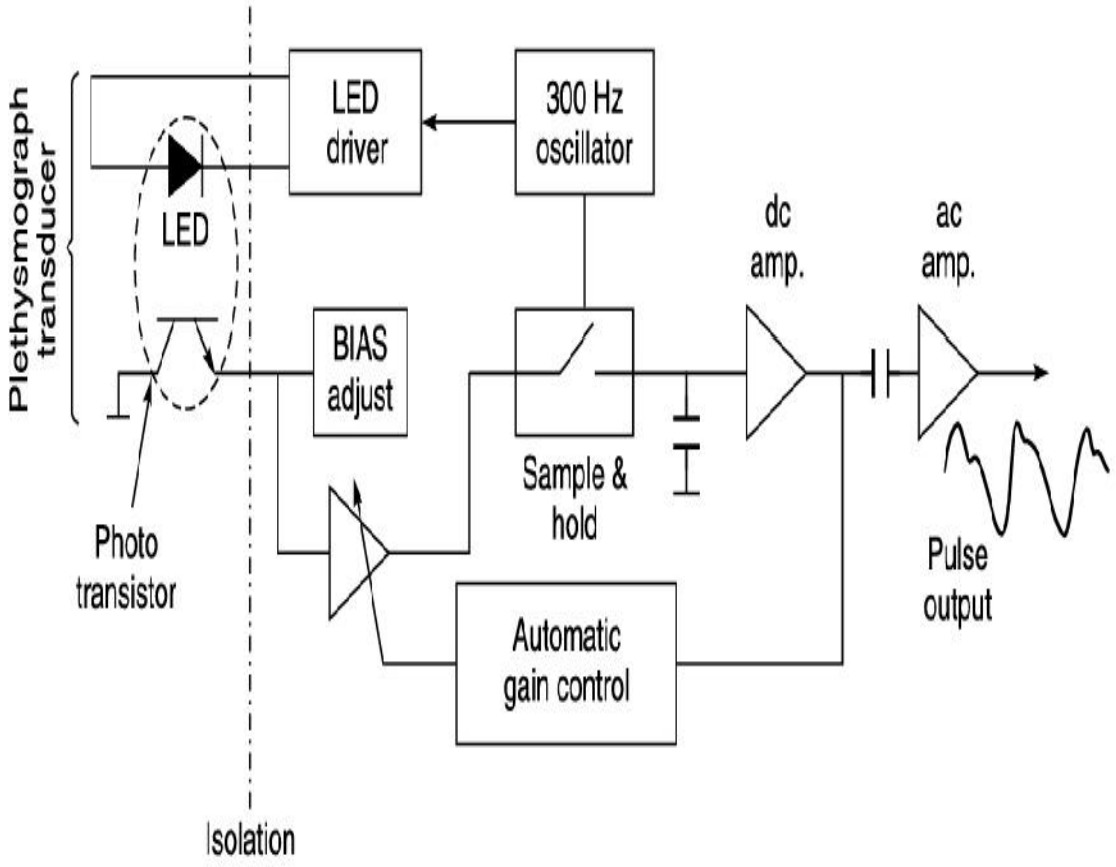


Fig. 6.19 *Block diagram for processing plythysmographic signal*

Zikic (2006) describe the design of reflective photoplethysmograph probe for detection of an

recording paper and a paper speed of 10 mm/s.

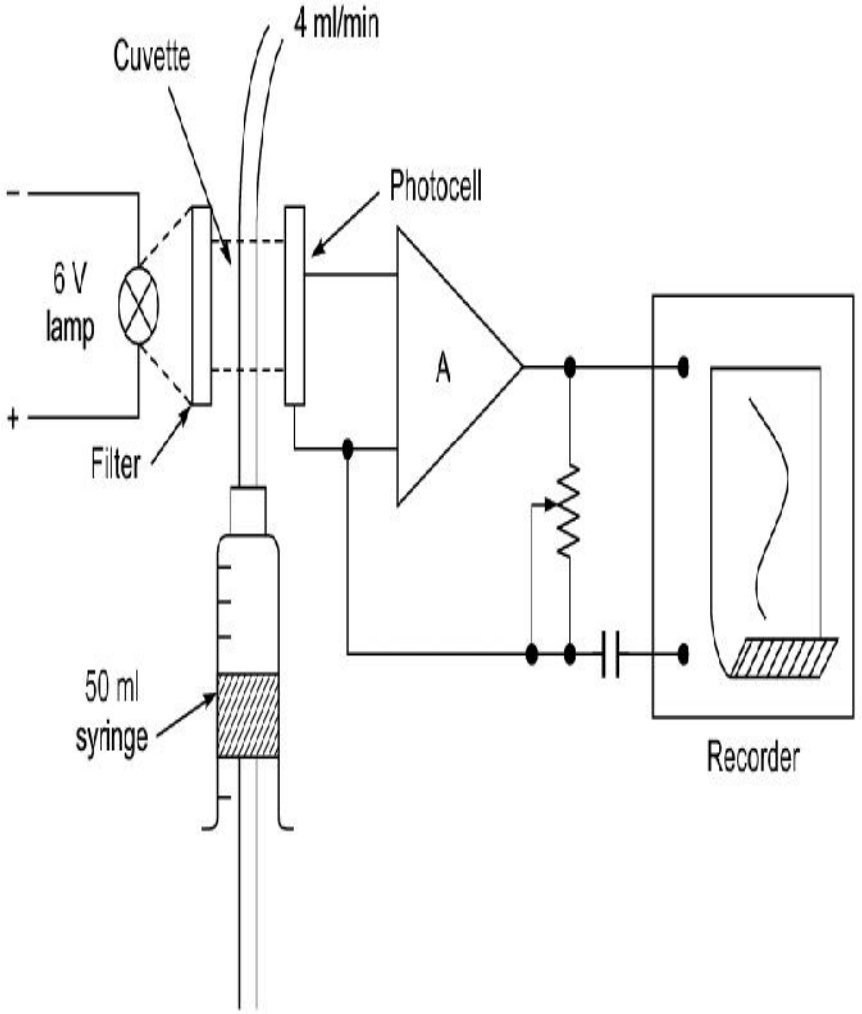


Fig. 10.14 *Diagrammatic representation of a densitometer for quantitative measurement of dye concentration (Redrawn after Jarlov and Holmkjer, 1972; by permission of Med. & Biol. Eng.)*

al ultrasound Doppler instrument
continuous cardiac output and
has been introduced by M/s Deltex
This is shown in Fig. 10.20. A single
meter (6 mm) probe is inserted into
and a continuous Doppler signal is
quipment utilizes descending aortic
e a real-time assessment of the left
formance. The system works on a
Hz ultrasound frequency.

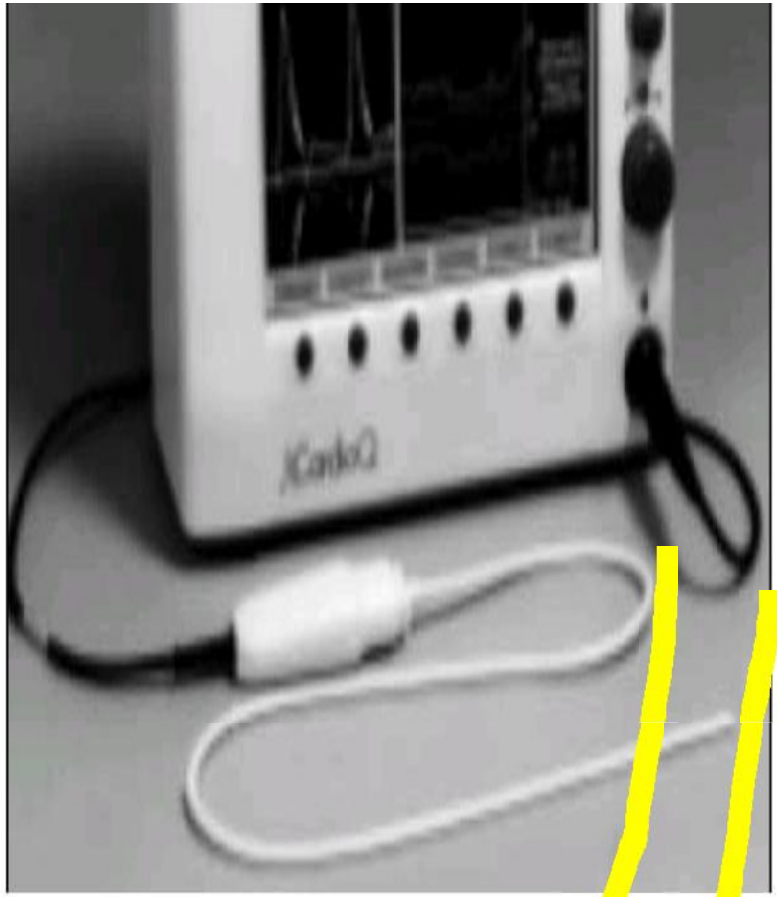


Fig. 10.20 *Cardio Q–Doppler shift based cardiac output and aortic volume measurement and display system (Courtesy: Deltex Medical U.S.A.)*

