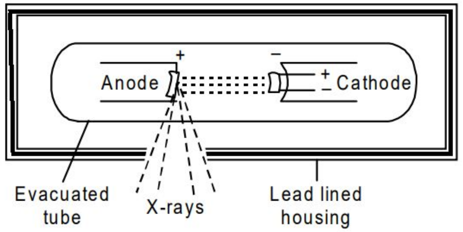
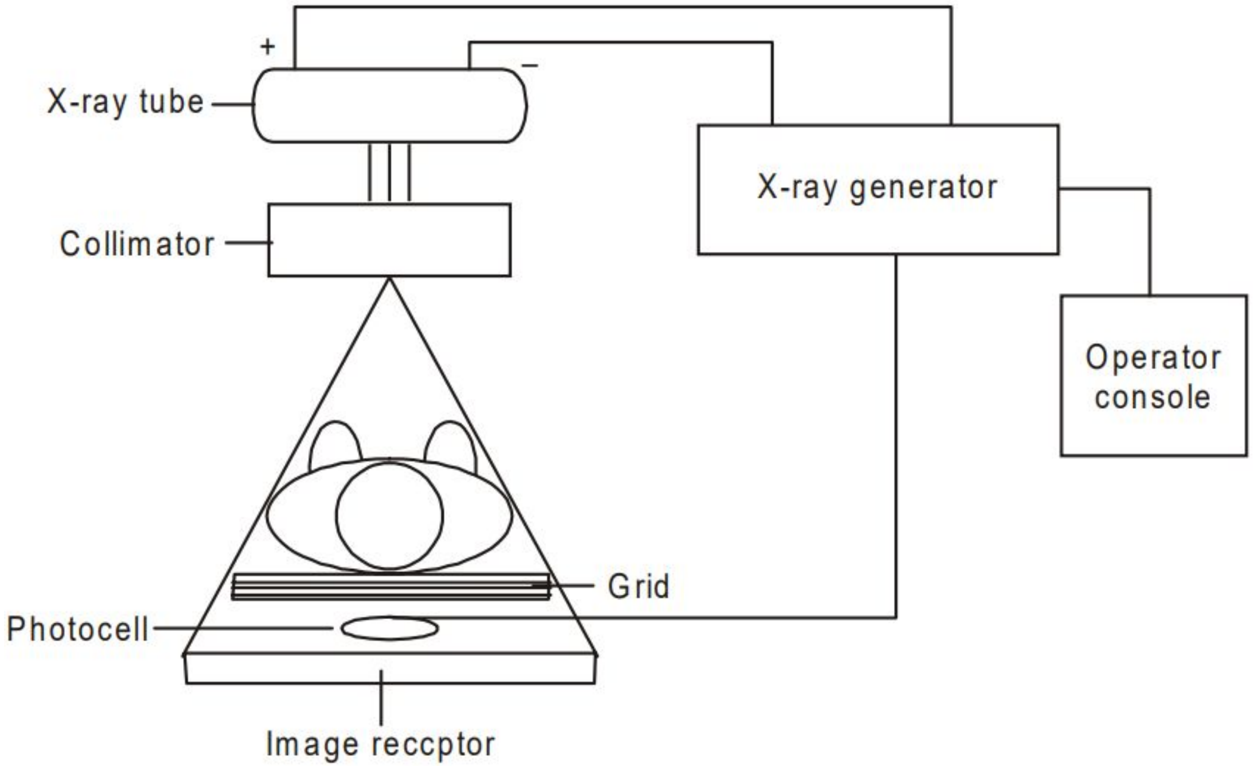
Medical Imaging

X-Ray Imaging System



X-Ray Tube

Working Principle: X-rays are absorbed by the body in relation to specific density and atomic number of various tissues. In irradiating a volume of interest, these absorption differences are recorded on an image receptor.



X-Ray Imaging System block diagram

- A vacuum tube device as shown in the figure is used to produce x-rays. The tube contains a tungsten filament (the cathode) and a metal target (the anode) which is also made of tungsten. The filament cathode is heated with electric current.
- A high voltage is applied between the anode and the cathode. The high voltage facilitates the electrons of the cathode to be drawn off and accelerated towards the anode.
- The accelerated electrons strike the anode. This results into the production of characteristic x-rays (characteristic of tungsten metal).
- The x-ray tube is completely enveloped by lead casing on all sides except for a small exit port. The lead casing is used as the lead can absorb most of the emitted x-rays. Hence x-rays can come out of the port only. These x-rays are used for radiography.

