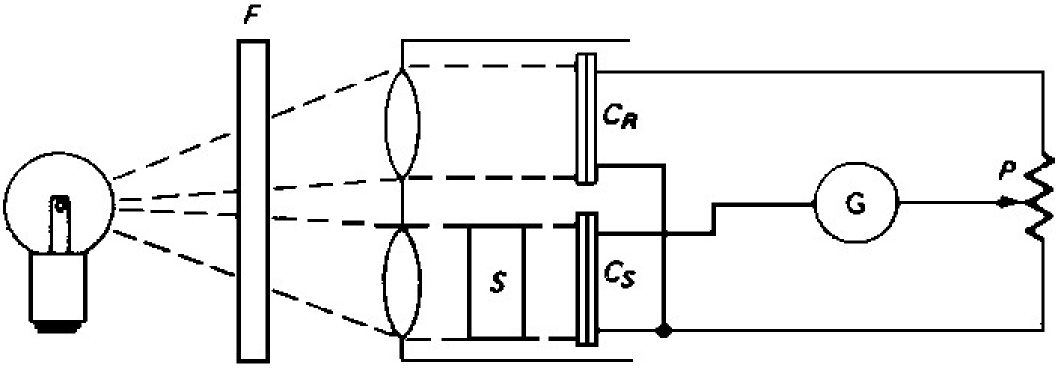
UNIT – IV

MEASUREMENT OF NON-ELECTRICALPARAMETERS

1. FILTER PHOTOMETER (COLORIMETER):

The schematic diagram of a simple filter photometer is as shown in the figure below. It is used to measure transmittance.



Filter photometer

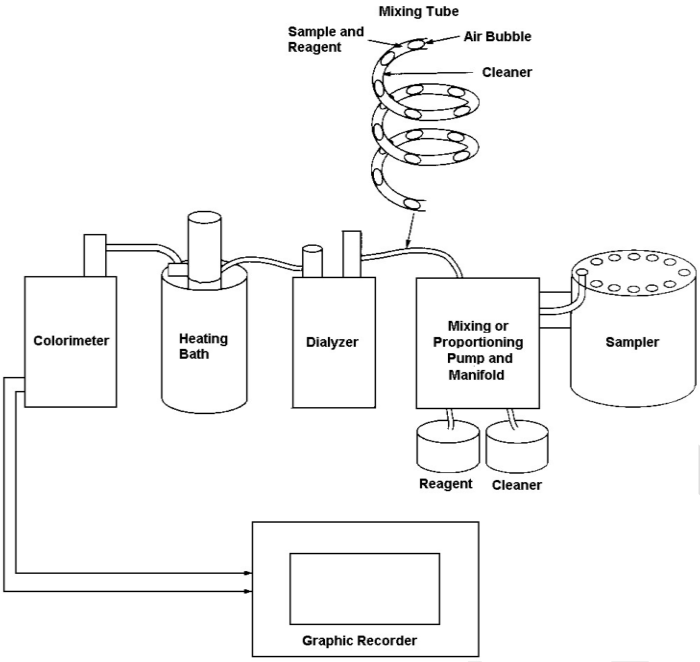
Light from a halogen lamp is made to incident on a filter, F. It transmits only a suitable wavelength range, at which the measurement is performed. The divergent transmitted light is converted into two parallel beams by an optical arrangement. One beam on a reference selenium photoelectric cell, C_R and other beam fall on a sample selenium photoelectric cell Cs after passing through sample in the cuvette. Without the sample, the outputs from photoelectric cells are same. When the sample is placed in the path, the output of the sample cell is reduced and hence the potentiometer is adjusted that both the cells C_R and Cs give the same output which is indicated by the null deflection in the galvanometer 'G'. Since the potentiometer is calibrated in terms of transmittance, the concentration of the given substance in the sample can be determined.

2. AUTOANALYSER:

The autoanalyzer sequentially measures blood chemistry and displays this on a graphic readout. As shown in Figure below, this is accomplished by mixing, reagent reaction, and colorimetric measurement in a continuous stream. The system includes the following elements.

1. Sampler - aspirates samples, standards, and wash solutions to the autoanalyzer system.
2. Proportioning pump and manifold - introduces (mixes) samples with reagents to effect the proper chemical color reaction to be read by the colorimeter. It also pumps fluids at precise flow rates to other modules, as proper color development depends on reaction time and temperature.
3. Dialyzer - separates interfacing substances from the sample material by permitting selective passage of sample components through a semipermeable membrane.
4. Heating bath - heats fluids continuously to exact temperature (typically 37°C incubation, equivalent to body temperature). Temperature is critical to color development.

5. Colorimeter - monitors the changes in optical density of the fluid stream flowing through a tubular flow cell. Color intensities (optical densities) proportional to substance concentrations are converted to equivalent electrical voltages
6. Recorder – Converts optical density electrical signal from the colorimeter into a graphic display on a moving chart.



The heart of the autoanalyzer system is the proportioning pump. This consists of a peristaltic pump. Air segmentation in the mixing tube separates the sample / reagent mixture from the cleaning fluid and other samples. As these air-separated fluids traverse the coil of the mixing tube, effective mixing action is achieved.

One problem with automatic analyzer is certain identification of samples. Patient data can be intermixed with that of other patients if care is not taken.

Sterilization is also needed for samples, glassware and equipment parts that are contaminated with disease. Diseases such as hepatitis or other communicable infections can be spread to equipment operators.

3. <u>RESPIRATORY MEASUREMENT:</u>

Measurement of Respiration rate:

The transducers commonly used to measure respiration rate are,

i) Thermistor placed in front of the nostril ii)
Displacement transducer put across the chest iii)
Impedance electrodes

❖ The respiratory signal from any one of these transducers is amplified and the time interval is measured between two successive pulses.

- ❖ The measuring range is 0-50 respiration / minute.
- ❖ The methods used to measure respiration rate are, ○ Thermistor method ○ Impedance Pneumography ○ CO_2 measurement of respiration rate ○ Displacement method

1. Thermistor Method:

In this method a thermistor is placed in front of the nostrils by means of a suitable holding device to detect the difference in temperature between the inspired and expired air.

Since the inspired air passes through the lungs and respiratory tract, its temperature is increased while coming out. This change in temperature is detected by using thermistor.

Incase the difference in temperature of the outside air and expired air is small, the thermistor can be initially heated to an appropriate temperature and the variation of its resistance in synchronous with the respiration rate can be detected.

