ROHINI
COLLEGE OF ENGINEERING AND TECHNOLOGY
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DEPARTMENT OF BIOMEDICAL ENGINEERING

BM3491 Biomedical Instrumentation

UNIT-IV MEASUREMENT OF BIO SIGNALS

4.1 Temperature, Respiration Rate and Pulse Rate Measurement

4.1.1 TEMPERATURE MEASUREMENT

Body temperature is one of the oldest known indicators of the general well-being of a person. Two basic types of temperature measurements are Systematic temperature measurement and Skin surface measurement.

Systematic Temperature:

It is the temperature of the internal regions of the body. This temperature is maintained through a carefully controlled balance between the heat generated by the active tissues of the body and heat last by the body to the environment.

Measurements of systematic temperature are accomplished by temperature sensing devices placed in mouth, under the armpits or in the rectum. Systematic temperature most accurately measured at the tympanic membrane in the ear. Exercise may cause a temporary rise in the temperature about (0.5 to 2^0 C i.e 0.9 to 3.6^0 F) the systematic temperature is not affected by the ambient temperature even for low as (-18^0 C (0^0 F)) rise to over (38^0 C (100^0 F)).

Temperature control of the body is located deep within the brain. Warm, cooling, ambient temperature production of perspiration due to secretion of the sweat glands and increase circulation of blood. The only deviation from normal temperature control is a rise in temperature called fever. At the beginning of a fever the skin is often pale, dry and shivering usually takes place then the skin and muscles react to the coolness. At the conclusion of the fever, as the body temperature is lowered to normal, increased sweating body heat is eliminated.

Measurement of systematic body temperature:

The mercury thermometer is still the standard method or measurement. These devices are inexpensive, easy to use and sufficiently accurate. Two types of electronic temperature sensing devices are found in bio-medical applications. Thermocouple: A junction of two dissimilar metals that produces as output voltage nearly proportional to the temperature at that junction with respect to a reference junction.

Thermistor: A semiconductor element whose resistance varies with temperature. Thermistors are used more frequently than thermocouples because of greater sensitivity. Thermistors are variable resistance devices formed into disks, beads, rods or other desired shapes. Thermistors are manufactured from mixtures of various elements such as nickel, copper, magnesium, manganese, cobalt, titanium and aluminium. This mixture is compressed into shape with high temperature into a solid mass. It's results resistor with a large temperature coefficient. Unfortunately, the relationship between resistance change and temperature change is non-linear. Therefore, the resistance R_{t1} of thermistor at temperature T_1 determined by the equation.

$$R_{t1} = R_{t0}\, e^{\beta}\left(\frac{1}{T_1} - \frac{1}{T_0}\right)$$

where,

R_{t1} – resistance at temperature T_1

R_{t0} – resistance at reference temperature T_0

e - base of natural algorithms

β - temperature coefficient (range of 3000-4000)

T_1 – – temperature at which measurement is taken

T_0 – reference temperature (degree kelvin)

Selection of thermister probe

1. Physical configuration of probe

2. Sensitivity of the device

3. Absolute temperature range over which the thermister is designed to operate

4. Resistance range probe

Skin Temperature:

Surface or skin temperature is also result of a balance. But the balance between the heat supplied by blood circulation and cooling by conduction, radiation, convection and evaporation.

Skin temperature measurement:

1. Skin temperature is a function of surface circulation, environmental temperature, air circulation from which the measurement taken and perspiration. Systematic temperature remaining very constant throughout the body. But skin temperature can vary several degrees from one point to another.
2. Skin temperature measurements are frequently made by using small, flat thermistor probes. The human skin has been found to be an almost perfect emitter of infrared radiation. Such a device called an infrared thermometer.
3. Body temperature is one of the most tightly controlled physiological variables and one of the four basic vital signs used in the daily assessment of a patient's health. The interior (core) temperature in the body is remarkably constant, about 37^0 C for a healthy person, and is normally maintained within $\pm 0{:}5^0$ C. Therefore, elevated body temperature is a sign of disease or infection, whereas a significant drop in skin temperature may be a clinical indication of shock.
4. There are two distinct areas in the body where temperature is measured routinely: the surface of the skin under the armpit or inside a body cavity such as the mouth or the rectum.
5. The two most commonly used devices to measure body temperature are thermistors, which require direct contact with the skin or mucosal tissues, and non-contact thermometers, which measure body core temperature inside the

auditory canal. Thermistors are temperature-sensitive transducers made of compressed sintered metal oxides (such as nickel, manganese, or cobalt) that change their resistance with temperature. Commercially available thermistors range in shape from small beads to large disks, as illustrated in Figure.

