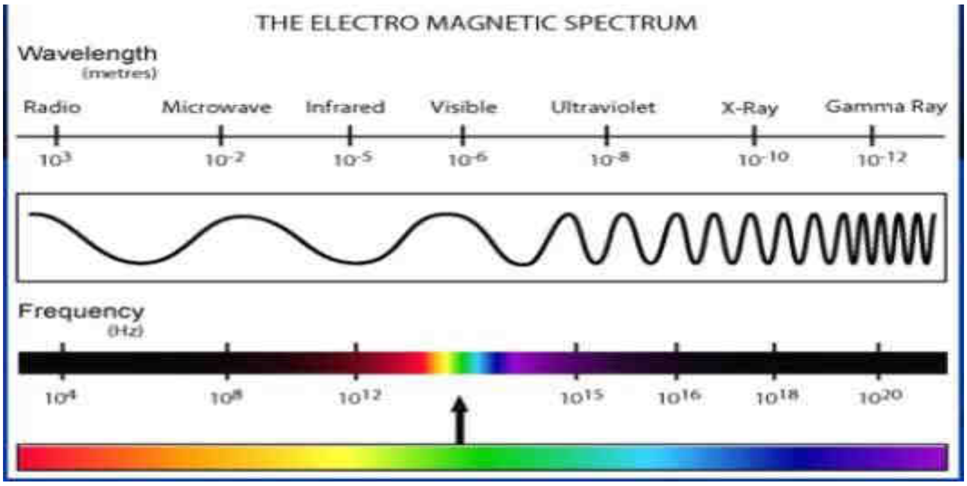
MODULE 5
Medical Imaging Systems



Properties of x-rays

- Are electromagnetic radiations composed of small packets of energy called photons.
- Travel at speed of light.
- Travel in straight lines.
- Highly penetrating.
- Invisible.
- Blacken radiographic films.
- Produce scatter.

- Are unaffected by electric and magnetic fields.
- X-rays are able to penetrate through materials because of short wavelength and extremely high energy.
- Are absorbed when passing through matter. The extent of absorption depends upon the density of the matter.

Production of X-rays

- X-rays are produced whenever electrons collide at very high speed with matter and suddenly stopped.
- The kinetic energy accrued by the electrons is converted into X-rays.

X-ray tube basically comprises

- A source for the production of electrons
- An energy source to accelerate the electrons
- A free electron path
- Means of focusing the electron beam and a device to stop the electrons

The x-ray tube.

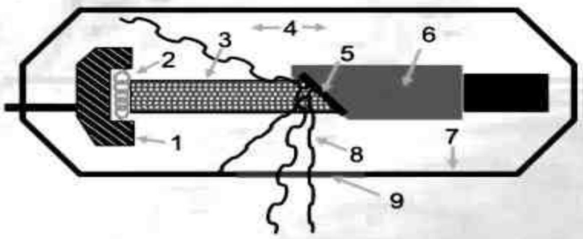
- The tube head consists of a pair of electrodes.
  - A negatively charged cathode with include a heater filaments.
  - A positively charged a node with a tungsten target.

Steps in x-ray production.

- Filament is heated and gives off cloud of electrons.
- A large electrical charge is placed in the cathode/anode space causing the electrons to race toward the anode.
- When they crush into the anode it causes x-ray to be given off.

(Studty the diagram given in the class,these two slides are good for understanding)

X-ray Tube Components



1. focusing cup
2. filament
3. electron stream
4. vacuum
5. target
6. copper stem
7. leaded glass
8. x-rays
9. beryllium window

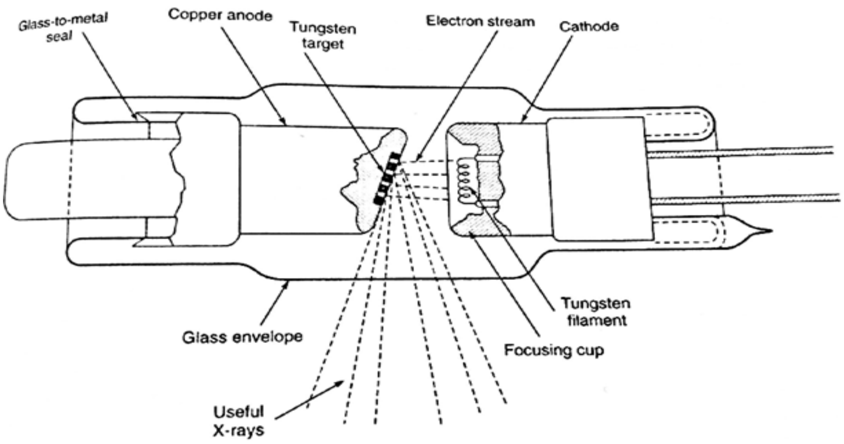
(for description, see next slide)

X-ray Tube Components (continued)

1. Focusing cup: focuses electrons on target
2. Filament: releases electrons when heated
3. Electron stream: electrons cross from filament to target during length of exposure
4. Vacuum: no air or gases inside x-ray tube that might interact with electrons crossing tube
5. Target: x-rays produced when electrons strike target
6. Copper stem: helps remove heat from target
7. Leaded glass: Keeps x-rays from exiting tube in wrong direction
8. X-rays produced in target are emitted in all directions
9. Beryllium window: this non-leaded glass allows x-rays to pass through. The PID would be located directly in line with this window.

<u>Production of X-rays</u>

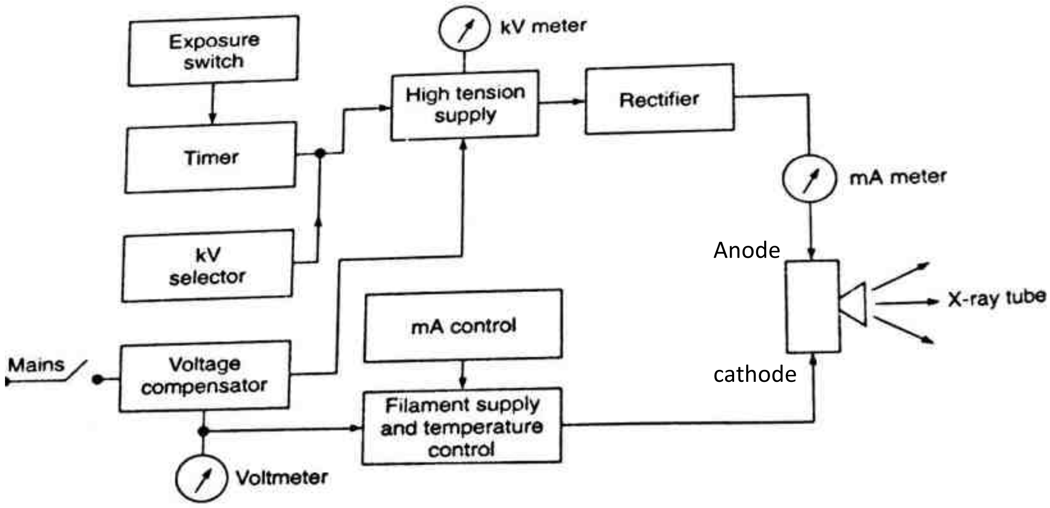
Stationary Anode Tube



X-ray machine components.

- **<u>The tube head</u>** where the x-rays are generated.
- **<u>The control panel</u>** which regulate the strength and amount of the x-rays produced and trigger the exposure.
- **<u>The power supply</u>** which provide the energy to creates the x-rays.