- A high voltage generator as shown in the figure, supplies the essential power to x-ray tube. A **collimator** is used at the exit port of the x-ray tube to limit the extent of the x-ray field.
- The x-ray exposure is kept for precise and finite duration by an electronic time switch. The exposure is also automatically terminated after a certain amount of radiation has been received by the image receptor with the help of **photo timing circuit**.
- The operator selects all operating parameters like exposure and dose of radiation from the **operator's console**.
- **An image receptor** is a device which can detect and record an x-ray image. It is placed below the patient so that x-ray after passing through patient falls on the image receptor.
- The patient's anatomy modulates the intensity of the x-ray field as it passes through his body. The differential x-ray absorption and transmission by tissues of the body results in an exit radiation beam that varies in intensity in two dimensions. The exit radiation beam reaches a detector which detects and records the two-dimensional intensity distribution.
- The image receptors used in diagnostic radiology can be : (a) **Photographic film**, coupled with an intensifying phophor screen. (b) **Storage phosphor screen**. (c) **Direct digital readout device**.

Computed Tomography Scan (CT Scan)

- In this technique the images of selected layers are recorded sharply while images of other layers are unsharp.
- The technique involves some form of movement of the patient or equipment during the exposure. The movement causes images from the unwanted layers to move relative to the film during exposure resulting into un-sharpness.
- Computed tomography is the name given to the diagnostic imaging technique in which tissues of the body are digitally reconstructed from attenuated x-rays data obtained from many directions in a particular plane.
- A tomographic image can be generated by following methods of coordination of movement during exposure :

(a) The patient remains stationary while the x-ray tube and the film (or detector) move in coordination. This is most widely used method.

(b) The x-ray tube remains stationary while the film (or detector) with the patient move in coordination.

(c) The film (or detector) remains stationary while x-ray tube with the patient move in coordination.

Working Principle:

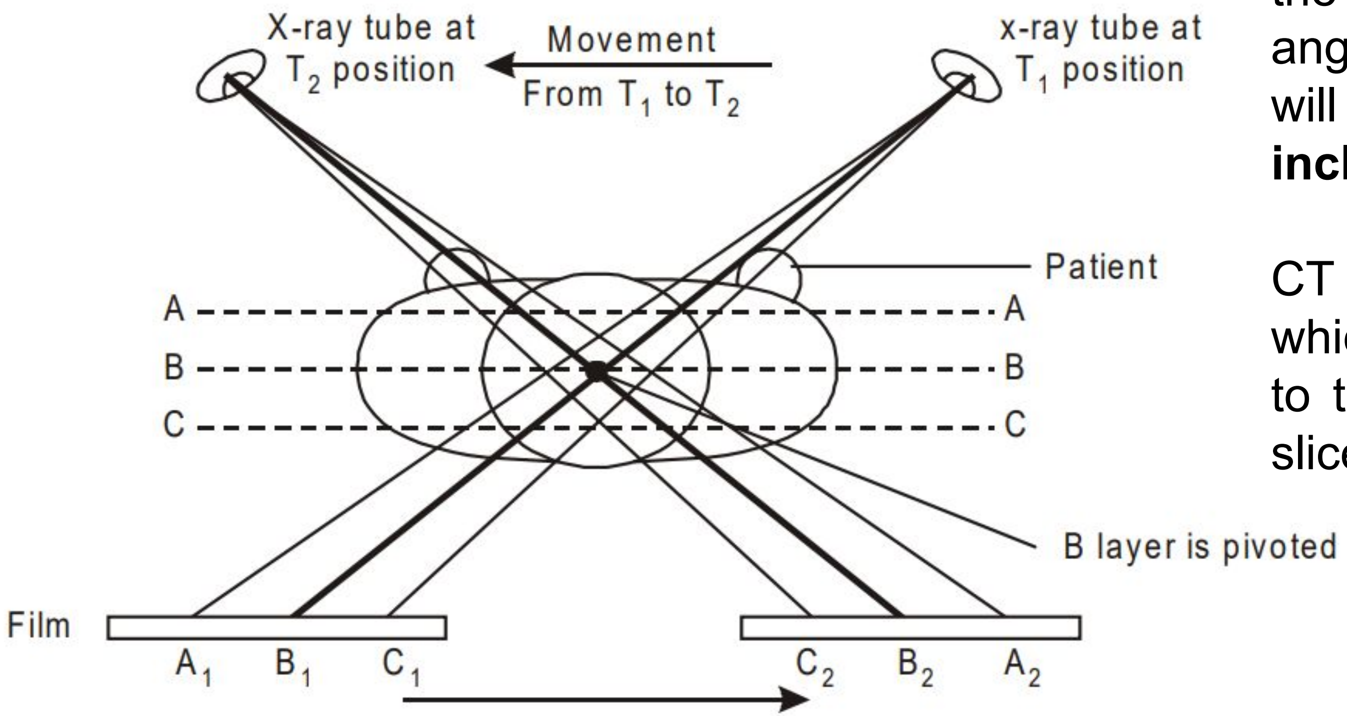
When the x-ray tube moves over the patient, the projected images of structures on different levels of the body move with different velocities. The structure which is nearer to x-ray tube will have its image moving faster. Similarly farther the structure is to the x-ray tube, the slower its image will move as the movement of x-ray tube and film is linked through a pivot. Hence the film moves at the same velocity as images of the structures only at the level of the pivot. Only these images are recorded on the same part of the film throughout the movement. Images of structures on all other layers move at a different velocity to that of the film and these images are not recorded on the same part of the film throughout the movement. These images are therefore recorded as blurred.

