BME63 – MEDICAL IMAGING TECHNIQUES

UNIT-1

PART-A

1. List a few applications of diagnostic ultrasound. (April/May 2014)

- Ultrasound imaging uses sound waves to produce pictures of the inside of the body.
- It is used to help diagnose the causes of pain, swelling and infection in the body's internal organs and to examine a baby in pregnant women and the brain and hips in infants.

2. Give the relationship between frequency and wavelength. (April/May 2014)

The wavelength and frequency of light are closely related. The higher the frequency, the shorter the wavelength. Because all light waves move through a vacuum at the same speed, the number of wave crests passing by a given point in one second depends on the wavelength.

3. Name the properties of an image. (April/May 2016)

- The image obtained is virtual.
- The image is laterally inverted.
- The image is erect.
- The size of the image is the same as the size of the object.
- The distance between the image obtained is the same as the distance between the object from the mirror.

4. What is the principle behind fluoroscopy? (April/May 2016)

During a fluoroscopy procedure, an X-ray beam is passed through the body. The image is transmitted to a monitor so the movement of a body part or of an instrument or contrast agent ("X-ray dye") through the body can be seen in detail.

5. Mention any two properties of x-rays. (May 2017)

- They have a shorter wavelength of the electromagnetic spectrum.
- Requires high voltage to produce X-Rays.
- They are used to capture the human skeleton defects.
- They travel in a straight line and do not carry an electric charge with them.
- They are capable of travelling in a vacuum.

6. Mention few image modalities. (November/December 2017)

- Computed Tomography.
- Ultrasound.
- Magnetic Resonance Imaging.
- Positron Emission Tomography and Single Photon Emission Computed Tomography.
- Fluoroscopy.

7. What are the detectors commonly used in x-ray radiography? (November/December 2017)

The detector efficiency depends on the radiation energy to be determined and the density and type of detector material. In XRF spectrometers three different types of X-ray detectors are used: gas-filled detectors, scintillation detectors and semiconductor detectors.

8. What is attenuation? (April/May 2018)

The act or process of attenuating something or the state of being attenuated such as a lessening in amount, force, magnitude, or value, weakening Sound can travel thousands of kilometers in this planar acoustic waveguide with little attenuation.

9. Define Fluoroscopy. (April/May 2018)

Fluoroscopy is an imaging technique that uses X-rays to obtain real-time moving images of the interior of an object. In its primary application of medical imaging, a fluoroscope allows a physician to see the internal structure and function of a patient, so that the pumping action of the heart or the motion of swallowing, for example, can be watched. This is useful for both diagnosis and therapy and occurs in general radiology, interventional radiology, and image-guided surgery.

10. Define image intensifier. (November/December 2018)

An image intensifier tube is a device that intensifies (or amplifies) low light level images to levels that can be seen with the human eye or detected by digital image sensors. All modern tubes consist of three main components, a photocathode, a Microchannel Plate (MCP) and a phosphor screen.

11. How the X-RAYS are produced? (May 2019)

X-rays are commonly produced in X-ray tubes by accelerating electrons through a potential difference (a voltage drop) and directing them onto a target material (i.e. tungsten).

The incoming electrons release X-rays as they slowdown in the target (braking radiation or bremsstrahlung).

12. Compare radiography and fluoroscopy. (May 2019)

Radiography or X-ray and fluoroscopy procedure seem similar. However, fluoroscopy obtains moving images of the inner part of the body and radiography uses gamma rays to develop a static image of the internal structure of a body.

13. State the principle of X-RAYS. (September 2020)

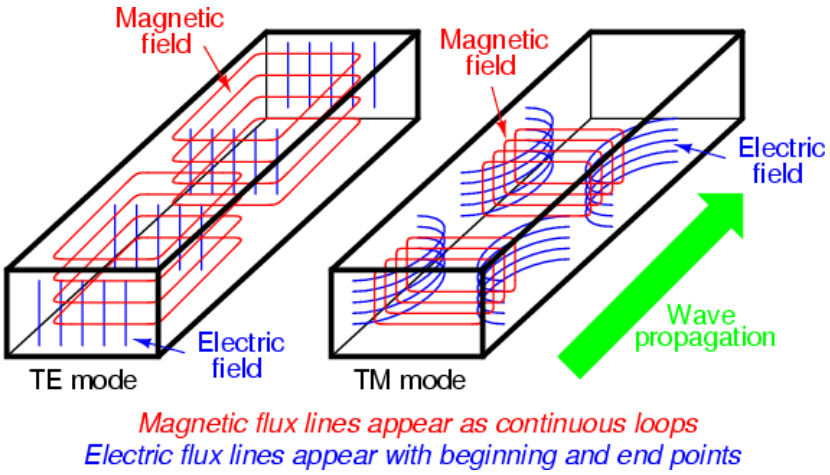
X-ray imaging begins with a beam of high energy electrons crashing into a metal target and x-rays are produced. A filter near the x-ray source blocks these low energy rays, which means only the high energy rays pass through a patient toward a sheet of photographic film. X-ray can penetrate liquids, gas and solids.

PART-B

1. **Explain the principle of T-M mode.(April/May2014)**

- In the Transverse Magnetic (TM) mode, the magnetic field is transverse to the direction of propagation while the electric field is normal to the direction of propagation.
- A transverse mode of electromagnetic radiation is a particular electromagnetic field pattern of the radiation in the plane perpendicular (i.e., transverse) to the radiation' s propagation direction.
- Transverse modes occur in radio waves and microwaves confined to a waveguide, and also in light waves in an optical fiber and in a laser's optical resonator.
- Transverse modes occur because of boundary conditions imposed on the wave by the waveguide. For example, a radio wave in a hollow metal waveguide must have zero tangential electric field amplitude at the walls of the waveguide, so the transverse pattern of the electric field of waves is restricted to those that fit between the walls.
- For this reason, the modes supported by a waveguide are quantized. The allowed modes can be found by solving Maxwell's equations for the boundary conditions of a given waveguide.
- **TM mode** : Transverse magnetic waves, also called E waves are characterised by the fact that the magnetic vector (H vector) is always perpendicular to the direction of propagation.

- TEM **mode**: The Transverse electromagnetic wave cannot be propagated within a **waveguide**, but is included for completeness.



- Where in TM modes the electric field is in the direction perpendicular to that of propagation, so ONLY the magnetic field propagates within the waveguide, and vice versa for TE modes. This is why the electric or magnetic components are considered 0 (given that we're assuming z to be the direction of propagation).
- So you have two instances for TM and TE waves, where the electric field is zero or the magnetic field is zero - why you have two sets of equations.
- This differs in TEM modes where neither propagate in the direction of the waveguide, however at least two conductors are required for any TEM modes to exist.

2. What are the applications of A-scan? Explain.(April/May2014)

- The A-scan provides data on the length of the eye, which is a major determinant in common sight disorders.
- The most common use of the A-scan is to determine eye length for calculation of intraocular lens power.
- When a cataract is removed, the lens is replaced by an artificial lens implant.
- A-scan ultrasound biometry, commonly referred to as an A-scan (short for Amplitude scan), is a routine type of diagnostic test used in optometry or ophthalmology.
- The A-scan provides data on the length of the eye, which is a major determinant in common sight disorders.
- The most common use of the A-scan is to determine eye length for calculation of intraocular lens power.

- Briefly, the total refractive power of the emmetropic eye is approximately 60. Of this power, the cornea provides roughly 40 diopters, and the crystalline lens 20 diopters.
- When a cataract is removed, the lens is replaced by an artificial lens implant. By measuring both the length of the eye (A-scan) and the power of the cornea (keratometry), a simple formula can be used to calculate the power of the intraocular lens needed.
- There are several different formulas that can be used depending on the actual characteristics of the eye. All the information here is not valid for medical purposes.
- The other major use of the A-scan is to determine the size and ultrasound characteristics of masses in the eye, in order to determine the type of mass. This is often termed quantitative A-scan.
- Instruments used in this type of test require direct contact with the cornea, however a non-contact instrument has been reported. Disposable covers, which come in actual contact with the eye, have also been evaluated.

3. (a)Give the detail account on X-ray generators(April/May2016)

(b)Explain the working of X-ray generators.(November/December2017, November/December2019)

An X-ray generator is a device that produces X-rays. Together with an X-ray detector, it is commonly used in a variety of applications including medicine, X-ray fluorescence, electronic assembly inspection, and measurement of material thickness in manufacturing operations. In medical applications, X-ray generators are used by radiographers to acquire x-ray images of the internal structures (e.g., bones) of living organisms, and also in sterilization.

Structure

An X-ray generator generally contains an X-ray tube to produce the X-rays. Possibly, radioisotopes can also be used to generate X-rays.

An X-ray tube is a simple vacuum tube that contains a cathode, which directs a stream of electrons into a vacuum, and an anode, which collects the electrons and is made of tungsten to evacuate the heat generated by the collision. When the electrons collide with the target, about 1% of the resulting energy is emitted as X-rays, with the remaining 99% released as heat. Due

to the high energy of the electrons that reach relativistic speeds the target is usually made of tungsten even if other material can be used particularly in XRF applications.

An X-ray generator also needs to contain a cooling system to cool the anode; many X-ray generators use water or oil recirculating systems.

Medical imaging

In medical imaging applications, an X-ray machine has a control console that is used by a radiologic technologist to select X-ray techniques suitable for the specific exam, a power supply that creates and produces the desired kVp (peak kilovoltage), mA (milliamperes, sometimes referred to as mAs which is actually mA multiplied by the desired exposure length) for the X-ray tube, and the X-ray tube itself.

Applications

X-ray machines are used in health care for visualising bone structures, during surgeries (especially orthopedic) to assist surgeons in reattaching broken bones with screws or structural plates, assisting cardiologists in locating blocked arteries and guiding stent placements or performing angioplasties and for other dense tissues such as tumours. Non-medicinal applications include security and material analysis.

Medicine

The main fields in which x-ray machines are used in medicine are radiography, radiotherapy, and fluoroscopic-type procedures. Radiography is generally used for fast, highly penetrating images, and is usually used in areas with a high bone content but can also be used to look for tumors such as with mammography imaging. Some forms of radiography include:

- orthopantomogram — a panoramic x-ray of the jaw showing all the teeth at once
- mammography — x-rays of breast tissue
- tomography — x-ray imaging in sections

In fluoroscopy, imaging of the digestive tract is done with the help of a radiocontrast agent such as barium sulfate, which is opaque to X-rays.

Radiotherapy — the use of x-ray radiation to treat malignant and benign cancer cells, a non-imaging application

Fluoroscopy is used in cases where real-time visualization is necessary (and is most commonly

encountered in everyday life at airport security). Some medical applications of fluoroscopy include:

- angiography — used to examine blood vessels in real time along with the placement of stents and other procedures to repair blocked arteries.
- barium enema — a procedure used to examine problems of the colon and lower gastrointestinal tract
- barium swallow — similar to a barium enema, but used to examine the upper gastrointestinal tract
- biopsy — the removal of tissue for examination
- Pain Management - used to visually see and guide needles for administering/injecting pain medications, steroids or pain blocking medications throughout the spinal region.
- Orthopedic procedures - used to guide placement and removal of bone structure reinforcement plates, rods and fastening hardware used to aide the healing process and alignment of bone structures healing properly together.

X-rays are highly penetrating, ionizing radiation, therefore X-ray machines are used to take pictures of dense tissues such as bones and teeth. This is because bones absorb the radiation more than the less dense soft tissue. X-rays from a source pass through the body and onto a photographic cassette. Areas where radiation is absorbed show up as lighter shades of grey (closer to white). This can be used to diagnose broken or fractured bones.

4. Give the detail account on Intensifying screens(April/May2016)

INTENSIFYING SCREENS.

- An intensifying screen is a plastic sheet coated with fluorescent material called phosphors. Phosphors are materials which convert photon energy to light.
- LUMINESCENCE is the emission of light from a substance bombarded by radiation. There are two types; fluorescence and phosphorescence.
- Fluorescence means that luminescence is excited only during the period of irradiation and will terminate at completion of the X-ray exposure.
- The phosphors in intensifying screens produce fluorescence.
- Phosphorescence is afterglow.

- The irradiated material continues to emit light for a time after cessation of exposure to radiation and will continue to produce an image which you do not want. The luminescent effect is used radiographically in two way.
- To obtain an image on a fluorescent screen as in fluoroscopy, and To increase the photographic response of the silver halide emulsion.
- In this case the fluorescent material is placed in the emulsion layer on the intensifying screen, in direct contact with the film during exposure. Since X-ray films are coated with emulsion on both sides, intensifying screens are employed in pairs.
- Each emulsion surface is placed in close contact with the effective surface of one intensifying screen, to avoid loss of image sharpness.
- Speeds of Intensifying Screens.
  - Fast screens - thick layer, and relatively large crystals used, maximum speed is attained but with some sacrifice in definition.
  - Slow screens or high definition screens - a thin layer and relatively small crystals are used; detail is the best, but speed is slow necessitating a higher dose of ionizing radiation.
- Medium screens - medium thick layer of medium sized crystals in order to provide comprise between speed and definition.
- There are three types of intensifying screens
  - Standard - slow screens
  - Rare earth - fast screens
  - Combination Standard screens use calcium tungstate phosphors, while rare earth screens use gadolinium or lanthanum phosphors.
- The commercial name for rare earth screens is Lanex.
- Rare earth phosphors are more efficient at converting X-rays to visible light thus reducing the radiation further to the patient.
- The manufacturers name and the type of screen are printed on the one side of the screen and this information appears on the radiograph.
- The intensifying screen is placed in a cassette in close contact with a film.
- The visible light from its fluorescent image will add to the latent image on the film. Its function is to reinforce the action of X-rays by subjecting the emulsion to the effect of light as well as ionizing radiation.
- The benefit is the reduction in dose of ionizing radiation to the patient.

Characteristics of Intensifying Screens:

1) An intensifying screen consists of a base of polyester or cellulose triacetate similar to radiographic film.

2) This base must be radioparent.

3) Chemically inert.

4) It must combine characteristics of toughness and flexibility

5) Should neither cur

6) Not discolor with age.

7) The base is first coated with a reflective layer of titanium dioxide to bounce light back onto the film.

8) Divergence of the light rays causes unsharpness of the image with a uniform homogeneous phosphor layer- standard or rare earth.

9) this is covered with a thin transparent supercoat consisting of gelatin. The purpose of the latter is protective, and is very thin and care is always required in handling intensifying screens to avoid any kind of abrasion

10) The flexibility of the material is important to allow the screen to bend without cracking - an intensifying screen of this type is used in the panoramic cassette. Each crystal on the screen emits bluish light for regular screens (or green light for rare-earthscreens)

- Brightness is related directly to the intensity of the X-rays in that minute portion of the image. Thus, over the entire surface of the screen, differences in X-ray intensities are transformed into differences of bluish light (green light) brightness to which the film is highly sensitive. The entire image is thus intensified for recording by the film.
- The larger the crystals and the thicker the fluorescent layer on the screen, the more light is produced and the greater the intensification. However, the light spreads more widely and the sharpness of detail of the image is decreased accordingly.
- Manufactures have attempted to improve image quality without sacrifice to film speed by using phosphor crystals of different shapes. An example of this is the T-Mat film that we use for panoramic and extraoral radiographs.