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 respiration rate.

Occasionally, unconscious patients display a tendency for the uncontrolled tongue to block the breathing system. Under such systems not a single milliliter of air is inhaled, but the patient's thorax is carrying out large air through frustral breathing.

The impedance pneumograph and switch methods will show the correct state.

2. Displacement Method:

During each respiratory cycle, the thoracic volume changes. These changes can be sensed by means of displacement transducer.

The transducer is held by an elastic band which goes around the chest.

The respiratory movement results 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

During inspiration, the chest expands and the rubber tube increases in length and the resistance of the mercury from one end of the tube to the other end changes. The change in resistance can be measured by sending a constant current through it and measured in terms of change in voltage during each respiratory cycle.

3. Impedance Pneumography:

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

Impedance Pneumograph is based on the fact that the impedance across the chest changes during each respiratory cycle.

In this method, a low voltage 50 to 500KHz AC signal is applied to the chest of the patient through surface electrodes and the modulated signal is detected.

The signal is modulated by changes in the body impedance accompanying the respiratory cycle.

High value fixed resistors are connected in series with each electrode to create a constant AC current source. The signal voltage applied to the differential AC amplifier is the voltage drop across the resistance representing patient's thoracic impedance. **$E_o = I.(R \pm \Delta R)$**

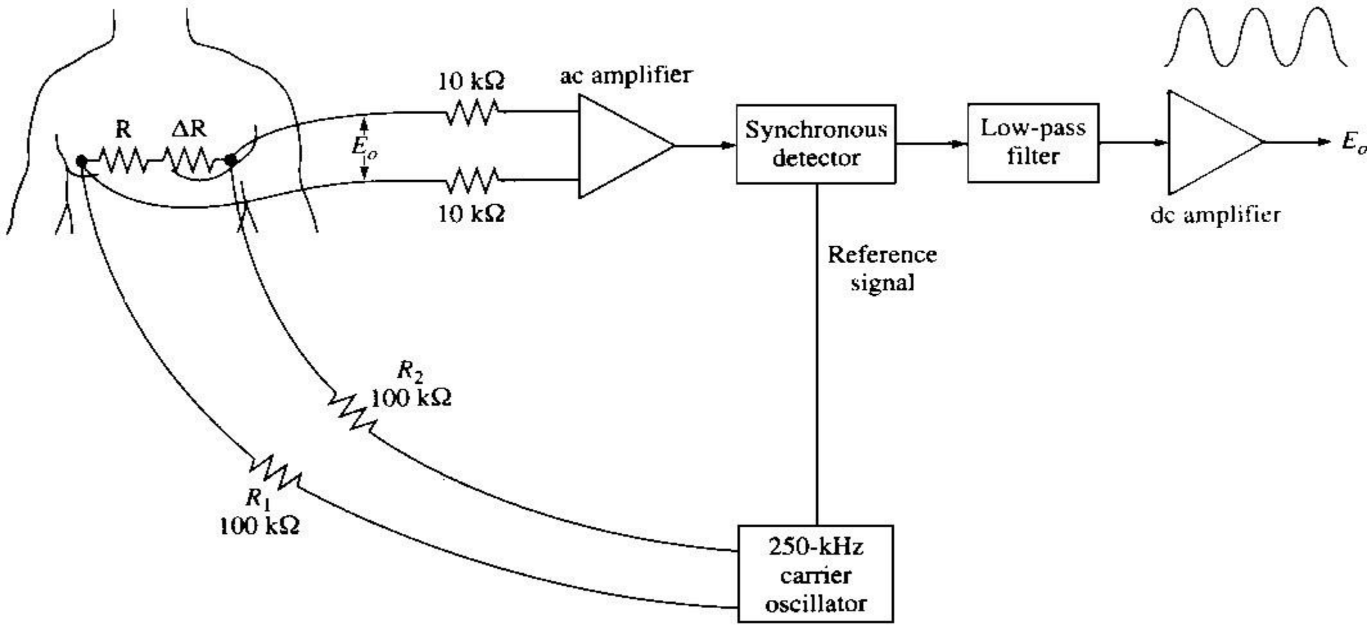
Where,

E_o – Output potential in volts.

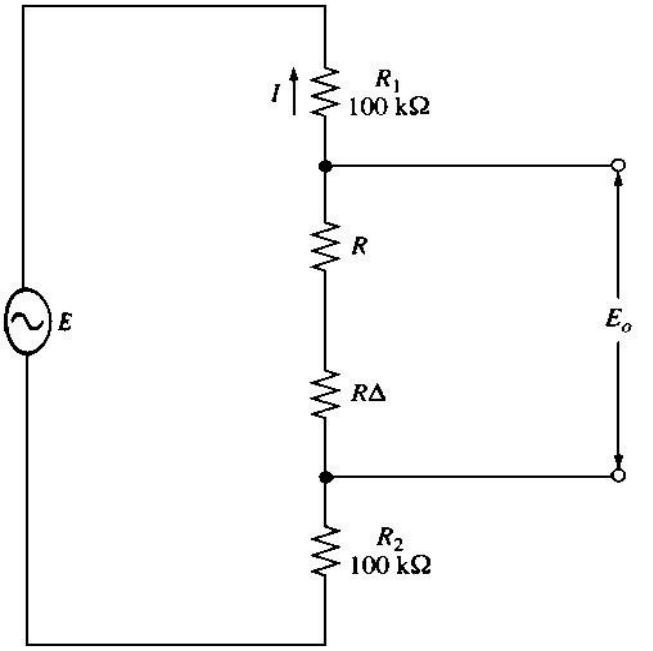
I – Current through the chest in amps.

R – Chest impedance without respiration in ohms.

ΔR – Change of chest impedance caused by respiration in ohms.