X-ray Machine



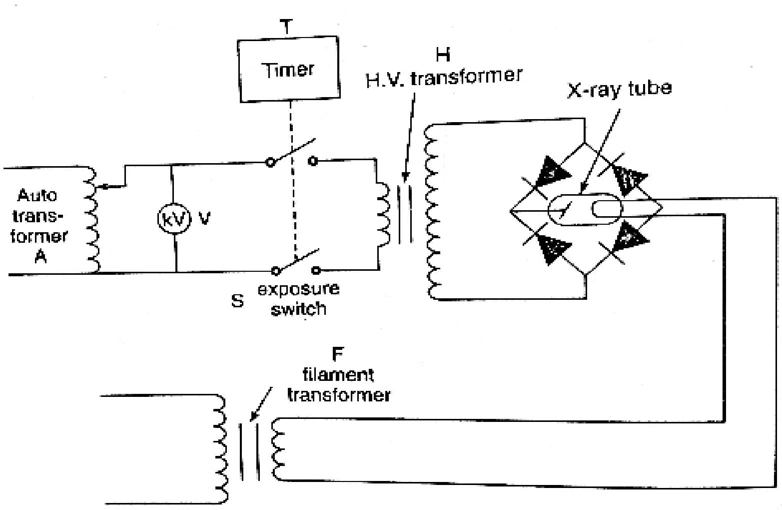
The control panel.

- The three factors that can be varied during producing radiograph are
- The kilovoltage (KV) difference applied between the anode and cathode during exposure.
- The milliamperage (mA) applied to the filament.
- The duration of exposure.

Control panel

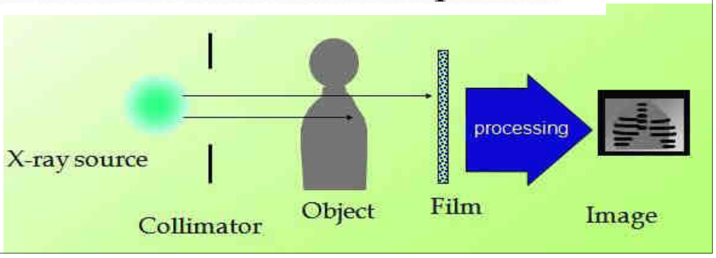
- Higher kv attract the electrons toward the anode by greater force.
- They smash the anode harder and produce x-ray with higher energy and greater tissue penetrating power.
- Increasing mA increase the number of electrons cloud around the filament. Result in higher number of x-ray produced per second.

A single phase full wave rectified circuit



Collimator

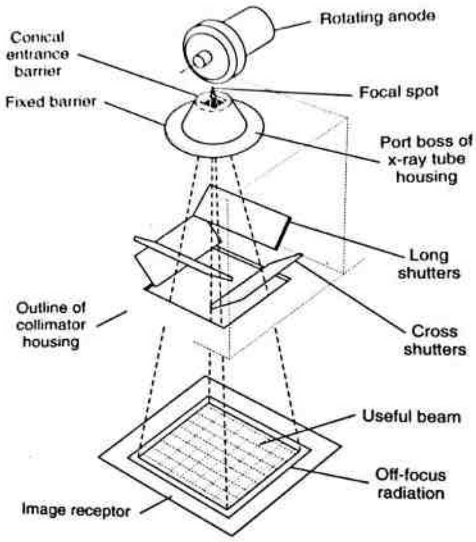
- It is the best X-ray restrictors
- It defines the size and shape of X-ray field
- It attached to the tube
- Collimator consists of two sets of shutters. Namely Longitudinal and Transverse
- Which can be moved independently
- Shutter consists of four or more lead plates



Cnt……

- The collimator also has a light and mirror arrangement, to illuminate the X-ray field
- The light bulb is positioned laterally and the mirror is mounted in the path of the X-ray beam at an angle 45 degree

Collimators



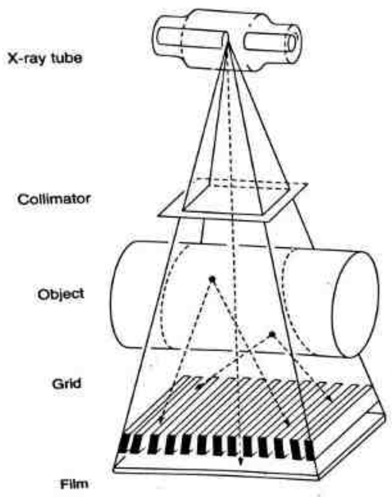
Grids

- Composed of hundreds of alternating thin lead strips with aluminum or fiber interspaces.
- X-ray can pass through the interspaces without interaction.
- Lead strips absorb weak energy scatter x-ray that hit them.
- Strips is encased in protective cover.

Grids

- A beam of X-ray passes through the beam is absorbed and scattered
- The absorbed primary beam gives a useful shadow
- Scattered radiation will tend to spoil the shadow
- Scattered radiation will increase the noise in the image

Grids



Cnt….

- The ratio between the amount of scattered radiation energy to the amount of primary radiation energy at a point is called as scattered to primary ratio(SPR)
- scattered radiation must be removed, in order to increase the image contrast

Cnt…..

- The scattered radiation can be removed by a grid
- The grid is placed between the film and the patient
- Cardboard, aluminium, or wood are low attenuating materials
- Primary radiation is parallel in direction
- Scattered radiation is non-parallel direction

Cnt….

- The grid may be made to move continuously in one direction
- The grid motion is timed by the exposure control of the X-ray machine
- The travelling period should be greater than the exposure time
- The use of grid will always increase the exposure, because it will absorb some of the primary radiation

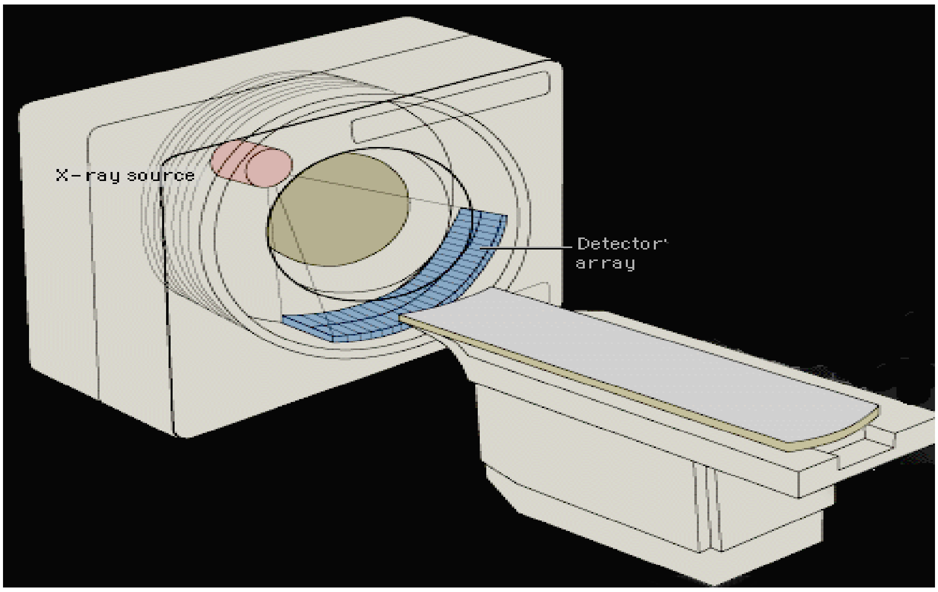
Applications of X ray

- X ray is used to visualize skeletal structure
- X ray is used to take chest radiograph
- Heart examinations are performed by taking frontal and lateral X ray film images
- Gastro intestinal tract can be imaged by using X ray
- Urinary tract can be examined by using X rays

Limitations of Conventional X-rays

The super-imposition of the three-dimensional information on to a single plane makes diagnosis confusing and difficult.