UNIT V BIO-CHEMICAL MEASUREMENT (9 Hrs)

Biochemical sensors - pH, pO2 and pCO2, Ion selective Field effect Transistor (ISFET immunologically sensitive FET (IMFET), Blood glucose sensors - Blood gas analyzers, colorimeter, flame photometer, spectrophotometer

,

blood cell counter, auto analyzer (simplified schematic description).

MODEL QUESTIONS

1. What is the function of a blood gas analyser? Why is it necessary to maintain acid-base balance in the body? Indicate the normal blood pH value.
2. Write the equation giving relationship between potential generated and pH (nearest equation) for a glass electrode. Define slope factor and draw a graph showing relationship between pH and emf at 25 °C.
3. Draw a diagram showing the constructional details of microcapillary electrode for measurement of blood pH. What is the effect of blood on the working of the glass electrode and measures taken to minimize the effect?
4. What is blood pCO_2 and how is it measured? Explain the construction of blood pCO_2 electrode.
5. Explain the technique for measuring blood pO_2. Draw the construction of blood pO_2 electrode and the circuit diagram for measurement of signal developed at the electrode.
6. Why is it necessary to maintain a constant temperature for blood pH electrode? Explain the circuit diagram for temperature control of blood gas analyser electrodes.
7. Explain in vivo technique for measuring blood gases with the help of a block diagram. How are the fibre optic-based gas sensors work in such measurement?
8. What is the method for in vivo measurement of blood pH? Draw the block diagram of fibre optic-based gas sensor and measurement system.

MODEL QUESTIONS

1. Define transmittance, absorbance and Beer-Lambart law with the help of a diagram.
2. Draw the arrangement of various components of a spectrophotometric instrument. Explain the various radiation sources and filters.
3. What is a monochromator and what are their various types? Explain how diffraction gratings are used as monochromators. Compare the radiation energy available through a colour filter and monochromator.
4. What is the function of using a microprocessor in a spectrophotometer circuit? Explain with the help of a diagram.
5. Draw the schematic diagram of an automated continuous flow type analysis system and explain in brief the working of each of the building blocks.
6. What are the essential parts of a flame photometer? Explain their function. What is the special clinical application of a flame photometer?
7. Define a selective-ion electrode. What are the four major groups of ion-selective electrodes? Explain them along with advantages of using ion-selective electrodes.
8. Explain with the help of a block diagram the working of a microprocessor based ion analyser.

provides only historical values of the patient's blood chemistry, because there is a delay between when the sample is obtained and when the result is reported. (The sample must be transported to the main clinical-chemistry laboratory, and the appropriate analyses must be performed.) This inherent delay is approximately 30 min or more. Other significant drawbacks plague central-laboratory analyses of patient chemistry, including potential errors in the origin of the sample and in sample-handling techniques, and (because of the delay) the timeliness of the therapeutic intervention.

For these reasons, there has been a movement to decentralize clinical testing of the patient's chemistry (Collison and Meyerhoff, 1990). This is particularly important in the critical-care and surgical settings. The decentralized approach has resulted from a number of improvements in biosensor technology, including the development of blood-gas and electrolyte monitoring systems equipped with self-calibration for measuring the patient's blood chemistry at the bedside.

Table 10.2 Examples of Arterial Blood Gases in Different Clinical Situations

Example	PCO_2, mm Hg	pH	PO_2, mm Hg	Interpretation	Likely Causes	Therapy
1	40 ± 3	7.40 ± 0.03	90 ± 5	Normal blood gas		None
2	44 ± 3	7.37 ± 0.03	88 ± 5	Normal blood gas while asleep		
3	22	7.57	106	Hyperventilation	Anxiety	None
4	68	7.10	58	Hypoventilation	Central nervous system depression; blockage of upper airway	Mechanical ventilation; relieve the cause
5	58	7.21	39	Hypoventilation and hypoxemia	Pneumonia; small-airway obstruction; severe asthma	Oxygen; bronchodilators; mechanical ventilation
6	61	6.99	29	Combined respiratory and metabolic acidosis and hypoxemia	Birth asphyxia; near-drowning	Oxygen; mechanical ventilation; buffers?
7	60	7.37	106	Chronic respiratory acidosis with metabolic compensation; patient is receiving supplemental oxygen	Patient has chronic lung disease and is on oxygen	Treat chronic disease; no additional therapy may be necessary
8	29	7.31	106	Metabolic acidosis with respiratory compensation	Diabetic; ketoacidosis; dehydration	Treat the cause; buffers?

B. G. Nickerson and F. Monaco, "Carbon dioxide electrodes, arterial and transcutaneous," in J. G. Webster (ed.), Encyclopedia of Medical Devices and tation. New York: Wiley, 1988, pp. 564–569.

Table 10.1 Critical-Care Analytes and Their Normal Ranges in Blood

Blood Gases and Related Parameters		Electrolytes		Metabolites	
Po_2	80–104 mm Hg	Na^+	135–155 mmol/l	Glucose	70–110 mg/100 ml
Pco_2	33–48 mm Hg	K^+	3.6–5.5 mmol/l	Lactate	3–7 mg/100 ml
pH	7.31–7.45	Ca^{2+}	1.14–1.31 mmol/l	Creatinine	0.9–1.4 mg/100 ml
Hematocrit	40–54%	Cl^-	98–109 mmol/l	Urea	8–26 mg/100 ml
Total hemoglobin	13–18 g/100 ml				
O_2-saturation	95–100%				

Source: M. E. Collison and M. E. Meyerhoff, "Chemical sensors for bedside monitoring of

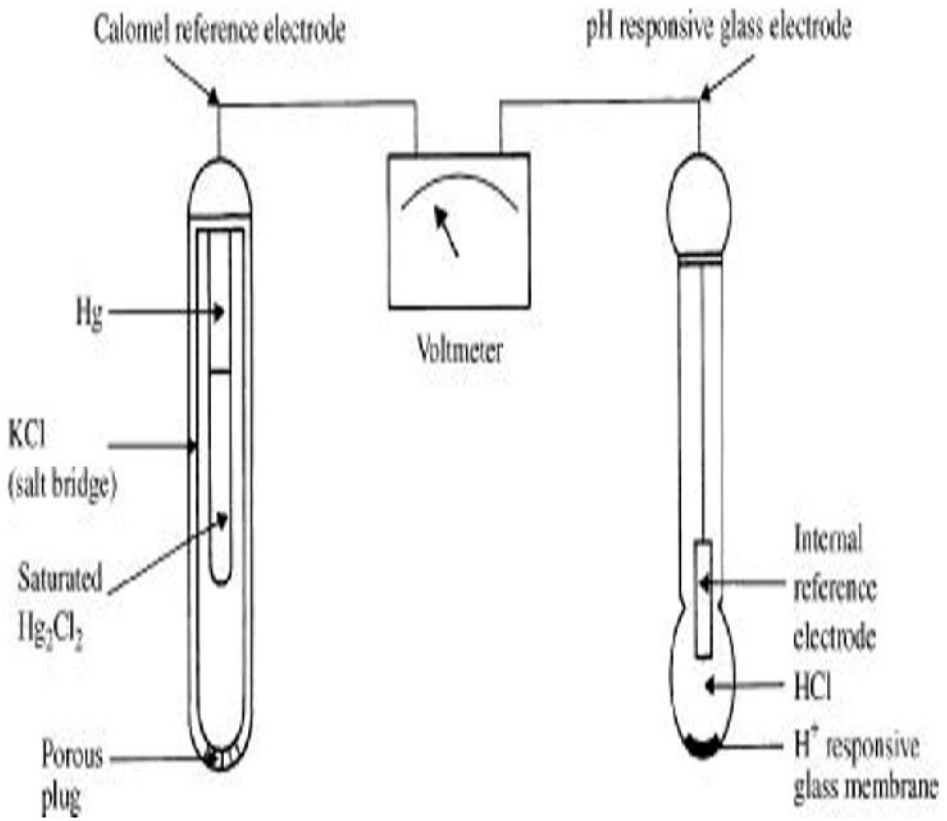


Figure 10.2 pH electrode (From R. Hicks, J. R. Schenken, and M. A. Steinrauf, Laboratory Instrumentation. Hagerstown, MD: Harper & Row, 1974. Used with permission of C. A. McWhorter.)