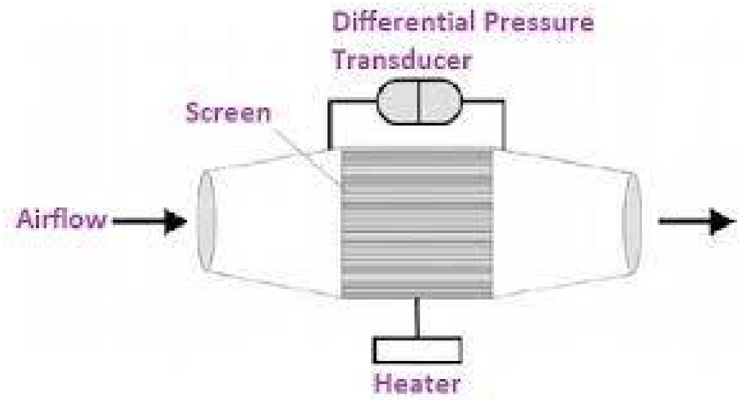


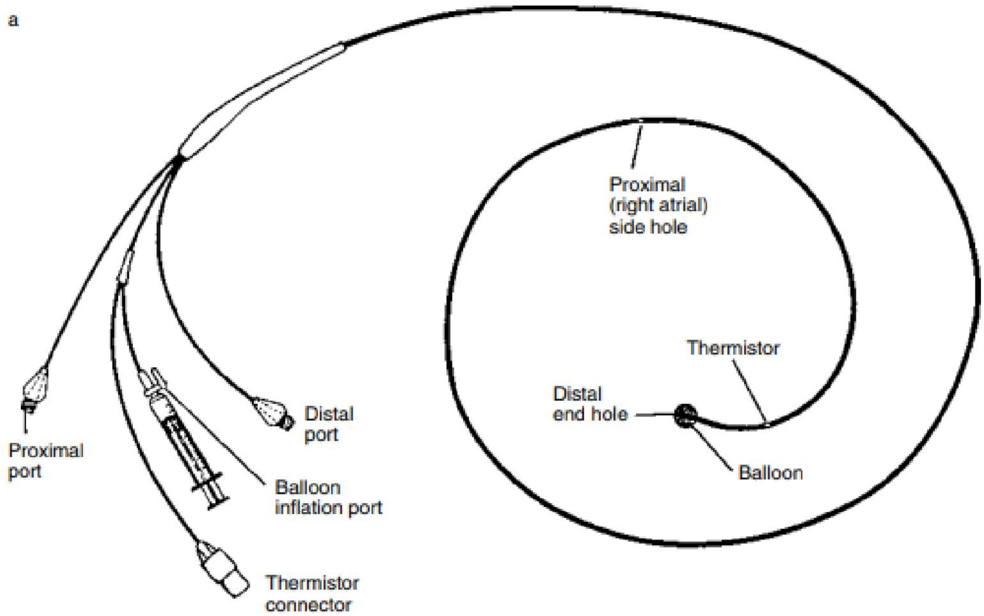
Figure 4.1 Fleish airflow transducer

6. The size and mass of a thermistor probe in a medical thermometer must be small in order to produce a rapid response time to temperature variations. The probe is normally covered with a very thin sterile plastic sheet that is also disposable to prevent cross contamination between patients.

Swan-Ganz thermodilution technique:

- A ***thermistor*** sensor can be employed in a ***Swan-Ganz thermodilution*** technique for measuring cardiac output (the volume of blood ejected by the heart each minute) and assessing ventricular function.
- The procedure is normally performed in the operating room or the intensive care unit. It involves a rapid bolus injection of a cold indicator solution, usually 3–5 ml of a sterile saline or dextrose solution kept at 0^0 C, into the right atrium via a flexible pulmonary artery catheter (Figure 4.2).
- The 5 or 7 French-size thermodilution catheter contains a small balloon (Fig. 4.2 b) and is normally inserted into either the femoral or internal jugular veins. The catheter is constructed of a radiopaque material to enable easy visualization by an x-ray machine.

- It contains three lumina: a balloon inflation port to guide the flexible tip to the right location, a proximal central venous port, and a distal pulmonary artery port. After the balloon is inflated, the tip of the flexible catheter is passed across the tricuspid valve through the right ventricle, across the pulmonary valve, and into the pulmonary artery.
- The proximal and distal ports can be connected to pressure transducers that measure blood pressures inside the right side of the heart while the catheter is advanced into the right atrium.



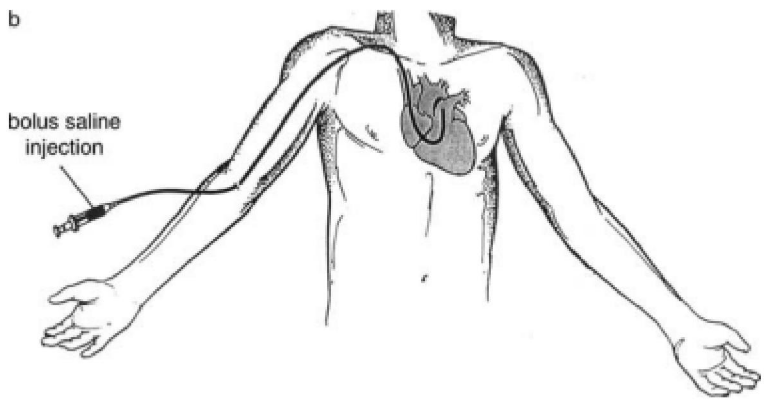


Figure 4.2 A Swan-Ganz thermodilution catheter

- After the catheter is inserted, a cold bolus is injected into the right atrium through the proximal lumen of the catheter. The bolus solution mixes with the venous blood in the right atrium and causes the blood to cool slightly.
- The cooled blood is ejected by the right ventricle into the pulmonary artery, where it contacts a thermistor that is located in the wall of the catheter near its distal tip.
- The thermistor measures the change in blood temperature as the blood passes on to the lungs. An instrument computes the cardiac output by integrating the change in blood temperature immediately following the bolus injection, which is inversely proportional to cardiac output.

Noncontact-type infrared ear thermometer:

1. Noncontact thermometers measure the temperature of the ear canal near the tympanic membrane, which is known to track the core temperature by about 0.5–1.0^0 C. Basically, as illustrated in Figure 4.3,
2. Infrared radiation from the tympanic membrane is channeled to a heat-sensitive detector through a metal waveguide that has a gold-plated inner surface for better reflectivity.
3. The detector, which is either a thermopile or a pyroelectric sensor that converts heat flow into an electric current, is normally maintained at a constant temperature environment to minimize inaccuracies due to fluctuation in ambient temperature.
4. A disposable speculum is used on the probe to protect patients from cross contamination.