X-Ray Computed Tomography



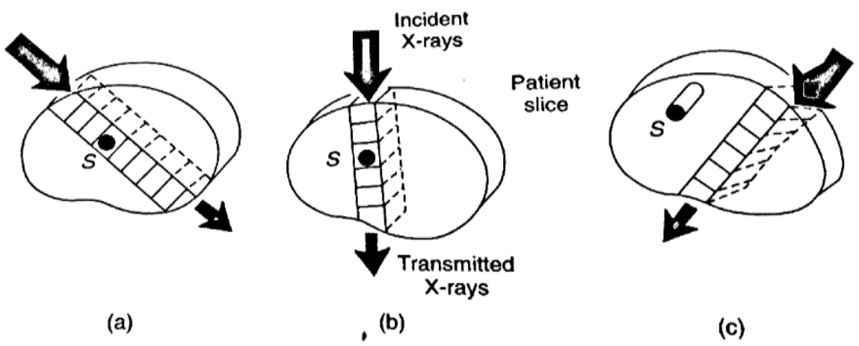
Definition / facts about CT

- **Computer tomography** (CT), originally known as **computed axial tomography** (CAT or **CT scan**) and **body section rentenography.**
- **it** is a medical imaging method employing tomography where digital geometry processing is used to generate a three-dimensional image of the internals of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation.
- The word "*tomography*" is derived from the Greek *tomos* (slice) and *graphein* (to write). CT produces a volume of data which can be manipulated, through a process known as *windowing*, in order to demonstrate various structures based on their ability to block the X-ray beam.

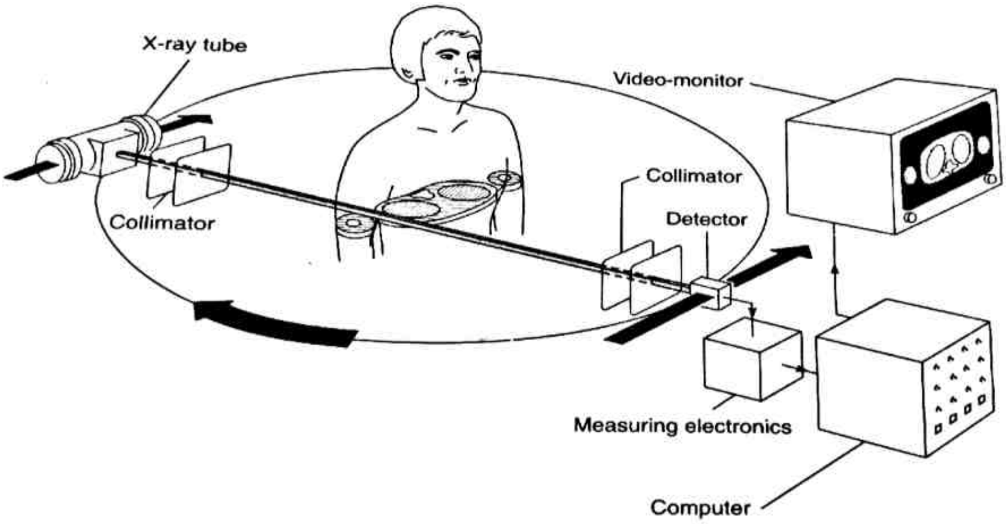
X-Ray Computed Tomography

- Computed tomography (or computerized axial tomography) is an examination that uses X-ray and computer to obtain a cross-sectional image of the human body.
- In this, the X-ray tube and photographic film are moved in synchronisation.
- X-ray imaging from numerous angles.
- The pictures displayed are reconstructed(windowing) from a large number of absorption profiles taken at regular angular intervals around a slice.
- Each profile made up from a parallel set of absorption values through the object.

X-ray incident on patient from different directions



Technique of producing CT images



Block Diagram of the CT Scan

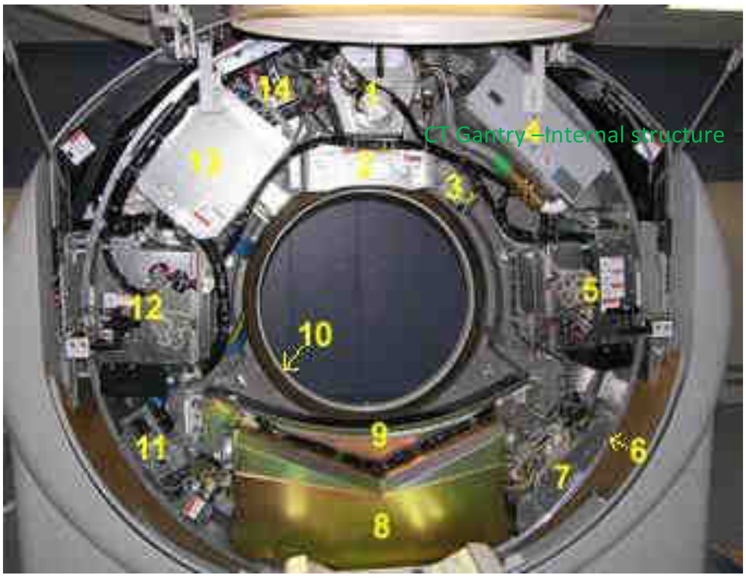
- The **X ray source and the detectors are mounted opposite each other in a rigid gantry with the patient lying in between, and by moving one or both of these around and across the relevant sections.**

- **The patient lies on a motorized couch and is moved in to the aperture of the gantry, with the location to be accurately determined by means of a narrow strip of light that falls on the body from the gantry and illuminates the section to be examined.**

Modern CT scanner

1. gantry aperture (720mm diameter)
2. microphone
3. laser alignment light
4. patient guide lights
5. x-ray exposure indicator light
6. emergency stop buttons
7. gantry control panels
8. external laser alignment lights
9. patient couch
10. ECG gating monitor

CT Gantry – Internal structure



1. x-ray tube
2. filters, collimator, and reference detector
3. internal projector
4. x-ray tube heat exchanger (oil cooler)
5. high voltage generator (0-75kV)
6. direct drive gantry motor
7. rotation control unit
8. data acquisition system (DAS)
9. detectors
10. slip rings

Scanning System

- **The purpose of the scanning system is to acquire enough information to reconstruct a picture for an accurate diagnosis.**
- **A sufficient number of independent readings must be taken to allow picture reconstruction for diagnosis purpose.**
- **The readings are taken in the form of profiles.**
- There are **several designs of scanning gantry, they use different mechanical configuration.**

Components in CT Scan

- A CT system consists of the following four major sub system.

1. **Scanning System**
   - It includes X-ray source and detectors
2. **Processing Unit**
   - Converts the readings into intelligible picture information.
3. **Viewing part**
   - It presents this information in visual form and includes other manipulative aids to assist diagnosis.
4. **Storage unit**
   - It stores the information in visual form or digital form.

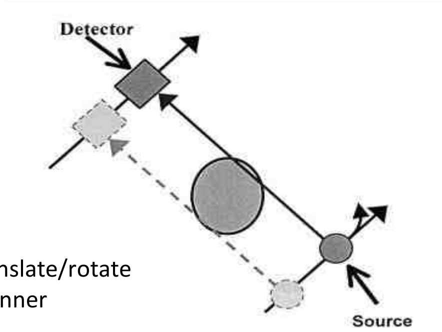
Scanning System

Generations

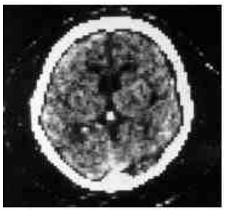
generation	configuration	detector	beam	Min scan time
first	Translate -rotate	1-2	Pencil thin	2.5min
second	Translate -rotate	3-52	Narrow fan	10sec
Third	Rotate- rotate	256-1000	Wide fan	0.5sec
fourth	Rotate- fixed	600-4800	Wide fan	1sec
fifth	Electron beam	1284	Wide fan electron beam	33ns