includes essentially all the values of clinical interest. This result can be established by examining some fundamental chemical relationships among H^+, H_2CO_3, HCO_3^-, and P_{CO_2}. The first three quantities are related by the equilibrium equation

$$H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \tag{10.3}$$

In addition, the relationship between P_{CO_2} and the concentration of CO_2 dissolved in the blood, $[CO_2]$, is given by

$$[CO_2] = a(P_{CO_2}) \tag{10.4}$$

where $a = 0.0301$ mmol/liter per mm Hg P_{CO_2}. The mass relationship corresponding to (10.3) can then be written as

$$k' = \frac{[H^+][HCO_3^-]}{[H_2CO_3]} \tag{10.5}$$

Next we use the fact that $[H_2CO_3]$ is proportional to $[CO_2]$ to obtain the result

$$k = \frac{[H^+][HCO_3^-]}{[CO_2]} \tag{10.6}$$

where k represents the combined values of k' and the proportionality constant between $[H_2CO_3]$ and $[CO_2]$. Now, using (10.4), we obtain the following result:

$$k = \frac{[H^+][HCO_3^-]}{aP_{CO_2}} \tag{10.7}$$

Next, taking the base-10 logarithm of (10.7) and rearranging, we obtain

$$\log[H^+] + \log[HCO_3^-] - \log k - \log a - \log P_{CO_2} = 0 \tag{10.8}$$

Using the definition of pH yields

$$\text{pH} = \log[HCO_3^-] - \log k - \log a - \log P_{CO_2} \tag{10.9}$$

This shows that pH has a linear dependence on the negative of log P_{CO_2}.

the values of two potentiometers.

THE P_{O_2} ELECTRODE

Figure 10.4 shows the basic components of the Clark-type polarographic electrode. The measurement of P_{O_2} is based on the following reactions. At the cathode, reduction occurs:

$$O_2 + 2H_2O + 4e^- \rightarrow 2H_2O_2 + 4e^- \rightarrow 4OH^-$$

$$4OH^- + 4KCl \rightarrow 4KOH + 4Cl^- \qquad (10.10)$$

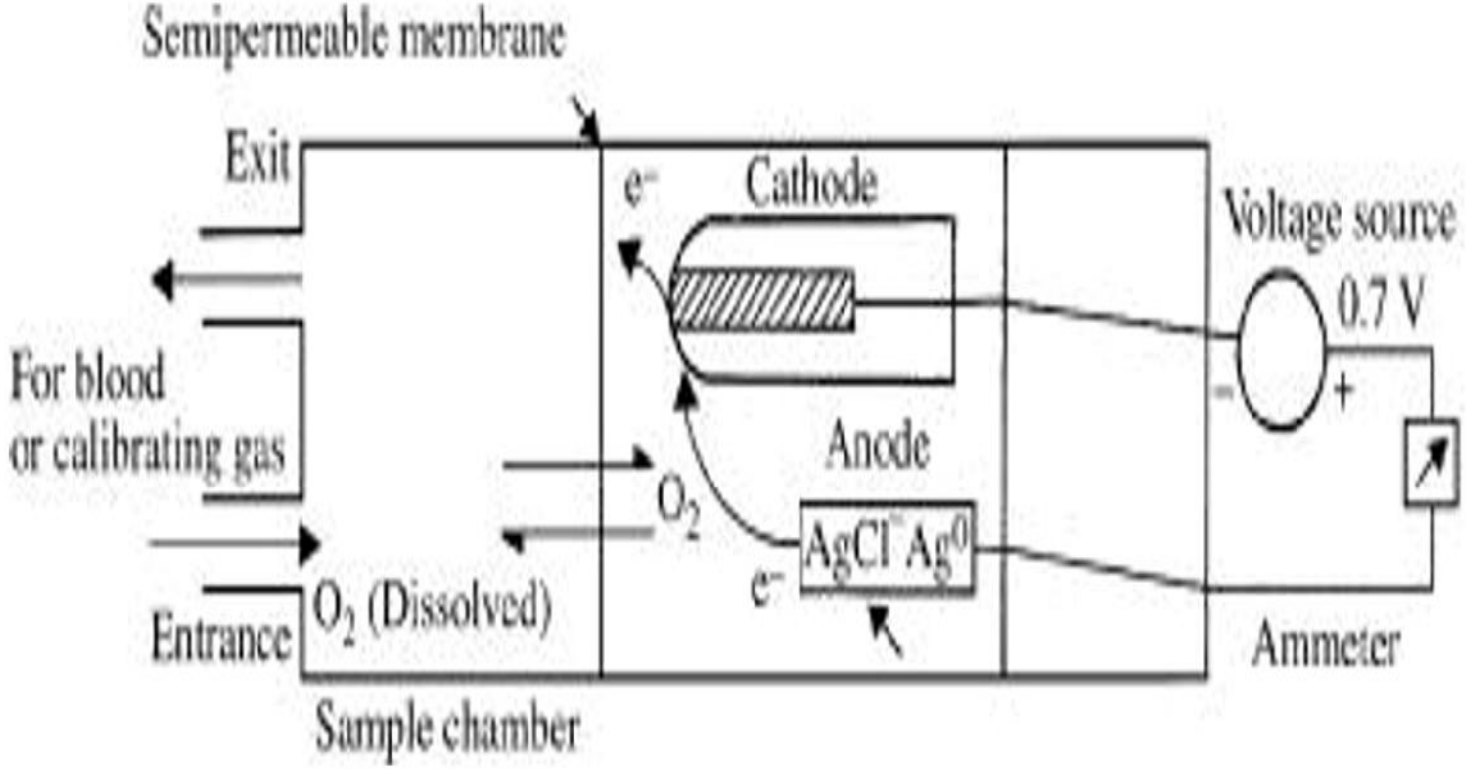


Figure 10.4 P_{O_2} **electrode** (From R. Hicks, J. R. Schenken, and M. A. Steinrauf, Laboratory Instrumentation. Hagerstown, MD: Harper & Row, 1974. Used with permission of C. A. McWhorter.)

for the specimen and a second containing a pH electrode of the type discussed. In contrast to the basic pH-measurement device in which the pH electrode is placed in the specimen, in this case the pH electrode is bathed by a buffer solution of bicarbonate and NaCl.

The two chambers are separated by a semipermeable membrane, usually made of Teflon or silicone rubber. This membrane allows dissolved CO_2 to pass through but blocks the passage of charged particles, in particular H^+ [illegible] HCO_3^-. When the specimen is placed in its chamber, CO_2 diffuses across membrane to establish the same concentration in both chambers. If there net movement of CO_2 into (or out of) the chamber containing the buffer, [increases (or decreases), and the pH meter detects this change. Because relationship between pH and the negative log P_{CO_2} is only a proportional it is necessary to calibrate the instrument before each use with two gase known P_{CO_2}.

Using the values of pH obtained by processing these two standards, obtain a calibration curve of P_{CO_2} versus pH. We then use the measured value to obtain the specimen's P_{CO_2} from this curve. With some instrume the capability of calibrating the P_{CO_2} electrode is built into the instrumen that the calibration curve is set up in the electronics of the instrument by setting the values of two potentiometers.

