

Unit II : Non-Electrical Vital Sign Measurement (Blood Pressure · Pulse Oximetry · Spirometry)

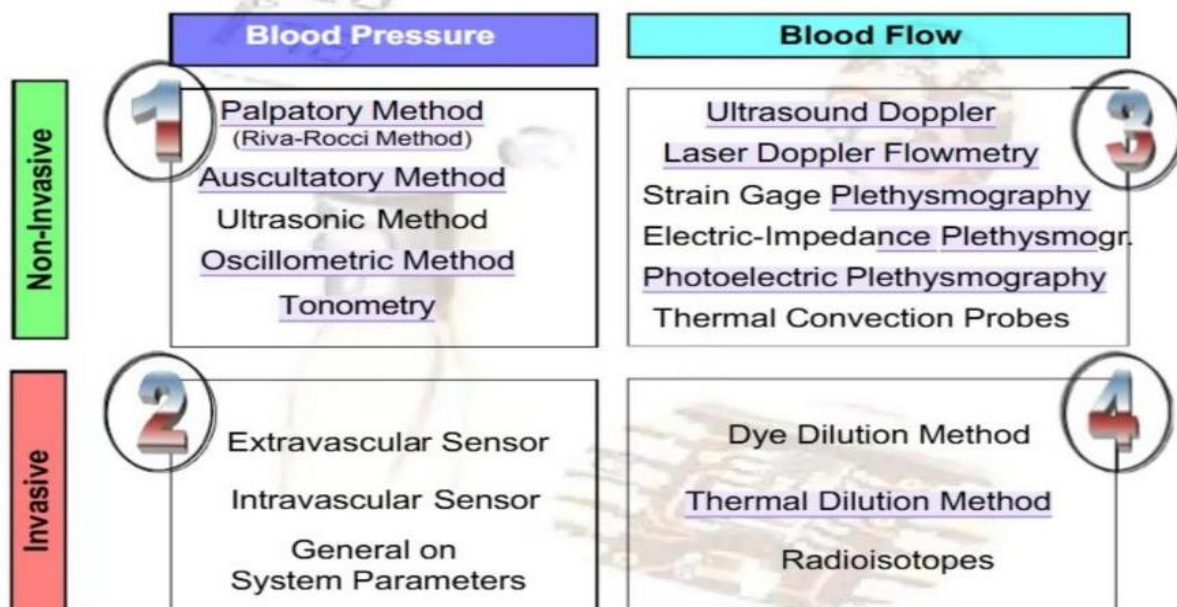
4. Blood Pressure Measurement

4.1 Basic Definitions

- Blood Pressure = the force exerted by blood against the vessel wall. **BP = Heart Rate × Total Peripheral Resistance.**
- Depends on: blood volume, blood viscosity, vessel elasticity, sympathetic activity, kidney function.

Parameter	Diastolic	Systolic
Definition	Pressure during heart's relaxation (lowest)	Pressure during heart's contraction (highest)
Normal range (adult)	60–80 mmHg	90–120 mmHg
Ventricles of the heart	Fill with blood	Contracted
Blood vessels	Relaxed	Contracted
Etymology (Greek)	diastole = 'a drawing apart'	systole = 'a drawing together / contraction'

Types of Measuring



4.2 Measurement Techniques

Non-invasive methods

- **Palpatory method** — cuff + pulse palpation (systolic only).
- **Auscultatory method** — cuff + stethoscope, listening for Korotkoff sounds (gold-standard manual method).
- **Oscillometric method** — automatic cuff senses pressure oscillations (used in digital BP monitors).
- **Tonometry** — arterial wall tonometer measures pressure waveform directly over a superficial artery.

Invasive methods

- Extravascular sensor, Intravascular sensor, General/system parameters (used in ICU/OT settings for continuous, beat-to-beat monitoring).

4.3 Korotkoff Sounds (Auscultatory Method)

Phase	Description
Phase I	Clear tapping sound; onset marks systolic pressure
Phase II	Tapping sound followed by a murmur
Phase III	Loud, crisp tapping sound
Phase IV	Abrupt, distinct muffling of sound, gradually decreasing in intensity
Phase V	Disappearance of sound — taken as diastolic blood pressure