(a) Block diagram



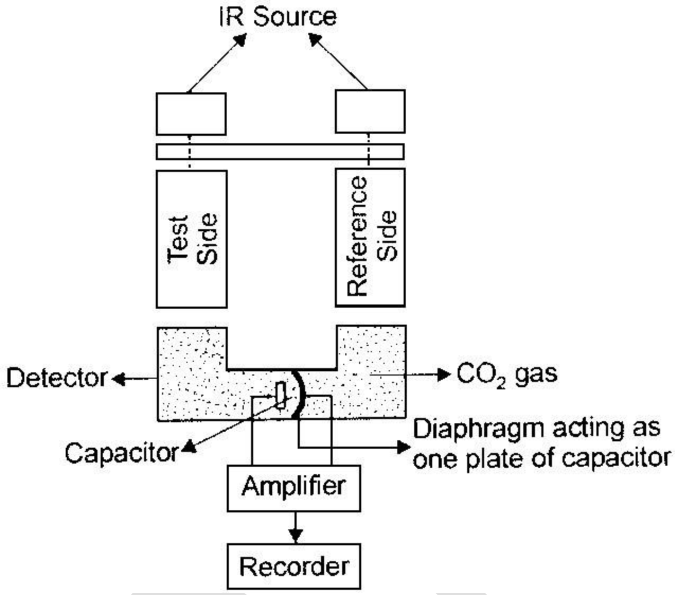
(b) Equivalent circuit

The current passed through the patient's chest is very small. The signal E_o is amplified and then demodulated by AM detector.

The Low Pass Filter removes the residual carrier signal and a DC amplifier scales the output waveform to the level required by the display device.

4. CO_2 method of respiration rate measurement:

Respiration rate can also be measured 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 used to determine the concentration of specific gases (like CO, CO_2, and NO_2) present in the expired air.

Rare gases and diatomic gases do not absorb infrared rays.

When infrared rays are passed through the expired air containing a certain amount of CO_2 some of the radiations are absorbed by it. There is a proportional loss of heat energy associated with the rays.

The detector converts this heat loss of the rays into an electrical signal. This signal is used to obtain the average respiration rate.

The arrangement for detection of CO_2 in the expired air is shown in the above figure.

Two beams of equal intensity of infrared radiations from the infrared source fall on one half of each of the condenser microphone assembly.

The infrared rays from the infrared source are chopped at 25 KHz by the chopper motor. A disc is connected to the spindle of the chopper motor.

The detector has two identical portions separated by a thin flexible metal diaphragm. One is called test side and the other is called as reference side.

The detector is filled with a sample of pure CO_2. Because of 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 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 the capacitor.

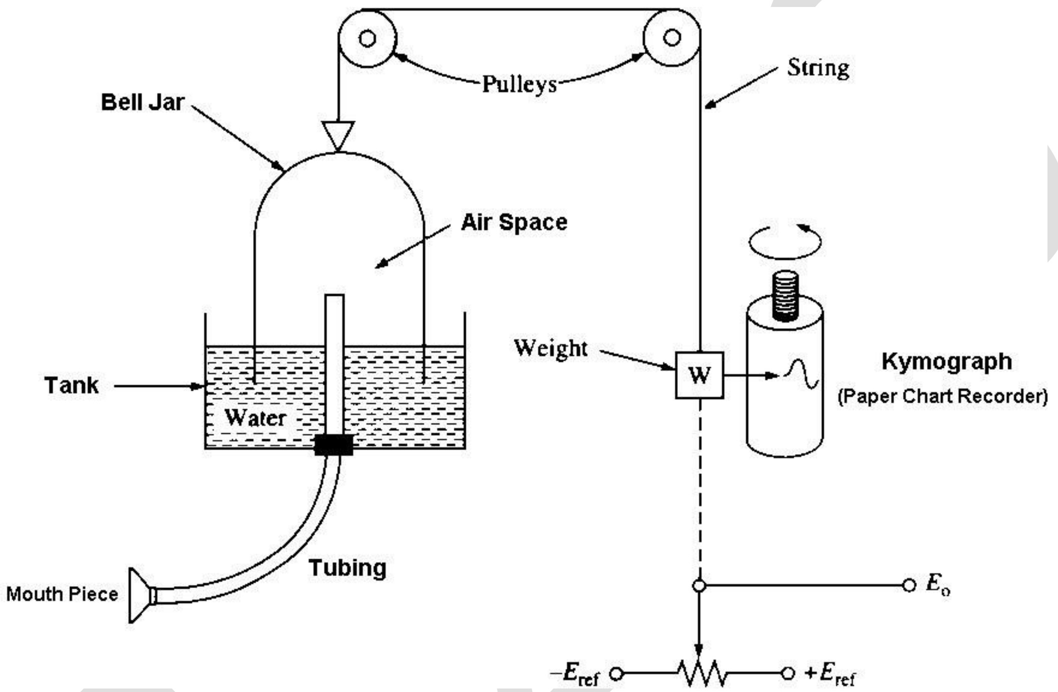
The voltage developed across the diaphragm is amplified, shaped and suitably integrated to the give the respiration rate.

Spirometer:

Conventional spirometer is shown in figure below. This instrument uses a bell jar, suspended from above, in a tank of water. An air hose leads from a mouthpiece to the space inside of the bell above the water level. A weight is suspended from the string that holds the bell in such a way that it places a tension force on the string that exactly balances the weight of the bell at atmospheric pressure.

When no one is breathing into the mouthpiece, the bell will be at rest with a fixed volume above the water level. But when the subject exhales, the pressure inside the bell increases above atmospheric pressure causing the bell to rise. Similarly, when the patient inhales, the pressure inside the bell decreases. The bell will rise when the pressure increases and drop when the pressure decreases.

The change in bell pressure changes the volume bell, which also causes the position of the counterweight to change. We may record the volume changes on a piece of graph paper by attaching a pen to the counterweight or tension string.



Bell-Jar mechanical Spirometer

The chart recorder is a rotary drum model called a **kymograph**. It rotates slowly at speeds between 30 and 2000 mm/min.

Some spirometers also offer an electrical output that is the electrical analog of the respiration waveform. Most frequently the electrical output is generated by connecting the pen and weight assembly to a linear potentiometer. If precise positive and negative potentials are connected to the ends of the potentiometer, then the electrical signal will represent the same data as the pen. When no one is breathing into the mouthpiece, E_o will be zero. But when a patient is breathing into the tube, E_o will take a value proportional to the volume and a polarity that indicates inspiration or expiration.

4. <u>TEMPERATURE MEASUREMENT:</u>

Temperature measurement is one of the most essential commonly used parameter in the medical field.

The variation in the temperature is a direct result of the variation in blood pressure. The metabolic rate and temperature have a close relation.

Body temperature is one of the indicators of a person being normal.

Basically two types of temperature measurement cam be obtained from the human body

1. Systemic

2. Skin surface

Systemic Temperature:

Systemic temperature is the temperature of the internal regions of the body. This temperature is maintained by balancing the heat generated by the active tissues of the body (muscles & Liver) and the heat lost by the body to the environment.

Systemic temperature is measured by using temperature sensing devices placed in mouth, under the armpits or in the rectum.