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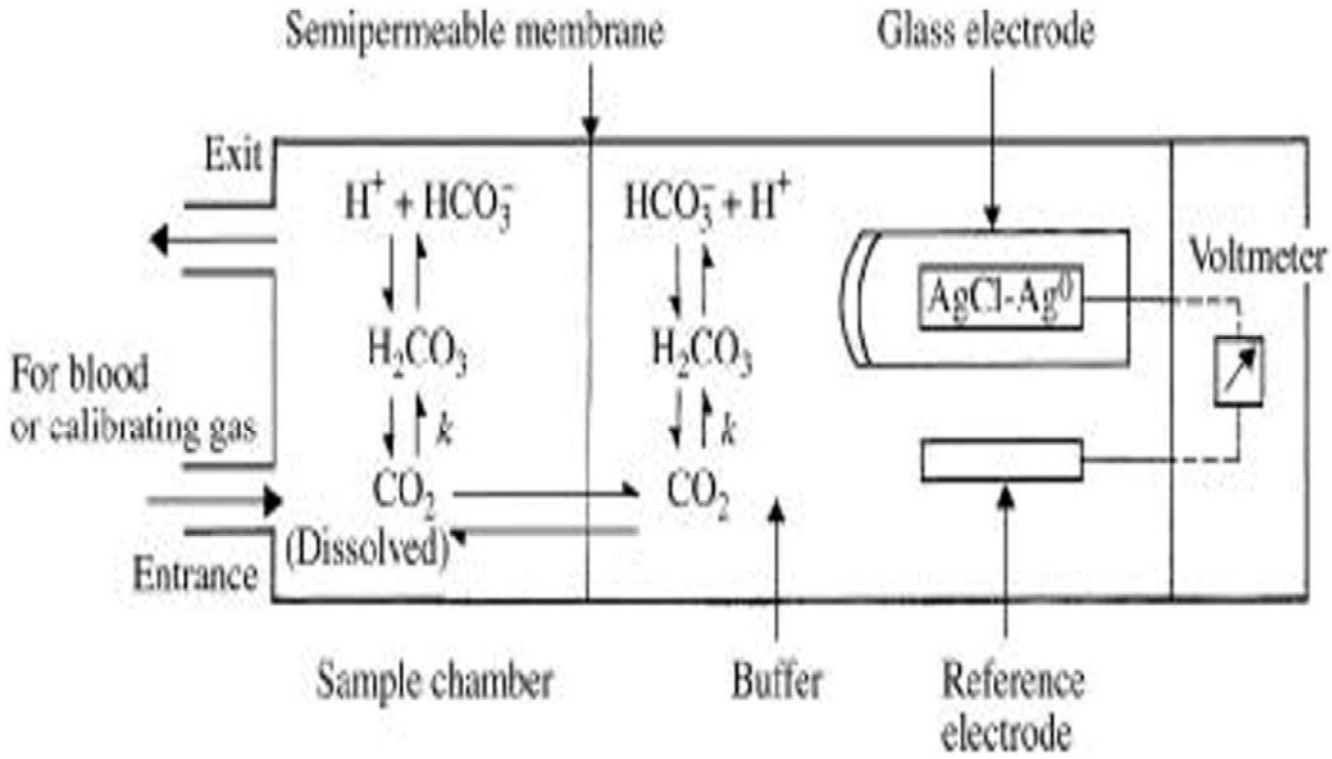


Figure 10.3 P_{CO_2} **electrode** (From R. Hicks, J. R. Schenken, and M. A. Steinrauf, Laboratory Instrumentation. Hagerstown, MD: Harper & Row, 1974. Used with permission of C. A. McWhorter.)

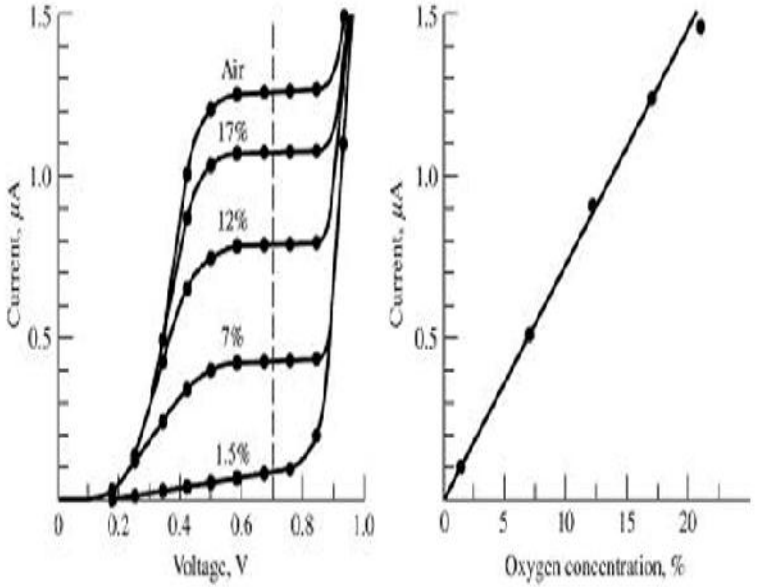
The hydroxyl ions created in this reaction are buffered by the electrolyte. At the anode, which in this Po_2 electrode is the reference electrode, oxidation occurs.

$$4Ag + 4Cl^- \rightarrow 4AgCl + 4e^- \qquad (10.11)$$

This produces the four electrons required for the reaction in (10.10).

The cathode is constructed of glass-coated Pt, and the reference electrode is made of Ag/AgCl.

The plot of current versus polarizing voltage of a typical Po_2 electrode (polarogram) is shown in Figure 10.5(a). The polarizing voltage is selected in the "plateau" region to provide a sufficient potential to drive the reaction, without permitting other electrochemical reactions that would be driven by greater voltages to take place. Thus the resulting current is linearly proportional to the number of O_2 molecules in solution [see Figure 10.5(b)]. The O_2 membrane is permeable to O_2 and other gases and separates the electrode from its surroundings.



Chemical fibrosensors offer several desirable features.

1. They can be made small in size.
2. Multiple sensors can be introduced together, through a catheter, for intracranial or intravascular measurements.
3. Because optical measurements are being made, there are no electric hazards to the patient.
4. The measurements are immune to external electric interference, provided that the electronic instrumentation is properly shielded.
5. No reference electrode is necessary.

In addition, fibrosensors have a high degree of flexibility and good thermal stability, and low-cost manufacturing and disposable usage are possible. In reversible sensors, the reagent phase is not consumed by its reaction with the analyte. In nonreversible sensors, the reagent phase is consumed. The con-