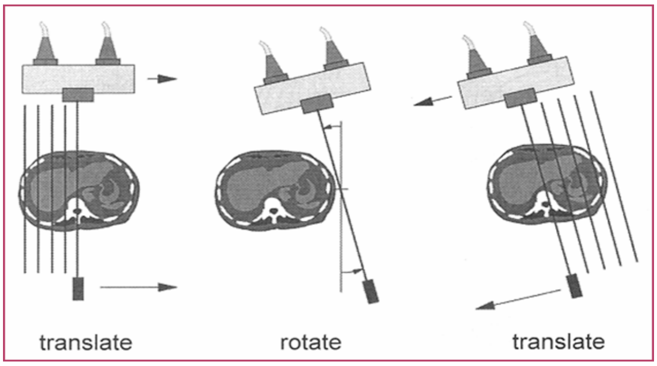
First Generation CT

- **single X-ray source and single X-ray detector** cell to collect all the data for a single slice y Source and detector, rigidly coupled
- Beam: Pencil beam -- translated across patient to obtain set of parallel projection measurements at one angle
- Source/detector rotate slightly and a subsequent set of measurements are obtained during a translation past patient
- Process is repeated once for each projection angle until 180 projections.
- Translation and rotation process, this geometry is referred to as a translate/rotate scanner



translate/rotate
scanner





Second Generation Design: multiple detectors

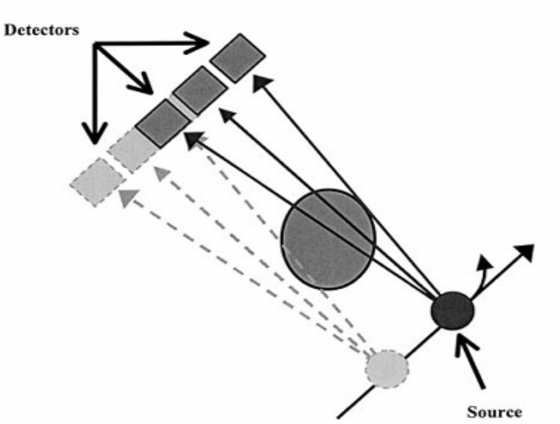
- X-ray source emits radiation over a large angle, the efficiency of measuring projections was greatly improved

- Source and array of detectors are translated as in a first generation system but since beam measured by each detector is at a slightly different angle with respect to object, each translation step generates multiple parallel ray projections.

- Multiple projections obtained during each traversal past the patient this scanner is significantly more efficient and faster than 1 st generation.(Reduced scan time.)

This generation :a translate/rotate scanner

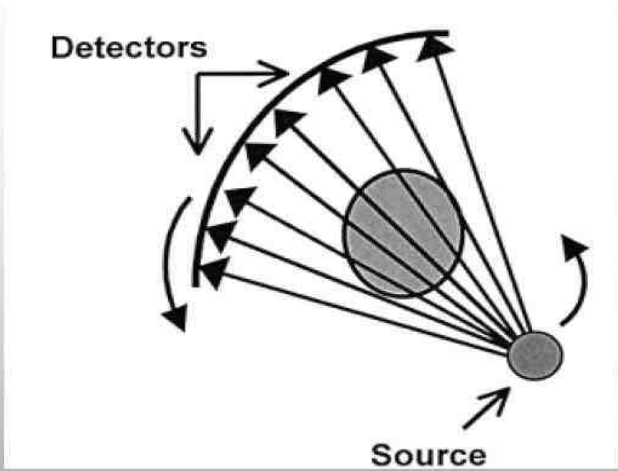
Second Generation CT



Third Generation

- Design: larger array Of detectors
  - (300-700detectors, usually circular
  - Shorter scanning time (2 sec)
  - Designers: pure rotational scanning motion could be used , then it would be possible to use higher-power ,rotating anode x-ray tubes and thus improve scan speeds in thicker body parts
- "Slam-bang translational motion" was replaced with smooth rotational motion
  - higher-output rotating anode x-ray tubes could be used
  - greatly reducing scan times
- X-ray tube is collimated to a wide x-ray beam (fan-shaped)
- Directed toward an arc-shaped row of detectors
- Tube and detector array rotate around patient
- Different projections are obtained during rotation by pulsing x-ray source or by sampling the detectors at a very high rate

Third Generation CT

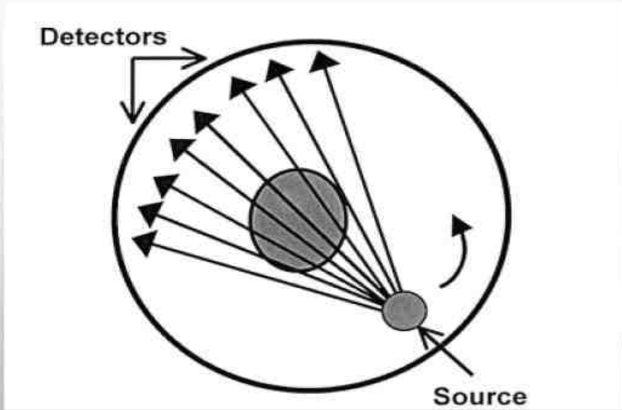


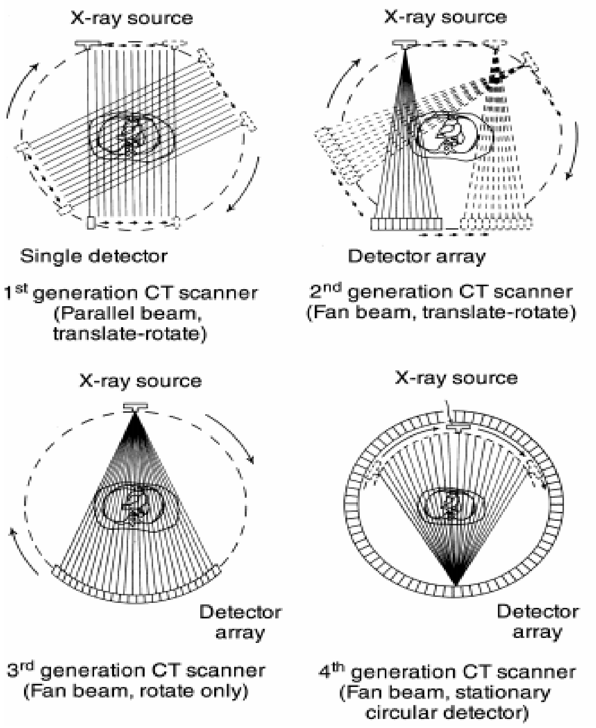
Fourth Generation

- Design: stationary detector ring & rotating X-ray tube
- Reduced motion resulted in reduction in complexity
- Stationary detector requires a larger acceptance angle for radiation, and is therefore more sensitive to scattered radiation than the 3rd generation geometry
- Require larger number of detector cells and electronic channels (higher cost) to achieve the same spatial resolution and dose efficiency as a 3rd generation system

- Design: also eliminated translate-rotate motion (Here rotate - stationary) Circular array of FIXED detectors, Source only rotates within a stationary ring of detectors
- Larger fan beam and Shorter scanning time
- Early versions: had some 600 detectors ,Later versions: had up to 4,800

Fourth CT

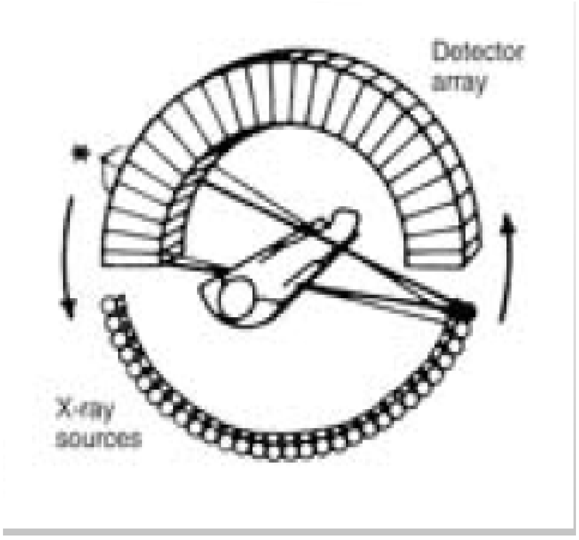

Detectors
Source


X-ray source
Single detector
1st generation CT scanner
(Parallel beam, translate-rotate)
X-ray source
Detector array
2nd generation CT scanner
(Fan beam, translate-rotate)
X-ray source
Detector array
3rd generation CT scanner
(Fan beam, rotate only)
X-ray source
Detector array
4th generation CT scanner
(Fan beam, stationary circular detector)