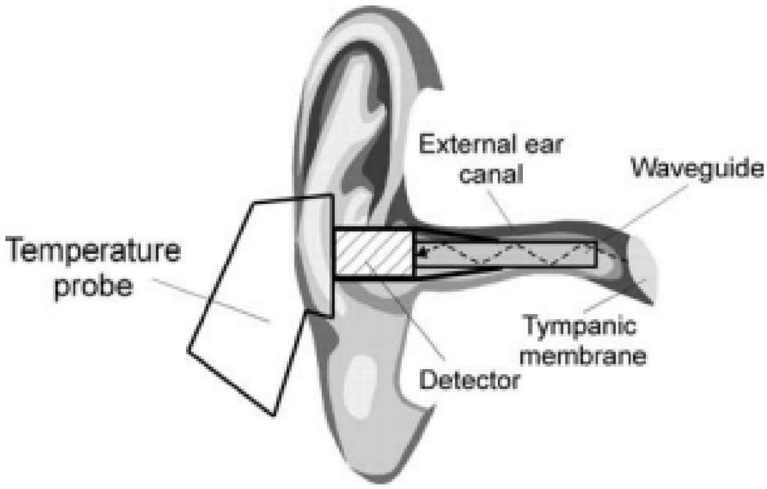


Figure 4.2 Noncontact-type infrared ear thermometer

4.1.2 RESPIRATION RATE MEASUREMENT :

- The respiratory rate is the rate at which breathing occurs.
- The respiration rate is the number of *breaths a person takes per minute*. The rate is usually measured when a person is at rest and simply involves counting the number of breaths for one minute by counting how many times the chest rises.

Age	Respiratory rate (breaths per minute)
Newborns	44
Infants	20-40
Preschool children	20-30
Older children	16-25
Adults	12-20
Adults during strenuous exercise	35-45
Athletes	60-70(**Peak**)

- **Respiration Rate**: This is the number of breaths per second. It represents total respiratory rate of the patient.

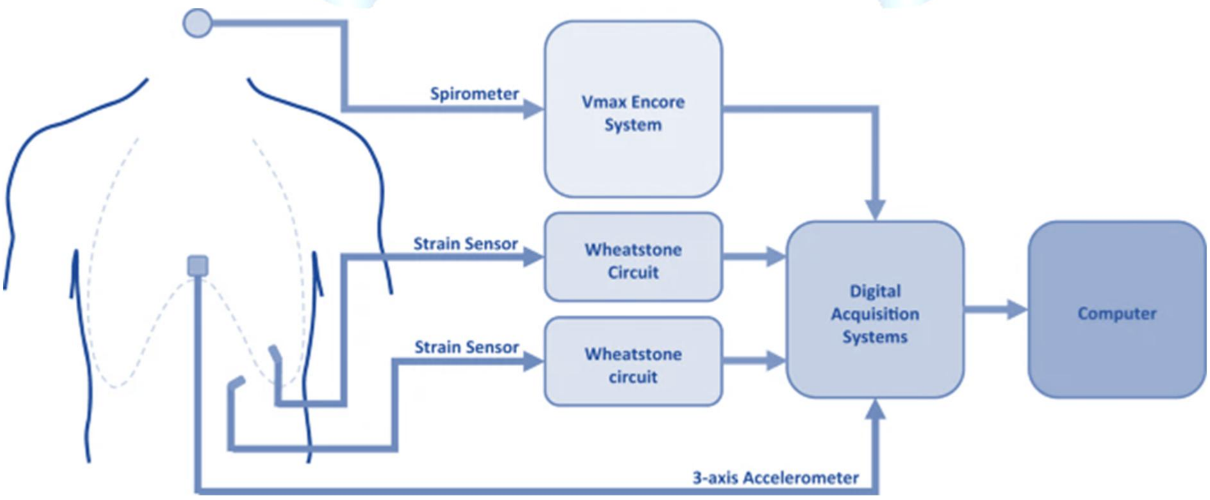
- The primary functions of the respiratory system are to supply oxygen and remove carbon dioxide from the tissues.
- Several techniques have been developed for the measurement of the respiration rate

Measurement of the respiration rate:

1. Displacement Method
2. Thermistor Method
3. Impedance Pneumography
4. CO2 Method of Respiration Rate Measurement

- 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.

Measurement of Respiration Rate – 1. Displacement Method

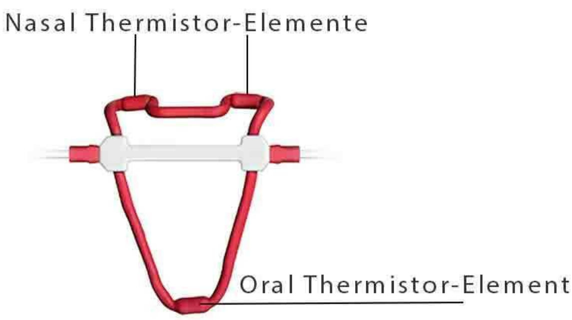


- The spirometer (blue circle) was placed in the mouth and held in place using a strap; a nose plug was used to prevent breathing through the nose.
- The strain sensors (gray rectangles) were placed perpendicular to each other on the chest and abdomen.
- ***The Accelerometer*** (purple square) was placed right below the sternum.
- Airflow was measured by the ***spirometer*** and processed by the Vmax Encore system; the data was then outputted in real time to one of the analog inputs on the digital acquisition system.
- Two ***Wheatstone bridges*** were used to calculate resistance using 4.7 kΩ resistors.
- The output from the accelerometer was directly measured by the ***digital acquisition*** system
- The resistance reading from the strain sensor was first filtered using a ***low pass filter*** with a cutoff frequency of 20 Hz.
- 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.

