Biomedical Engineering

ECT414 – Module 1

Quick Reference Notes with Diagrams

1. Introduction to Biomedical Engineering

Definition	Application of engineering principles and design concepts to medicine and biology. Provides electrical, electronic, and computer engineering support for clinical applications.

Measurement Type	Description / Example
In Vivo	Measurement on or inside the body — e.g., pH sensor inserted into the bloodstream
In Vitro	Measurement outside the body — e.g., measuring blood pH from a collected blood sample

Biomedical Instrumentation System

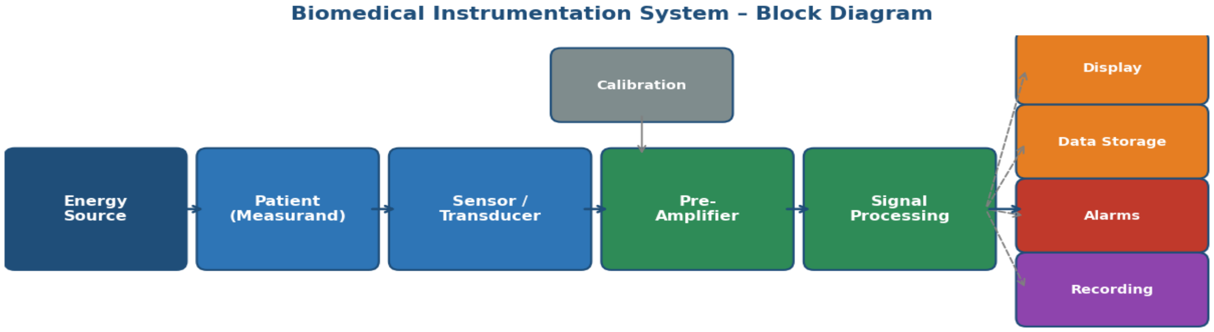

Fig 1.1 – Block diagram of a biomedical instrumentation system

2. Anatomy & Physiological Systems of the Body

Term	Definition
Anatomy	Study of the structure and shape of the body and its parts
Gross Anatomy	Study of large structures visible to the naked eye (heart, bones)
Microscopic Anatomy	Study of cells (cytology) and tissues (histology) under a microscope
Physiology	Study of how body parts function