The normal **oral** (**mouth**) temperature of a healthy person is **37˚C**. The normal **under arm** temperature of a healthy person is **36˚C** and The normal **rectum** temperature of a healthy person is **38˚C**.

The systemic body temperature can be measured more accurately at the tympanic membrane in the ear.

Even for the healthy person, the temperature will not be constant. It will vary about 1 to 1 ½ ˚C in the early morning compared to the late afternoon.

The temperature control center for the body is located deep within the brain. Here the temperature of the blood is monitored and its control functions are coordinated.

If the surrounding temperature is warm, then the body is cooled by perspiration due to secretion of the sweat glands and by increased circulation of blood near the surface. The body acts as a radiator.

If the surrounding temperature becomes too low, then the body conserves heat by reducing the blood flow near the surface to the minimum required for maintenance of the cells. At the same time metabolism is increased.

Surface of Skin temperature:

Surface or skin temperature is a result of a balance but here the balance is between the heat supplied by blood circulation in the local area and the cooling of that area by conduction, radiation, convection and evaporation. Thus skin temperature is a function of the surface circulation, environmental temperature, air circulation around the area from which the measurement is to be taken and perspiration.

To obtain a meaningful skin temperature measurement, it is usually necessary to have the subject remain with no cloth covering the region of measurement in a fairly cool ambient temperature.

Measurement of systemic Body temperature:

1. Mercury Thermometer:

Mercury thermometer is the standard method of temperature measurement.

Mercury thermometer is used where continuous recording of temperature is not required. Mercury thermometers are inexpensive, easy to use and sufficiently accurate.

2. Electronic Thermometer:

Now-a-days electronic thermometers are available as a replacement of mercury thermometer. IT has disposable tip and requires only less time for reading and also much easier to read the value.

Electronic thermometers are used where continuous recording and accuracy of the temperature is necessary.

Two types of electronic temperature sensing devices are found in biomedical applications. They are,

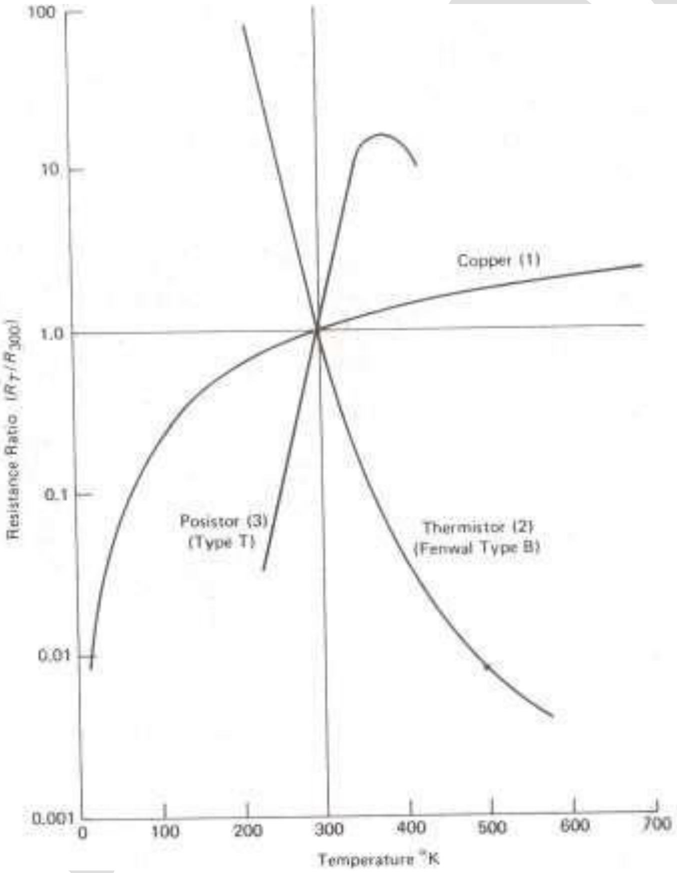
1. Thermocouple
2. Thermistor

Thermistors are variable resistance devices formed into disks, Beads, Rods or other desired shapes. They are manufactured from mixtures of oxides of various elements such as nickel, copper, magnesium, manganese, cobalt, titanium and aluminium.

After the mixture is compressed into shape, it is shaped at a high temperature into a solid mass. The result is a resistor with a large temperature coefficient.

Most metals show an increase in resistance of about 0.3 to 0.5 percent per ˚C temperature rise and the thermistors show decrease in resistance by 4 to 6 percent per ˚C temperature rise.

A Comparison of resistance Vs Temperature curves for copper, thermistor, posistor is as shown below.



Skin temperature Measurement:

Although the systemic skin temperature remains very constant throughout the body, skin temperature can vary several degrees from one point to another. The range is usually from about 30 to 35°C (85 to 95F). Exposure to ambient temperatures, the covering of fat over capillary areas, and local blood circulation patterns are just a few of the many factors that influence the distribution of temperatures over the surface of the body. Often, skin temperature measurements can be used to detect or locate defects in the circulatory system by showing differences in the pattern from one side of the body to the other.

Skin temperature measurements from specific locations on the body are frequently made by using small, flat thermistor probes taped to the skin. The simultaneous readings from a number of these probes provide a means of measuring changes in the spatial characteristics of the circulatory pattern over a time interval or with a given stimulus.

Although the effect is insignificant in most cases, the presence of the thermistor on the skin slightly affects the temperature at that location. Other methods of measuring skin temperature that draw less heat from the point of measurement are available. The most popular of these methods involve the measurement of infrared radiation.

The human skin has been found to be an almost perfect emitter of infrared radiation. That is, it is able to emit infrared energy in proportion to the surface temperature at any location of the body. If a person is allowed to remain in a room at about 21°C (70°F) without clothing over the area to be measured, a device sensitive to infrared radiation can accurately read the surface temperature. Such a device, called an ***infrared thermometer***.

Infrared thermometers in the physiological temperature range are available commercially and can be used to locate breast cancer and other unseen sources of heat. They can also be used to detect areas of poor circulation and other sources of coolness and to measure skin temperature changes that reflect the effects of circulatory changes in the body.

An extension of this method of skin temperature measurement is the ***Thermograph***. This device is an infrared thermometer incorporated into a scanner so that the entire surface of a body, or some portion of the body, is scanned in much the same way that a television camera scans an image, but much slower. While the scanner scans the body, the infrared energy is measured and used to modulate the intensity of a light beam that produces a map of the infrared energy on photographic paper. This presentation is called a ***thermogram****.*

The advantage of this method is that relatively warm and cool areas are immediately evident. By calibrating the instrument against known temperature sources, the picture can be read quantitatively.