As shown in the figure, the film is pivoted at B layer. When x-ray tube moves from T1 to T2 position during exposure, the quality of images at different level of layers are :

(a) Images layer B move at the same velocity as the film and images are recorded on the same part of the film throughout the exposure. The images recorded at point B1 and B2 are sharp.

(b) Images of layer A move faster than the film. The images of A move from the left of B1 to the right of B2 as shown in the figure. Images are not recorded on the same part of the film and images are therefore blurred.

(c) Images of layer C move slower than the film. Images are therefore blurred.

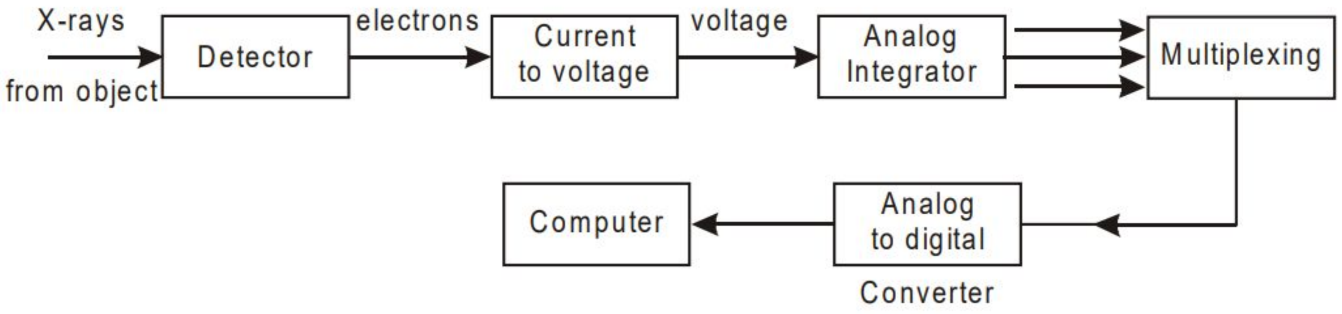


Priniciple of Tomography

The layer recorded sharply is called the **object plane**. It is parallel to the film. Generally the film is parallel to the table to at the level of the plane. If the film lies at angle of the table top during the movement, the layer will be visualized same angle. This technique is called **inclined plane tomography**.

CT technique generates a two dimensional picture in which each picture element (pixel) value corresponds to the attenuation coefficient of a **voxel** in the object slice.

- Two elements are required to acquire digital images.
- (a) The **detector** (sensing device) an electrical signal output which is proportional to the level of x-rays sensed.
- (b)The **digitizer** which is a device for converting the electrical output of the sensing device into digital form.
- The **detectors** for CT systems must have high overall efficiency (so as to minimize the patient radiation dose), large dynamic range (the ratio of the smallest and just detectable signal to the largest signal without causing saturation), stable with time and insensitive to temperature variation.
- Three types of detectors are commonly used in CT scanners. They are (1) xenon gas ionization (2) scintillation detector like sodium iodide, bismuth germanate and cesium iodide crystals which convert kinetic energy into flashes of light which can be detected by a photo multiplier. (3) solid state detector (single crystal ($Cd\,WO_4$ and ceramic Cd_2O_2S with photo diodes) which can detect x-ray photons.
- The output from the detector is variation of electrons (current) as per the intensity of x-rays with the help of **current to voltage converter**.
- The **multiplexing** is a device to take readings from two or more analog integers with a single analog to digital converter.
- An **analog to digital converter** is device that accepts a continuous analog voltage signals as input and converts them in to digital output signals.