The So Called 5th Generation

- *Design: x-ray tube is* a large ring that circles patient, opposed to detector ring
- *Use:* for cardiac tomographic imaging **"cine CT"**
- X - rays produced = high - energy electron beam
- No moving parts to this scanner gantry
- It is capable of 50 - millisecond scan times and can produce 17 CT slices/second
- *stationary/stationary geometry*

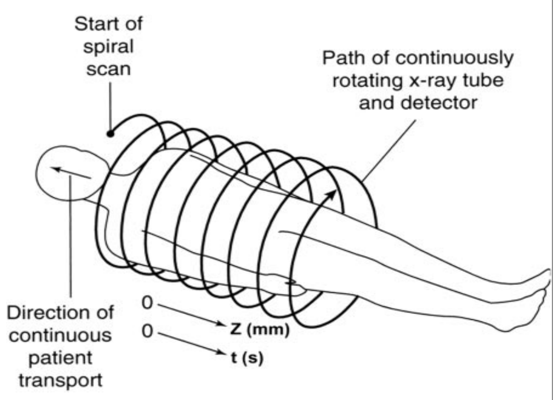
Fifth Generation CT



- No mechanical scanning motion
- X-ray detector and tube anode are stationary
- Anode, is a very large semicircular ring that forms an arc around the patient scan circle
- Source of X-rays is moved around the same path as a fourth generation CT scanner by steering an electron beam around the X-ray anode
- Terms millisecond CT, ultrafast CT and electron beam CT have also been used, although the latter can be confusing since the term suggests that the patient is exposed to an electron beam

Spiral/Helical CT (6 th Generation)

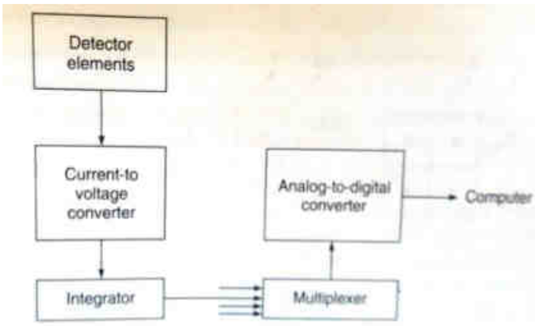
- Design: x-ray tube rotates as patient is moved smoothly into x-ray scan field
- Simultaneous source rotation, table translation and data acquisition
- Produces one continuous volume set of data for entire region



2) Processing Unit

- converts thee readings into intelligible picture information.
- It consists of:
  - Data acquisition system
  - Processing unit
  - Computer system

- **Data acquisition system** – to obtain an optimal image .

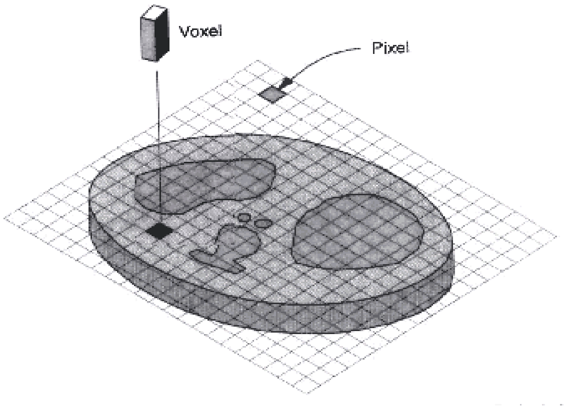


➤ Fig. 20.10 *Data acquisition system in a CT scanner*

- X-ray photons come on the detector.
- The detector detects the intensity in form of current.
- The current is converted into voltage.
- The analog integrator removes spikes.
- The analog signal is converted into digital form.
- This signal can now be processed and reconstructed in the computer.

Processing unit

- *Pixel*– picture element – a 2D square shade of gray.
- *Voxel*– volume element – a 3D volume of gray.
- This is a result of a computer averaging of the attenuation coefficients across a small volume of material. This gives depth information.
- Each voxel is about 1mm on a side and is as thick as 2 – 10mm depending on the depth of the scanning x-ray beam.



Attenuation

- X-ray beam passes through patient
- Each structure attenuates X-ray beam differently
  - According to individual densities
- Radiation received by detector varies according to these densities

IMAGE RECONSTRUCTION

- Back projection
- Iterative reconstruction
- Analytical methods
- 1. Filtered backprojection
- 2. Fourier filtering

BACK PROJECTION method

- The detectors see the **forward projected x-rays** and measure the intensity; given that the x-ray intensity without the body present is known.
- The intensity is written as sum of attenuation coefficients along a given x-ray path.
- This generates a shade of gray and a number associated with this shade.
- Then the detector changes angles and the process repeats.

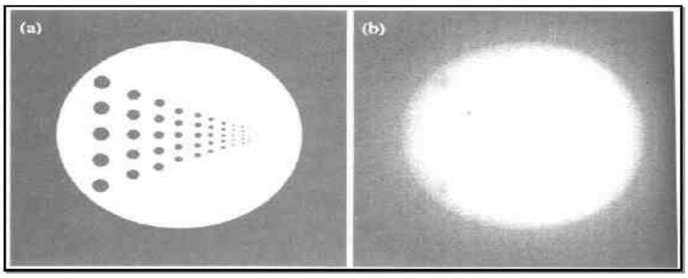
The images are reconstructed by a method called ***backprojection***, or tracing backwards along the x-rays forward path to reconstruct the image.

This a mathematically tedious process, but is handled easily with computers.

Iterative reconstruction

- Successive approximation method to obtain an **image of attenuation coefficients** from the **measured intensity** form **Object slice**

- Problems with back-projection include mainly severe blurring in the computed images



Analytical methods

- **Current Commercial scanner uses** this method
- A mathematical technique known as **convolution or filtering**
- Technique employs a **spatial filter for remove blurring artifacts.**
- **2 types of method**
  1) **Filtered back projection**
  2) **Fourier filtering**

Filtered back projection.

- The projection data are **convoluted** with suitable processing function before **back projection**

Fourier filtering

- A property of the Fourier transform
- Relates the projection data in the spatial domain to the **Frequency domain**

3) Viewing part

- It presents this information in visual form and includes other manipulative aids to assist diagnosis.
- In most of the CT,final picture is available on a television type picture tube.

4) Storing and documentation

• For subsequent processing or evaluation of a CT picture, various methods of storage are used.
• This enables the information to be stored for subsequent analysis.
•The data carriers generally employed are magnetic disc, magnetic tape and floppy disc.

- **Applications** and Clinical Benefits of **CT** Imaging. Unlike other medical imaging techniques, such as conventional x-ray imaging (radiography), **CT** enables direct imaging and differentiation of soft tissue structures, such as liver, lung tissue, and fat.
- Cardiac CT, Denta Scan, Multiphasic Liver scan, Angiographies, 3 D imaging of bones,High resolution scan of thorax.

Ultrasonic Imaging Systems

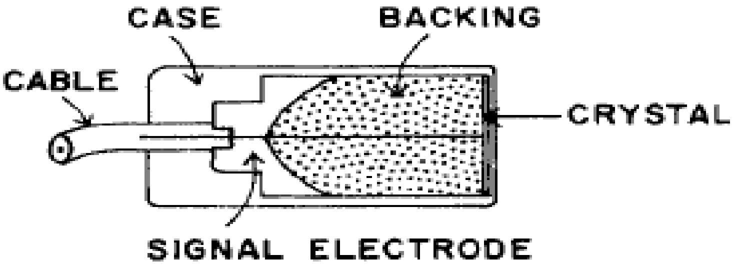
Ultrasound

- Ultrasound is a **mechanical disturbance that moves as a pressure wave through a medium.**
- Ultrasound is **high frequency mechanical vibrations** or pressure waves **above a frequency the human ear can hear**.