A similar device, called ***Thermovision****,* has a scanner that operates at a rate sufficiently high to permit the image to be shown in real time on an oscilloscope. The raster has about 100 vertical lines per frame, and the horizontal resolution is also about 100 lines, which seems to be adequate for good representation. The intensity of the measured infrared radiation is reproduced by Z-axis modulation of the oscilloscope beam. One advantage of this system is that certain portion of the grey scale can be enhanced to bring out specific features of the picture. Also, the image can be changed so that warm spots appear dark instead of light.

5. MEASUREMENT OF PULSE RATE:

Whenever 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 traveling through the vessels causes vessel wall displacement which is measurable at various points of peripheral circulatory system.

The pulse can be felt by placing the finger tip over the radial artery in the wrist or some other locations where an artery seems just below the skin.

The pulse pressure and waveform are indicators for blood pressure and blood flow. The instrument used to detect the arterial pulse and pulse pressure waveform is called as plethysmograph.

The pulse waveform travels at 5 to 15 m/sec depending up on the size and rigidity of arterial walls.

The methods used to detect volume (pulse) change due to blood flow are,

1. Electrical Impedance changes
2. Strain Gauge or microphone (mechanical)
3. Optical change (Changes in density)

Electrical Impedance changes:

Electrical Impedance method measures the impedance change between 2 electrodes caused by the change in blood volume between them.

The change in the impedance (0.1 ohm) may be as 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 current (10 – 100 KHz) is used.

Strain Gauge or microphone (mechanical):

The mechanical method involves the use of strain gauge connected to a rubber band placed around the limb or finger.

Expansion in the band due to change in blood volume causes a change in resistance of the strain gauge. (OR)

A sensitive crystal microphone is placed on the skin surface to pick up the pulsation.

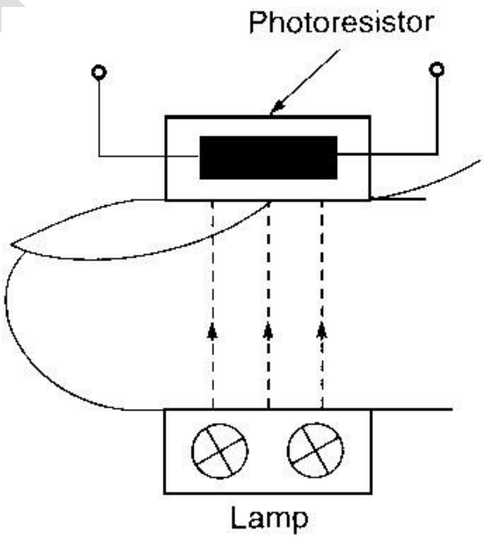
Optical change (Changes in density):

The most commonly used method to measure blood volume change is photo electric method. In this method we have 2 types of method

1. Transmittance method
2. Reflectance method

1. Transmittance method:

In transmittance method, a light emitting diode (LED) and photoresistor are mounted in an enclosure that fits over the tip of the patient's finger. The 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.

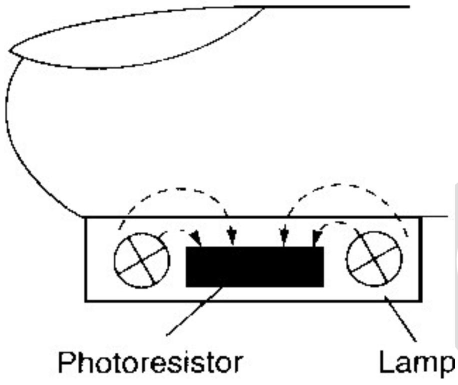


transmission method

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.

2. Reflectance method:

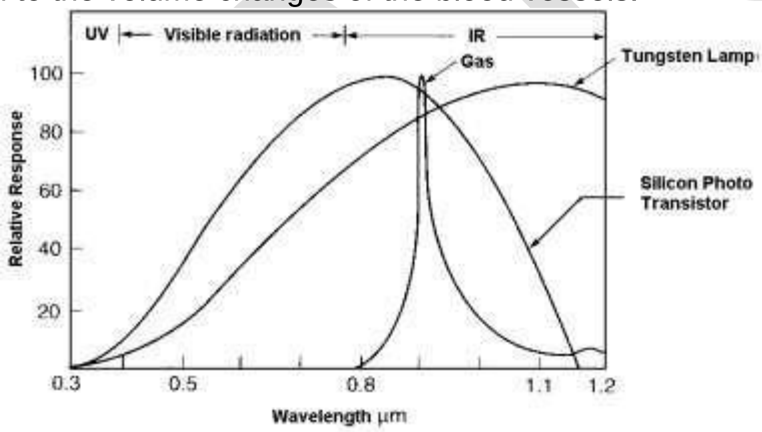
The arrangement used in the reflectance method of photoelectric plethysmography is shown in the figure below.



reflectance method

The photoresistor is placed adjacent to the exciter lamp. Part of the light rays emitted by the LED is reflected and scattered from the skin and the tissues and falls on the photoresistor.