<u>Measurement of Respiration Rate – 2. Thermistor Method</u>

- 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*.



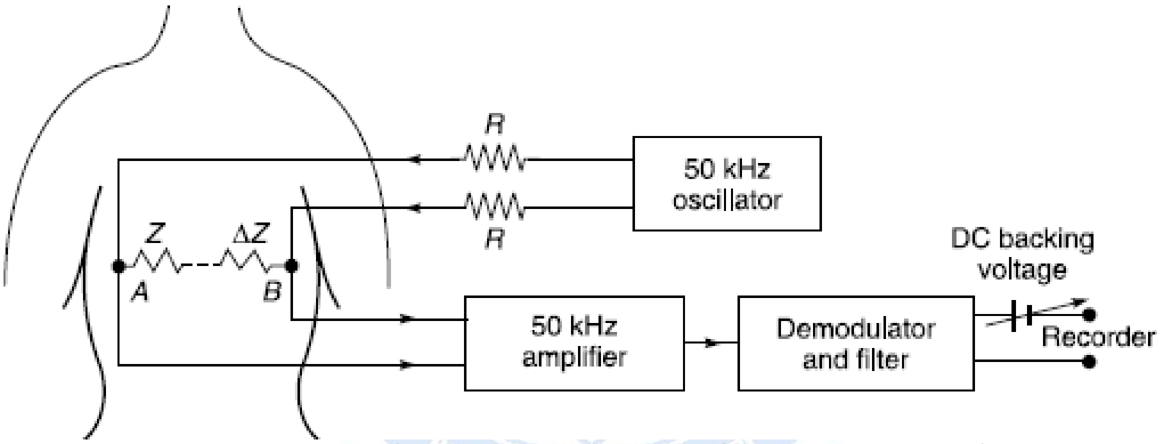
- In case the difference in temperature of the outside air and that of the expired air is small, the ***thermistor*** can even be ***initially heated*** to an appropriate temperature and the variation of its resistance in synchronism with the respiration rate, as a ***result of the cooling effect*** 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 case of some patients who object to having anything attached to their nose or face.
- **<u>Limitations of Thermistor Method:</u>**

1. **Invasive Placement**: Depending on the design of the thermistor system, it may require invasive placement such as ***insertion into the nostrils or mouth***. This can be uncomfortable for the subject and may affect the natural breathing pattern, potentially leading to inaccurate measurements.
2. **Limited Compatibility**: Thermistors may ***not be compatible*** with all types of respiratory monitoring systems or devices. Integration with existing equipment or data collection systems may require additional adaptation or modification.

3. **Signal Interference**: Like any electronic sensor, thermistors are susceptible to ***signal interference*** from other electronic devices or electrical noise. This interference can distort the readings and affect the accuracy of respiration rate measurements.
4. **Calibration Requirements**: Thermistors may require ***regular calibration*** to maintain accuracy

Measurement of Respiration Rate – 3. Impedance Pneumography :

- This is an indirect technique for the measurement of respiration rate.



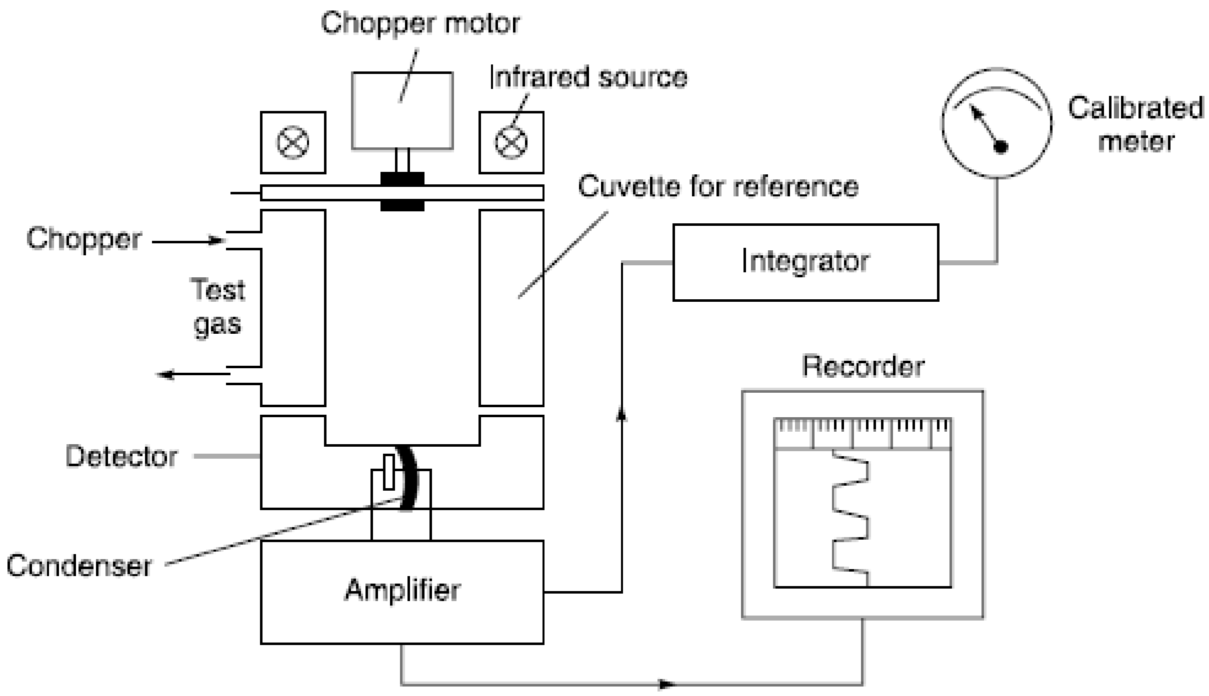
Principle of impedance pneumograph (two electrode method)