- Increasing Film Speed.

    1. Thicker phosphor layers.
    2. Higher conversion efficiency.
    3. Higher absorption phosphor.
    4. Decreased resolution of image

- The film-screen combination must be matched so that the emission characteristics of the screen match the spectral sensitivity of the film. It is also important to note that when double-loading cassettes, one must use a faster film (e.g.: T-Mat H) or increase the kVp as only one side of each film will be in contact with the intensifying screens.

5. Explain about the conventional X-ray radiography. (April/May2016, April/May2018)

- Radiography is the use of x-rays to visualize the internal structures of a patient. X-Rays are a form of electromagnetic radiation, produced by an x-ray tube.
- The x-rays are passed through the body and captured behind the patient by a detector; film sensitive to x-rays or a digital detector.
- There is variance in absorption of the x-rays by different tissues within the body, dense bone absorbs more radiation, while soft tissue allows more to pass through.
- This variance produces contrast within the image to give a 2D representation of all the structures within the patient.

Common clinical applications

- Chest: to assess lung pathology
- Skeletal: to examine bone structure and diagnose fractures, dislocation or other bone pathology
- Abdomen: can assess abdominal obstruction, free air or free fluid within the abdominal cavity
- Dental: to assess common dental pathologies such as cavities or abscesses

Safety

- Radiography utilizes x-rays, a proportion of which are absorbed within the body. The potential effects on the body from ionizing radiation are categorized as

deterministic (including skin reddening or burns) dependent on the dose or stochastic (long term effects such as cancer).

- Due to the potential risk from ionizing radiation, exposures from radiography procedures must adhere to the ALARA principal; "as low as reasonable achievable" to obtain a diagnostic examination.
- Special consideration should be given to pregnant women and children as they are more sensitive to radiation.
- X-ray personnel should at all times ensure that the benefit of the examination will outweigh potential risk from radiation exposure, and that the patient is exposed to as little radiation as possible.

When the density of adjacent tissues is similar, a radiopaque contrast agent (see Radiographic Contrast Agents and Contrast Reactions) is often added to one tissue or structure to differentiate it from its surroundings. Structures typically requiring a contrast agent include blood vessels (for angiography) and the lumina of the gastrointestinal, biliary, and genitourinary tracts. Gas may be used to distend the lower gastrointestinal tract and make it visible.

Other imaging tests (eg, CT, MRI) have largely replaced contrast studies because their tomographic images provide better anatomic localization of an abnormality. Endoscopic procedures have largely replaced barium contrast studies of the esophagus, stomach, and upper intestinal tract.

Fluoroscopy

A continuous x-ray beam is used to produce real-time images of moving structures or objects. Fluoroscopy is most often used

- With contrast agents (eg, in swallowing studies or coronary artery catheterization)
- During medical procedures to guide placement of a lead, catheter, or needle (eg, in electrophysiologic testing or percutaneous coronary interventions.
- Fluoroscopy can also be used in real time to detect motion of the diaphragm and of bones and joints (eg, to assess the stability of musculoskeletal injuries).

Disadvantages

- Diagnostic accuracy is limited in many situations. Other imaging tests may have advantages,
- such as providing better detail or being safer or faster.
- Contrast agents such as barium and gastrografin, if used, have disadvantages (see Disadvantages of CT), and IV contrast agents have risks.
- Fluoroscopy may involve high doses of radiation (see Risks of Medical Radiation).

6. With neat diagram explain the different types of X-rays detectors.(May 2017)

X-ray Detectors

The two most common types of X-ray detector used in the laboratory for powder diffraction (excluding the case of X-ray film) are the scintillation and the gas-filled detectors, both of which are described below.

Scintillation Detectors

In the scintillation counter, the conversion of X-ray photons into an electrical signal is a two-stage process. The X-ray photon collides with a phosphor screen, or scintillator, which forms the coating of a thallium-doped sodium iodide crystal. The latter produces photons in the blue region of the visible spectrum. These are subsequently converted to voltage pulses by means of a photomultiplier tube attached directly behind the scintillator.

The number of electrons ejected by the photocathode is proportional to the number of visible photons which strike it, which in turn is proportional to the energy of the original X-ray photon.

Due to a large number of losses, the energy resolution of the detector is poor, and as such it cannot be used to resolve X-ray photons due to Kα and Kβ radiation.

However, it has a very high quantum efficiency and a very low dead time making it the ideal detector for the point intensity measurements required for step-scanning diffractometers.

Gas-filled Detectors

The second type of detector commonly used in the laboratory is the gas-filled detector. This detector works on the principle that X-ray photons can ionize inert gas atoms such as argon or

xenon into an electron (e^-) and ion (e.g. Ar^+) pair. The ionization energy required to eject an outer electron is low (10-20 eV) compared to the energy of the X-ray photon (8 keV) so that one X-ray photon can produce several hundred ion pairs.

A wire placed inside the detector is set to a potential of about 1,000 V. This accelerates the electrons of the ion pair towards the wire causing further ionization and an enhanced signal by gas amplification.

The burst of electrons on the wire is converted into a voltage pulse which is then shaped and counted by the electronics. In order to minimise the dead time of the system, a quenching gas such as methane (CH_4) is mixed with the inert gas (e.g. 90% Ar : 10% CH_4).

A disadvantage of gas-filled detectors is their loss of linearity at high count rates, but they have a better energy resolution than scintillation detectors. The simple gas-filled detector is much less-commonly used than a more sophisticated form known as a position sensitive detector or PSD.

PSDs are gas-filled detectors with a long poorly-conducting anode wire to which a high tension voltage is applied at both ends. In consequence, the pulse moves towards both ends of the wire simultaneously and by measuring the rate at which it arrives at both ends of the wire, it is possible to determine from whereabouts on the wire the pulse originated.

The pulses are stored in a multi-channel analyser (MCA) device according to the pulse position on the wire. This enables PSDs to record data over a whole range of scattering angles, which can be useful where speed of acquisition is crucial.

E.g. in time-resolved powder diffraction or thermodiffractometry. PSDs come in a variety of shapes and sizes: Small PSDs usually have a straight wire and can only collect data over, say, 5-10° 2θ.

Large PSDs require curved wires, but collect over a much wider range of scattering angle. In addition, some gas-filled PSDs are sealed, while others require a continuous flow of gas for their operation.

Calibration

In contrast to the scintillation and simple gas-filled detectors used for point intensity measurements, position sensitive detectors require careful calibration for both wire position and efficiency so that both scattering angles and intensities can be reliably determined. For each channel of the MCA an exact 2θ position is required together with an efficiency coefficient. The wire efficiency can be determined using a sample such as an amorphous iron foil that produces a very high flat background and no Bragg peaks. The 2θ calibration is achieved by scanning the different parts of the detector through the Bragg reflection of a strong peak (or peaks), e.g. the Si 111 peak. For very large curved detectors, the 2θ calibration has to be made using many diffraction peaks.

7. Write short notes Angiography(May2017,April/May2016, November/December2018)

Angiography or arteriography is a medical imaging technique used to visualize the inside, or lumen, of blood vessels and organs of the body, with particular interest in the arteries, veins, and the heart chambers. This is traditionally done by injecting a radio-opaque contrast agent into the blood vessel and imaging using X-ray based techniques such as fluoroscopy.

The term angiography has been applied to radionuclide angiography and newer vascular imaging techniques such as CO2 angiography, CT angiography and MR angiography.The term isotope angiography has also been used, although this more correctly is referred to as isotope perfusion scanning.

Types of angiography

- coronary angiography – to check the heart and nearby blood vessels.
- cerebral angiography – to check the blood vessels in and around the brain.
- pulmonary angiography – to check the blood vessels supplying the lungs.
- renal angiography – to check the blood vessels supplying the kidneys.
- Digital subtraction angiography (DSA) -is a fluoroscopic technique used extensively in interventional radiology for visualizing blood vessels

CORONARY ANGIOGRAPHY:

Coronary CT angiography is the use of computed tomography angiography to assess the coronary arteries of the heart. The subject receives an intravenous injection of radiocontrast

and then the heart is scanned using a high speed CT scanner, allowing physicians to assess the extent of occlusion in the coronary arteries, usually in order to diagnose coronary artery disease.

Coronary angiography. Coronary angiography is a procedure that uses a special dye (contrast material) and x-rays to see how blood flows through the arteries in your heart. Coronary angiography is often done along with cardiac catheterization. During the procedure a long, thin, flexible tube called a catheter is inserted into a blood vessel in your groin or arm. Using X-ray images as a guide, the tip of the catheter is passed up to the heart and coronary arteries. It is important to detect blockages because over time they can cause chest pain, especially with physical activity or stress, or a heart attack. If you are having a heart attack, coronary angiography can help your doctors plan your treatment.

A coronary angiogram is a procedure that uses X-ray imaging to see your heart's blood vessels. The test is generally done to see if there's a restriction in blood flow going to the heart.Coronary angiograms are part of a general group of procedures known as heart (cardiac) catheterizations. Cardiac catheterization procedures can both diagnose and treat heart and blood vessel conditions.

CEREBRAL ANGIOGRAPHY:

Cerebral angiography is a form of angiography which provides images of blood vessels in and around the brain, thereby allowing detection of abnormalities such as arteriovenous malformations and aneurysms. It was pioneered in 1927 by the Portuguese neurologist Egas Moniz at the University of Lisbon, who also helped develop thorotrast for use in the procedure.

CT angiography of the cerebral arteries (also known as a CTA carotids or an arch to vertex angiogram) is a noninvasive technique allows visualization of the internal and external carotid arteries and vertebral arteries and can include just the intracranial compartment or also extend down to the arch of the aorta.

In cerebral angiography, a catheter (long, thin, flexible tube) is inserted into an artery in the arm or leg. Using the catheter, a technician injects a special dye into the blood vessels that lead to the brain. It is a way to produce x-ray pictures of the insides of blood vessels.

Cerebral angiography can help diagnose: aneurysm. arteriosclerosis. arteriovenous malformation. vasculitis, or inflammation of the blood vessels. brain tumors.

PULMONARY ANGIOGRAPHY:

Pulmonary angiography is medical fluoroscopic procedure used to visualize the pulmonary arteries and much less frequently, the pulmonary veins. Conventional pulmonary angiography is a minimally invasive procedure performed most frequently by an interventional radiologist or interventional cardiologist. This form of angiography has the added benefit of the ability to treat certain conditions.

Pulmonary angiography (or pulmonary arteriography) is medical fluoroscopic procedure used to visualize the pulmonary arteries and much less frequently, the pulmonary veins.

Selective pulmonary angiogram revealing significant thrombus (labelled A) causing a central obstruction in the left main pulmonary artery. Pulmonary angiography (or pulmonary arteriography) is medical fluoroscopic procedure used to visualize the pulmonary arteries and much less frequently, the pulmonary veins.

Pulmonary angiography is performed using the technique described by Seldinger in 1953. 7 The veins used for catheterization of the pulmonary artery are the femoral, jugular and upper extremity vein. Of these, the right femoral vein is preferable because it provides a relatively straight course to the inferior vena cava and right heart.

RENAL ANGIOGRAPHY:

A renal angiogram is an imaging test to look at the blood vessels in your kidneys. Your healthcare provider can use it to look at the ballooning of a blood vessel (aneurysm), narrowing of a blood vessel (stenosis), or blockages in a blood vessel.

In case of renal angiography, CT is the preferred procedure. CT procedures require that a tracer (contrast material or radioactive chemical) be injected in order to highlight tissues and blood vessels and offer detailed images of the same.

Renal Angiogram and Angioplasty. Renin keeps blood pressure normal. People with kidney disease may also develop high blood pressure, which can in turn be associated with other problems such as heart attacks and stroke. Erythropeitin tells the body to make red blood cells. Lack of this hormone can result in anaemia.

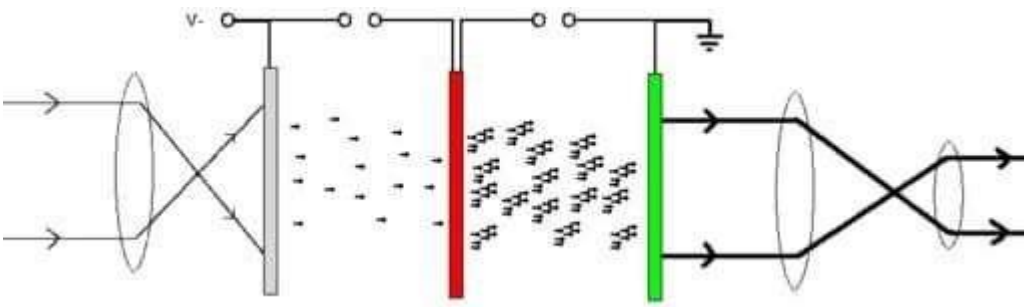
DIGITAL SUBTRACTION ANGIOGRAPHY:

Digital subtraction angiography (DSA) is a fluoroscopic technique used extensively in interventional radiology for visualizing blood vessels. Radiopaque structures such as bones are eliminated ("subtracted") digitally from the image, thus allowing for an accurate depiction of the blood vessels.

There are numerous indications for angiography and their number has been on the rise ever since interventional radiology has been shown to successfully supplant many open vascular procedures. Salient examples include:

- endovascular aneurysm repair
- arterial balloon angioplasty
- arterial stenting
- endovascular embolization
- thrombectomy

8. Draw a labelled diagram and explain the working of image intensifier tube. (November/December2017,May 2019, November/December2019,September 2020)



An image intensifier or image intensifier tube is a vacuum tube device for increasing the intensity of available light in an optical system to allow use under low-light conditions, such as at night, to facilitate visual imaging of low-light processes, such as fluorescence of materials in X-rays or gamma rays (X-ray image intensifier), or for conversion of non-visible light sources, such as near-infrared or short wave infrared to visible.

They operate by converting photons of light into electrons, amplifying the electrons (usually with a microchannel plate), and then converting the amplified electrons back into photons for viewing. They are used in devices such as night-vision goggles.

Image intensifier tubes (IITs) are optoelectronic devices that allow many devices, such as night vision devices and medical imaging devices, to function. They convert low levels of light from various wavelengths into visible quantities of light at a single wavelength.

Image intensifiers convert low levels of light photons into electrons, amplify those electrons, and then convert the electrons back into photons of light. Photons from a low-light source enter an objective lens which focuses an image into a photocathode.

The photocathode releases electrons via the photoelectric effect as the incoming photons hit it. The electrons are accelerated through a high-voltage potential into a microchannel plate (MCP). Each high-energy electron that strikes the MCP causes the release of many electrons from the MCP in a process called secondary cascaded emission.

The MCP is made up of thousands of tiny conductive channels, tilted at an angle away from normal to encourage more electron collisions and thus enhance the emission of secondary electrons in a controlled Electron avalanche.

All the electrons move in a straight line due to the high-voltage difference across the plates, which preserves collimation, and where one or two electrons entered, thousands may emerge.

A separate (lower) charge differential accelerates the secondary electrons from the MCP until they hit a phosphor screen at the other end of the intensifier, which releases a photon for every electron.

The image on the phosphor screen is focused by an eyepiece lens. The amplification occurs at the microchannel plate stage via its secondary cascaded emission.

The phosphor is usually green because the human eye is more sensitive to green than other colors and because historically the original material used to produce phosphor screens produced green light (hence the soldiers' nickname 'green TV' for image intensification devices).