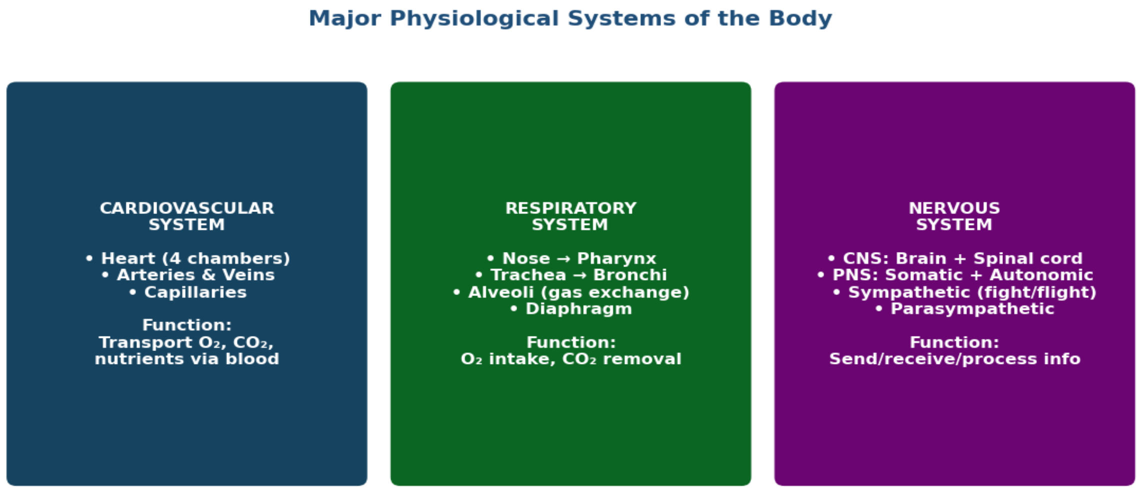

Fig 2.1 – The three major physiological systems

Nervous System Structure

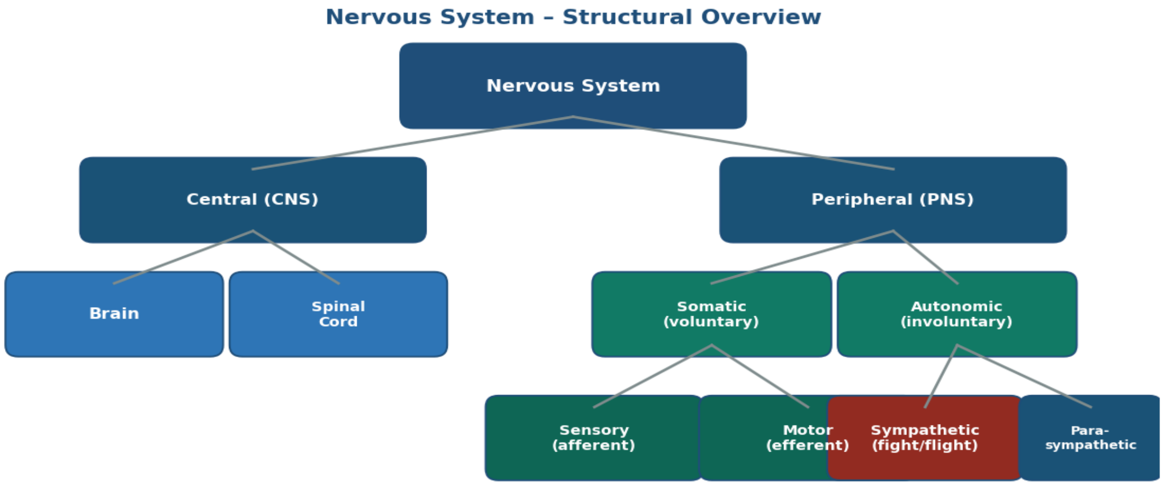

Fig 2.2 – Nervous system hierarchy: CNS and PNS divisions

Key Facts – Respiratory System

- Air path: Nose/Mouth → Pharynx → Trachea → Bronchi → Bronchioles → Alveoli
- Gas exchange occurs in the Alveoli (O_2 in, CO_2 out via capillaries)
- Diaphragm controls breathing; flattens on inhalation, expands on exhalation
- Normal adult breathing rate: 12–20 breaths/min; up to 45/min during exercise

3. Sources of Bioelectric Potential

Bioelectric potentials are ionic voltages produced by the electrochemical activity of excitable cells (neurons, muscle cells). Electrodes convert these ionic potentials into measurable electrical signals.

Resting Potential (Polarised State)