1. **Infra sound** Below 20Hz
2. **Audible** 20Hz and 20 000Hz.
3. **Ultrasound** Above 20 000Hz

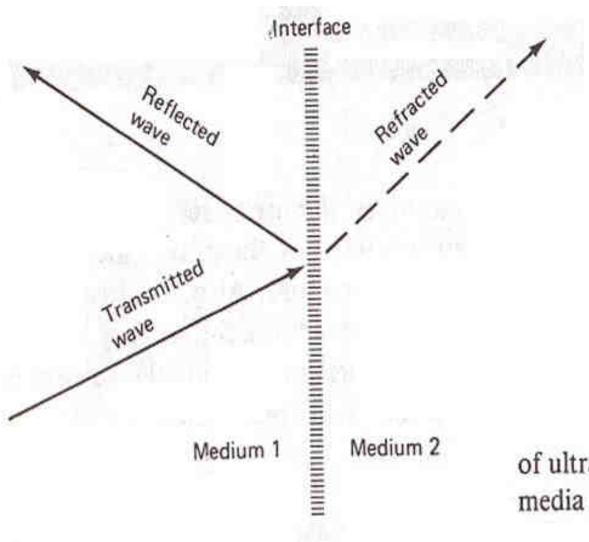
Ultrasound Transducer

- Ultrasonic energy can be used to detect the state of the internal body organs.
- Bursts of ultrasonic energy are transmitted from a piezo electric transducer.



- **Process Overview**
  - **Transducer (electrical signal ⇄ acoustic signal) generates pulses of ultrasound and sends them into patient**
  - **Organ boundaries and complex tissues produces echoes (reflection or scattering) which are detected by the transducer**
  - **Echoes displayed on a grayscale anatomical image**
    - **Each point in the image corresponds to an anatomical location of an echo-generating structure**
    - **Brightness corresponds to echo strength**

Properties of an ultrasound wave

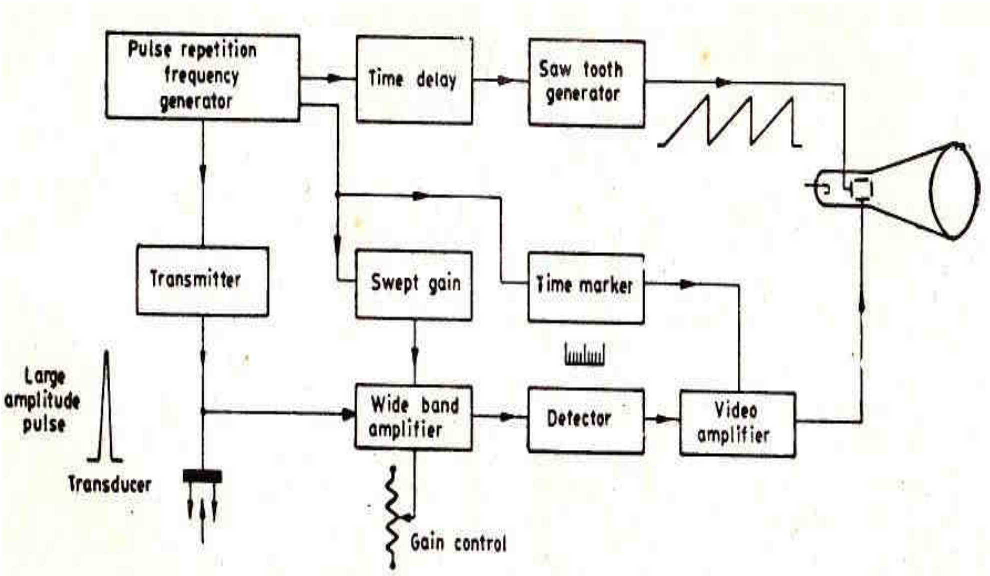


Reflection and refraction of ultrasound at an interface between media of different densities.

Properties of an Ultrasound wave

- **Attenuation** is the **rate at which intensity wave diminishes with the depth it covers or its penetration.**
- **3 Types of attenuation:**
  1. **Scattering /Refraction**
  2. **Absorption**
  3. **Reflection**
- When an **ultrasound wave passes through tissues**
  - **Attenuation: Reduction in amplitude and intensity of wave.**
  - **Refraction : Change in direction & velocity of wave**
- **The combined effect** of **scattering and absorption is called attenuation.**
- **The reflected energy is dependent on the difference of densities between the two media and the angle at which the transmitted beam hits the medium.**

Pulse Echo system



Block diagram of a basic pulse-echo system.

- Transducer:Imaging system utilizes the pulsed ultrasound. The transducer generates a train of pulses of short duration at specific frequency determined by the pulse repetition frequency generator. These are converted into corresponding pulse of the ultrasonic waves by the piezo-electric crystal acting as a transmitting transducer.

- PRF generator:A single astable multivibrator is used to generate a train of pulses with required frequency and then use them to trigger monostable multivibrator which produces pulses of required width with the short pulse duration.

- Transmitter:It is driven by a pulse from PRF generator and is made to trigger an SCR circuit, which discharges a capacitor through the piezo-electric crystal.

- Swept Gain Control:The changes in tissue properties can shift the echo amplitudes to vary over a wide range. The gain is varied with distance and slope.
- Detector:This is of the capacitor type with an inductive filter to have additional filtering of the carrier frequency.
- Video amplifier: The signal requires amplification after its demodulation in the detector circuit before it is given to the CRT.
- Time Delay: It is desired in the special case such as the trace on CRT can be delayed so that it can be expanded to obtain a better display.

- Time maker: This produces pulses of known time. They are given to the video amplifier and then to the CRT for the display along with the echos.
- Display: There are three display format. They are : A-mode display,B-mode display and T-M mode (or M mode) display.

Display Modes

- The reflected echoes are now displayed on the screen as a useful image.
- The various modes are

1. A Mode
2. B Mode
3. M mode or T-M Mode

A-scans

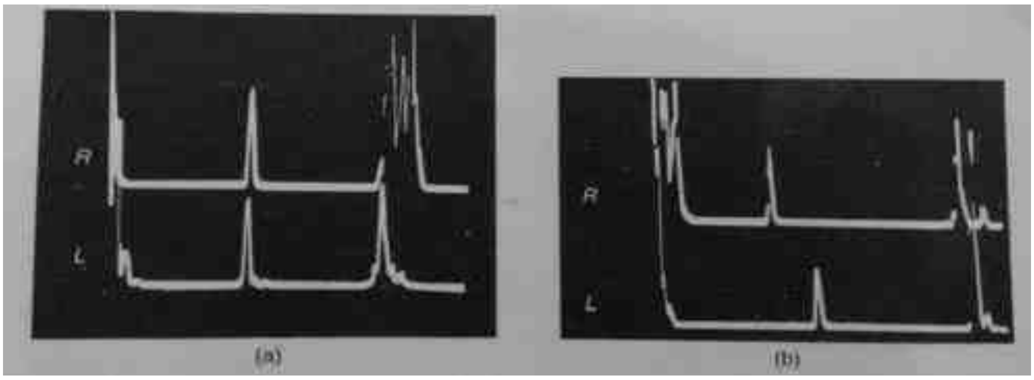
- In the A-mode presentation of ultrasound images, **echoes returning from the body** are displayed as signals on an oscilloscope.
- A mode means amplitude modulation
- In this mode , the reflected echoes are displayed as vertical spikes.
- A-scans can be used in order to measure distances.
- A transducer emits an ultrasonic pulse and the time taken for the pulse to bounce off an object and come back is graphed in order to determine how far away the object is.
- A-scans only give one-dimensional information and therefore are not useful for imaging.