THE NATURE OF X-RAYS ARE GIVEN BELOW:

- They have a shorter wavelength of the electromagnetic spectrum.
- Requires high voltage to produce X-Rays.
- They are used to capture the human skeleton defects.
- They travel in a straight line and do not carry an electric charge with them.

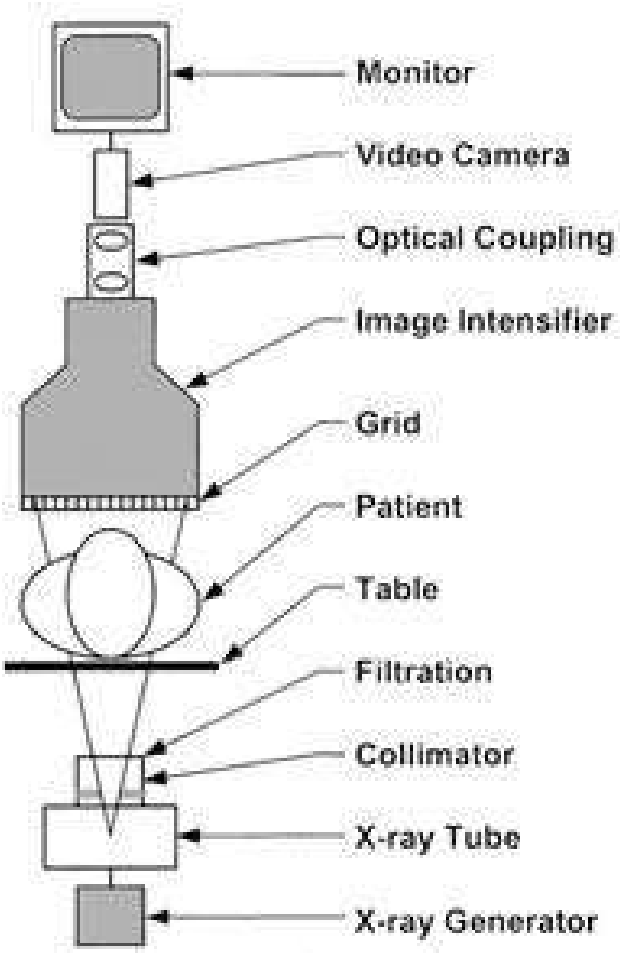
- They are capable of travelling in a vacuum.
- Highly Penetrative
- Highly Absorptive
- Highly Ionizing
- Produce Fluorescence

9. Write short notes on Fluoroscopy(May2017, November/December2018,May 2019, September 2020)

- Fluoroscopy is an imaging technique that uses X-rays to obtain real-time moving images of the interior of an object. In its primary application of medical imaging
- A fluoroscope allows a physician to see the internal structure and function of a patient, so that the pumping action of the heart or the motion of swallowing.
- For example, can be watched. This is useful for both diagnosis and therapy and occurs in general radiology, interventional radiology, and image-guided surgery.
- Fluoroscopy, or real-time projection X-ray imaging, has been in clinical use since shortly after Roentgen's discovery of X-rays. Early fluoroscopes consisted simply of an X-ray source and a fluorescent screen, between which the patient was placed.
- After passing through the patient, the remnant beam impinged upon the fluorescent screen and produced a visible glow, which was directly observed by the practitioner.
- In modern systems, the fluorescent screen is coupled to an electronic device that amplifies and transforms the glowing light into a video signal suitable for presentation on an electronic display.
- One benefit of the modern system compared to the earlier approach is that the fluoroscopist need not stand in close proximity to the fluorescent screen in order to observe the live image.
- This results in a substantial reduction in radiation dose to the fluoroscopist. Patients receive less radiation dose as well, because of the amplification and overall efficiency of the imaging system.

- The key components include an X-ray tube, spectral shaping filters, a field restriction device (aka collimator), an anti-scatter grid, an image receptor, an image processing computer and a display device.

- Ancillary but necessary components include a high-voltage generator, a patient-support device (table or couch) and hardware to allow positioning of the X-ray source assembly and the image receptor assembly relative to the patient.



X-ray Source

The high-voltage generator and X-ray tube used in most fluoroscopy systems is similar in design and construction to tubes used for general radiographic applications. For special purpose rooms such as those used for cardiovascular imaging, extra heat capacity is needed to allow angiographic "runs," sequences of higher-dose radiographic images acquired in rapid succession to visualize opacified vessels. These runs are often interspersed with fluoroscopic

imaging in a diagnostic or interventional procedure, and the combination can result in a high demand on the X-ray tube. Special X-ray tubes are generally found in such systems.

Beam Filtration

It is common for fluoroscopic imaging systems to be equipped with beam hardening filters between the X-ray tube exit port and the collimator. Added aluminum and/or copper filtration can reduce skin dose at the patient's entrance surface, while a low kVp produces a spectral shape that is well-matched to the barium or iodine k-edge for high contrast in the anatomy of interest.

Collimation

Shutters that limit the geometric extent of the X-ray field are present in all X-ray equipment. In fluoroscopy, the collimation may be circular or rectangular in shape, matching the shape of the image receptor.

Patient Table and Pad

Patient tables must provide strength to support patients and are rated by the manufacturer for a particular weight limit. It is important that the table not absorb much radiation to avoid shadows, loss of signal and loss of contrast in the image.

Anti-Scatter Grid

Anti-scatter grids are standard components in fluoroscopic systems, since a large percentage of fluoroscopic examinations are performed in high-scatter conditions, such as in the abdominal region. Typical grid ratios range from 6:1 to 10:1. Grids may be circular (XRII systems) or rectangular (FPD systems) and are often removable by the operator.

Image Receptor — X-ray Image Intensifier (XRII)

The X-ray image intensifier (Figure 2) is an electronic device that converts the X-ray beam intensity pattern (aka, the "remnant beam") into a visible image suitable for capture by a video camera and displayed on a video display monitor. The key components of an XRII are an input phosphor layer, a photocathode, electron optics and an output phosphor.

Image Receptor — Flat Panel Detector (FPD)

In recent years we have seen the introduction of fluoroscopic systems in which the XRII and video camera components are replaced by a "flat panel detector" (FPD) assembly. When flat panel X-ray detectors first appeared in radiography, they offered the advantages of a "digital camera" compared with existing technologies.

Image Display

Fluoroscopy requires high-quality video displays that allow users to appreciate fine details and subtle contrast differences in the anatomy of interest. Medical image display technology has been fortunate to "ride on the coattails" of the television industry over the last several years.

10. Explain in detail the interaction between X-ray and matter. Also explain intensity of x-ray.(April/May2018)

X-ray photons are created by the interaction of energetic electrons with matter at the atomic level. Photons (x-ray and gamma) end their lives by transferring their energy to electrons contained in matter. X-ray interactions are important in diagnostic examinations for many reasons. For example, the selective interaction of x-ray photons with the structure of the human body produces the image; the interaction of photons with the receptor converts an x-ray or gamma image into one that can be viewed or recorded. This chapter considers the basic interactions between x-ray and gamma photons and matter.

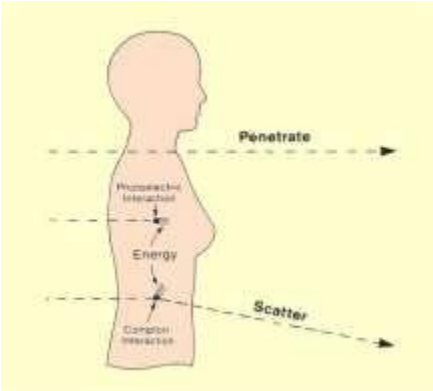
As an x-ray beam or gamma radiation passes through an object, three possible fates await each photon, as shown in the figure below:

1. It can penetrate the section of matter without interacting.

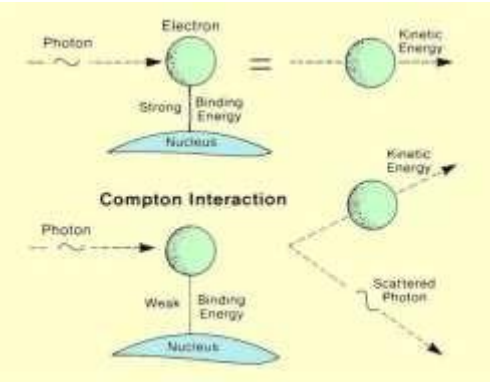
2. It can interact with the matter and be completely absorbed by depositing its energy.

3. It can interact and be scattered or deflected from its original direction and deposit part of its energy.

Photons Entering the Human Body Will Either Penetrate, Be Absorbed, or Produce Scattered Radiation



There are two kinds of interactions through which photons deposit their energy; both are with electrons. In one type of interaction the photon loses all its energy; in the other, it loses a portion of its energy, and the remaining energy is scattered. These two interactions are shown below.



In the photoelectric (photon-electron) interaction, as shown above, a photon transfers all its energy to an electron located in one of the atomic shells. The electron is ejected from the atom by this energy and begins to pass through the surrounding matter. The electron rapidly loses its energy and moves only a relatively short distance from its original location. The photon's energy is, therefore, deposited in the matter close to the site of the photoelectric interaction. The energy transfer is a two-step process. The photoelectric interaction in which the photon transfers its energy to the electron is the first step. The depositing of the energy in the surrounding matter by the electron is the second step.

Photoelectric interactions usually occur with electrons that are firmly bound to the atom, that is, those with a relatively high binding energy. Photoelectric interactions are most probable when the electron binding energy is only slightly less than the energy of the photon. If the binding energy is more than the energy of the photon, a

photoelectric interaction cannot occur. This interaction is possible only when the photon has sufficient energy to overcome the binding energy and remove the electron from the atom.

The photon's energy is divided into two parts by the interaction. A portion of the energy is used to overcome the electron's binding energy and to remove it from the atom. The remaining energy is transferred to the electron as kinetic energy and is deposited near the interaction site. Since the interaction creates a vacancy in one of the electron shells, typically the K or L, an electron moves down to fill in. The drop in energy of the filling electron often produces a characteristic x-ray photon. The energy of the characteristic radiation depends on the binding energy of the electrons involved. Characteristic radiation initiated by an incoming photon is referred to as fluorescent radiation. Fluorescence, in general, is a process in which some of the energy of a photon is used to create a second photon of less energy. This process sometimes converts x-rays into light photons. Whether the fluorescent radiation is in the form of light or x-rays depends on the binding energy levels in the absorbing material.

Compton

A Compton interaction is one in which only a portion of the energy is absorbed and a photon is produced with reduced energy. This photon leaves the site of the interaction in a direction different from that of the original photon, as shown in the previous figure. Because of the change in photon direction, this type of interaction is classified as a scattering process. In effect, a portion of the incident radiation "bounces off' or is scattered by the material. This is significant in some situations because the material within the primary x-ray beam becomes a secondary radiation source. The most significant object producing scattered radiation in an x-ray procedure is the patient's body. The portion of the patient's body that is within the primary x-ray beam becomes the actual source of scattered radiation. This has two undesirable consequences. The scattered radiation that continues in the forward . direction and reaches the image receptor decreases the quality (contrast) of the image; the radiation that is scattered from the patient is the predominant source of radiation exposure to the personnel conducting the examination

Coherent scatter

There are actually two types of interactions that produce scattered radiation. One type, referred to by a variety of names, including coherent, Thompson, Rayleigh, classical, and elastic, is a pure scattering interaction and deposits no energy in the material. Although this type of interaction is possible at low photon energies, it is generally not significant in most diagnostic procedures.

Pair production

Pair production is a photon-matter interaction that is not encountered in diagnostic procedures because it can occur only with photons with energies in excess of 1.02 MeV. In a pair-production interaction, the photon interacts with the nucleus in such a manner that its energy is converted into matter. The interaction produces a pair of particles, an electron and a positively charged positron. These two particles have the same mass, each equivalent to a rest mass energy of 0.51 MeV.

Electron interaction

The interaction and transfer of energy from photons to tissue has two phases. The first is the "one-shot" interaction between the photon and an electron in which all or a significant part of the photon energy is transferred; the second is the transfer of energy from the energized electron as it moves through the tissue. This occurs as a series of interactions, each of which transfers a relatively small amount of energy.

Several types of radioactive transitions produce electron radiation including beta radiation, internal conversion (IC) electrons, and Auger electrons. These radiation electrons interact with matter (tissue) in a manner similar to that of electrons produced by photon interactions.

In photoelectric interactions, the energy of the electron is equal to the energy of the incident photon less the binding energy of the electron within the atom. In Compton interactions, the relationship of the electron energy to that of the photon depends on the angle of scatter and the original photon energy. The electrons set free by these interactions have kinetic energies ranging from relatively low values to values slightly below the energy of the incident photons.

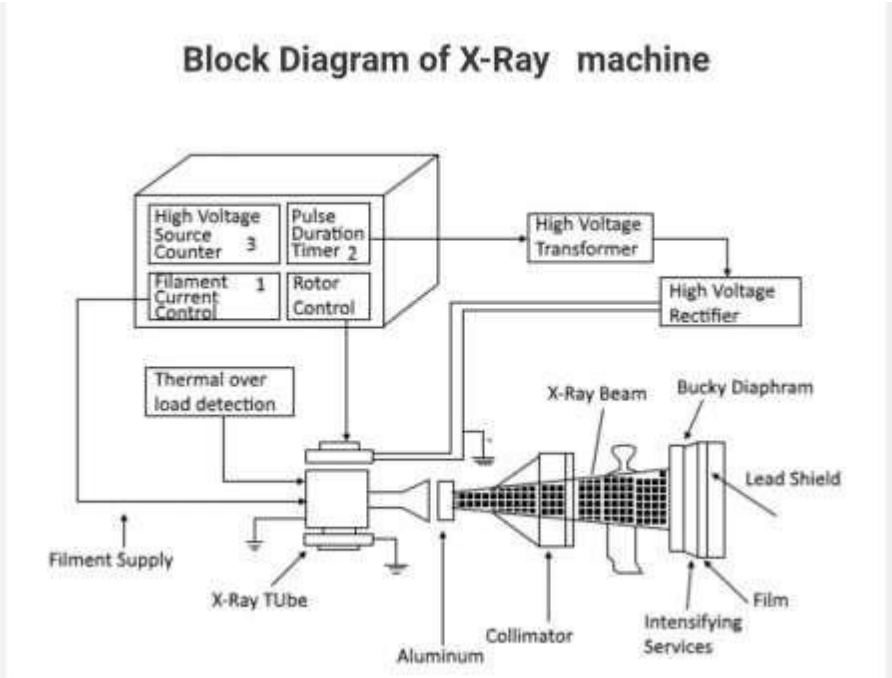
As the electrons leave the interaction site, they immediately begin to transfer their energy to the surrounding material, as shown below. Because the electron carries an electrical charge, it

can interact with other electrons without touching them. As it passes through the material, the electron, in effect, pushes the other electrons away from its path. If the force on an electron is sufficient to remove it from its atom, ionization results. In some cases, the atomic or molecular structures are raised to a higher energy level, or excited state. Regardless of the type of interaction, the moving electron loses some of its energy. Most of the ionization produced by x- and gamma radiation is not a result of direct photon interactions, but rather of interactions of the energetic electrons with the material. For example, in air, radiation must expend an average energy of 33.4 eV per ionization. Consider a 50-keV x-ray photon undergoing a photoelectric interaction. The initial interaction of the photon ionizes one atom, but the resulting energetic electron ionizes approximately 1,500 additional atoms.