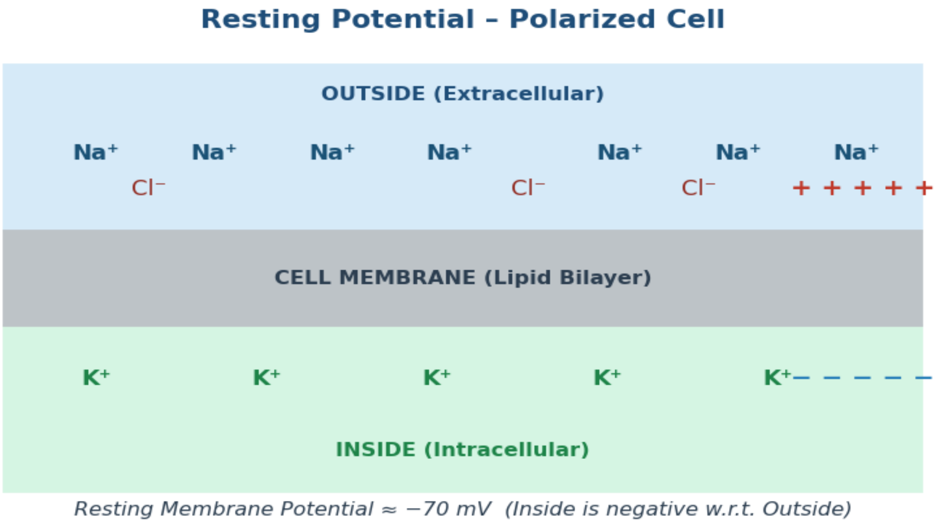

Fig 3.1 – Ion distribution creating resting membrane potential of −70 mV

- **Inside cell:** high K^+ (potassium), low Na^+ and Cl^-
- **Outside cell:** high Na^+ and Cl^-, low K^+
- Charge separation across the membrane = Resting Potential ≈ −70 mV (range: −60 to −100 mV)
- A cell at rest is called a polarised cell

Action Potential

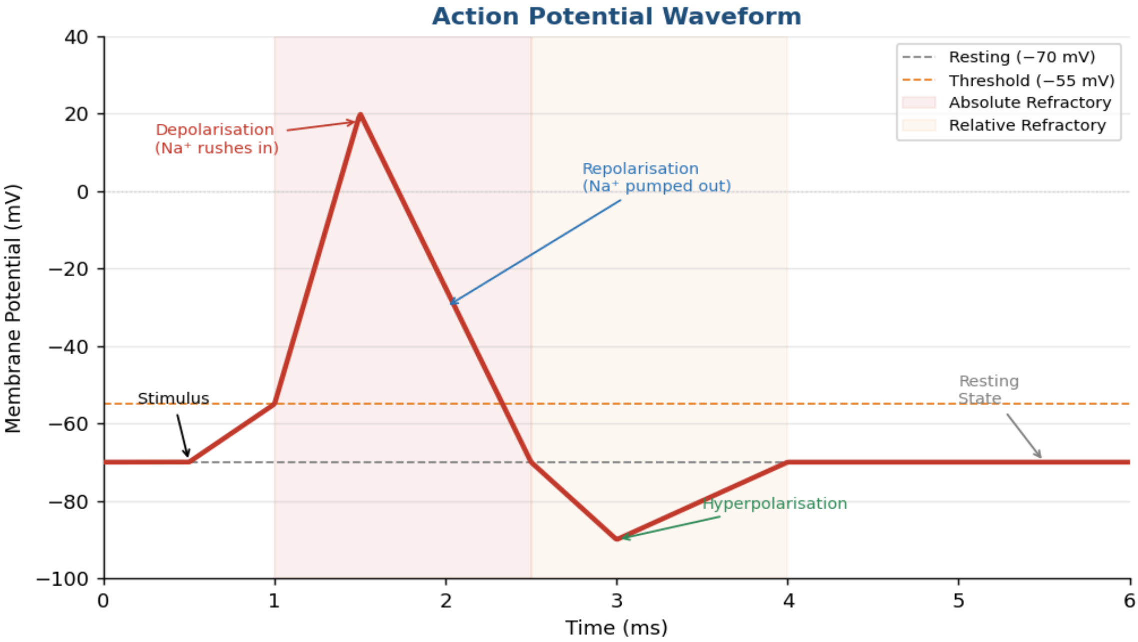

Fig 3.2 – Action potential waveform showing all phases

Phase	Event	Voltage
Resting	K^+ inside high; Na^+ outside high	−70 mV
Threshold	Stimulus reaches trigger level	−55 mV
Depolarisation	Na^+ channels open → Na^+ floods in → inside becomes +ve	+20 mV
Repolarisation	Na^+ channels close; sodium pump restores ions	−70 mV
Hyperpolarisation	Brief dip below resting (K^+ still leaving)	<−70 mV

Refractory Period	Explanation
Absolute (~1 ms)	Cell cannot fire at all — Na^+ channels inactivated
Relative	Cell can fire only with a stronger-than-normal stimulus

All-or-Nothing Law	Stimulus BELOW threshold → no action potential. Stimulus AT or ABOVE threshold → full action potential fires. No partial responses.