Data Acquisition

- The converters can be

(1) voltage to frequency converter with a counter (voltage is converted into pulses and number of pulses is proportional to voltage)

(2) pulse width convertor (discharged capacitor is charged at fixed rate until it is charged to analog voltage and resulting pulse width is proportional to the analog voltage)

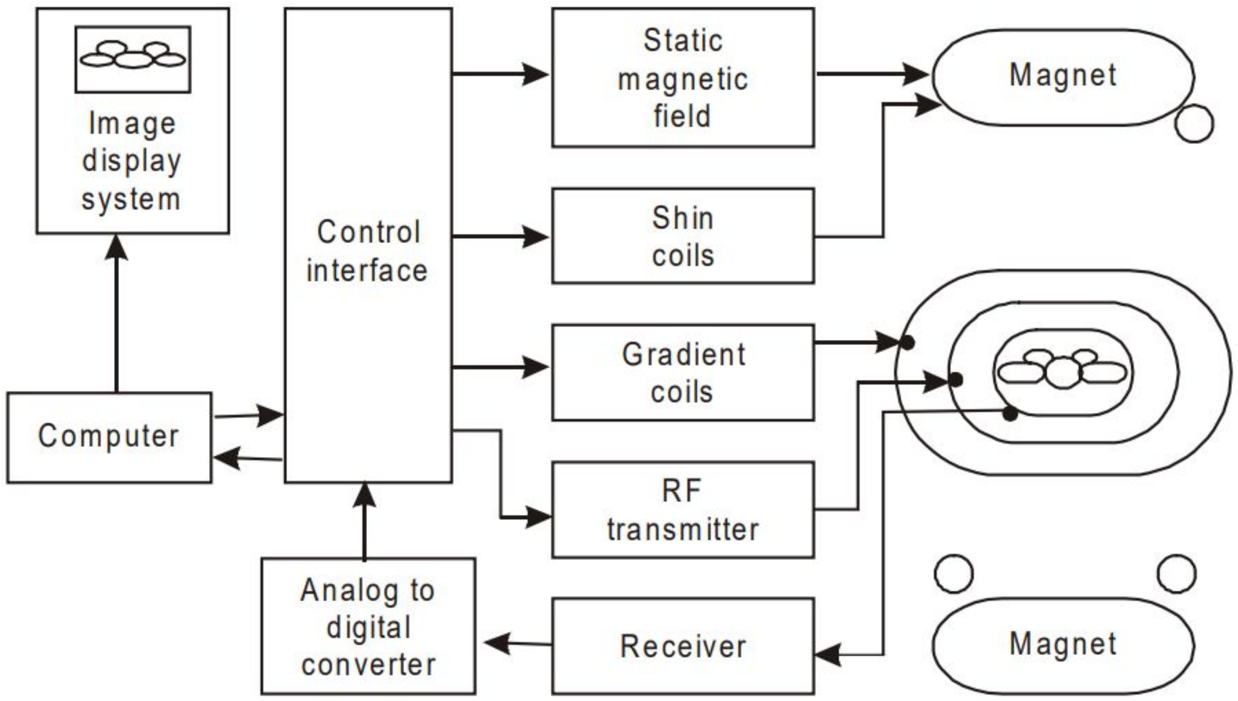
(3) up and down integrator converter (the input of analog integrator is alternately switched between the analog voltage to be digitized and a constant reference voltage and output of analog integrator is used to charge a capacitor at fixed rate as done in pulse width converter.

- The reconstruction of images from the scanning data is carried out by the computer. The data received by the computer contains following information :– (a) Positional information about scanning frame. (b) The value of absorption or attenuation. (c) Reference information of x-ray output from the reference detector. (d) Calibration information which is available at the end of each traverse.
- The reconstruction methods are : (a) Interactive methods (b) Analytic methods with the concept of back projection. (c) Analytic methods with the concept of filtered back projection.