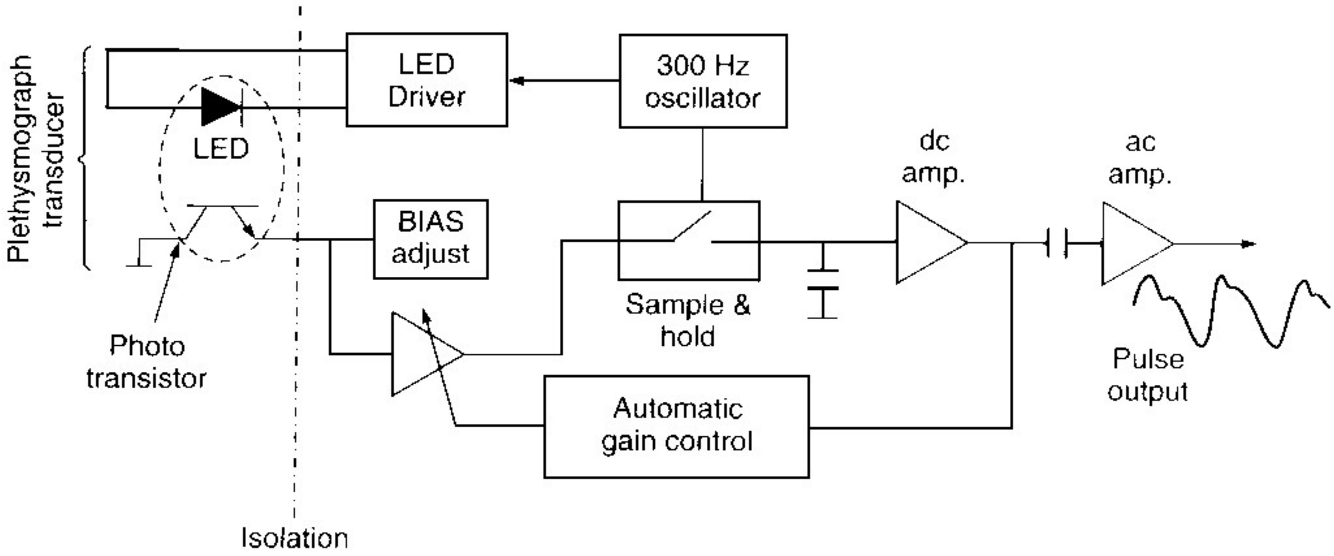
The quantity of light reflected depends upon the amount of blood filling the capillaries and, therefore, the voltage drop across the photoresistor, connected as a voltage divider, will vary in proportion to the volume changes of the blood vessels.



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

The LED phototransistor-photoplethysmograph transducer (Lee et al, 1975) consists of a Ca-As infrared emitting diode and a phototransistor in a compact package measuring 6.25 x 45 x 4.75 mm. The peak spectral emission of the LED is at 0.94 m with a 0.707 peak bandwidth of 0.04 m. The phototransistor is sensitive to radiation between 0.4 and 1.1 m as shown above.

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. The measuring range is 0-250 bpm. Careful placement and application of the device is essential in order to prevent movement artifacts due to mechanical distortion of the skin. The figure below shows the block diagram for processing the plethysmographic signal detected from a photoelectric transducer.



Block diagram for processing plythysmographic signal

The circuit consists of two parts, a LED oscillator and driver, which produce 300 Hz, 50 S 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.

MEASUREMENT OF BLOOD FLOW AND CARDIAC OUTPUT:

An adequate blood supply is necessary for all organs of the body; in fact, an impaired supply of blood is the cause of various diseases. The ability to measure blood flow in the vessel that supplies a particular organ would therefore be of great help in diagnosing such diseases. Unfortunately, blood flow is a rather elusive variable that cannot be measured easily.

The rate of flow of a liquid or gas in a pipe is expressed as the volume of the substance that passes through the pipe in a given unit of time. Flow rates are therefore usually expressed in liters per minute or milliliters per minute (cm^3/min).

Methods used in industry for flow measurements of other liquids, like the turbine flowmeter and the rotameter, are not very suitable for the measurement of blood flow because they require cutting the blood vessel. These methods also expose the blood to sharp edges, which are conducive to blood-clot formation.

Practically all blood flow meters currently used in clinical and research applications are based on one of the following physical principles:

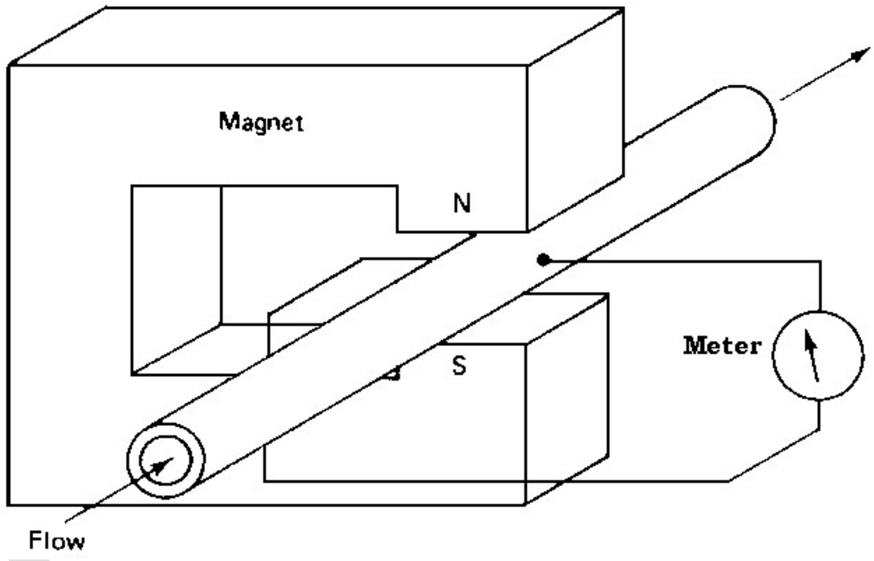
1. Electromagnetic induction.
2. Ultrasound transmission or reflection.
3. Thermal convection.
4. Radiographic principles.
5. Indicator (dye or thermal) dilution

Magnetic and ultrasonic blood flow meters actually measure the velocity of the bloodstream. Because these techniques require that a transducer surround an excised blood vessel, they are mainly used during surgery. Ultrasound, however, can be used transcutaneously to detect obstructions of blood vessels where quantitative blood flow measurements are not required.

A ***plethysmograph****,* which actually indicates volume changes in body segments, can be used to measure the flow of blood in the limbs.

Magnetic Blood Flow Meters:

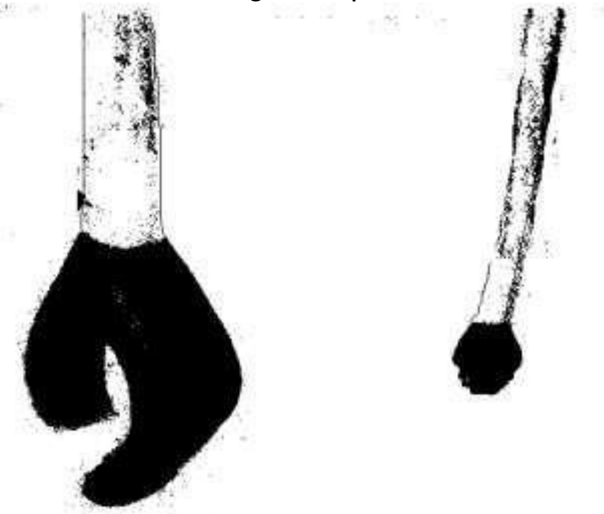
Magnetic blood flow meters are based on the principle of magnetic induction. When an electrical conductor is moved through a magnetic field, a voltage is induced in the conductor proportional to the velocity of its motion. The same principle applies when the moving conductor is not a wire, but rather a column of conductive fluid that flows through a tube located in the magnetic field.