Propagation of Action Potentials

- Action potential travels like a wave along the axon from one end to the other
- Refractory period behind the wavefront prevents backward propagation
- **Nerve conduction velocity:** 20–140 m/s
- **Heart muscle conduction velocity:** 0.2–0.4 m/s (much slower)

4. Bioelectric Potential Examples

Signal	Full Name	Source / What it Measures
ECG	Electrocardiogram	Electrical activity of the heart muscles
EEG	Electroencephalogram	Neuronal activity of the brain
EMG	Electromyogram	Electrical activity of skeletal muscles
ERG	Electroretinogram	Bioelectric potential from the retina of the eye
EOG	Electro-oculogram	Corneal-retinal potential (eye position & movement)
EGG	Electrogastrogram	Gastric myoelectric activity (stomach)

ECG – Electrocardiogram

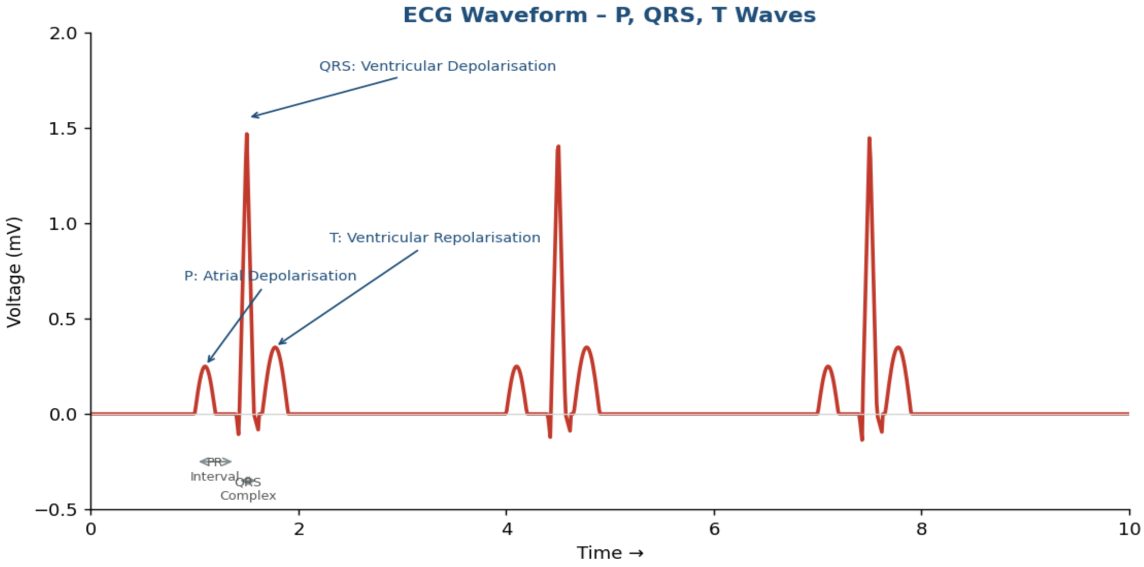

Fig 4.1 – ECG waveform with P, QRS complex, and T wave labelled

ECG Feature	Physiological Meaning
P wave	Atrial depolarisation — SA node fires, atria contract
PR interval	Conduction delay at AV node (allows ventricles to fill)
QRS complex	Ventricular depolarisation — ventricles contract (main pumping)
ST segment	Beginning of ventricular repolarisation (should be flat/isoelectric)
T wave	Ventricular repolarisation — ventricles relax