Magnetic Resonance Imaging

(MRI)

- It employs a strong magnetic field and radio frequency pulses to provide remarkably clear and detailed pictures of internal organs and tissues, thereby eliminating the need of x-ray radiation as in the case of radiography and CT scan.
- It provides very good distinction between adjacent structures and excellent tissue contrast without injection of potentially toxic contrast agents.
- In MRI, bone does not interfere with the signals emitting from the tissues which carry the images of the areas under observation. Previously such areas could not be imaged non invasively such as brain stem and spinal cord.
- MRI can help in detecting diseases of earlier stages that previously could not be done with available methods.



The Components of a MRI System

- In MRI, protons of the nuclei of hydrogen atoms are subjected to radio frequency pulses in a strong magnetic field. The protons get thereby “excited” to higher energy level. Protons also get “relaxed” to the lower energy level on the switching off radio frequency pulses. The protons emit radio frequency signals when they move from “excited” to “relaxed” state. These radio signals can be detected by a receiver and a computer can further process the output into an image. In our body tissues, protons of hydrogen are most abundant as hydrogen atoms of water molecules. Hence MRI image shows difference in the water content and distribution in various body tissues.

- The **components of a MRI system** are
  (1) a magnet (2) gradient coils (3) a transmitter (4) a receiver (5) a computer and (6) shin coils.
- A strong **magnet** is provided to produce a highly uniform static magnetic field (1 to 3 Tesla) which is 10,000 to 30,000 times stronger than the earth's magnetic field. The magnet can be permanent or electromagnetic type. The magnet is a large and has cylindrical shape with a large aperture at centre to enclose the sliding table on which a patient can lie down for imaging.
- The **gradient coils** are provided to create magnetic field gradient in the tissues of the body to be imaged for spatial encoding of the signals.
- The **transmitter** operates at radio frequency to generate pulse sequence to resonate the hydrogen protons (nuclei) of the tissues.
- The **receiver** is required to detect the MRI signals emitted by nuclei of hydrogen during relaxation. The output of the receiver is linked to the computer.
- The **computer and display** system is provided to control the system operation so that images can be processed, stored, reconstructed and displayed, as and when required.
- **Shin coils** are placed at suitable places to maintain the homogeneity of the magnetic field.

Working Principle:

When a radiofrequency current is pulsed through the patient, the protons are stimulated, and spin out of equilibrium, straining against the pull of the magnetic field. When the radiofrequency field is turned off, the MRI sensors are able to detect the energy released as the protons realign with the magnetic field. The time it takes for the protons to realign with the magnetic field, as well as the amount of energy released, changes depending on the environment and the chemical nature of the molecules. Physicians are able to tell the difference between various types of tissues based on these magnetic properties.

Ultrasound Imaging

(US)

- The application of ultrasound in medical field is based on the **sonar principle** as used by bats, ships at sea and anglers with fish detectors.
- **Acoustic waves** are easily transmitted in water but they are reflected from an interface according to the change in the acoustics impedance. Leaving bones and lungs, all tissues of our body are composed of water which can transmit acoustic waves easily.
- Ultrasound can be used for obtaining images of internal organs by sending high frequency sound waves into the body. The reflected sound waves (returning echoes) are recorded and processed to reconstruct real time visual images by the computer.
- The returning sound waves (echoes) reflect the size and shape of the organ and also indicate whether the organ is solid, fluid or something in between.
- Unlike x-rays, ultrasound requires no exposure to ionization radiation. It is also a real time technique.
- Ultrasound has **frequency greater than 20,000 hertz**. Diagnostic ultrasound has the range of 1 to 10 megahertz.
- Ultrasound travels in the form of longitudinal wave i.e., the particles of the medium move in same direction in which the wave propagates. The wave transfers energy through the motion of regions of **compression and rarefaction** within the wave.
- The propagation of wave depends upon the elastic properties of the medium. If pressure change is ΔP and $\Delta V/V$ is corresponding change in the volume of the medium, than $\Delta P = -\beta\ \Delta V/V$, where β = modulus of elasticity.
- The average speed of wave in biological tissues is given by relation $C = \sqrt{(\beta/\rho_0)}$ where ρ_0 = density of the medium without disturbance. The average speed in tissue is taken as **1540 m/sec**.
- A special jelly is used therefore to minimize reflected energy from the interface of skin and transducer (in air) so that ultrasound can penetrate the body for the imaging of organs.

Working Principle:

- As the ultrasound beam encounters tissues of different acoustic impedance, velocities are altered such that returning echoes are received by the receiver at different times and echoes have different intensities.
- The differences in time and intensity have useful information. This information as well as the knowledge about velocity in the tissue are used by the computer to generate the image on the monitor.
- Ultrasound power is expressed by decibel (dB).