11. Explain the working of X-ray machine used for diagnostic purposes in biomedical field.(November/December2018,May 2019)

X-RAYS:

Three types of rays emits continuously from a radium material. These rays are known as alpha rays (a rays). Beta rays (p rays) and gamma rays (x rays). Gamma rays also know as x-rays. The frequency of x-rays as approximately 1020 Hz and its wave length is approximately 10"10 meter. X-rays are electromagnetic wave which are widely used in medical field and industries for inspection of human body or any other thing.



PRODUCTION OF X-RAYS:

X-rays can be produced with the help of high vacuum tube with a heater, cathode and anode. Vacuum tube is operate at very high voltage. A special electron tube (vacuum tube) is which is used for production of x-rays. Such a tube has a hot filament cathode an anode made a very heave metal Electron flow from the cathode to anode as in any diode tube. However a large DC voltage is used between cathode and anode of x- rays tube.

Operation/Working of X-Ray Machine

High voltage source and high voltage transformer

High voltage source is responsible for providing high voltage to the H.V transformer for a decided time. The H.V transformer produces 20 KV to 200 KV at the O/P. These voltages are used to determine the contrast of the image. High voltages have higher contrast.

High voltage rectifier

This rectifier rectifies the high voltage produced by the H.V.T and supplies them to the anode of the X-ray tube

Thermal overload detector

The heat of the X-ray tube (should not be increase by a specified range). If the heat is exceed from a specified value, and then the thermal over load detector is used to turn off system.

Rotor control

Most of the X-ray tube anodes are rotated by an induction motor, in order to limit beam power at any spot and helps to cool the anode.

Pulse duration timer

The duration of the time must be very small so that

1. The patient does not receive the excessive dose.

2. The film does not become over exposed.

3. The X-ray tube does not over neat. The pulse duration timer determines this pulse duration.

Aluminum Filter

The X-ray beam used in the medical field which contains a broad band of frequencies (1) The unwanted frequencies in the x-ray based create side effects e.g extra dose for patient causing tumor also reduce the contrast in the image. These are called soft x-ray. To eliminate these effects Aluminum filter is used.

Collimator

Another mean to reduce the dose of patient is to confine the x-ray beam only on the region of interest on the body of patient. An external collimator placed between patient and filter does this.

Diaphragm

X- rays inside the patient create x-ray scattering, which tends to burned the image to absorb the scattered x-rays and eliminate the burning of an image a lead grid is used which is called diaphragm.

Film and lead shield

The x-rays passed from the desired region of the patient body are made to strike on the film where they produce an image of the body soft and hard parts. A lead shield is use to collect the x-rays after striking on film.

The H.V. source produces high voltage supply, which are rectified by rectifier and applied to anode of the x-ray tube Filament supply is also provided. As a result x-rays tube producing an x-ray beam which is passed through the body and produces image of body and the film, which is examined in laboratory

Application of the X-Ray

- Detection of the fraction in bones
- Infection of lungs, kidneys and other injury
- Presence of Tumour
- X-rays are used for treatment for Tumour.

Use of X-rays in industry

- For industrial radiography and fluoroscopy.
- For measuring the thickness of material
- Inspection of metals.
- Inspection of fruits before packing.

BM E63 – MEDICAL IMAGING TECHNIQUES

UNIT-2

PART-A

1. **What are the four major subsystems of computed tomography?(April/May2014, November/December2017)**

   A CT scanner is made up of 4 main components, the gantry (frame) houses the X-ray source and detectors and has a large opening in the middle (patient port), the subject table which moves in and out of the patient port, the x-ray source and detectors, and a computer system that gathers information from the detectors and produces an image from the information.

2. **What is the special advantage of spiral CT? (April/May2014)**

   The most important advantages of helical CT over conventional CT are

   (1) The shorter examination time, which decreases image degradation from motion artifact, even in infants and young children

   (2) the capability for retrospective image reconstruction, which decreases image degradation from volume averaging

   (3) improved multiplanar reconstructions.

3. **What are detector arrays? (April/May2016)**

   - A detector has elements that convert the incident electromagnetic radiation into electrical signals.
   - A readout circuit that relays and multiplexes the electrical signal from each detector element (or pixel) to a small number of output amplifiers (usually one or two).

4. **How can you improve the image quality in CT? (April/May2016)**

   CT image quality can be improved with the IQE protocols created in this study, to provide better soft tissue contrast, which would be beneficial for use in radiation therapy, e.g., for planning data acquisition or for IGRT for hypo-fractionated treatments.

5. **Write the basic principle of working of the Xray write computed tomography machine.(May 2017)**

   Cross-sections are reconstructed from measurements of attenuation coefficients of x-ray beams in the volume of the object studied. CT is based on the fundamental principle

that the density of the tissue passed by the x-ray beam can be measured from the calculation of the attenuation coefficient.

6. **Mention the value of the maximum skin dose of a single slice in a CT machine. (May2017)**

   The *CT dose index* (*CTDI*) is a measure of dose from a single rotation of the gantry. a typical dose profile along the *z*-axis is needed for an axial scan. It is drawn for a beam collimated to a width of 10 mm. It has a relatively flat peak, and the peak value is the maximum absorbed dose in the scan plane at the position of measurement.

7. **Give the basic principle of detector.(November/December2017)**
   - In their basic principles of operation, most detectors of ionizing radiation follow similar characteristics.
   - Detectors of ionizing radiation consist of two parts that are usually connected.
   - The radiation enters the detector, interacts with atoms of the detector material and deposits some energy to sensitive material.

8. **Write any two applications of computed tomorography. (November/December2017, November/December2019)**

   Applications of CT angiography include diagnosis of pulmonary embolism, aneurysm in major blood vessels, aortic dissection, atrial fibrillation, visualization of the renal arteries, arteriovenous malformation, and coronary artery disease, among others.

9. **Write the principle behind CT. (April/May2018,November/December2019)**
   - CT uses ionizing radiation, or x-rays, coupled with an electronic detector array to record a pattern of densities and create an image of a “slice” or “cut” of tissue.
   - The x-ray beam rotates around the object within the scanner such that multiple x-ray projections pass through the object

10. **Write the need for radiation dose. (April/May2018)**
    - Absorbed dose is the concentration of energy deposited in tissue as a result of an exposure to ionizing radiation.
    - Absorbed dose describes the intensity of the energy deposited in any small amount of tissue located anywhere in the body.

11. **Justify Xenon gas detector in a stable detector.(November/December2017)**
    - *Xenon gas* is used because it can remain *stable* under pressure and is significantly less expensive when compared to the solid-state variety.
    - Its also easier to calibrate and is highly *stable*.

- A *Xenon Detector* Channel consists of three tungsten plates. The *xenon gas* is ionized when a photon enters the channel.

12. State the advantages of sectional images.(May 2019)

C-S ***imaging*** can reliably measure muscle and fat distribution and uniquely discriminate between intra-abdominal organ and muscle component of fat-free mass. It precisely tracks changes within an individual, but is less able to distinguish true differences in whole body estimates between individuals.

13. Define Relaxation process.(May 2019)

Relaxation processes allow nuclear spins to return to equilibrium following a disturbance, e.g. a radiofrequency pulse. The first is closely related to spin–lattice relaxation, and arises from the finite lifetime of the spin states, through the uncertainty principle.

14. What are the characteristics of CT detectors?(September 2020)

Detector characteristics are crucial for obtaining good CT image quality. The main requirements are: accuracy, dynamic range, stability (short- and long-term), uniformity, speed of response, resolution, geometric efficiency, detector quantum efficiency and cross-talk (spatial and temporal).

15. What is Spiral CT?(September 2020)

Spiral CT is a type of computed tomography (CT) scan. It is being used more and more in medical centers across the country to diagnose lung cancer. Spiral CT uses a faster machine that spins continuously around the body. This allows it to more quickly detect images and spot problems.

PART-B

1. Explain the principle of iterative reconstruction method. (April/May2014)

Data Acquisition System: Although good detector properties are a pre-requisite for obtaining optimal image quality, the measuring electronics must have a large dynamic range to back up the detector. The dynamic range defines the ratio of the smallest, just detectable signal to the largest signal without causing saturation.

The dynamic range in a typical situation is 1:4,00,000. This implies that with such systems, an optimal image will always be obtained irrespective of whether the patient is obese or thin, or whether we are concerned with bones or soft tissues.

A typical data acquisition system is shown in Fig. 20.10. It consists of precision pre-amplifiers, current to voltage convertor, analog integrators, multiplexers and analog-to-digital convertors.

Data transfer rates of the order of 10 Mbytes/s are required in some scanners. This can be accomplished with a direct connection for systems having a fixed detector array. The third generation slip ring systems make use of optical transmitters on the rotating gantry to send data to fixed optical receivers.

Processing Unit: Although for the CT image, the patient slice is divided up into numerous three dimensional voxels, the image of the slice is a two-dimensional picture in which each picture element (pixel) value corresponds to the attenuation coefficient of a voxel in the object slice.the iterative or successive approximation method may be used to obtain an image of attenuation coefficients from the measured intensity data.

Suppose the attenuation coefficients of the objects (not known before hand) in the first row is 4 and 6, and in the second row it is 1 and 8, representing the characteristics of tissue within the patients. When the object is scanned with X-rays, the sum of the values along various rays/directions are obtained.

For example, for scan I, the vertical sums 5 and 14 are obtained; for scan II, the diagonal sums are 1, 12 and 6, and for scan III, the horizontal sums of 10 and 9 are obtained. This scan data will be now used to calculate the image matrix.

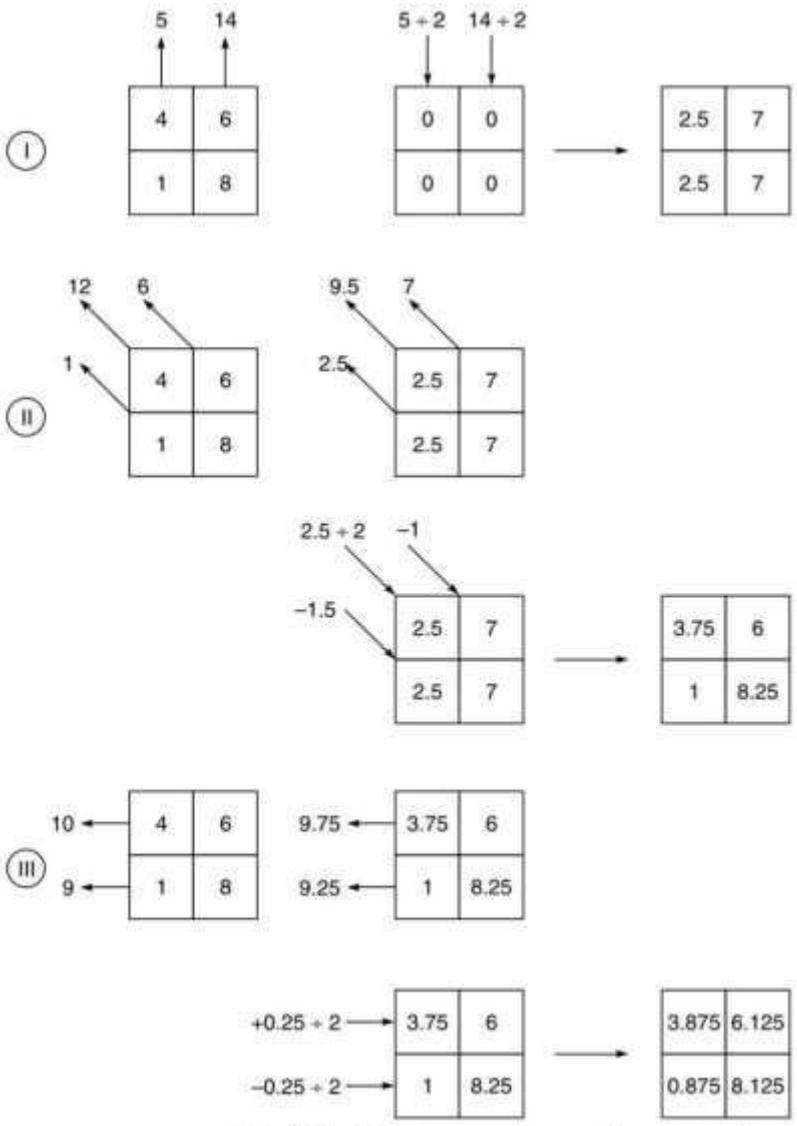
As the first step, the data from scan I is back-projected or distributed along the appropriate vertical column with equal weighting, by making the first estimate by placing 5/2 (2.5) in each pixel of that column. Similarly, the second column data value 14, is back-projected, giving 14/2 (7) for pixel in the second column.

The matrix of the resulting image of the first iteration is next summed up diagonally and its ray sums of 2.5, 9.5 and 7 are compared with the experimental data of 1, 12 and 6 obtained from scan II. The differences of –1.5, 2.5 and –1 are back-projected with equal weighting diagonally so as to match the experimental data of the scanned object.

Similarly, the resulting image matrix of the second iteration is now summed up horizontally to obtain the third iteration result. It is obvious that with more and more iterations, the image matrix matches more and more closely with the object matrix, thereby generating the image of an unknown object with the help of a computer.

The information received by the computer from the scanning gantry needs to be processed for reconstructing the pictures. The data from the gantry contains information on the following parameters:

- Positional information, such as which traverse is being performed and how far the scanning frame is along its traverse;
- Absorption information including the values of attenuation coefficient from the detectors;



Principle of iterative reconstruction method

2. What is the purpose of scanning systems? (April/May2014)

A scanner is a device usually connected to a computer. Its main function is to scan or take a picture of the document, digitize the information and present it on the computer screen.

A scanner is a device that captures images from photographic prints, posters, magazine pages, and similar sources for computer editing and display. Scanners come in hand-held, feed-in, and flatbed types and for scanning black-and-white only, or color..

3. (a)Explain about the generation of CT machines. (April/May2016, September 2020)

(b) Explain the generation of CT and also discuss the advantages and disadvantages in each generation.(May 2019)

(c) Explain the different generation of scanning systems. (April/May2014)

Computer tomography has two basic functions: user and utility. The user function carries out the tasks associated with the preparation of the scanner for operation, the management of the scanning process itself, the acquisition of the projection data, image reconstruction, support functions aiding diagnosis from the reconstructed images and archiving of the tomographic images.

The utility function deals with the technical parameters of the scanner, the diagnosis of errors and other service tasks. A CT scanner consists of the following main elements

•Data acquisition system that carries out the X-ray projections,

•Computer to reconstruct the images from the projections and to assist in the analysis of the reconstructed images,

•a variable power supply,

•A monitor to display the routine operation of the computer system and to act as an interactive interface in the diagnosis of the reconstructed images,

•a documentation camera to produce an image on film similar to traditional X-ray images,

•other data archiving systems, such as tape or disk, collectively referred to as storage devices,

The scanner itself is situated behind a screen to protect the operators from the harmful effects of the X-rays emitted by the tube. The other components of the CT system are located in the same room as the Technicians and doctors.