Magnetic Blood flow meter, Principle

A permanent magnet or electromagnet positioned around the blood vessel generates a magnetic field perpendicular to the direction of the blood flow. The voltage induced in the moving blood column is measured with stationary electrodes located on opposite sides of the blood vessel and perpendicular to the direction of the magnetic field

The most commonly used types of implantable magnetic blood flow probes are shown in Figures below. The *slip-on* or C *type* is applied by squeezing an excised blood vessel together and slipping it through the slot of the probe. In some transducer models the slot is then closed by inserting a keystone-shaped segment of plastic. Contact is provided by two slightly protruding platinum disks that touch the wall of the blood vessel. For proper operation, the orifice of the probe must fit tightly, around the vessel. For this reason, probes of this type are manufactured in sets, with diameters increasing in steps of 0.5 or 1 mm from about 2 to 20 mm.



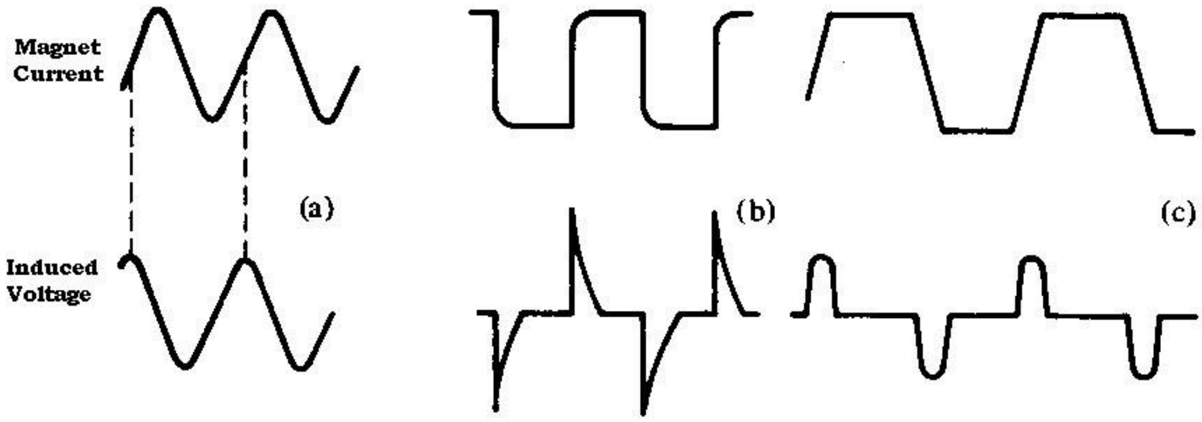
Sample of large and small lumen diameter blood flow probes

Blood flow probe – clip-on type for use during surgery

In the ***cannula-type transducer****,* the blood flows through a plastic cannula around which the magnet is arranged. The contacts penetrate the walls of the cannula. This type of transducer requires that the blood vessel be cut and its ends slipped over the cannula and secured with a suture. A similar type of transducer is also used to measure the blood flow in extracorporeal devices, such as dialyzers.

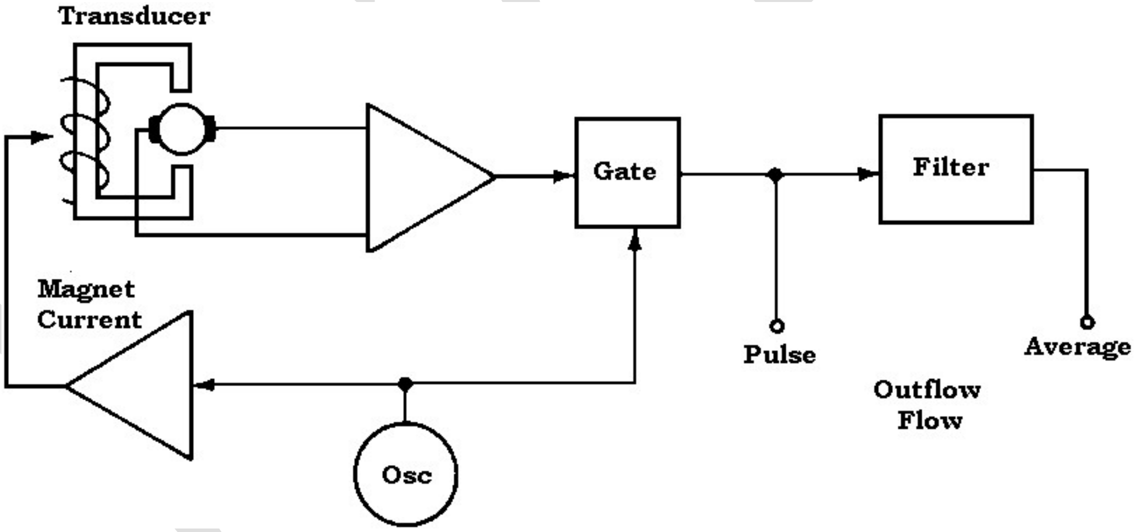
Magnetic blood flow meters actually measure the mean blood velocity. Because the cross-sectional area at the place of velocity measurement is well defined with either type of transducer, these transducers can be calibrated directly in units of flow

The output voltage of a magnetic blood flow transducer is very small, typically in the order of a few microvolts. In early blood flow meters, a constant magnetic field was used, which caused difficulties with electrode polarization and amplifier drift. To overcome these problems, all contemporary magnetic blood flow meters use electromagnets that are driven by alternating currents. But, the change of the magnetic field causes the transducer to act like a transformer and induces error voltages that often exceed the signal levels by several orders of magnitude. Thus, for recovering the signal in the presence of the error voltage, amplifiers with large dynamic range and phase-sensitive or gated detectors have to be used. To minimize the problem, several different waveforms have been advocated for the magnet current, as shown in figure below. With a sinusoidal magnet current, the induced voltage is also sinusoidal but is 90° out of phase with the flow signal.



Waveforms used in magnetic blood flow meter and error signals induced by the current
(a) Sine Wave (b) Sqaure Wave (c) Trapezoidal wave

With a suitable circuit, similar to a bridge, the induced voltage can be partially balanced out. With the magnet current in the form of a square wave, the induced voltage should be zero once the spikes from the polarity reversal have passed. In practice, however, these spikes are often of extremely high amplitude, and the circuitry response tends to extend their effect. A compromise is the use of a magnet current having a trapezoidal waveform. None of the three waveforms used seems to have demonstrated a definite superiority.