- Using externally applied ***electrodes on the thorax***, the impedance pneumograph measures rate through the relationship between respiratory depth and ***thoracic impedance change.***
- The technique ***avoids encumbering*** the subject with masks, tubes, flowmeters or spirometers.
- It does not impede respiration and has ***minimal effect*** on the ***psychological*** state of the subject.
- Passing a ***high frequency current*** through the appropriately placed electrodes on the surface of the body and detecting the modulated signal.
- The signal is ***modulated*** by changes in *the body* ***impedance***, accompanying the respiratory cycle.

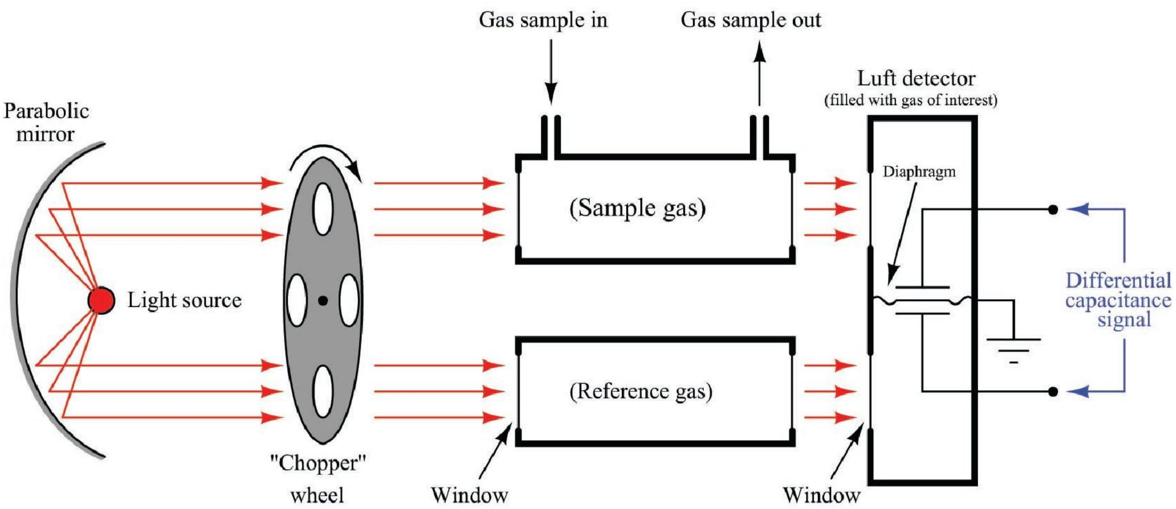
- The electrode used for impedance pneumograph are of the ***self-adhesive*** *type.*
- Contact with the skinis made through the *electrode cream layer* for minimizing ***motion artefacts.***
- The electrodes, when the skin is properly prepared, offer an impedance of ***150 to 200 W.***
- The change in impedance corresponding to each respiratory cycle is of the order of ***1% of the base impedance.***
- The ***two-electrode impedance pneumograph*** is convenient for use with quiet subjects.
- Movement artifacts are produced due to changes in the electrode contact impedance, in case the subject is moving. These artefacts can be significantly reduced by using a ***four- electrode impedance pneumograph*****.**
- **To avoid** the stimulation of **sensory receptors**, nerves and muscle, currents ***higher in frequency than 5 kHz*** must be used for the measurement of physiological events by impedance.
- Frequencies ***lower than 5 kHz are particularly hazardous*** since ventricular fibrillation may be produced with substantial current flow.
- The use of higher frequencies not only provides the protection sought in the avoidance of tissue stimulation, but also provides the ***safe use of currents*** of magnitude, which could be ***lethal*** if the frequencies were lower.
- The impedance-based method of measuring respiration rate is commonly employed in ***patient monitoring systems****.*
- The *electrodes* used for this purpose are the same as those used for ***ECG.***
- measurement. The dynamic measuring range of the amplifier is ***0.1 to 3.0 W*** with a frequency response of ***0.2 to 3.0 Hz*** *corresponding to respiratory rate of* ***12 to 180 per minute****.*
- The ***amplifier*** operates within an impedance window established by the static impedance level (approx. 3 k ohms) and its ***output*** produces a ***respiratory waveform*** *from* which respiratory rate is derived.

Measurement of Respiration Rate – 4. CO_2 Method:

- Respiration rate can also be derived by ***continuously monitoring the CO_2*** contained in the subject's alveolar air.
- The measurement is based on the ***absorption property of infrared rays*** by certain gases.
- Suitable ***filters are required*** to determine the concentration of specific gases (like CO_2, CO, and NO_2) constituting the expired air.
- When infrared rays are passed through the expired air containing a certain amount of CO_2, some of the ***radiations are absorbed*** *by* it.