Whatever the differences in design of the different generations of scanners, the main elements remain the same. Figure 3.2 presents three orthogonal views of a standard design of data

acquisition system. Some elements of the apparatus are immediately recognisable, while others are part of the larger units and are not visible.

The main components of the scanner design are:

•The gantry with a central opening, into which the patient is moved during the examination. This is the most recognisable element of the CTscanner;

•The X-ray tube, the source of the X-rays that pass through the body situated in the gantry and carry the information about the structure of the body to the detectors. The information is in the form of a series of projections;

•The detector array converts the projection values, in the form of radiation Intensities, into electrical quantities. Usually, the whole detector array rotates synchronously with the X-ray tube around the test object;

•The table allows the patient to be maneuvered easily into position. The table can be controlled manually before the actual scan begins, but it moves automatically during the scan. The table can be moved into or out of the gantry along the axis of the patient‟s body, as well as up and down. This allows the patient to be appropriately positioned depending on which part of the body is being examined.

• The scanner also contains a number of sub-systems that drive and control the device, enable precise positioning of the patient during the scan as well as facilitate Communication with the patient.

The evolution of CT scanners has been marked by changes to the design of the projection sub-systems of the data acquisition system. In comparing these designs, only those that represent commonly used classes of CT devices are listed below; non-typical or prototype designs have been omitted.

The design of each of the CT scanner generations contains one of three basic Tube-detector projection systems

- a projection system using a parallel beam of radiation (a parallel-beam System),
- a system using a beam of radiation in the shape of a fan (a fan-beam system),
- a system using a beam of radiation in the shape of a cone (a cone-beam system).

First-Generation Scanners

First-generation scanners sometimes called pencil beam or translation/rotation Single detector scanners; belong to the class of device that uses a parallel-beam projection system.

In this type of scanner, there are two components to the movement of the rigidly coupled tube-detector system: a lateral movement to make a single projection and a circular movement about the central opening in the gantry to gather all the projections necessary to reconstruct the image.

The acquisition of the individual projections can be either continuous or discrete, but each of these projections is obtained only at a discrete angle of rotation of the projection system. It is easy to see how this method of scanning is not fast enough (it takes approximately 5 min); both the single detector and the X-ray tube must travel a distance equal to the diameter of the gantry opening, twice during each projection.

First-generation scanners are prime examples of devices having a parallel-beam Projection system. The procedure for obtaining images of successive cross-sections With this type of scanner is explained using below diagram.

The short arrows in the diagram show the positioning of the patient lying on the table while successive cross-sections are obtained. They represent the small sliding Movements of the table that take place after all the projections needed to reconstruct the image of a single slice have been performed. After each movement, the procedure for the collection of the projections for the next image is repeated.

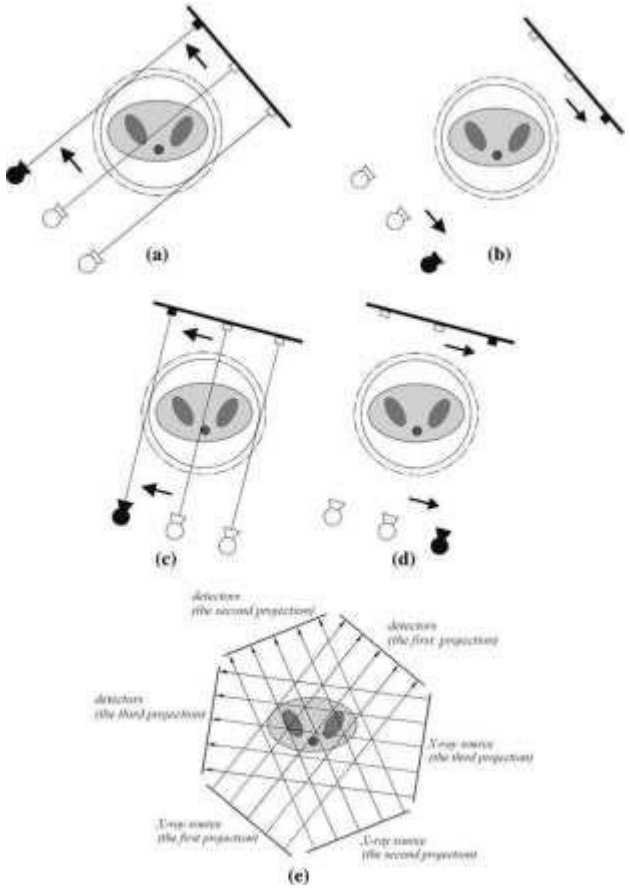
Design: single X-ray source and single X-ray detector cell to collect all the data for a single slice Source and detector, rigidly coupled

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, across a 24 cm.

•Translation and rotation process,this geometry is referred to as a translate/rotate scanner.



Disadvantages:

•Earliest versions:4.5 minutes for a single scan and thus were restricted to some regions (patient motion controlled)

•Later versions: procedures = series of scans procedure time reduced somewhat by using two detectors so that two parallel sections were acquired in one scan.

•Contrast resolution of internal structures was unprecedented, images had poor spatial.

•Resolution very poor.

Second-Generation Scanners

Great progress was made (compared to the design of first-generation scanners) when scanners with a larger number of detectors in the array were introduced around 1972. These second-generation scanners, sometimes called partial fan-beam or translation/rotation multiple detector scanners, had between 3 and 52 detectors in the array. The use of the fan-shaped radiation beam [3, 18] enabled the projections to cover a larger area of the patients body at any one time and resulted in the reduction of the number of projections needed to reconstruct an

image of satisfactory quality. Figure below illustrates the scanning sequence for this generation of scanner.

In this approach, the time to obtain the projections necessary for the reconstruction of one image was reduced to about 300 s, even though the movement of the tube- detector array was still a combination of lateral and rotational motion. This system can be considered as a transitional stage between the parallel-beam projection system and the fan-beam system.

•**Design:** multiple detectors B/C 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 significant ly more efficient and faster than 1st generation.

•This generation is a translate/rotate scanner second generation ct scanners.

Merits

•reducing scan time

•The trunk could be imaged

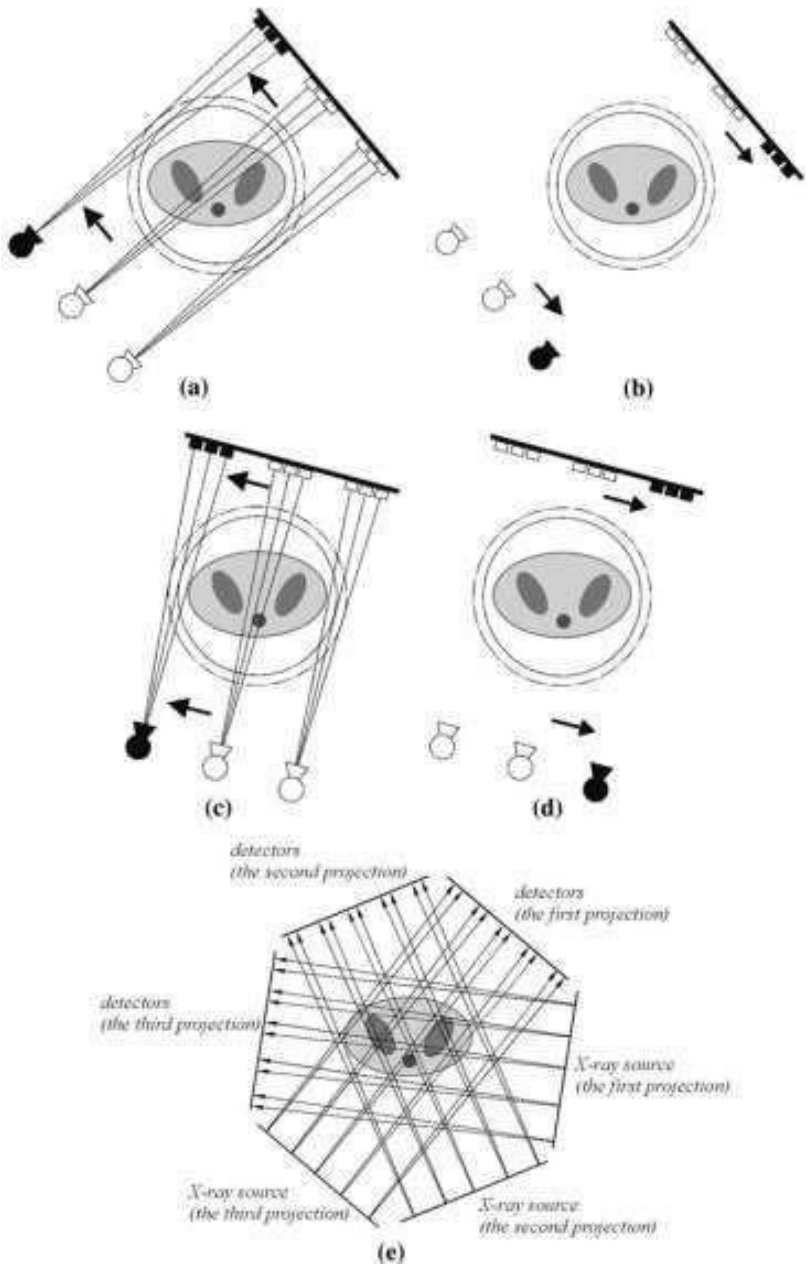
•By adding detectors angularly displaced, several projections could be obtained in a single translation

•Early versions: 3 detectors each displaced by1°Since each detector viewed the x-ray tube at a different angle, a single translation produced 3 projection.

•The system could rotate 3° to the next projection rather than 1° make only 60 translations instead of 180 to acquire a complete section. Scan times were reduced X 3.

•Later versions: up to 53 detectors Fast enough (tens of seconds)to permit acquisition during a single breath hold

•First designs to permit scans of the trunk. Because rotating anode tubes could not.



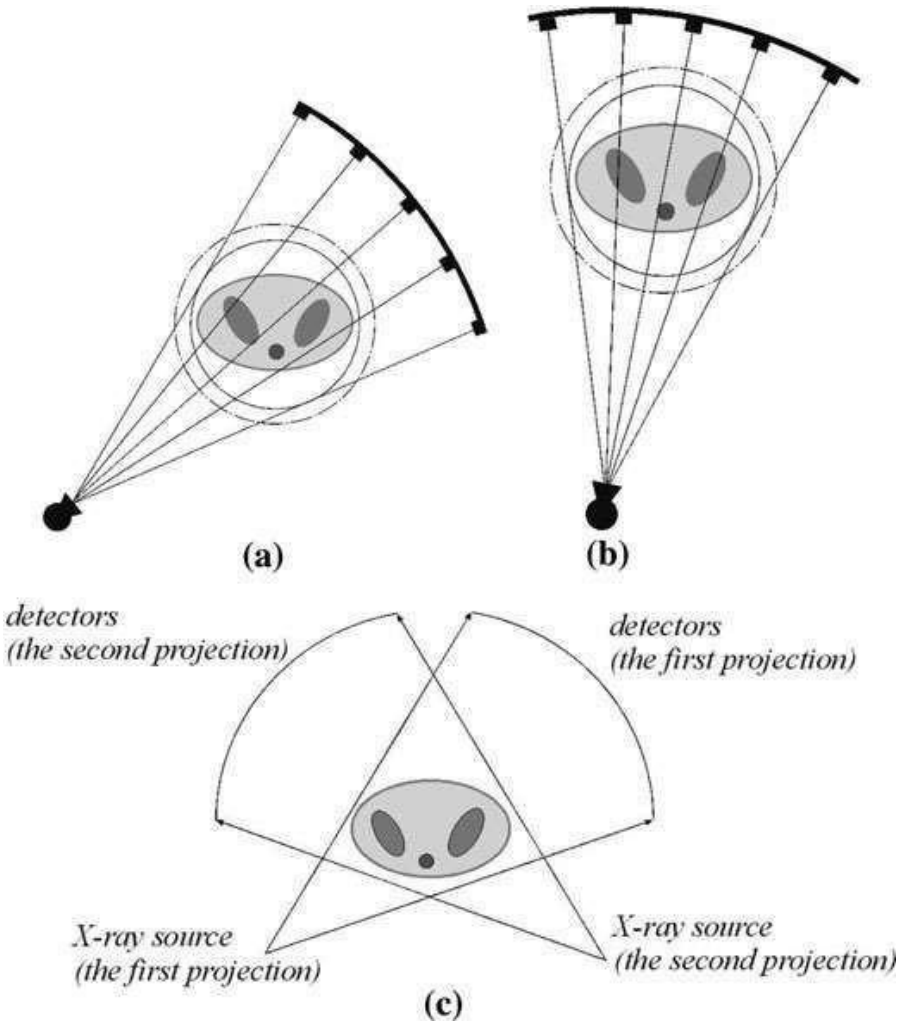
Third-Generation Scanners

Further steps to improve the CT scanner were next directed towards the elimination of the lateral movement of the tube-detector system. In 1976, scanner designers managed to limit the movement in the projection system exclusively to rotational movement. This was the so-called fan-beam or continuous rotation scanner. By fan-beam, we mean here a projection system with a beam of radiation in the shape of a fan with an angular spread of between 40 and 55 degrees, enough to encompass the whole of the test object, as shown in Fig. below.

An obvious consequence of this modification was the need to increase the number of detectors in the array moving synchronously with the rotating X-ray tube (up to 1,000 detector elements). As a result of these design changes, the time to acquire a reconstructed image was reduced to about 5 s. Scanners of this generation are examples of the implementation of the fan-beam projection system in its purest form.

In this scanner, after all the projections have been made for the first image, the table moves and the whole procedure is repeated for the next cross-section of the body. The sequence of projections for reconstructing the images.

- Improvement in detector and data acquisition technology detector array with enough, high spatial resolution cells to allow measurement of a fan-beam projection of entire patient cross-section



•Sampling considerations required scanning an additional arc of one fan angle beyond 180°, although most scanners rotate 360° for each scan.

•Current helical scanners are based on modifications of rotate-rotate designs Scan times = few seconds or less, and recent versions are capable of sub second scan times

•Imaging process is significantly faster than 1st or 2nd generation systems

•Number of detectors increased substantially (to more than 800detectors)

•Angle of fan beam increased to cover entire patient Eliminated need for translational motion

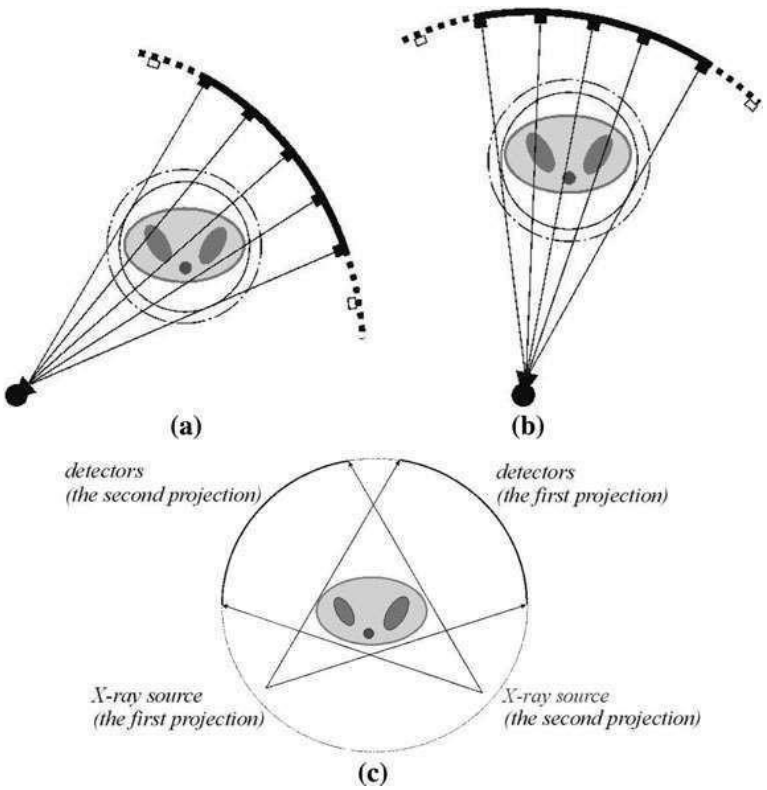
•Mechanically joined x-ray tube and detector array rotate together

•Newer systems have scan times of½second

•Cons: very high performance detectors are needed to avoid ring artifacts and the system is more sensitive to aliasing than 1st or 2nd generation scanners

Fourth-Generation Scanners

The next, fourth generation of scanners, introduced in 1978, differed only slightly from the third generation. In the earlier designs, the detector array moved around the test object together with the X-ray tube. Now the rotation of the array was eliminated by arranging it on a stationary ring with a radius larger than the radius of the circle described by the tube.