Cardiac Conduction Pathway

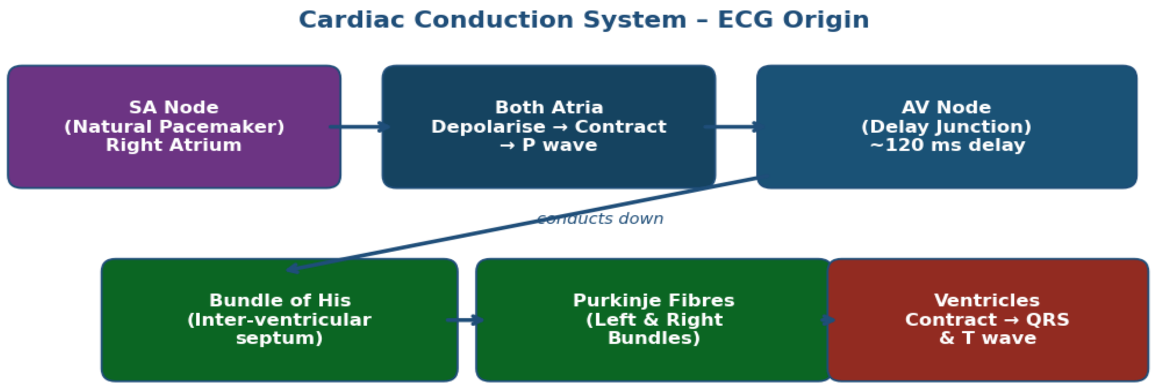

Fig 4.2 – How the electrical signal travels through the heart

EEG Brain Waves

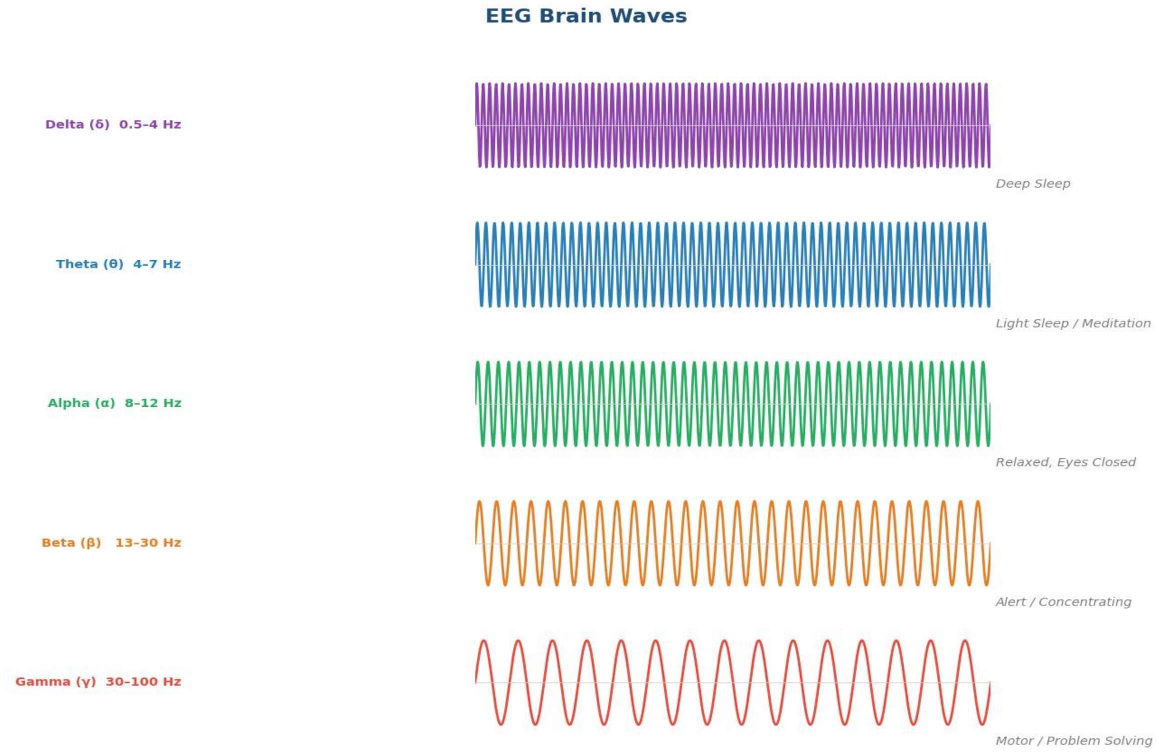

Fig 4.3 – Five types of EEG brain waves and their associated states

5. Electrode Theory

Nernst Equation

Formula	$E = -(RT / nF) \times \ln(C1 \cdot f1 / C2 \cdot f2)$ $R = 8.31$ J/(mol·K) T = temperature (Kelvin) n = valence of electrode material $F = 96{,}500$ C/mol C1, C2 = ion concentration on each side f1, f2 = activity coefficients of ions on each side

The Nernst equation gives the electric potential that develops across a semi-permeable membrane due to differing ionic concentrations on each side.