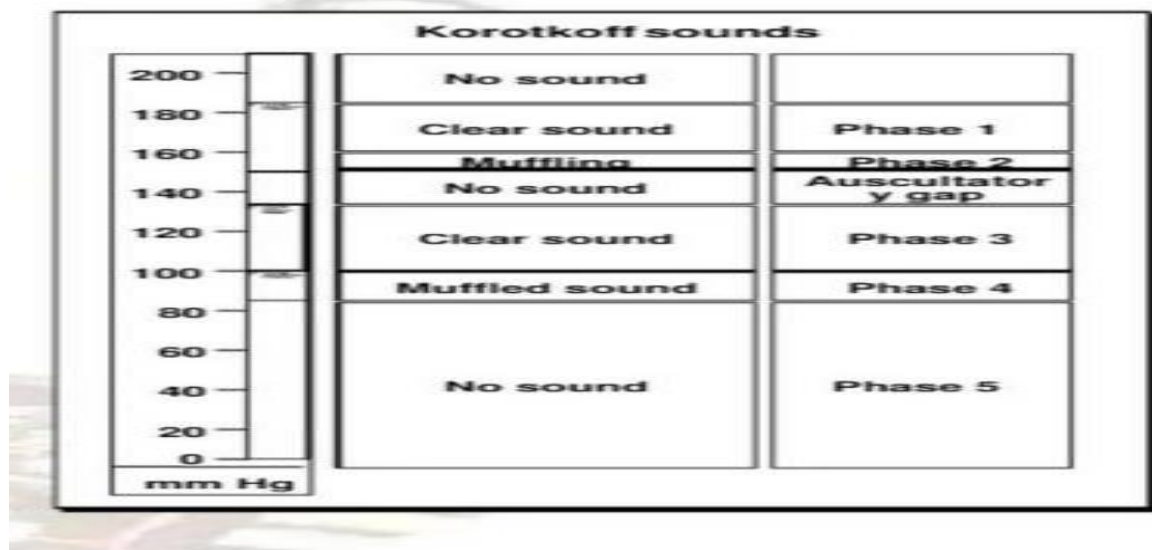


Fig 4.2 — Korotkoff sound phases during cuff deflation and recommended cuff-based measurement technique

4.4 BP Categories for Diagnosis

Systolic (mmHg)		Diastolic (mmHg)	Category
< 120	and	< 80	Normal
120–139	or	80–89	Pre-hypertension
140–159	or	90–99	Stage 1 Hypertension
≥ 160	or	≥ 100	Stage 2 Hypertension

Quick Revision — Blood Pressure

- $BP = \text{Heart Rate} \times \text{Total Peripheral Resistance}$.
- Normal adult: Systolic 90–120 mmHg, Diastolic 60–80 mmHg.
- Auscultatory (Korotkoff sounds): Phase I = systolic onset, Phase V = diastolic (sound disappears).
- Non-invasive: palpatory, auscultatory, oscillometric, tonometry. Invasive: intra-arterial catheter/transducer.

5. Pulse Oximetry

5.1 Principle — Dual-Wavelength Absorption

Pulse oximetry exploits the fact that oxygenated haemoglobin (HbO_2) and reduced haemoglobin (Hb) absorb red (≈ 660 nm) and infrared (≈ 940 nm) light differently. The Beer-Lambert law relates absorbance A to incident/transmitted intensity, extinction coefficient (ϵ), path length (d) and concentration (C):

$$A = -\log_{10}(I/I_0) = \epsilon \cdot d \cdot C$$

- Light passing through tissue encounters multiple layers: skin pigment, tissue, cartilage, bone, and venous/arterial blood — producing a static (DC) baseline absorbance plus a small dynamic (AC) pulsatile component caused by arterial pulsation.

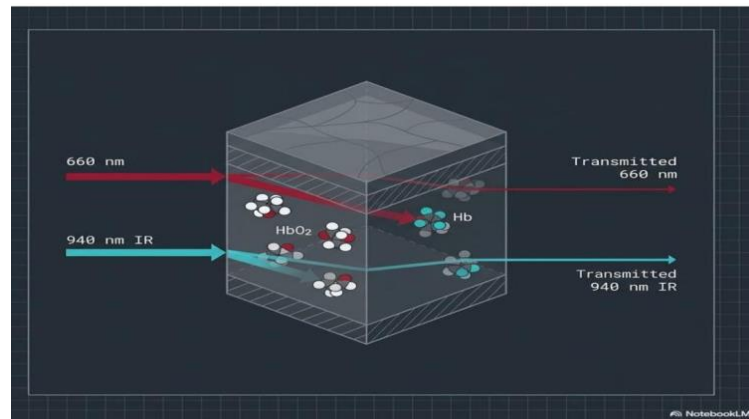


Fig 5.1 — Dual-wavelength absorption principle: red and infrared LEDs transmitted through tissue

5.2 Isolating the Arterial (Pulsatile) Signal

- The photodetector receives a composite signal from skin, bone, venous and arterial blood — only the pulsatile arterial (AC) component, riding on the constant (DC) background, is diagnostically relevant.
- The microcontroller separates the pulsatile arterial fraction from the constant venous/tissue baseline.