The result was a scanner known as the rotate-fixed scanner; the word rotate in the name refers to the movement of the tube and the word fixed to the array of detectors. In order to maintain an adequate resolution of the radiation intensity measurements, the number of detectors in the array was increased and now ranged from 600 to 5,000 detector elements. The time taken to obtain one image using this design however was still about 5 s. The group to which this scanner belonged remained the same; it was still classified as a fan beam scanner.

•Design: also eliminated translate-rotate motion Circular array of FIXED detectors, Source only rotates within a stationary ring of detectors

•Larger fan beam

•Shorter scanning time

•Early versions: had some 600detectors

•Later versions: had up to4,800

Limitation: less efficient use of detectors, less than 1/4 are used at any point during scanning Only the x-ray generator and tube rotate at 360, thus shortening the scanning time even more.

4. Discuss about the digital image display radiation dose in detail. (April/May2016)

Medical use of ionizing radiation now represents > 95% of all man-made radiation exposures and is the largest single radiation source after natural background radiation. Therefore, it is important to quantify the amount of radiation received by a patient during a radiological examination for many reasons:

To optimize radiological procedures because the operators can improve remarkably their performances by identifying the examination protocols that maximize image quality (when patient dose is kept constant) or minimize patient dose (when image quality is kept constant). To establish the approximate risk from a particular examination and to measure the risk to an individual patient (for example in the case of an unsuspected pregnancy).

To compare doses in different examinations or departments and to ensure compatibility with recommended standards, because it is well known that doses can be unnecessarily high (for example, due to inattention or too much work pressure), and those comparisons can promote changes in working procedures by showing what is possible in other centres.

To document the adequacy of the dosimetric aspects of a quality assurance program. To study medical doses with respect to man-made exposures and natural background. Because of all these reasons there is a need for fully investigating radiation doses to patients undergoing radiographic examinations, of course by paying careful attention at the same time to the image quality.

An X-ray examination is usually associated with a benefit, which originates from the capability to obtain suitable clinical information from the image, and with a risk because ionizing radiations have harmful effects on living tissues.

A higher radiation dose to the image detector, and therefore to the patient, reduces the noise levels in the final image and consequently can be strictly related to image quality and at last to the benefit of the examination to the patient; a higher patient dose can therefore potentially increase both the benefit and the risk of the examination.

Frequent evaluations of radiological procedures, systems performance, and patient dose are necessary to ensure that optimal conditions are achieved. In order to accomplish this task it is necessary to first define some quantities useful in characterizing the “dose” concept. The radiation generated by an X-ray tube can be quantified by the radiated energy fluence, but is most conveniently expressed by measuring the amount of charge produced by ionization in a volume of air placed in the X-ray beam.

Therefore, a quantity called “exposure” (X) has been defined as the charge “dQ” (in Coulomb, C) produced per unit mass of air “dm” (in kg): $X = dQ/dm$. In the SI unit system, exposure is measured in [C/kg], and in the non-SI system exposure is measured in Roentgen (R), where $1\ R = 2.58 \times 10^{-4}$ C/kg.

The exposure is directly related to the intensity of a radiation source, and it is independent of any material that may be situated in the radiation beam. Conversely, another radiation quantity called “absorbed dose” (D) generally depends on which material is placed into an X-ray beam: for a given exposure, a high atomic number material will absorb more radiation energy than a low atomic number material.

Therefore, it is possible to define the absorbed dose as the mean energy imparted ($d\varepsilon$) by ionizing radiation to material of mass dm: $D = d\varepsilon/dm$. In the SI unit system, absorbed dose is

measured in gray (Gy), where 1 Gy = 1 J/kg, and in the non-SI system absorbed dose is measured in rad, where 1 rad = 10 mGy = 100 erg/g.

When a given mass of air receives an exposure of 1 R it is possible to calculate by definition how many electrons have been released: since the mean energy required to produce an ion pair in air is 33.97 eV, an exposure of 1 R corresponds to an air dose of 8.76 mGy (= 0.876 rad). Air dose is thus an alternative to exposure for quantifying the intensity of an X-ray beam, and measures the energy deposited in the air.

5. (a)With a neat block diagram explain the construction and working of a CT machine.(May 2017)

(b)Explain the principle and working of CT in detail. (April/May2018, November/December2018)

Computed tomography (CT) scanning is an extremely common imaging modality in modern medicine. With advancements in technology, it is rapidly replacing many diagnostic radiographic procedures.

Basic Principles

CT scans are created using a series of x-rays, which are a form of radiation on the electromagnetic spectrum. The scanner emits x-rays towards the patient from a variety of angles – and the detectors in the scanner measure the difference between the x-rays that are absorbed by the body, and x-rays that are transmitted through the body. This is called attenuation.

The amount of attenuation is determined by the density of the imaged tissue, and they are individually assigned a Hounsfield Unit or CT Number.

- High density tissue (such as bone) absorbs the radiation to a greater degree, and a reduced amount is detected by the scanner on the opposite side of the body

- Low density tissue (such as the lungs), absorbs the radiation to a lesser degree, and there is a greater signal detected by the scanner.

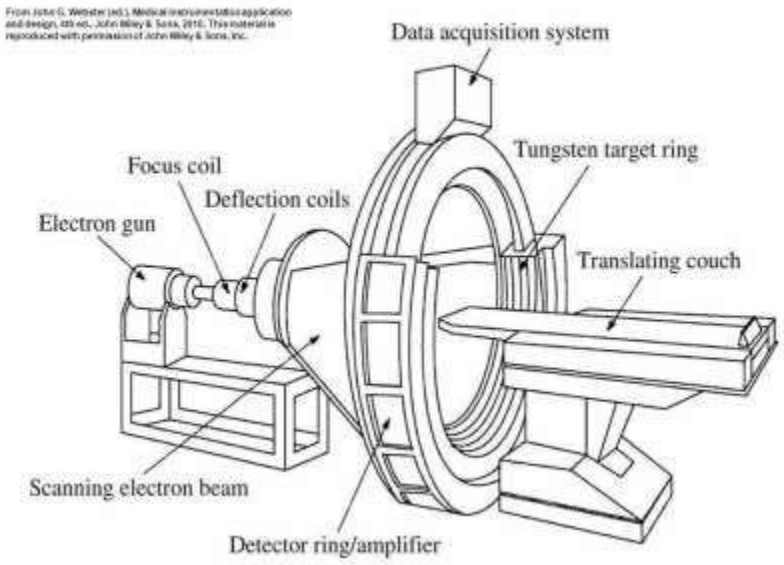
Conventional x-rays provide the radiographer with a two-dimensional image, and require the patient to be moved manually to image the same region from a different angle. In contrast, because of the advanced mathematical algorithms involved with CT, the three-dimensional

planes of the human body can be imaged and displayed on a monitor as stacked images, detailing the entirety of the field of interest.

Purpose

CT-scans provide detailed cross-sectional images of various internal structures for example internal organs, blood vessels, bones, soft tissue etc, and can be used for:

- Diagnostic purposes
- Guidance for specific treatment or further tests- surgeries, biopsies and radiation therapy
- Detection and monitoring of conditions- Cancer, heart disease, lung nodules, liver masses



Indications for CT Scans:

- Traumatic injuries
- Degenerative conditions, such as stenosis and osteoarthritis when an MRI is contraindicated
- Post-operative conditions
- Neoplastic conditions
- Infectious processes
- Image guidance during injections, biopsy's and aspirations
- Abnormalities of bony alignment, such as scoliosis
- Processes involving the spinal cord when MRI is contraindicated

Technique

Most modern CT machines take continuous pictures in a helical (or spiral) fashion rather than taking a series of pictures of individual slices of the body, as the original CT machines did. Helical CT has several advantages over older CT techniques: it is faster, produces better 3-D pictures of areas inside the body, and may detect small abnormalities better. The newest CT scanners, called multislice CT or multidetector CT scanners, allow more slices to be imaged in a shorter period of time.

Digital geometry processing is used to generate a three-dimensional image of the inside of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation. CT produces a volume of data which can be manipulated, through a process known as "windowing", in order to demonstrate various bodily structures based on their ability to block the X-ray/Röntgen beam.

Sometimes, CT involves the use of a contrast (imaging) agent, or “dye.” The dye may be given by mouth, injected into a vein, given by enema, or given in all three ways before the procedure. The contrast dye highlights specific areas inside the body, resulting in clearer pictures. Iodine and barium are two dyes commonly used in CT

Benefits/Risks

When used appropriately, the benefits of a CT scan far exceed the risks. CT scans can provide detailed information to diagnose, plan treatment for, and evaluate many conditions in adults and children. Additionally, the detailed images provided by CT scans may eliminate the need for exploratory surgery.

Concerns about CT scans include the risks from exposure to ionizing radiation and possible reactions to the intravenous contrast agent, or dye, which may be used to improve visualization. The exposure to ionizing radiation may cause a small increase in a person’s lifetime risk of developing cancer.

Exposure to ionizing radiation is of particular concern in pediatric patients because the cancer risk per unit dose of ionizing radiation is higher for younger patients than adults, and younger patients have a longer lifetime for the effects of radiation exposure to manifest as cancer. However, in children and adults, the risk from a medically necessary imaging exam is quite small when compared to the benefit of accurate diagnosis or intervention.

6. Briefly explain the different types of detectors and detector arrays used in CT machines.(May2017)

An overview of the two types of detector systems employed with CT. Both types of systems are usually arranged in linear arrays with up to about 1,000 detector elements or as rings with even more elements in the case of systems with geometry. At least one commercial system uses two adjacent rows of detector elements in order to scan two slices simultaneously.

For scintillation based detectors the most commonly used scintillator materials have been cesium iodide (CsI) and cadmium tungstate, as well as ceramic scintillators employing rare-earth oxides and oxysulfides. A particularly critical parameter for CT detector scintillators is their afterglow behavior. Since CT data acquisition systems do not use pulse counting as in most nuclear applications, but rather integrate the detector current, the afterglow leads to measurement errors near tissue/air and tissue/bone interfaces.

Data correction schemes have been developed to at least compensate for first-order effects related to the detector afterglow. Compared to the rare-gas ionization detector, the scintillation detector usually has a lower geometric efficiency (ratio of active versus ineffective frontal area), which is, however, generally more than compensated for by the latter's higher quantum efficiency.2 In fan beam systems a collimator is usually employed in front of the scintillator elements to reduce the effects of scattering.

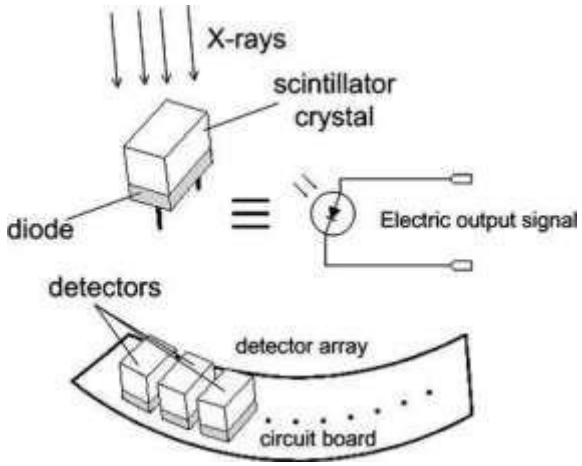
X-ray Detectors: X-ray detectors have a similar function in computed tomography to photographic film in conventional X-ray radiography, that of creating the image from a projection of X-rays . The following types of X-ray detector are currently used in computed tomography

- Xenon proportional chambers, in which the electrical output signal is proportional to the intensity of the radiation that ionizes the gas atoms inside micro gap gas chambers (MGC).
- Scintillation detectors: Most third-generation scanner use xenon proportional chambers, as they are much cheaper than the scintillation detectors used in subsequent generations. The gas in the ionization chamber of a xenon detector is at high pressure (about10atm)

In this detector, a high voltage of about 140 kV is applied across the electrodes. The voltage must not be too large however or it could cause so-called gas amplification. If an X-

ray photon penetrates the detector's window (typically aluminum), there is a high probability of it ionizing the xenon inside. The probability of this happening is proportional to the length of the chamber and the Pressure inside. The current that flows between the electrodes and through the gas ionized by the X-rays is proportional to the intensity of the X-rays. Xenon proportional chambers work in such a way that almost no heating occurs after the ionization event, and so it only takes a short time for them to return to a state of readiness. This is highly significant when applying the technique to spiral projection systems.

In later generations of CT scanner, from the fourth generation onwards, ceramic (scintillation) detectors are used to measure X-ray intensity.



When X-rays strike a scintillator crystal a range of physical phenomena are produced, namely the photoelectric effect,

•Compton effect,

•Pair production.

Scintillation detectors make use of the photoelectric effect. Photons of X-rays knock electrons out of their orbit and these, in the presence of a phosphor, produce a flash of light (luminescent radiation) in the ultraviolet or visible range of wavelengths. Detector arrays in the newer scanners are constructed with scintillation detectors made from materials such as sodium iodide (NaI) doped with thallium (Tl), caesium iodide (CsI), cadmium tungstate (CdWO4), zinc sulphide (ZnS), naphthalene, anthracene and other compounds based on rare earth elements, or gadoliniumoxysulfide (GD2O2S) and finally from rare earth based garnet material (98% garnet, 2% rare earth cerium).

The scintillator crystals have a thickness of 1 2 mm and are shaped so that the majority of the photons created as described above pass through the rear wall of the crystal. Here, a photomultiplier amplifies the light signal and photo-detectors convert the light into an electrical signal.

Scintillation detectors have a high time resolution. This is because the duration of the flash in a scintillator is extremely short; for example for NaI, it lasts 0.25 ns. In addition, because the materials from which scintillations are made have a large

atomic number, these sensors absorb radiation strongly and this affects their detection efficiency. Because there are two processes involved in this type of measurement, we have to take care that the light contact between the scintillator and the photo-detectors is good enough to maintain an adequate level of detection efficiency.