Measurement of Respiration using CO_2 Method



Schematic diagram of CO_2 Analyzer

- Two beams of equal intensity of ***infrared radiations*** from the hot-wire spirals fall on one half of each of the ***condenser microphone*** assembly.
- The detector has two identical portions separated by a thin, **flexible *metal diaphragm.***
- The detector is filled with a ***sample of pure CO_2.***
- Because of the ***absorption of CO_2*** in the analysis cell, the beam falling on the test side of the detector is ***weaker than*** that falling on the ***reference side.***
- The gas in the ***reference side*** would, therefore, *be* ***heated more*** *than* that on the analysis side.
- As a result, the ***diaphragm is pushed*** slightly to the analysis side of the detector.
- The diaphragm forms ***one plate of*** *a capacitor*
- The infrared beams are ***chopped at 25 Hz*** and the alternating signal which appears across the detector ***is amplified, shaped*** and suitably integrated to give ***the respiration rate***.

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4.1.3 PULSE RATE MEASUREMENT :

- The normal pulse for healthy adults ranges from 60 to 100 beats per minute. The pulse rate may fluctuate and increase with exercise, illness, injury, and emotions.

Age	Normal Resting Pulse (bpm)
0-1 months (newborns)	70-190
1-11 months (infants)	80-160
1-2 years	80-130
3-4 years	80-120
5-6 years	75-115
7-9 years	70-110
10-17 years	60-100
18-25 years	66-69
26-35 years	66-72
36-45 years	67-73
46-55	68-73
56-65	68-73
65+	66-72

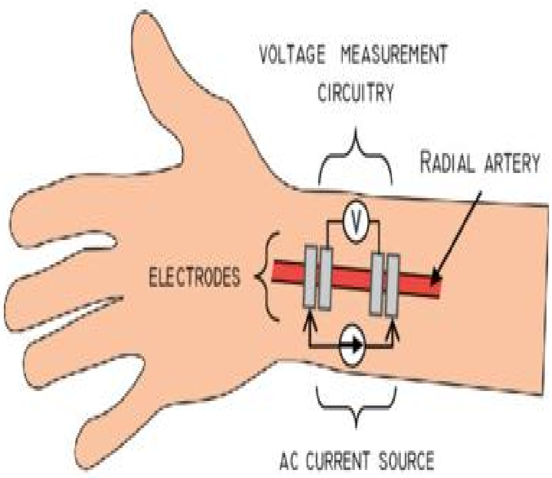
- Each time the heart muscle contracts, blood is ejected from the ventricles and a ***pulse** of **pressure is transmitted*** through the circulatory system.
- This pressure pulse when travelling through the vessels, causes ***vessel-wall displacement***, which is measurable at various points of the peripheral circulatory system.
- The pulse can be felt by placing the ***finger tip over the radial artery*** in the wrist or some other location where an artery seems just below the skin.
- The ***timing and wave shape*** of the pressure pulse are ***diagnostically important*** as they provide valuable information.

- Instruments used to detect the arterial pulse and pulse pressure waveforms in the extremities are called ***plethysmographs.***
- Most plethysmograph techniques respond to a ***change in the volume of blood*** as a measure of blood pressure.
- The methods used for the detection of *volume (pulse) changes* due to blood flow are:

   i. Electrical Impedance Changes
   ii. Strain gauge or microphone (Mechanical)
   iii. Optical Changes (Photoelectric method)

1. Electrical Impedance Changes: (Impedance Plethysmography) :

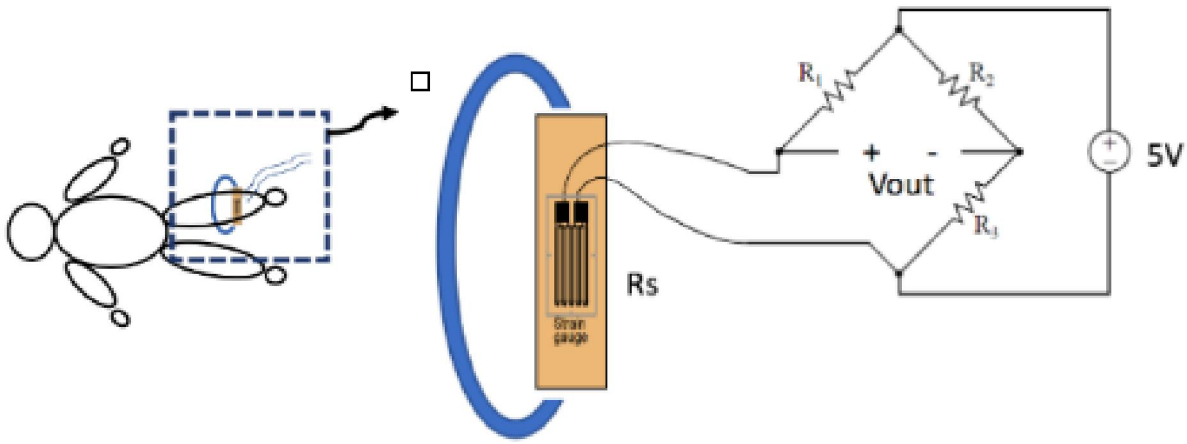
- An electric impedance method measures the ***impedance change between two electrodes*** caused by the change in blood volume between them.
- The change in impedance ***(0.1 ohm)*** may be small as compared to the total impedance (several hundred ohms).
- The impedance is measured by ***applying an alternating current*** between electrodes attached to the body.
- An alternating signal (10–100 kHz) is used (rather than DC) in order to ***prevent polarization*** of the electrodes.
- In a plethysmograph, changes in impedance are measured by applying a ***small electrical current*** through the body part being examined and then measuring the resulting voltage.