Electrode–Skin Interface

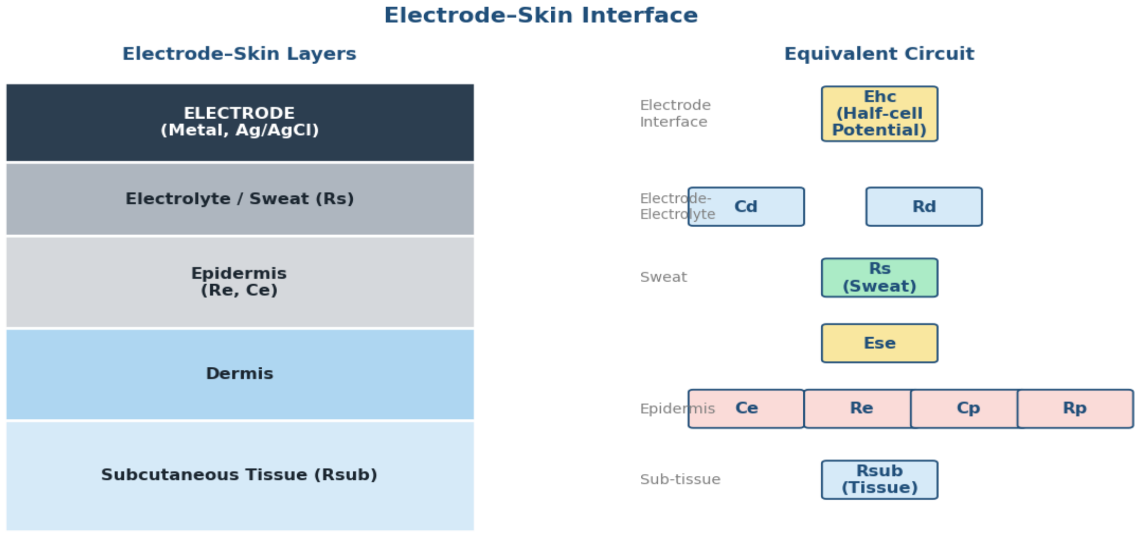

Fig 5.1 – Physical cross-section and equivalent circuit of electrode–skin interface

Component	Represents
Ehc	Half-cell potential at electrode–electrolyte interface
Rd & Cd	Impedance (resistance & capacitance) at electrode–electrolyte interface
Rs	Resistance of sweat/electrolyte layer
Re & Ce	Resistance and capacitance of epidermis (stratum corneum)
Rsub	Resistance of tissue underneath the skin

Polarisable vs Non-Polarisable Electrodes

Polarisable	Non-Polarisable
No charge crosses electrode–electrolyte interface	Current passes freely across the interface
Example: Platinum (Pt)	Example: Silver/Silver Chloride (Ag/AgCl)

Used as stimulating electrodes	Used as recording electrodes
Exhibits over-potential	Does NOT exhibit over-potential