Scanning:

- The scanning modes are : (1) bistable scanning (2) Grey scale imaging (3) A-mode (4) B-mode (5) M-mode and (6) real time
- **Bistable scanning** displays images in black and white.
- **Grey scale imaging** is commonly used in which an analog to digital scan converter transfers information from the receiver to the computer.
- **A-mode (amplitude mode)** displays the amplitude of individual echoes as a function of distance or time on cathode ray tube. The display is shown alongside the image which is helpful in determining the type of tissue i.e., cystic or solid.
- **B-mode (Brightness mode)** displays echoes as individual spots on the screen corresponding to the points of origin in the tissue. Differences in amplitudes of returning echoes manifest as different brightness of the dots. Using many pixels (picture elements), these numerous dots can be arranged in such a way as to appear in different shades of grey for good visualization.
- **M-mode (motion mode)** is nothing but the application of B-mode to a moving structure varying with time.
- **M-mode Echocardiogram** gives the movement of valves and other structures of the heart which are displayed as a function of time. **A-mode** is used for **echoencephalogram** which can determine the location of the problem of the brain. **B-mode** is used for diagnostic **scanning of the eye**.

The ultrasound transducer:

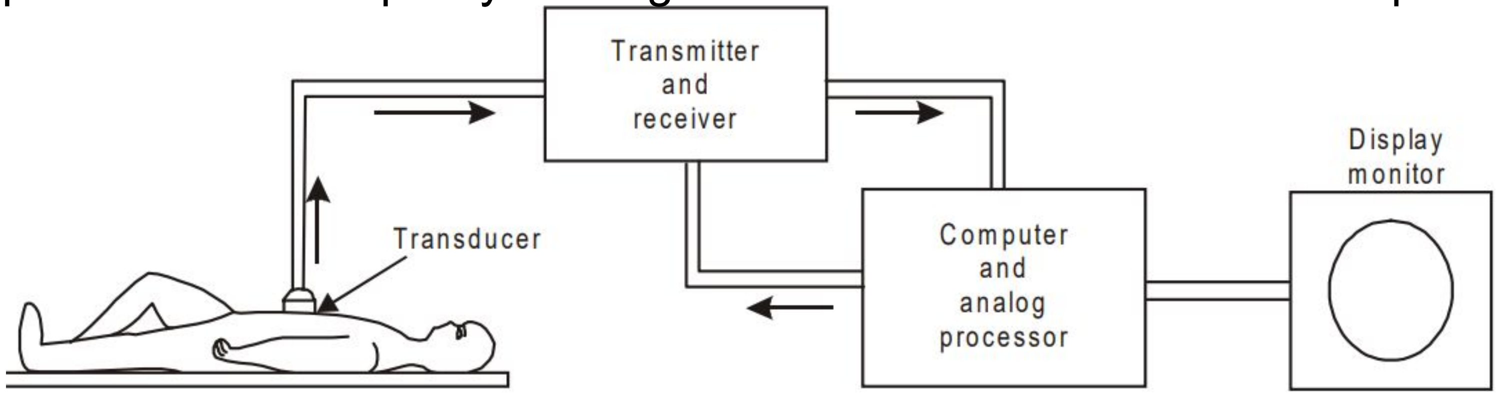
- In ultrasound, the transducer is both sender and receiver of ultrasound pulses and echoes. The transducer converts electrical impulses into ultrasound waves and vice versa.
- Generally a **piezoelectrical crystal** is used to create the ultrasound waves. As the receiver, the transducer has many functions like amplification, compensation, demodulation, compression and rejection. Man-made **lead zirconate and lead titanate** are also used as transducer. The electricity is applied to the transducer at a specific pulse rate which allows waves to travel and echo back to the receiver. The transducer sends pulse of one microsecond duration with the interval of 999 microseconds before sending next pulse.

Advantages:

- Ultrasound is relatively inexpensive and non invasive. It does not expose patients to ionizing radiation and hence it is safe. It is preferred for children and pregnant women. The machine is also comparatively inexpensive.

Disadvantages:

- Ultrasound imaging system is highly operator dependent. It cannot be used for full body survey. It can not image air containing organs or bones. The resolution of the ultrasound image is inversely related to the depth of penetration. The quality of image decreases in the case of obese patients.



Schematic Block Diagram of B-mode Ultrasound