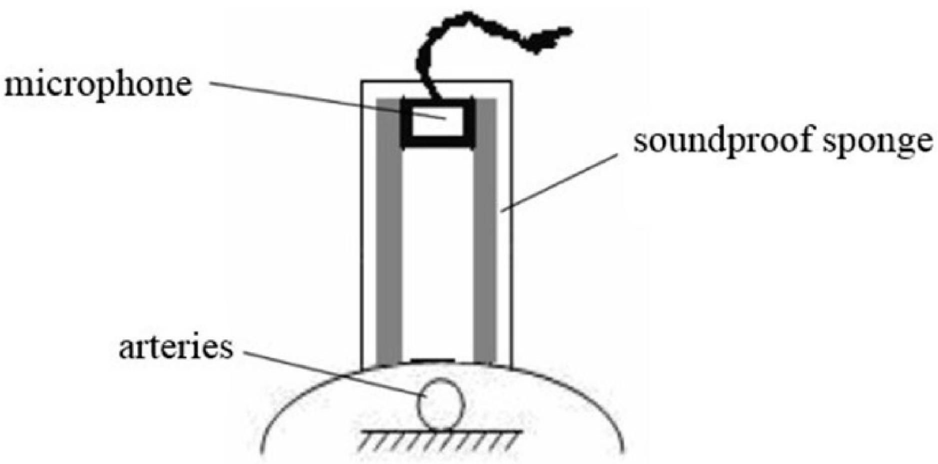


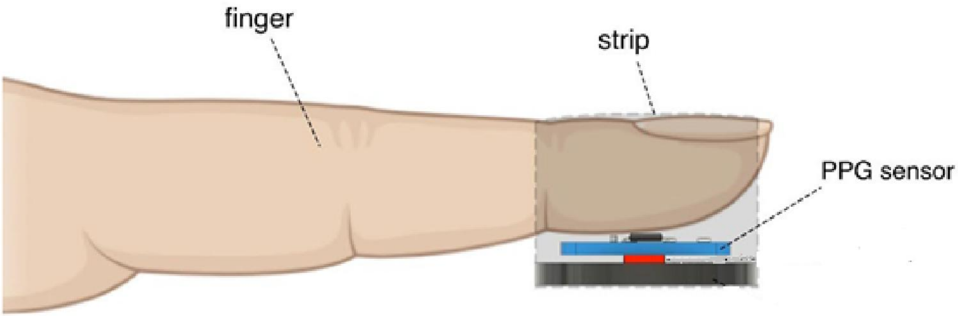
- As the volume of the body part changes (for example, due to blood flow), the ***impedance changes*** accordingly.
- By analyzing these changes, the device can provide information about ***blood flow, volume changes, and other physiological parameters***.

2. Strain gauge or microphone (Mechanical) :

- The mechanical method involves the use of a *strain gauge* connected to a rubber-band placed ***around a limb or finger***.
- Expansion in the band due to change in blood volume causes a change in ***resistance of the strain gauge***.
- In another technique, a sensitive *crystal microphone* is placed on the ***skin's surface*** to pick up the pulsation.

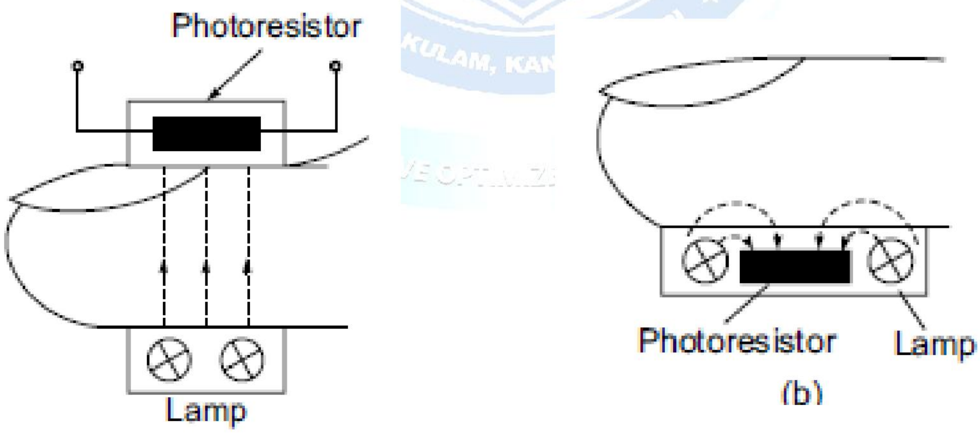






3. Photoelectric Method :

- The most *commonly used method* to measure pulsatile blood volume changes is by the photelectric method.
- Two methods are common:
  - ✓ *Reflectance* method and
  - ✓ *Transmittance* method.
- Figure shows the shape of pulse waveform picked up by photoelectric method.