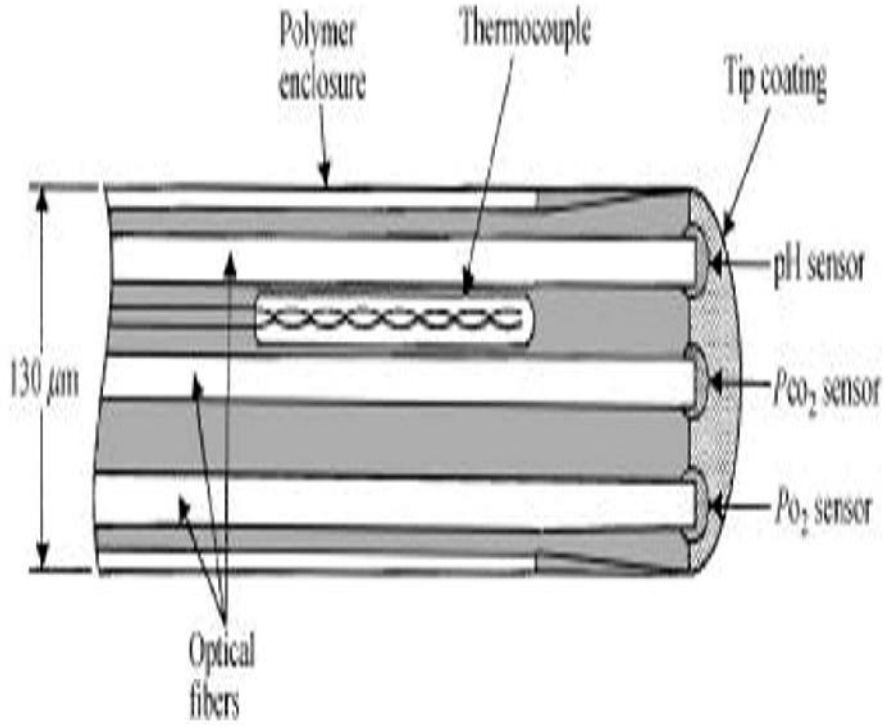
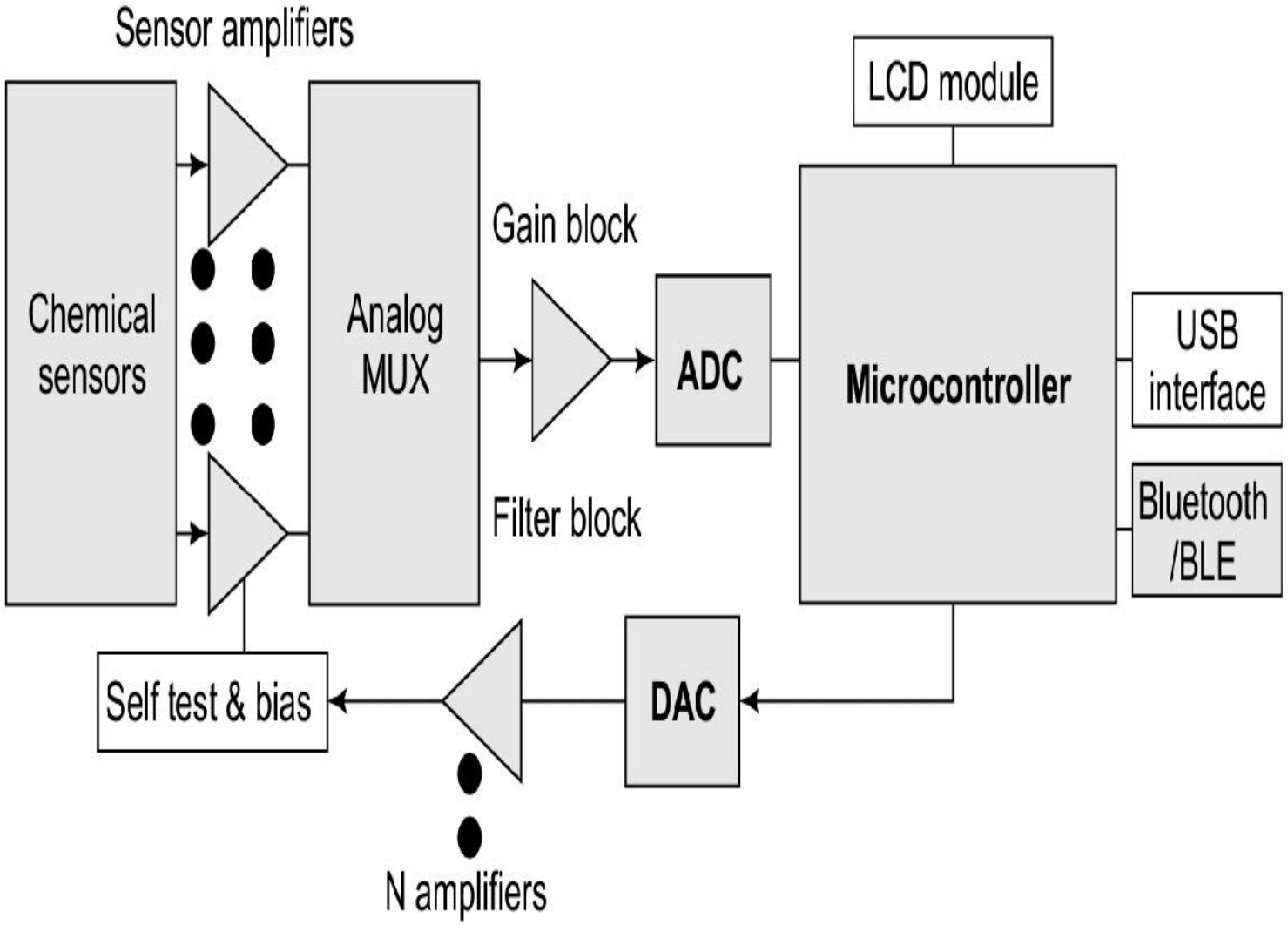


Figure 10.16 An intravascular blood-gas probe measure pH, Pco_2, and Po_2 by means of single fiber-optic fluorescent sensors. (From J. L. Gehrich, D. W. Lübbers, N. Optiz, D. R. Hansmann, W. W. Miller, J. K. Tusa, and M. Yafuso, "Optical fluorescence and its application to an intravascular blood gas monitoring system," *IEEE Trans. Biomed. Eng.*, 1986, BME-33, 117–132. Used by permission.)

vhen in the standby mode.



15.9 *Block diagram of a complete blood gas analyser (Adapted from M/s Texas Instrument*

Because a single-electrode technique is sensitive both to glucose and to the amount of oxygen present in the solution, a modification to remove the oxygen response by using two polarographic oxygen electrodes has been suggested (Updike and Hicks, 1967). Figure 10.24 illustrates both the principle of the enzyme electrode and the dual-cathode enzyme electrode. An active enzyme is placed over the glucose electrode, which senses glucose and oxygen. The other electrode senses only oxygen. The amount of glucose is determined as a function of the difference between the readings of these two electrodes. More recently, development of hydrophobic membranes that are more permeable to oxygen than to glucose has been described (Gilligan *et al.*, 2004). Placing these membranes over a glucose enzyme electrode solves the problem associated with oxygen limitation and increases the linear response of the

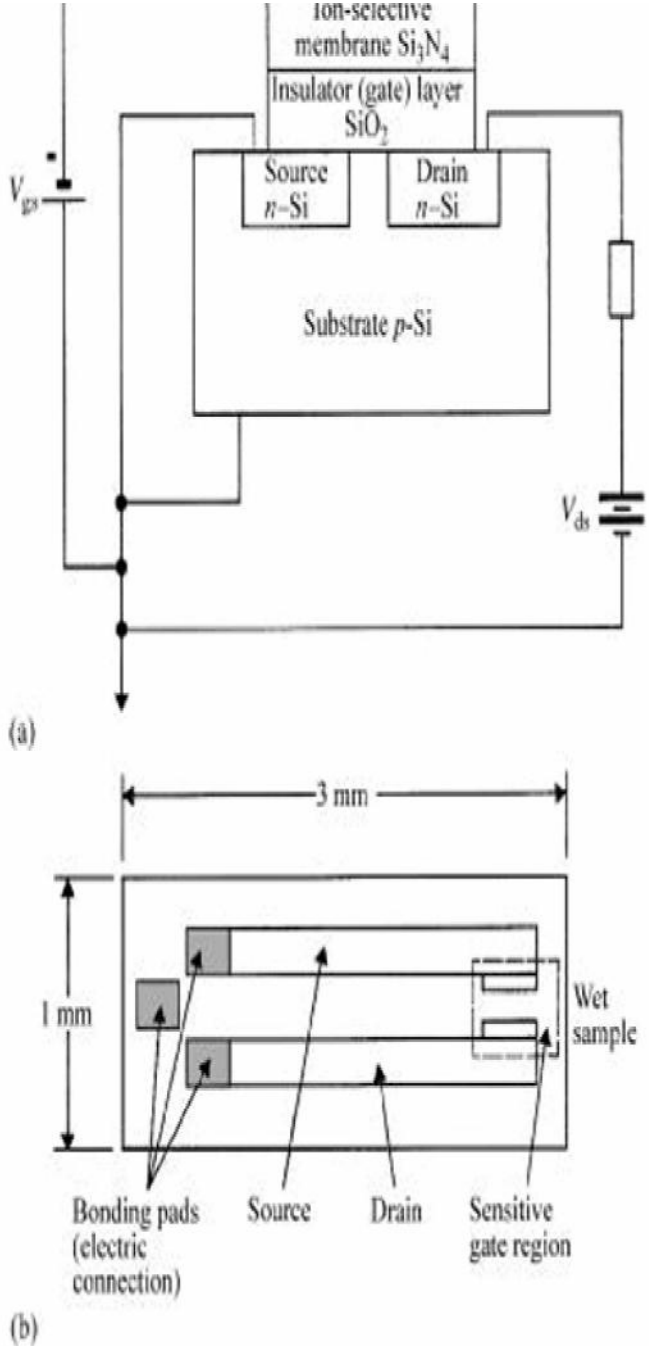
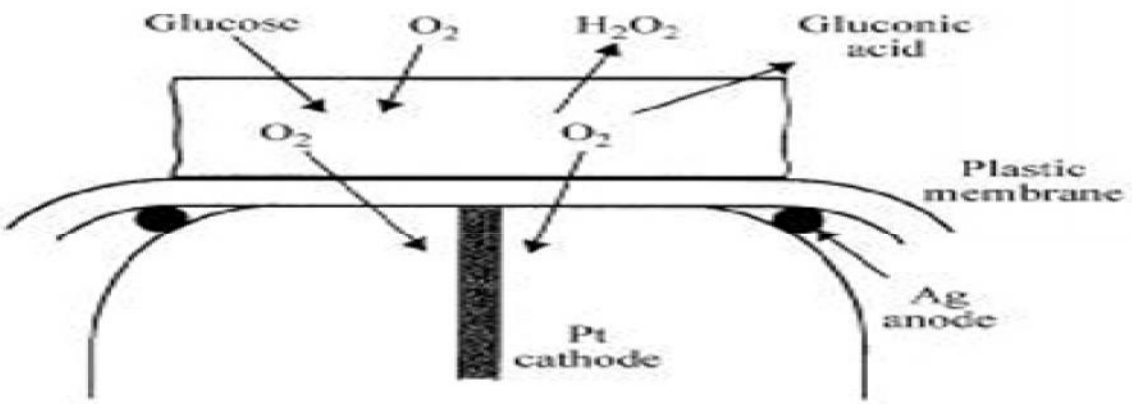