Detector Parameters

The literature lists the following parameters that describe the quality of measurements achieved by various X-ray detectors

- Quantum efficiency,
- Energy resolution,
- stability overtime,
- spatial resolution,
- resistance to irradiation damage,
- Internal detector noise.

7. (a) What is tomography? Describe the acquisition of image with computed tomography. (November/December2017, May 2019, September 2020)

(b) Describe the image acquisition and image formation in CT and its advantages. (April/May2018, November/December2018, November/December2019)

(c) What is conventional tomography? How does it differ from computed tomography? (November/December2017)

Tomography is a term derived from the Greek word ‘tomos’, meaning ‘to write a slice or

section' and is well-understood in radiographic circles. **Conventional tomography** was developed to reduce the super-imposition effect of simple radiographs.

In this arrangement, the X-ray tube and photographic film are moved in synchronisation so that one plane of the patient under examination remains in focus, while all other planes are blurred. In computed tomography (CT), the picture is made by viewing the patient via X-ray imaging from numerous angles, by mathematically reconstructing the detailed structures and displaying the reconstructed image on a video monitor.

The early CT scanners were specifically designed for neuro-radiological investigations. Computed tomography enabled radiologists to distinguish, for the first time, between different types of brain tissue, and even between normal and coagulated blood.

With CT images, radiologists could easily visualize the ventricles of the brain and repositories of the cerebro-spinal fluid. This capability made obsolete a rather unpleasant procedure known as 'pneumo-encephalography', in which air is pumped into the ventricles to displace the fluid and provide radiographic contrast.

The desirability of having body scanners was soon realized. The examination of the body sections, however, represents widely differing problems. Some of these problems include the movement of organs, the patient's respiratory action, the broader range of tissue densities encountered and the wide range of body sizes that have to be accommodated.

In spite of these difficulties, whole body CT scanners with a very wide range of clinical capabilities have been made commercially available. Since respiration does not normally involve gross movements of the head, its effect on the quality of brain pictures is negligible. Consequently, a brain scanner does not need to operate at the speed of a whole body machine.

Basic principle

Computed tomography differs from conventional X-ray techniques in that the pictures displayed are not photographs but are reconstructed from a large number of absorption profiles taken at regular angular intervals around a slice, with each profile being made up from a parallel set of absorption values through the object.

In computed tomography, X-rays from a finely collimated source are made to pass through a slice of the object or patient from a variety of directions. For directions along which the path

length through-tissue is longer, fewer X-rays are transmitted as compared to directions where there is less tissue attenuating the X-ray beam. In addition to the length of the tissue traversed, structures in the patient such as bone, may attenuate X-rays more than a similar volume of less dense soft tissue.

In principle, computed tomography involves the determination of attenuation characteristics for each small volume of tissue in the patient slice, which constitute the transmitted radiation intensity recorded from various irradiation directions. It is these calculated tissue attenuation characteristics that actually compose the CT image.

For a monochromatic X-ray beam, the tissue attenuation characteristics can be described by

It = Io e–mx

Io = Incident radiation intensity

It = Transmitted intensity

x = Thickness of tissue

m = Characteristic attenuation coefficient of tissue

Data acquisition refers to the method by which the patient is **scanned** to obtain enough **data** for image reconstruction. The beam geometry, which characterizes the particular **CT system** and also plays a central role in spatial resolution and artifact production.

8. Explain the principle of generation of CT. Compare it with conventional X-ray imaging.(November/December2019)

Basic principle

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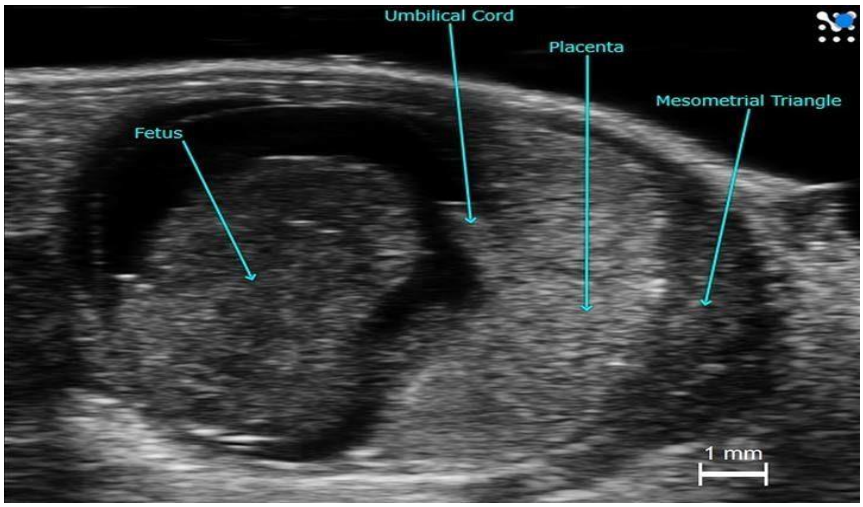
Conventional X-ray	**CT scan**
• Creates 2D image	• Creates 3D images
• Used primarily to see bones and to detect cancers and pneumonia	• Used primarily to diagnose conditions in organs and soft tissues
• Most common and widely available	• More powerful than an x-ray
• Uses radiation to produce images	• Take a 360 degree image

UNIT –III

TWO MARKS

1. **What is B mode display? (SEP 2020)**
   B-Mode is a two-dimensional ultrasound image display composed of bright dots representing the ultrasound echoes. The brightness of each dot is determined by the amplitude of the returned echo signal.



2. **How are ultrasounds generated and detected? (SEP 2020)**
   Ultrasound waves are **produced** by a transducer, which can both emit **ultrasound** waves, as well as **detect** the **ultrasound** echoes reflected back. In most cases, the active elements in **ultrasound** transducers are made of special ceramic crystal materials called piezoelectric.
3. **Define and classify resolution of an ultrasound. (NOV 19)**
   3 Image Resolution. Spatial or detail resolution is the ability to distinguish between distinct image points (reflectors) lying close to each other Lateral resolution describes the minimum separation of two reflectors aligned along a direction perpendicular to the ultrasound beam.
4. **Name some ultrasound transducers. (NOV 19)**

Below we list the three most common ultrasound transducer **types** – linear, convex (standard or micro-convex), and phased array.

Convex Transducers

Abdominal examinations.

Transvaginal and transrectal examinations.

Diagnosis **of** organs.

5. **What is A mode display? (NOV 18)**
   The term display mode refers to the characteristics of a computer display, in particular the maximum number of colors and the maximum image resolution (in pixels

horizontally by pixels vertically). There are several display modes that can be found in personal computer (PC) systems today.

6. **Give the principle of Doppler ultrasound. (MAY 19)**
   Ultrasound images of flow, whether color flow or spectral Doppler, are essentially obtained from measurements of movement. In ultrasound scanners, a series of pulses is transmitted to detect movement of blood. Echoes from stationary tissue are the same from pulse to pulse.
7. **Define attenuation. (NOV 18)**
   Generic term for a reduction or diminution of activity, intensity, power or virulence of a r eaction or effect, or an organism's ability to grow and or multiply.
8. **Define scattering and absorption. (MAY 18)**
   At its most basic, the interaction of light with matter entails the interaction of a single atom with a single quantum of light, called a photon. When an atom interacts with a photon, one of two things happen: it either absorbs (and later re-emits) the photon or it scatters the photon.
9. **What is Doppler Effect? (MAY 18)**
   Doppler ultrasound. An application of diagnostic ultrasound used to detect moving blood cells or other moving structures and measure their direction and speed of movement. The Doppler Effect is used to evaluate movement by measuring changes in frequency of the echoes reflected from moving structures.
10. **What are the significant parameters in diagnostic ultrasound? (NOV 17)**
    Axial resolution is dependent upon various factors, the most important of which being the length of the pulse used to form the beam. This is known as the spatial pulse length (SPL). The shorter the pulse length, the better the axial resolution. In fact the axial resolution limit is defined as being one half of the SPL.
11. **Name some ultrasonic transducers. (NOV 17)**
    The ultrasonic transducers are again having different types. They contact transducers, angle beam transducers, Delay line transducers, immersion transducers, and dual element transducers.
12. **Define the term specific acoustic impedance. (MAY 17)**
    Specific acoustic impedance is the complex ratio of the effective sound pressure at a point to the effective particle velocity at a point. This ratio is equal to the product of the density of the medium times the speed of sound in the medium.
13. **Mention any two medical applications of A scan mode in ultrasonic imaging.(MAY 17)**
    Medical ultrasound (also known as diagnostic sonography or ultrasonography) is a diagnostic imaging technique, or therapeutic application of ultrasound. ... It is used to create an image of internal body structures such as tendons, muscles, joints, blood vessels, and internal organs.
14. **What are the advantages of M mode scan over A mode and B mode scan? (MAY 16)**

It provides a mono dimensional view of the heart. All of the reflectors along this line are displayed along the time axis. The advantage of the M-mode is its very high sampling rate, which results in a high time resolution so that even very rapid motions can be recorded, displayed, and measured.

15. Name the principle of Doppler flow imaging. (MAY 16)

The Doppler principle

This relative motion resulted in either a red shift or blue shift in the light's frequency. This shift in observed frequencies of waves from moving sources is known as the Doppler Effect and applies to sound waves as well as light waves.

16. What are super conducting magnets? (MAY 14)

A superconducting magnet is an electromagnet made from coils of superconducting wire. In its superconducting state the wire has no electrical resistance and therefore can conduct much larger electric currents than ordinary wire, creating intense magnetic fields.

17. List out biological effects of MRI. (MAY 14)

In addition to mild heating, there are other biological effects that may result during MRI. Some of these are routinely encountered (such as audible noise); others occur very infrequently (such as RF burns). Although extremely rare, improper MR procedures have resulted in serious injury or death.

11 MARKS

1. Explain the following terms for ultrasound system(MAY 16)

(a) reflection

(b) refraction

(c)attention

(d)absorption

(e)scattering

ROLE OF ULTRASOUND IN MEDICAL IMAGING

Ultrasound not only complements the more traditional approaches such as x-ray, but also possesses
unique characteristics that are advantageous in comparison to other competing modalities such as x-ray
computed tomography (CT), radionuclide emission tomography, and magnetic resonance imaging (MRI).

Ultrasound is a form of nonionizing radiation and is considered safe to the best of present knowledge.

It is less expensive than imaging modalities of similar capabilities.

- It produces images in real time, unattainable at the present time by any other methods.
- It has a resolution in the millimeter range for the frequencies being clinically used today, which may be improved if the frequency is increased.
- It can yield blood flow information by applying the Doppler principle.
- It is portable and thus can be easily transported to the bedside of a patient.

Acoustic Propagation:

Ultrasound is a sound wave characterized by such parameters as pressure, particle (or medium) velocity, particle displacement, density, and temperature. It differs from a sound wave in that its frequency is higher than 20Hz to 20 kHz (kilohertz). The audible range of human ear is from 20 Hz to 20 kHz. Because ultrasound is a wave, it transmits energy just like an electromagnetic wave or radiation.

Unlike an electromagnetic wave, however, sound requires a medium in which to travel and thus cannot propagate in a vacuum.

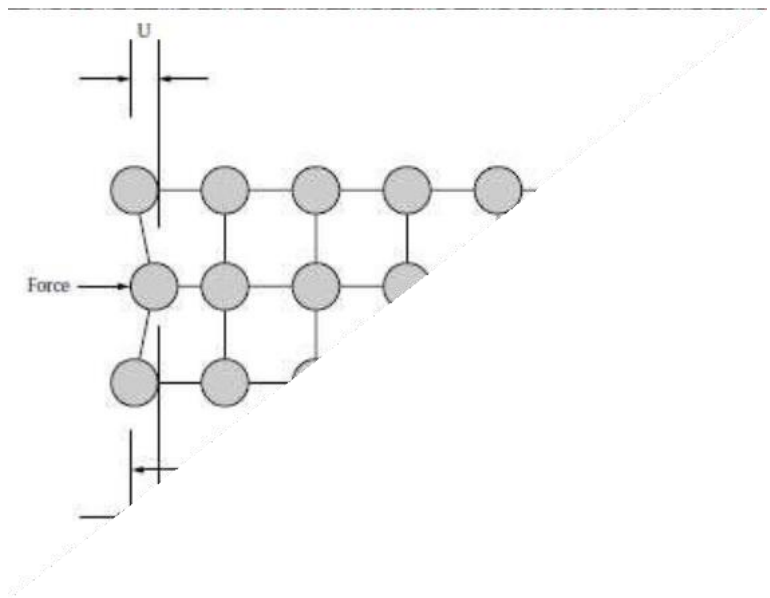


FIG 1 A two-dimensional matrix of molecules perturbed by an external force.

To better visualize how the sound propagates through a homogeneous medium, the medium can be modeled as a three-dimensional matrix of elements, which may represent molecules, atoms, or elemental particles, separated by perfect elastic springs representing inter element forces. To simplify the matter even more, only a two-dimensional lattice is shown in Figure.1, in which the elements are represented by spheres. When a particle is pushed to a distance from its neutral position, the disturbance or force is transmitted to the adjacent particle by the spring. This creates a chain reaction. The distance, *U*, traveled by the particle in the acoustic propagation is called particle or medium displacement, usually in the order of a few tenths of a nanometer in water. The velocity of the particle oscillating back and forth is called particle or medium velocity, *u*, and is in the order of a few centimeters per second in water. It must be noted that this velocity is different from the rate at which the energy is propagating through the medium. The velocity at

which the ultrasound energy propagates through the medium is defined as the phase velocity or the sound propagation velocity, *c*. In water, *C*=1500 m/s, this is illustrated in Figure 1,
which shows that the sound velocity is much faster than the particle velocity. Although the particle has only moved a short distance, the perturbation has already been transmitted to other particles over a much longer distance, U‘. The displacement of the particles, *U*, is in the same direction as the direction of wave propagation, *X*. This type of wave is called a longitudinal or compressional wave. The wavelength of a sound wave is defined as the distance between two points of the same phase in space. For example, two peaks, or the distance for one cycle of wave to occur at a fixed time and the period, *T*, is defined as the time lapse between two points in time of the same phase, that is, two peaks or the time that it takes for one, cycle of wave to occur at a fixed point in space. It follows from these definitions that Because frequency, f, is defined as f=1/ T, the above equation can be rewritten as For an ultrasonic wave at 5 MHz, the wavelength is about 300um. It will be shown later that the spatial resolution of an ultrasonic imaging system, that is, its capability to resolve an object spatially, is primarily determined by the wavelength. The ultimate resolution that a 5-MHz ultrasonic imaging system can achieve is 300um. To improve the resolution, one option is to increase the frequency. In contrast, the wavelengths involved in x-ray or optical imaging are much shorter. Thus, for these modalities, the frequency in general is not as critical when spatial resolution is concerned.

Attenuation, Absorption and Scattering:

When an ultrasonic wave propagates through a heterogeneous medium, its energy is reduced or attenuated as a function of distance. The energy may be diverted by reflection or scattering or absorbed by the medium and converted to heat. The reflection and scattering of a wave by an object actually are referring to the same phenomenon: the redistribution of the energy from the primary incident direction into other directions. This redistribution of energy is termed __reflection‖ when the wavelength and wavefront of the wave are much smaller than the object and __scattering‖ if the wavelength and the wavefront are greater than or comparable to the dimension of the object.