Applications of A-scan

- Echoencephalograph

Echoes received from the brain

(a) in the normal brain (b) in the abnormal case



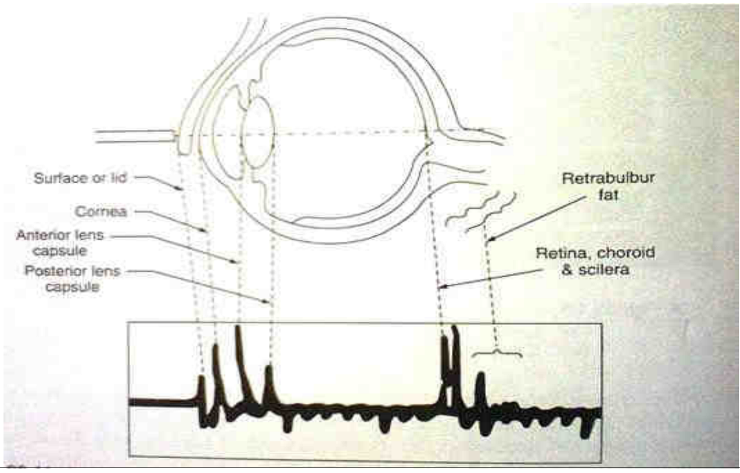
A-scans

Echoencephalograph In the normal brain, the mid-line surfaces are parallel to the flat areas of the bone near the ear. When there is a head injury, the brain gets tilted to one side or the other due to bleeding, but it still retains its normal shape. In such cases, the echoes can be easily obtained but they are placed at different distances from the probe, when the probe is placed first on one side and then on the other side of the skull

Even when a tumour grows in the brain, the anatomy of the brain becomes much altered and there is usually considerable tilting and displacement of the brain ventricles. Ultrasonic mid-line echo in such cases, immediately establishes the abnormality of the brain leaving it for x-ray examination to establish accurate diagnosis. This avoids submitting all patients with brain abnormalities to possible hazardous radiographic examinations.

Applications of A-scan

- Employed in opthalmology for finding defects in optic nerves.
- In the normal eye, the echo received is as shown:

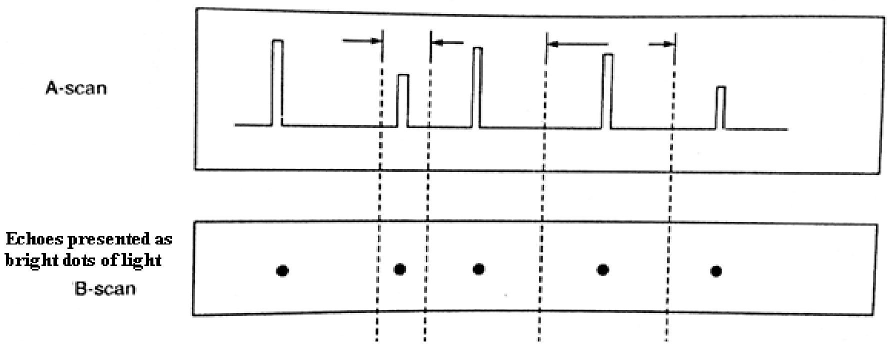


A-scans

Echo-ophthalmoscope A-mode ultrasonic technique has been found to be useful in ophthalmology for the diagnosis of retinal detachments, intraocular tumours, vitreous opacities, orbital tumours, and lens dislocation. It helps in the measurement of axial length in patients with progressive myopia, localisation of intraocular foreign bodies and extraction of non-magnetic foreign bodies.

B-scans

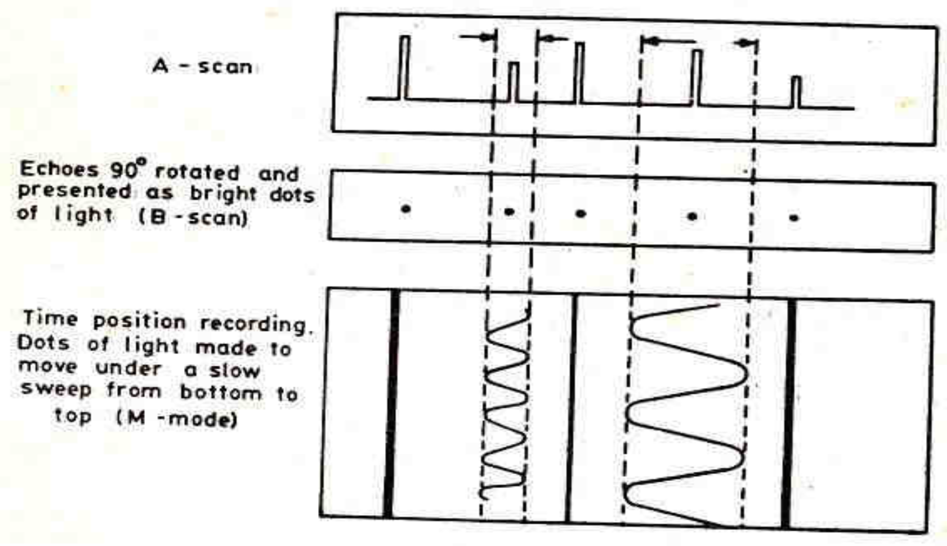
- B scan means brightness modulation.
- The reflected echoes are showed as dots on the screen
- B-scans can be used to take an image of a cross-section through the body.
- The transducer is swept across the area and the time taken for pulses to return is used to determine distances, which are plotted as a series of dots on the image.
- B-Scans will give two-dimensional information about the cross-section.



M-mode: In M-mode (motion mode) ultrasound, pulses are emitted in quick succession – each time, either an A-mode or B-mode image is taken.

Over time, this is analogous to recording a video in ultrasound. As the organ boundaries that produce reflections move relative to the probe, this can be used to determine the velocity of specific organ structures.

Comparison



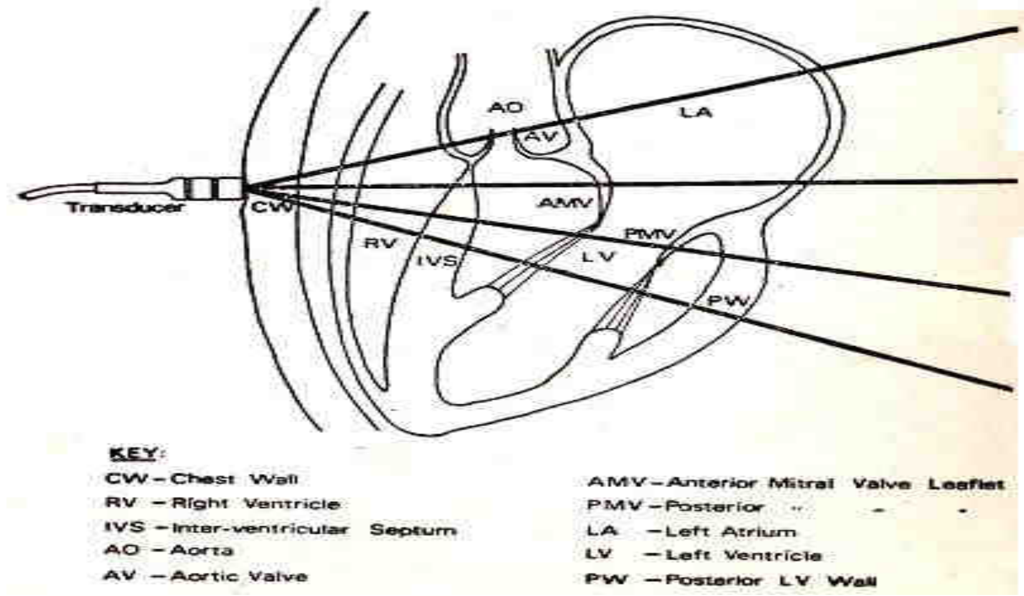
Principle of time-motion (M-mode) display.