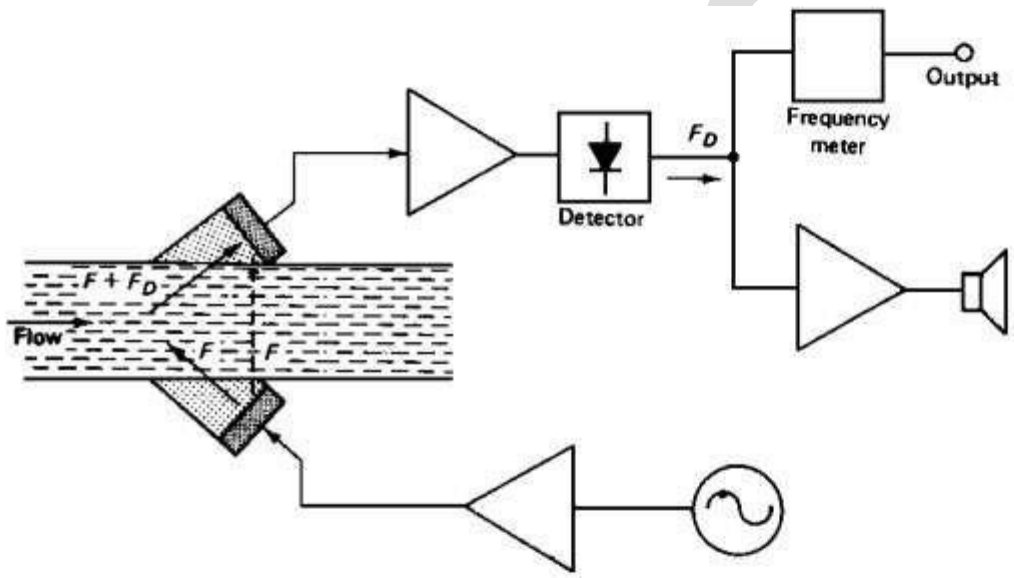


The block diagram of a magnetic blood flow meter is shown in above figure. The oscillator, which drives the magnet and provides a control signal for the gate, operates at a frequency of between 60 and 400 Hz. The use of a gated detector makes the polarity of the output signal reverse when the flow direction reverses. The frequency response of this type of system is mual!y high enough to allow the recording of the flow pulses, while the mean or average flow can be derived by use of a low-pass filter.

Ultrasonic blood flow meter

In an *ultrasonic blood flow meter,* a beam of ultrasonic energy is used to measure the velocity of flowing blood. This can be done in two different ways. In the ***transit time ultrasonic flow meter***, a pulsed beam is directed through a blood. vessel at a shallow angle and its transit time is then measured. When the blood flows in the direction of the energy transmission, the transit time is shortened. If it flows in the opposite direction, the transit time is lengthened.

More common are ultrasonic flow meters based on the Doppler principle. An oscillator, operating at a frequency of several megahertz, excites a piezoelectric transducer (usually made of barium titanate). This transducer is coupled to the wall of an exposed blood vessel and sends an ultrasonic beam with a frequency F into the flowing blood. A small part of the transmitted energy is scattered back and is received by a second transducer arranged opposite the first one. Because the scattering occurs mainly as a result of the moving blood cells, the reflected signal has a different frequency due to the Doppler effect. Its frequency is either $F + F_D$ or $F - F_D$, depending on the direction of the flow.



Ultrasonic blood flow meter, Doppler type

The Doppler component F_D is directly proportional to the velocity of the flowing blood. A fraction of the transmitted ultrasonic energy, however, reaches the second transducer directly, with the frequency being unchanged. After amplification of the composite signal, the Doppler frequency can be obtained at the output of a detector as the difference between the direct and the scattered signal components.

With blood velocities in the range normally encountered, the Doppler signal is typically in the low audio frequency range. Because of the velocity profile of the flowing blood, the Doppler signal is not a pure sine wave, but has more the form of narrow-band noise. Therefore, from a loudspeaker or earphone, the Doppler signal of the pulsating blood flow can be heard as a characteristic "swish-swish-." When the transducers are placed in a suitable mount (which defines the area of the blood vessel), a frequency meter used to measure the Doppler frequency can be calibrated directly in flow-rate units. Unfortunately, Doppler flow meters of this simple design cannot discriminate the direction of flow. More complicated circuits, however, which use the insertion of two quadrature components of the carrier, are capable of indicating the direction of flow.

Transducers for ultrasonic flow meters can be implanted for chronic use. Some commercially available flow meters of this type incorporate a telemetry system to measure the blood flow in unrestrained animals.

Blood Flow measurement by Thermal convection:

A hot object in a colder-flowing medium is cooled by thermal convection. The rate of cooling is proportional to the rate of the flow of the medium. This principle, often used to measure gas flow, has also been applied to the measurement of blood velocity. In one application, a thermistor in the bloodstream is kept at a constant temperature by a servo system. The electrical energy required to maintain this constant temperature is a measure of the flow rate. In another method an electric heater is placed between two thermocouples or thermistors that are located some distance apart along the axis of the vessel. The temperature difference between the upstream and the downstream sensor is a measure of the blood velocity. A device of the latter type is sometimes called *a thermostromuhr* (literally, from the German "heat current clock"). Thermal convection methods for blood flow determination, although among the oldest ones used for this purpose, have now been widely replaced by the other methods described in this chapter.

Blood Flow Determination by Radiographic Methods:

Blood is not normally visible on an X-ray image because it has about the same radio density as the surrounding tissue. By the injection of a contrast medium into a blood vessel (e.g., an iodated organic compound), the circulation pattern can be made locally visible. On a sequential record of the X-ray image (either photographic or on a videotape recording), the progress of the contrast medium can be followed, obstructions can be detected, and the blood flow in certain blood vessels can be estimated. This technique, known as *cine* (or *video) angiography,* can be used to assess the extent of damage after a stroke or heart attack.

Another method is the injection of a radioactive isotope into the blood circulation, which allows the detection of vascular obstructions (e.g., in the lung) with an imaging device for nuclear radiation, such as a scanner or gamma camera.

Vascular obstructions in the lower extremities can sometimes be detected by measuring differences in the skin temperature caused by the reduced circulation.