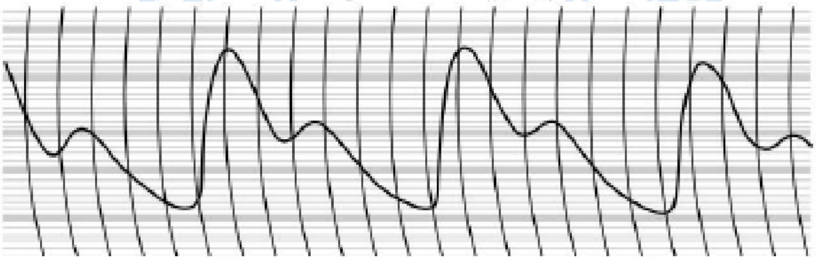


(a) Transmission method (b) reflectance method

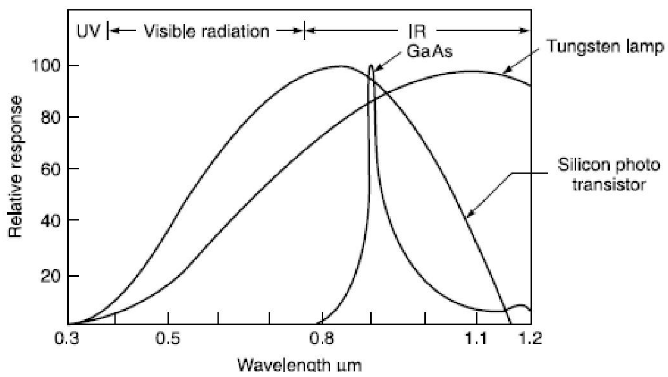
Arrangement of photoresistor and lamp in a finger probe for pulse pick-up

- In the transmittance method, a ***LED and Photoresistor*** are mounted in an enclosure that fits over the tip of the patient's finger.

- Light is ***transmitted*** through the finger tip of the subject's finger and the ***resistance of the photoresistor*** is determined by the amount of light reaching it.
- With each contraction of the heart, blood is ***forced to the extremities*** and the amount of blood in the finger ***increases.***
- It ***alters*** the ***optical density*** with the result that the light transmission through the finger reduces and the resistance of the photoresistor increases accordingly.
- The photoresistor is connected as part of a ***voltage divider*** *circuit* and produces a voltage that varies with the amount of blood in the finger.
- This voltage that closely follows the ***pressure pulse*** and its waveshape can be displayed on an ***oscilloscope*** or recorded on a strip-chart recorder.
- The arrangement used in the *reflectance method of photoelectric* plethysmography is shown in Fig. (b)



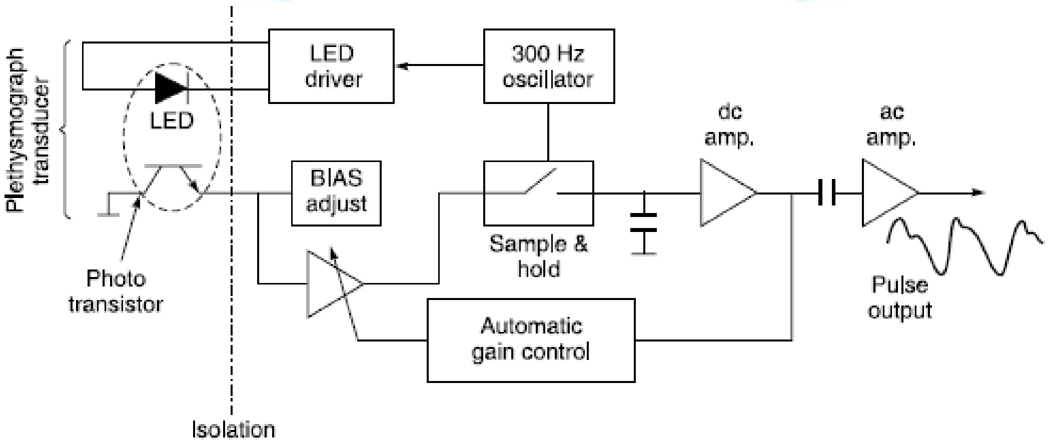
Pressure pulse waveform picked up by photoelectric method



Relative spectral response for silicon phototransistor and the radiant spectral distribution of a tungsten lamp and a gallium-arsenide lamp

Reflectance Method:

- Phototransistor is placed ***adjacent*** *to LED*
- Part of the Light rays emitted by LED is ***reflected and scattered*** from the skin and tissues and falls on the photoresistor
- The quantity of light reflected is determined by the ***blood saturation*** *of the* ***Capillaries***.
- Therefore, the voltage drops across the photoresistor, connected as a voltage divider, will vary in proportion to the ***volume changes of the blood vessels***.
- LED Phototransistor and Photo plethysmograph transducer consists of *Ga- As* ***Infrared emitting diode and a phototransistor*** in a compact package measuring 6.25 x 4.5 x 4.75 mm.
- The phototransistor is sensitive to radiation between ***400 and 1100 nm.***
- For pulse rate measurement, a photoelectric transducer suitable for use on the ***finger or ear lobe*** is used.
- The signal from the photocell is ***amplified and filtered*** **(0.5 to 5 Hz passband)** and the time interval between two successive pulses is measured.
- Careful *placement* and application of the device is essential in order to prevent ***movement artefacts*** due to mechanical distortion of the skin.
- Fig. shows the ***block diagram*** *for processing* the plethysmograph signal detected from a photoelectric transducer



Block diagram for processing plethysmographic signal

- Produce 300 Hz, 50 ms ***infrared light pulses*** to the finger probe attached to the patient, and a phototransistor that picks up the attenuated light.
- The electrical signal obtained from the phototransistor is *amplified* and its peak value is ***sampled*** *and* ***filtered*****.**
- An ***automatic gain control*** **circuit** adjusts the amplifier gain to yield a constant average pulse height at the output.
- The ac component with a frequency in the heart rate range (0.8–5 Hz), is *further* ***amplified*** to output the plethysmographic pulse rate form.
- This signal is transmitted across the ***isolation barrier, demodulated, low-pass filtered and transmitted*** *to the analog multiplexer* resident on the CPU board.

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