Types of Biopotential Electrodes

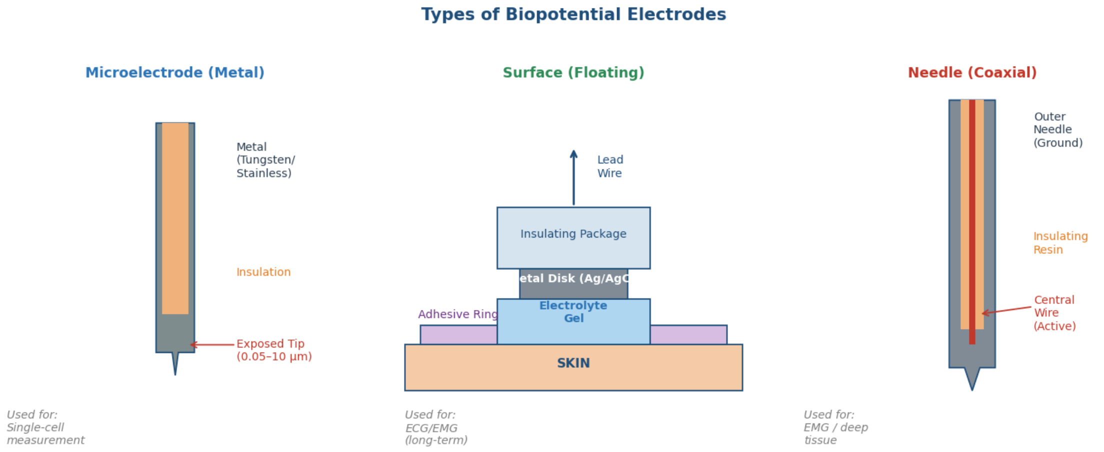

Fig 5.2 – Microelectrode, floating surface electrode, and coaxial needle electrode

Electrode Type	Application	Key Feature
Microelectrode (Metal)	Single-cell measurements	Tip 0.05–10 µm; tungsten/stainless steel; electrolytic etching
Micropipette	Intracellular recording	Glass capillary ~1 µm tip; filled with 3M KCl electrolyte
Surface – Metal Plate	ECG, EMG (skin surface)	Metallic conductor + electrolyte gel pad
Surface – Floating	Long-term ECG monitoring	Ag/AgCl disk; gel in recess; double-sided adhesive ring
Surface – Suction	Precordial (chest) ECG leads	Rubber bulb creates suction to hold electrode on chest
Needle – Coaxial	Deep tissue EMG/EEG	Central wire in needle lumen; insulating resin; coaxially shielded
Needle – Bipolar	Localised muscle activity	Two wires in one needle; connected differentially

6. Instrumentation Amplifiers

Instrumentation Amplifier (InAmp) – 3 Op-Amp Design

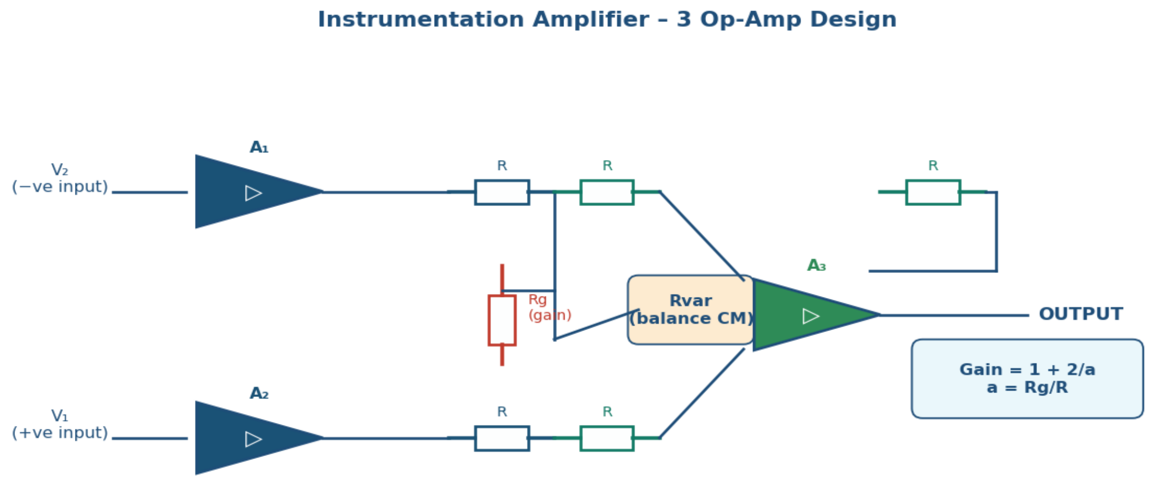

Fig 6.1 – Three op-amp instrumentation amplifier; A1 & A2 are buffers, A3 is differential