5.3 The R-Ratio

SpO₂ is derived from the ratio of the normalized AC/DC signal at each wavelength:

$$R = (AC_{660} / DC_{660}) \div (AC_{940} / DC_{940})$$

The ratio R is empirically mapped (via a calibration curve) to the arterial oxygen saturation (SpO₂ %).

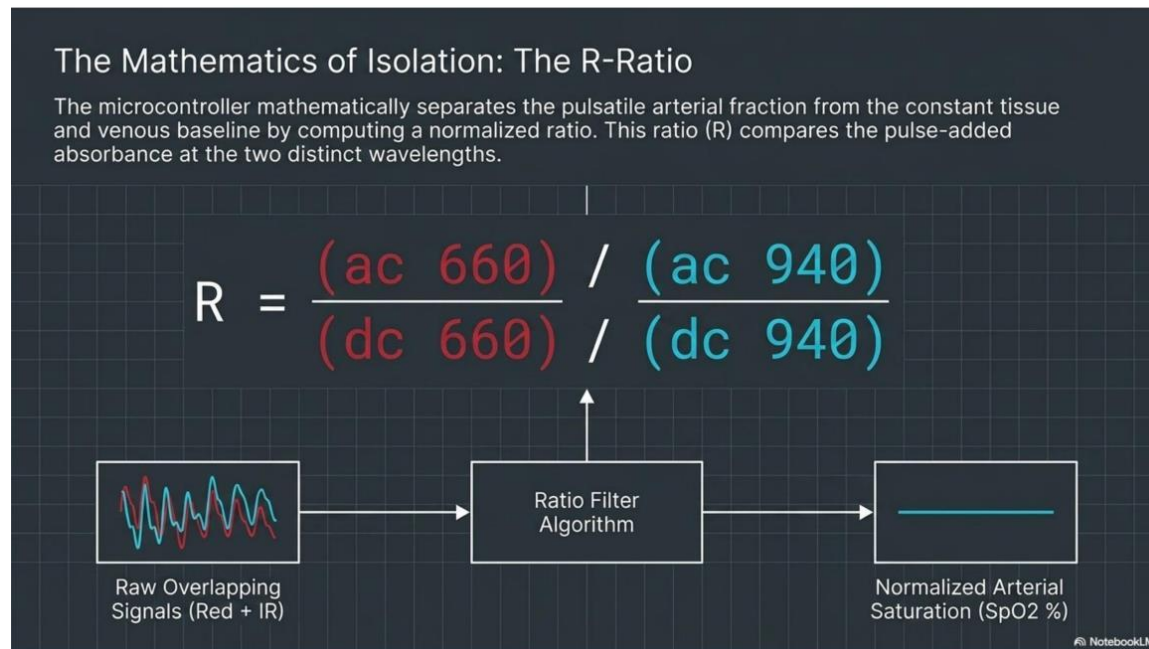


Fig 5.2 — The R-ratio: normalized AC/DC signals at 660 nm and 940 nm combined by the ratio-filter algorithm to yield SpO₂

5.4 Ambient-Light & Motion-Artefact Rejection

- **Temporal multiplexing:** red and IR LEDs are switched on/off at high frequency (e.g., 1 kHz cycle) so that a measurement taken during the 'off' period captures ambient light interference, which is then subtracted from the active readings.
- **Motion-artefact rejection:** uses quadrature/phase-based multiplexing to separate genuine pulsatile signal from motion-induced interference, since both occupy similar frequency ranges.

5.5 Oximetry Modalities

Parameter	Transmission Oximetry	Skin Reflectance Oximetry	Intravascular Oximetry
Primary mechanism	Transmitted light through tissue	Backscattered light from tissue	Direct reflection from red blood cells
Target anatomy	Fingertip, earlobe	Limbs, head, torso	Inside major blood vessels
Wavelengths	660 / 940 nm	660 / 935 nm	Multi-wavelength
Key engineering challenge	Ambient light & motion	Poor SNR & varying tissue properties	Fibre breakage & haematocrit variation