M-scans

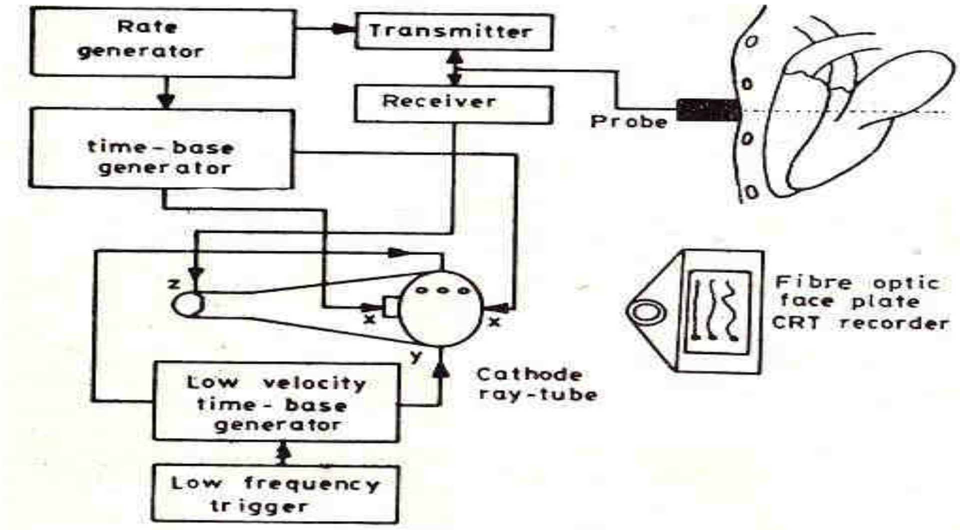
ECHOCARDIOGRAPH (M-MODE)

Echocardiograph is widely used and valuable instrument for carrying out cardiac examination and assessment of many congenital and acquired cardiac diseases. Using this instrument, it is possible to detect intra-cardiac structures. The movement of these structures can also be recorded with better resolution than with angiographic diagnostic technique. The instrument presents time-versus-motion information about heart structures on slow speeds normally used in electro-cardiogram recordings. When an ECG trace is superimposed on the ultrasonic display, the movement of structures detected ultrasonically can be conveniently correlated with known events in cardiac cycle

Echo Cardiography (Heart)



Echo Cardiograph



Block diagram of an echocardiograph circuit.

Real Time Ultrasonic Imaging

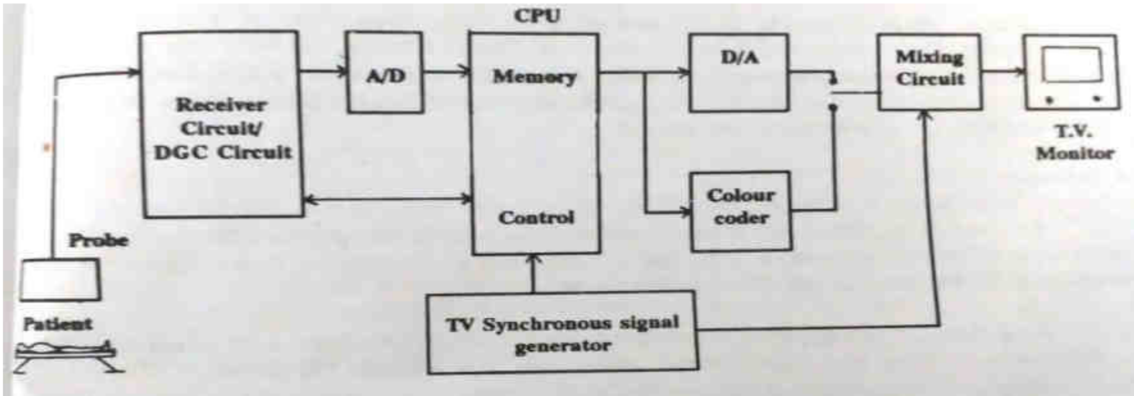
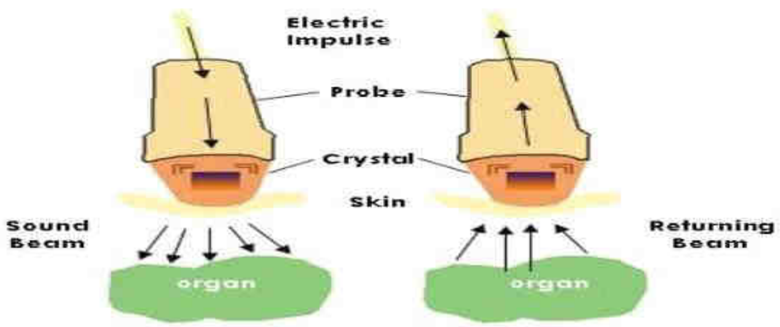


Fig.10.16. Digital real time ultrasonic scanner

Figure 10.16 shows the block diagram of a digital real time ultrasonic scanner. The echoes from the patient body surface are collected by the receiver circuit. Proper depth gain compensation is given by DCG circuit. The received signals are converted into digital signals and are stored in the memory. Meanwhile the scan converter control receives signals of transducer position and TV synchronous pulses and generates X and Y address information which is fed to the digital memory. The stored digital image signals are processed and colour coded and are given to digital-to-analog converter. Finally they are fed into video section of the television monitor. By this circuit operations can be performed quickly with higher

Ultrasonic probe

- Ultrasonic probe is a very important sensor which generate acoustic signals and also detect returned signals. The performance and imaging quality of ultrasonic scanner are highly affected by the characteristic and the structure(piezoelectric material, matching layer and acoustic lens) of probe.



TRANSDUCER PROBES

Probes are generally described by the size and shape of their face("footprint"). There are 3 basic types of probe used in emergency and critical-care ultrasound

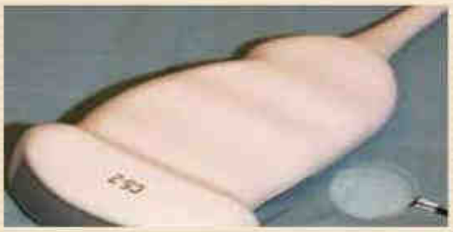
- Linear array probe
- Curvilinear array probe
- Phased array probe

STRAIGHT LINEAR ARRAY PROBE

- It is designed for superficial imaging
- Crystals are aligned in a linear fashion within a flat head and produce sound waves in a straight line.
- Image produced is rectangular in shape
- Probe has higher frequency (5-13 MHz) providing better resolution and less penetration.

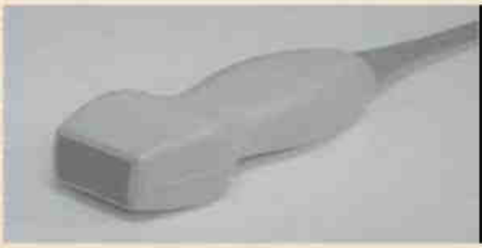
CURVILINEAR PROBE

- Also called convex probe
- Used for scanning deeper structures
- Crystals are aligned along a curved surface which results in a wide field of view
- Image created is sector shaped.
- Probes have frequency between 1-8 MHz allowing greater penetration and less resolution.
- Generally used in abdominal and pelvic applications.




PHASED ARRAY PROBE

- Crystals are grouped closely together.
- Sound waves originate from a single point and fan outward, creating a sector-type image.
- Has smaller and flatter footprint than the curvilinear probe.
- Probe has frequency between 2-8 MHz
- Generally used for cardiac imaging, Imaging between ribs and small spaces.




ENDOCAVITARY PROBE

- Has a curved face
- Has higher frequency than curvilinear probe (8-13 MHz)
- Probe's elongated shape allows it to be inserted close to the anatomy being evaluated.
- Curved face creates a wide field of view of almost 180^0
- High frequency provides superior resolution
- Most commonly used for gynecological applications