Feature	Advantage for Biomedical Use
Extremely high input impedance	Does not load the source (body signals are tiny)
Very high CMRR	Rejects noise that is common to both electrodes (e.g., 50 Hz mains)
Low bias & offset current	Accurate measurement of µV-level bioelectric signals
Single IC package	Compact, low-cost, easy to use
Gain set by single resistor Rg	Gain = 1 + 2/a, where a = Rg/R

Carrier Amplifier

Used with transducers (e.g., strain gauge pressure sensors) that produce very slow or DC-level signals.

Stage	Function
Carrier Oscillator	Generates an AC carrier signal to energise the transducer
Strain Gauge Transducer	Amplitude-modulates the carrier with the physiological variable
AC Amplifier	Amplifies the modulated (AM) signal across multiple stages
Rectifier	Converts AC output to unidirectional signal
Phase-Sensitive Detector	Demodulates to recover the original amplified bio-signal

Direct Writing Recorder	Records the final output signal

Chopper Amplifier

Eliminates DC drift by converting the input DC signal to AC, amplifying, then converting back to DC.

- **Problem solved:** DC offset / drift in direct-coupled amplifiers
- Signal path: DC Input → LPF → Chopper (oscillator-driven switch) → AC → Amplifier → Demodulator → DC Output
- Advantages: insensitive to temperature & ageing; very small offset; can amplify signals in the µV range

Isolation Amplifier

Protects the patient from dangerous leakage currents by breaking electrical continuity between the patient circuit and the mains-connected output circuit.

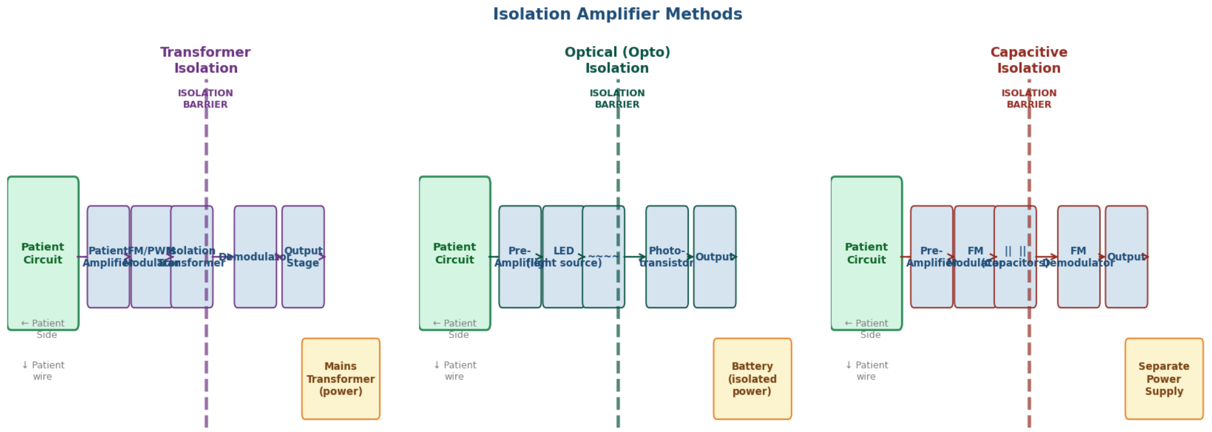

Fig 6.2 – Three isolation methods: transformer, optical, and capacitive

Method	Isolation Voltage	Key Notes
Transformer (most popular)	~1200 V	Uses FM or PWM carrier; internal dc-dc converter for isolated power supply
Optical / Opto-isolated	~800 V	LED → phototransistor; simplest & cheapest; no modulator/demodulator needed
Capacitive	~2200 V	Highest isolation voltage; most expensive; handles up to 70 kHz bandwidth

— End of Module 1 Notes —