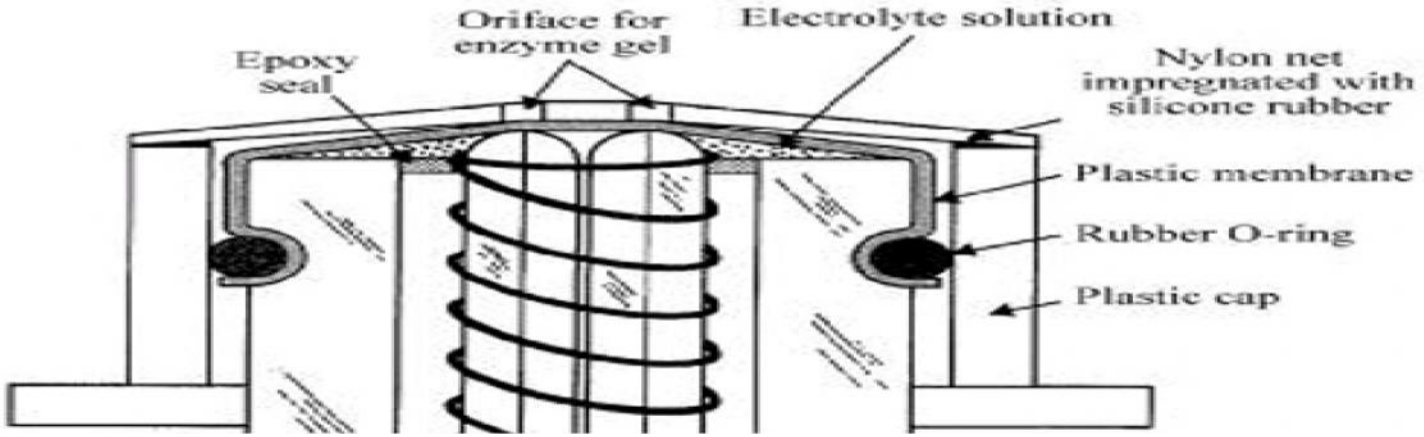
Figure 10.17 (a) In a chemically sensitive field-effect transistor, the ion-selective membrane modulates the current between the source and the drain. (b) A stretched

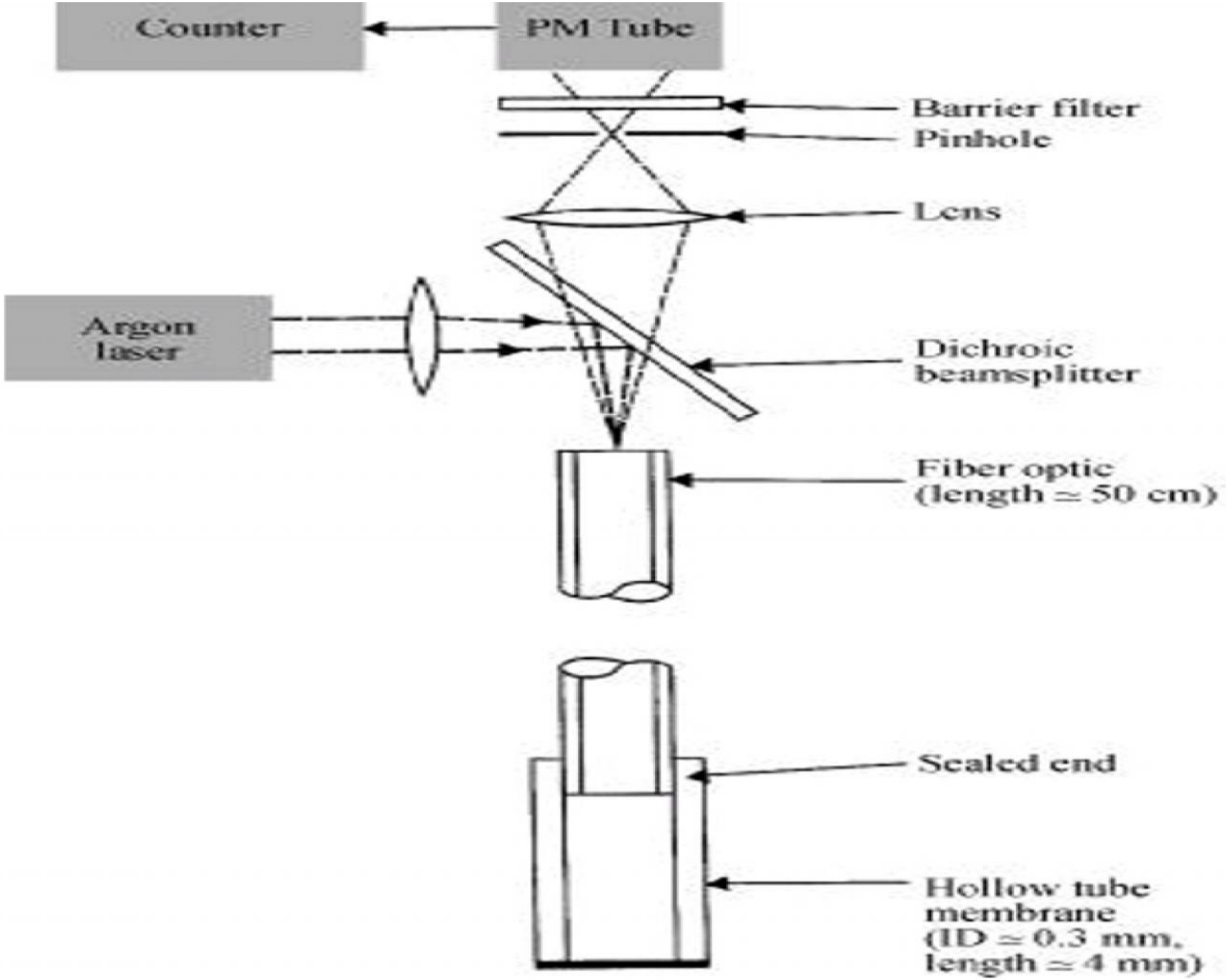
The immunologically sensitive field-effect transistor (IMFET) is an extension of the ISFET. As we noted, the ISFET takes advantage of the ion-sensitive or chemical sensitive properties of the field-effect transistor. As described above, the ISFET design makes use of the properties of the metal-insulator-semiconductor structure, in which the gate metal layer and the semiconductor layer form a capacitive sandwich by framing an insulating layer—normally SiO_2. Essentially, the system is a capacitor with a totally impermeable dielectric through which no charge passes.