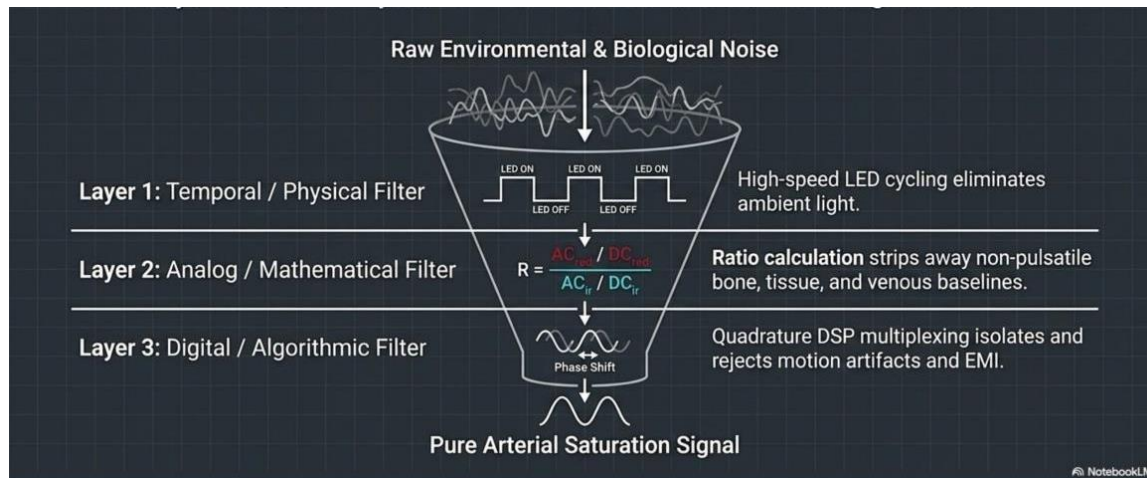


Fig 5.3 — Layered signal-processing architecture

5.6 SpO₂ Interpretation

SpO ₂ Range	Clinical Interpretation
95 – 100 %	Normal
91 – 94 %	Mild hypoxaemia
86 – 90 %	Moderate hypoxaemia
< 85 %	Severe hypoxaemia

Clinical note: SpO₂ ≤ 88% indicates need for supplemental oxygen; the pulse-oximeter waveform/pulse reading should match the ECG or palpated pulse.

6. Spirometry

6.1 Purpose

Every spirometer must accomplish three tasks: capture the volume/flow of a breath, translate it into a measurable electrical signal, and do so without restricting the patient's natural airflow.

6.2 Generations of Spirometer Design

Generation I — Water-Sealed (Bell) Spirometer

- A mechanical integrator: an inverted bell floats on a water seal; breathing displaces the bell, and a linear potentiometer converts bell excursion directly into a DC electrical signal.
- **Limitation:** inertia of the heavy bell mass and counterweight causes mechanical damping, limiting frequency response and risking oscillation on rapid breathing.

Generation II — Wedge (Bellows) Spirometer

- Uses a lightweight, hinged pan with flexible vinyl bellows instead of a heavy bell — minimal mass and negligible inertia, improving frequency response.

Generation III — Ultrasonic Spirometer

- No moving parts — uses piezoelectric transducers (40–200 kHz) transmitting pulses both upstream and downstream through the airflow.
- Flow velocity: $v = (D / 2\cos\theta) \cdot [f_2 - f_1]$, where D = separation distance, θ = beam angle, f_1/f_2 = upstream/downstream transit frequencies (time-of-flight principle).
- **Trade-off:** eliminating moving parts increases sensitivity to environmental factors (condensate/moisture, dead space, baseline drift from gas composition and temperature).

6.3 Comparison of Spirometer Types

Measurement Aspect	Water-Sealed	Wedge	Ultrasonic
Measurement principle	Mechanical integrator	Electro-mechanical	Acoustic / electronic (transit-time)
Key mechanism	Upright cylinder / inverted bell	Hinged pan / vinyl bellows	Transit-time frequency shift
Moving parts	High (heavy mass)	Low (lightweight pan)	None
Primary limitation	Inertia & oscillation	Physical barrier to flow	Condensation & gas composition sensitivity
Frequency response / signal	$\pm 10\%$ error at 10 Hz	Dual DC signals (volume & flow)	Nanosecond transit delays

Spirometry Diagnostic Matrix			
	Water-Sealed	Wedge	Ultrasonic
Measurement Principle	Mechanical Integrator	Electro-Mechanical	Acoustic / Electronic
Key Mechanism	Upright cylinder / inverted bell	Hinged pan / vinyl bellows	Transit-time frequency shift
Moving Parts	High (Heavy Mass)	Low (Lightweight Pan)	None
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Frequency Response / Signal	$\pm 10\%$ error at 10Hz	Dual DC signals (Vol & Flow)	Nanosecond transit delays

Fig 6.1 — Spirometry diagnostic comparison matrix across the three generations

Reference: R.S. Khandpur, *Handbook of Biomedical Instrumentation*, 3rd Edition (McGraw-Hill Professional, 2014). Lecture slide decks 2.1–2.5, *Advanced Biomedical Instrumentation*, prepared by Threase Sopra A., AP/DoBM.