The IMFET is similar in structure to the ISFET except that the solution-membrane interface is polarized rather than unpolarized; that is, charged species cannot cross the membrane (Zachariah *et al.*, 2006). The ISFET interacts through an ion-exchange mechanism with the chemical analyte that is being measured, whereas the IMFET operation is based on an antigen–antibody reaction. An antibody is immobilized on the membrane that is attached to the insulator of a FET. In this way the device is used as an antigen sensor. An antibody could be detected in a similar way: by immobilizing an antigen on the membrane. The IMFET measures charge, so in order to be sensed, the absorbing species on the membrane must possess a net

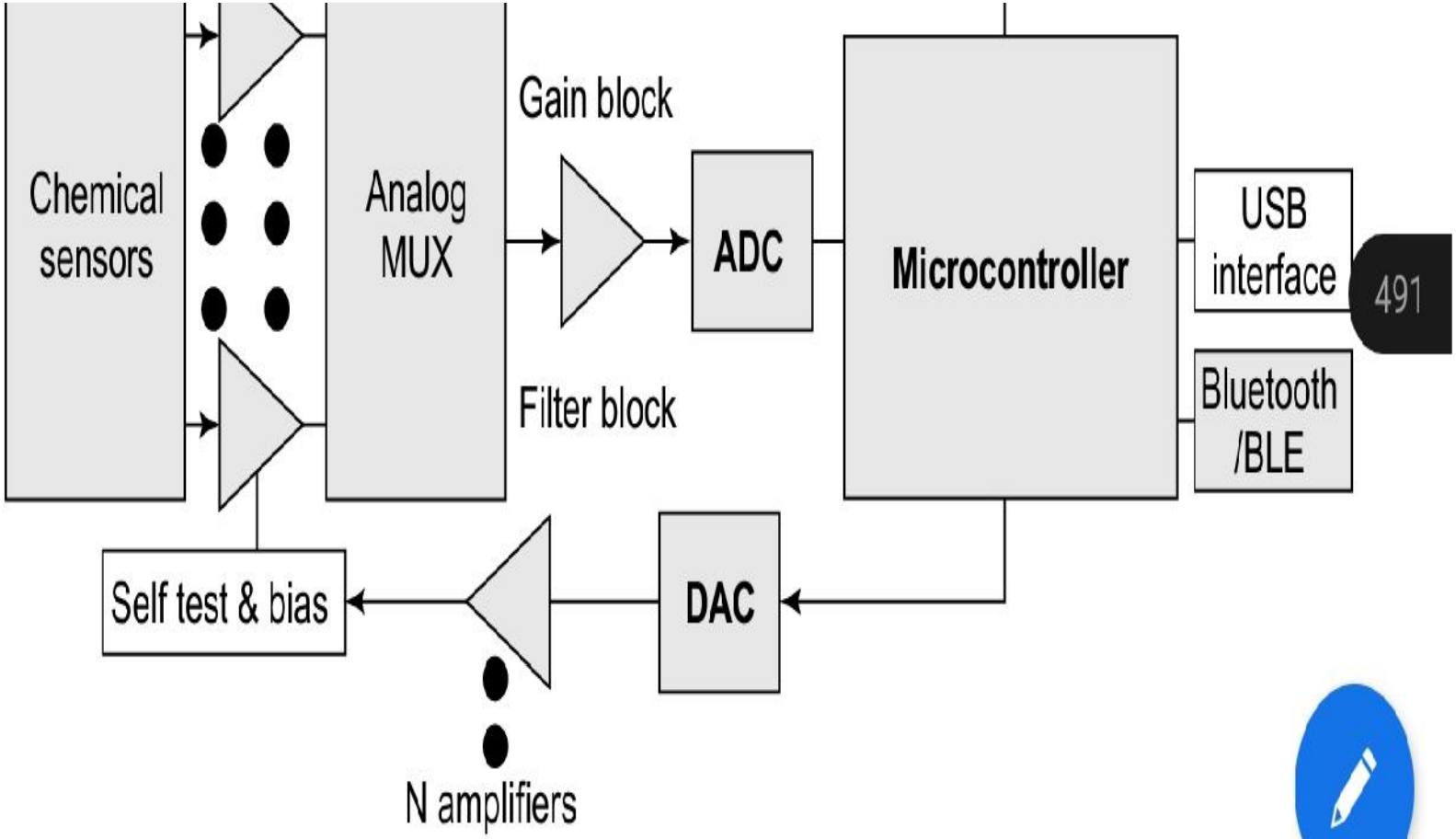

Glucose
O_2
H_2O_2
Gluconic acid
O_2
O_2
Plastic membrane
Ag anode
Pt cathode

(a)


Oriface for enzyme gel
Electrolyte solution
Epoxy seal
Nylon net impregnated with silicone rubber
Plastic membrane
Rubber O-ring
Plastic cap



The optical system for a glucose affinity sensor u
fiber-optic catheter. (From J. S. Schulz, S. Manouri, *e*



15.9 *Block diagram of a complete blood gas analyser (Adapted from M/s Texas Instrume*

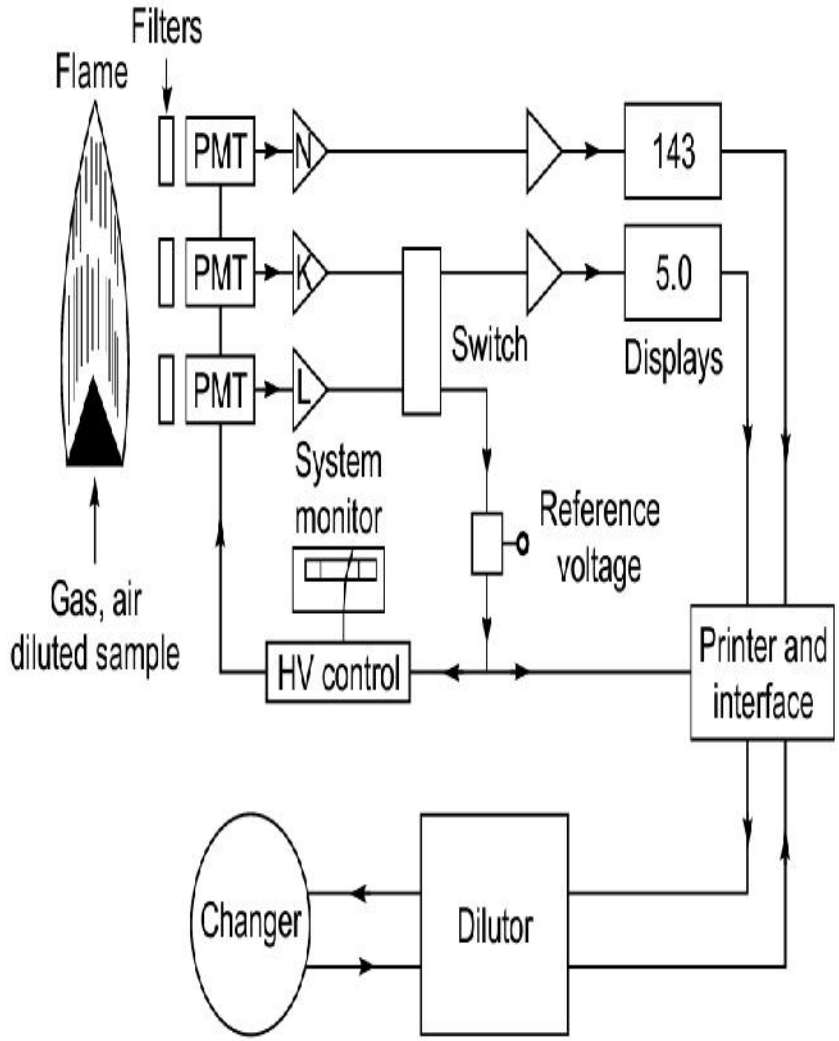


Fig. 14.17 *Schematic diagram of a flame photometer*

in a narrow band centered at 589 nm; the potassium detector responds only to wavelengths in a

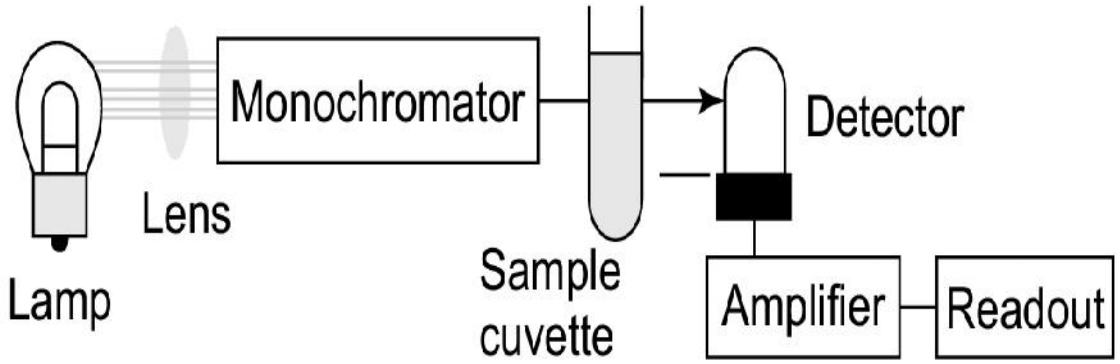


Fig. 14.4 *Various components of a spectrophotometer type instrumen*

iation Sources

16.2.3 Electrical Conductivity Method

Blood cell counters, operating on the principle of conductivity change, which occurs each time a cell passes through an orifice, are generally known as Coulter Counters. The method was patented by Coulter in 1956 and it forms the basis of several particle counting instruments manufactured by a number of firms throughout the world. The technique is extremely useful for determining the number and size of the particles suspended in an electrically conductive liquid.

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

To achieve optimum performance and to enable the relationship of change in resistance with volume of the cell to hold good, it is recommended that the ratio of the aperture length to the diameter of the aperture should be 0.75:1, i.e. for an orifice of 100 μ diameter the length should be 75 μ.

aperture 'A' is immersed into the suspension. The pressure difference created between the two sides of the aperture draws the suspension to flow through the aperture. This pressure difference is generated by a simple mechanical pump consisting of a syringe, a relay and other parts.

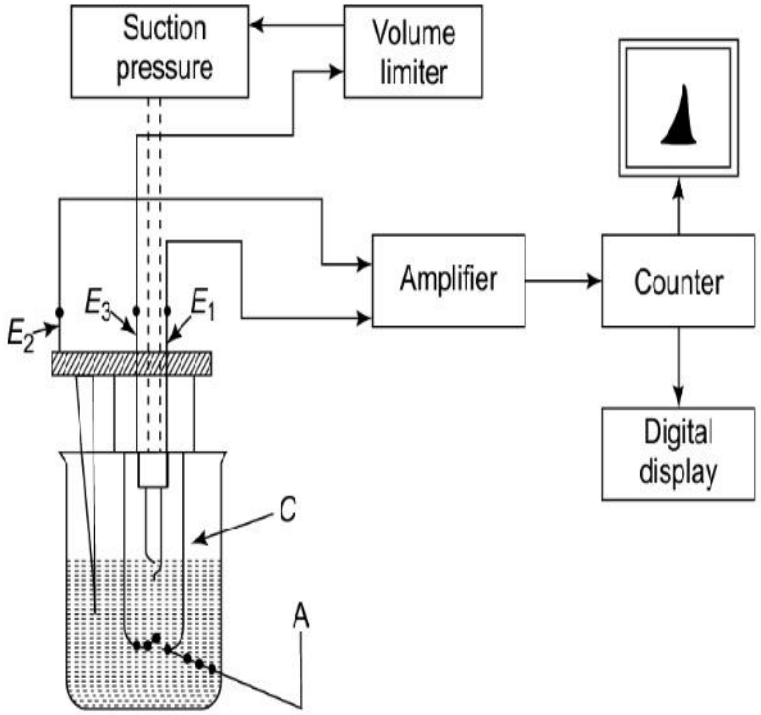


Fig. 16.4 *Block diagram of blood cell Coulter counter*

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16.5 AUTOMATIC RECOGNITION AND DIFFERENTIAL COUNTING OF CELLS

Along with the automated instruments for obtaining the erythrocyte, leucocyte and platelet counts, there has been a considerable interest in developing automated techniques for identifying and counting the different types of cells within a given class. Examples of this could be the immature red cell count, the differential leucocyte count and the recognition of normal versus malignant cells in other cell types. Various diseases affect the mechanism of blood cell formation in different ways. In particular, fractional proportion of the five major leucocytes is a sensitive measure for indicating and assisting in the diagnosis of various diseases. Furthermore, some diseases cause immature forms, which normally are present in the blood forming tissue to appear in the peripheral blood. Some diseases affect red cell morphology, and a qualitative report of red cells also forms a part of the differential count. There is, thus, a need for automation of acquisition and interpretation of data in routine clinical differential cell count. Several approaches have been employed in the pursuit of automating the techniques.

Miller (1976) describes a differential white blood cell classifier based upon a three-colour flying spot-scanner approach. It utilizes recognition parameters based on the principle of

into its red, green, and blue components, with highly sensitive photomultiplier tubes detecting the resulting radiation.

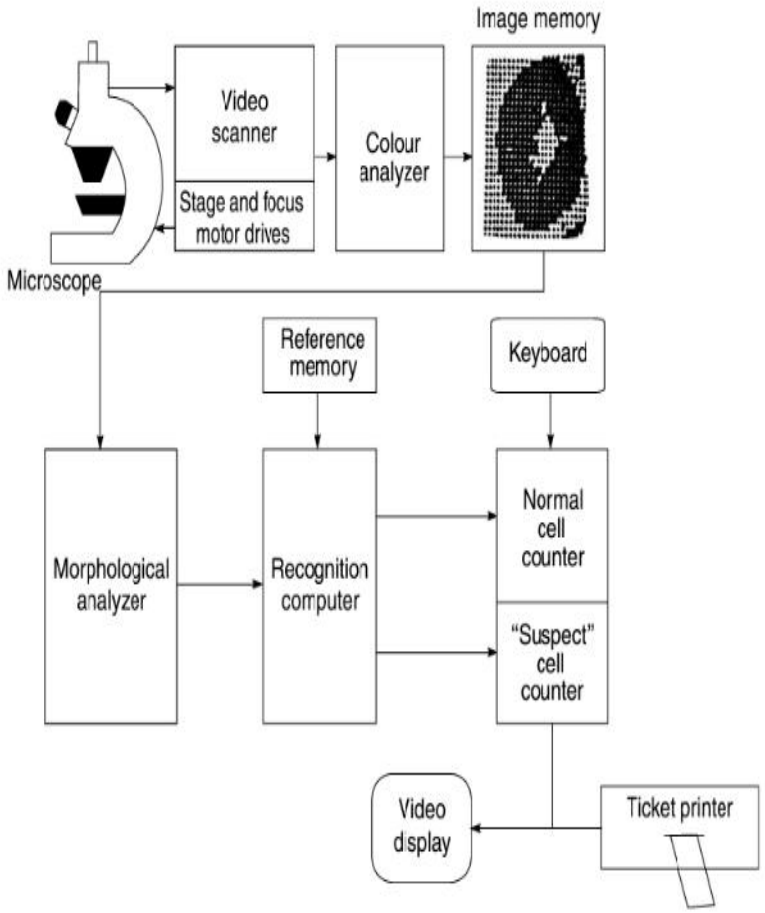

Fig. 16.10 *Block diagram of cell identification system*

Oppurtunities in India – CSIRLabs, DRDO labs, Systronics etc.

Global openings-

Siemens,Johnson&Jhonson etc.