Attenuation:

The pressure of a plane monochromatic wave propagating in the *Z*-direction decreases exponentially as a function of *z*:

Where, $p(z = 0)$ is the pressure at $z = 0$ and α is the pressure attenuation coefficient. Therefore,

The attenuation coefficient has a unit of nepers per centimeter and is sometimes expressed in units of decibels per centimeter or To convert alpha in nepers per centimeter to decibels per centimeter, simply multiply alpha in nepers per centimeter by 8.686. If a tissue has an attenuation coefficient of 0.1 np/cm, then in decibels per centimeter, $\alpha = 8.686*0.1$ dB/cm = 0.8686 dB/cm.

Absorption & Scattering:

A pressure wave travelling through a medium will decrease in intensity with distance. The loss of intensity is due to the divergence of the beam, scattering which is not specular, mode conversion at interfaces and absorption. Beam divergence and scattering reduce the intensity but not the energy of the beam, whereas mode conversion and absorption both result in the beam

energy being converted to another form. The most important contribution to absorption comes from relaxation processes, in which the ultrasound energy is converted into, for instance, vibrational energy of the molecules of the tissue. This is not a one-way process there is an exchange of energy. If an increase in pressure compresses the tissue, work is done on the tissue which is recovered as the pressure drops and the tissue expands. In general, the returned energy is out of phase with the travelling wave, so the beam intensity is decreased. The lost energy is converted to heat. The absorption is frequency dependent and varies for different materials. As the absorption usually increases with frequency, it is normally quoted in terms of dB cm-1 MHz−1, but this should not be taken to mean that the absorption is strictly linear with frequency. The very high absorption in bone and lung tissue means that they are effectively opaque to ultrasound, and structures which are behind them will be hidden. As the absorption rises with frequency, there will be a maximum depth for detecting echoes with ultrasound of a particular frequency. Frequencies of 5 to 10 MHz can be used for scanning the eye, but the upper limit for the abdomen is 2 to 3 MHz.

The scattering of the beam is dependent on the relative size of the scattering objects and the wavelength of the ultrasound. The earlier treatment assumed that a plane wave was incident on a plane boundary that was large compared to the wavelength. For 1 MHz ultrasound in soft tissue, the wavelength is 1.54 mm, so the large object scenario would correspond to scattering from the surface of major organswithin the body. If the irregularities in the scattering surface are about the same size as the wavelength, diffuse reflection will occur. If the scatterers are very small compared with the wavelength, then Rayleigh scattering will take place, in which the incident energy is scattered uniformly in all directions, with a scattering cross-section proportional to $k4a6$, where a is the radius of the scatterer. Obviously, with this form of scattering, very little energy will be reflected back to the transducer. Red blood cells are about 8– 9 μm in diameter and act as Rayleigh scatterers. In practice, the scattering from small objects is complex, because there are many scatterers, and the scattering cannot be treated as a single-body problem. Even in blood, which is a fluid, 36–54% by volume of the blood is red cells, and the mean distance between cells is only 10% of their diameter. The signal which is received by the transducer will be greatly attenuateddue to all these mechanisms. Energy will be absorbed in propagating the mechanical vibrations through the tissue, and energy will be lost by scattering at every interface. Refraction at interfaces will divert the ultrasound away from the transducer, and the divergence of the ultrasound beam will also reduce the received energy. The received echoes used to form a typical abdominal scan may be 70 dB below the level of the transmitted signal, and the signals from moving red blood cells may be 100–120 dB below the transmitted signal. The attenuation will be roughly proportional to the frequency of the ultrasound and to the distance that the ultrasound has travelled through the tissue.

2. Describe in detail about the principle of color Doppler flow imaging and its application.(MAY 19)(SEP 2020)

Explain in detail about color Doppler flow imaging system (NOV 18)

Color Doppler Flow Imaging:

Color Doppler flow imaging systems are duplex scanners capable of displaying B-mode and Doppler blood flow data simultaneously in real time. The Doppler information is encoded in color.

Conventionally, the color red is assigned to indicate flow toward the transducer, and blue is assigned to indicate flow away from the transducer. The magnitude of the velocity is represented by different shades of the color. Typically the lighter the color, the higher the velocity. The color Doppler image is superimposed on the gray-scale B-mode image. The basic concept of the color Doppler is similar to that of the pulsed Doppler instruments that extract the mean Doppler shift frequency from a sample volume defined by the beam width and the gate width. The only exception is that the color Doppler instruments are capable of estimating the mean Doppler shifts of many sample volumes along a scan line in a very short period of time on the order of 30 to 50ms.

In a color Doppler system, the signal received by a probe is divided into three paths: one for Constructing the gray-scale B-mode image; one for calculating the flow information from Doppler data using a hard-wired autocorrelator; and one for conventional Doppler measurements. This is delineated in Figure 10. Eight or more shades are used in these systems to depict the magnitude of the velocity. The higher the velocity is, the lighter the shade is. Because the basic principle of Doppler flow mapping is similar to pulsed Doppler, the maximal Doppler frequency that can be detected without aliasing is one half of the pulse repetition frequency. Therefore, a higher pulse repetition frequency is favored for avoiding aliasing and increasing the accuracy of the autocorrelation.

However, limited by the frame rate and field of view, the pulse repetition frequency in most color Doppler systems is between 8 and 16 kHz. As a result, aliasing frequently occurs with color Doppler in cardiac imaging. To overcome these problems, one can reduce the image size or use M-mode color Doppler, in which the beam is fixed in one direction. In the heart, the myocardium is in motion during a cardiac cycle. Tissue color Doppler images of this motion can be acquired with color Doppler methods. The difference lies in that myocardial motion is slower than blood flow and myocardial echoes are stronger than blood. The spurious Doppler signals from blood in this case can be eliminated by thresholding the echoes.

FIG: 10 Block diagram of a color Doppler flow mapping system

Many clinical applications have been found for color Doppler flow imaging, including diagnosing tiny shunts in the heart wall and valvular regurgitation and stenosis. It considerably reduces the examination time in many diseases associated with flow disturbance. Problematic regions can be quickly identified first from the flow mapping. More quantitative conventional Doppler measurements are then made on these areas. Color Doppler has been now widely used in a variety of **medical disciplines**;
however, it has several shortcomings:
 Flow perpendicular to the beam cannot be reliably detected.
 Higher blood flow velocity results in aliasing.
 Its spatial resolution is poorer than B-mode gray-scale imaging.
 The mean velocity estimated is the average velocity within a pixel or voxel.
 Large echoes due to slow moving tissues can cause the ―color flash artifact‖ because they overlap echoes from flowing blood.

3. Explain about the different array element used in ultrasound imaging.

Explain the detail different types of scanner modes in ultrasound with application (MAY 18)

Ultrasonic transducers:
The vast majority of medical ultrasound imaging systems use the same transducer for both generation and reception of ultrasound; this is the so-called pulse-echo mode of operation. The transducer is coupled to the body using an __acoustic gel,‘‘ and a brief pulse-like acoustic wave is generated. This wave propagates into the body, where it encounters reflecting surfaces and small scatterers. These objects reflect or scatter the sound, a part of which returns to the

transducer. The transducer then converts the acoustic wave sensed at its face to an electrical signal that can be amplified, stored, and displayed. In this section, we will describe each of the components required to carry out this basic imaging paradigm. This sets the stage for the development of an imaging equation, the analysis of image quality, and an introduction to pulsed Doppler and three-dimensional imaging systems in subsequent sections.

FIG: 2 Block diagram of an ultrasound imaging system

i. Piezoelectric Transducers:

Medical transducers use piezoelectric crystals to both generate and receive ultrasound. These crystals have the property that an induced electric field produces a strain (mechanical displacement), which in turn causes an acoustic wave. They also satisfy the reciprocal property that a mechanical displacement creates an electric potential, which means that they can also sense an acoustic wave. Lead zirconate titanate, or PZT, is the piezoelectric material used in nearly all medical ultrasound transducers.

It is a ceramic ferroelectric crystal exhibiting a strong piezoelectric effect. These crystals can be manufactured in nearly any shape, and their axes of polarization can be oriented in nearly any direction The most common transducer shapes are the circle, for single-crystal transducer assemblies found in Doppler monitoring systems, and the rectangle, for multiple-transducer assemblies such as those found in linear and phased arrays. An ideal transducer material, when used in pulse-echo mode, should be both an efficient producer and sensitive receiver of

ultrasound waves. The transmitting constant d of a transducer is the strain produced by a unit electric field and has units of meters per volt. The receiving constant g is the potential produced by a unit stress and has units of volt-meters per Newton.

ii. Resonance Transducers:

Transducer crystals exhibit resonance that is; they tend to vibrate sinusoidally after electrical excitation has ended. The frequency of this vibration is called the fundamental resonant frequency fT of a transducer. In most systems, different transducers having resonant frequencies in the range 1–20 MHz can be __plugged‘‘ into the ultrasound scanner. The difference in resonant frequency between the different transducers has a profound influence on image quality. The resonant frequency of a transducer is largely determined by the thickness of its piezoelectric crystal. When the front face of the transducer is moved forward (by the electrically induced strain, for example), an acoustic wave is initiated forward into the medium (perhaps a human body) and backward into the transducer crystal itself. The backward-traveling wave will hit the back face of the transducer and reflect toward the front face again. Resonance is set up when the returning wave strikes the front face at the time when the wave reaches a __crest,‘‘ thus reinforcing the wave. This condition occurs when

$$f_T = \frac{c_T}{2d_T},$$

Where, C_T and d_T are the speed of sound in the transducer and the thickness of the transducer, respectively. Since $\lambda_T = c_T/f_T$, the resonance condition is equivalently given by,

$$\lambda_T = 2d_T$$

Transducer Arrays:

Arrays are transducer assemblies with more than one element. Transducer arrays mainly classified based on,

- Linear sequential array (switched array)
- Linear phased array (vector, sector)
- Curved sequential array (curvilinear sequential array).
- Curved phased array (curvilinear phased array).
- Annular array

i. Linear Arrays

Linear array transducers typically contain 256 to 512 elements; physically these are the largest transducer assemblies. In operation, the simultaneous firing of a small group of approximately 20 adjacent elements produces the ultrasound beam. The simultaneous activation produces a synthetic aperture (effective transducer width) defined by the number of active elements. Echoes are detected in the receive mode by acquiring signals from most of the transducer elements. Subsequent ―A-line‖ acquisition occurs by firing another group of transducer elements

displaced by one or two elements. A rectangular field of view (FOV) is produced with this transducer arrangement. For a curvilinear array, a trapezoidal FOV is produced.

ii. Phased Arrays

A phased-array transducer is usually comprised of 64 to 128 individual elements in a smaller package than a linear array transducer. All transducer elements are activated nearly simultaneously to produce a single ultrasound beam. By using time delays in the electrical activation of the discret elements across the face of the transducer, the ultrasound beam can be steered and focused electronically without physically moving the transducer on the patient. During ultrasound signal reception, all of the transducer elements detect the returning echoes from the beam path, and sophisticated detection algorithms synthesize the data to form the image

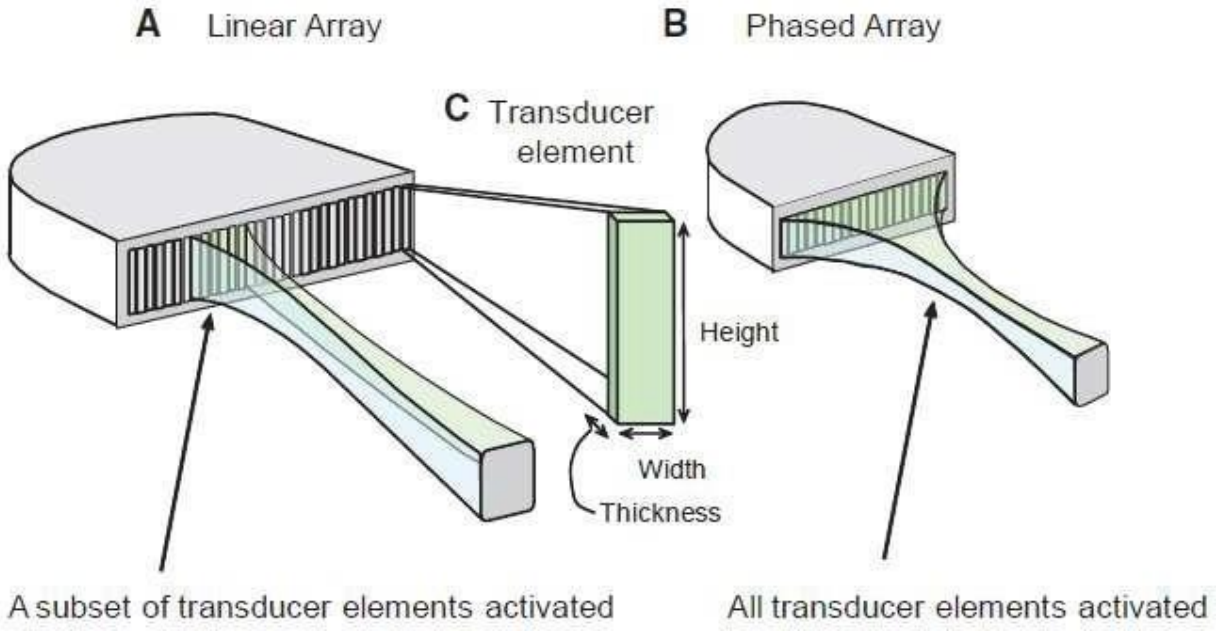


FIG: 3 Multielement transducer arrays.

A. A linear (or curvilinear) array produces a beam by firing a subset of the total number of transducer elements as a group. **B.** A phased array produces a beam from all of the transducer elements fired with fractional time delays in order to steer and focus the beam. **C.** The transducer element in an array has a thickness, width, and height; the width is typically on the order of ½ Wavelength and the height depends on the transducer design and slice-thickness requirements

A mode scanner:

A-mode is the simplest and earliest mode of ultrasonic imaging. A block diagram for A-mode instruments is shown in Figure 5. A signal generator that produces high-intensity short pulses or a pulser is used to excite a single-element transducer. The returned echoes from the tissues are detected by the same transducer, amplified, and processed for display. A coupling medium in the form of an aqueous gel or oil is used to couple the transducer to the body because of the mismatch in acoustic impedance between the body and the transducer. Without the gel, very little energy can be transmitted into the body. The echoes returned from various structures due to large interfaces between

organs or small in homogeneities in the organ, such as cells, small blood vessels, ducts, etc. are first amplified by a preamplifier. The preamplifier that provides the initial state of signal amplification with a gain of a few decibels is an amplifier with high input electrical impedance and low noise. A second-stage amplification is provided by the time–gain–compensation (TGC) amplifier that may have a gain greater than 40 db. TGC is needed because ultrasound energy is attenuated by tissues as it penetrates deeper into the body. Energy loss is affected not only by tissue attenuation that is exponentially related to the depth of penetration (as previously discussed) but also by beam diffraction. Therefore it is quite difficult to compensate for the energy loss accurately. A variety of TGC curves, shown in Figure 6, has been used and are usually available in an ultrasonic scanner for the operator to select. The amplified signal is then demodulated, involving envelope detection and filtering, and logarithmically compressed. Logarithmic compression is needed because the dynamic range of the received echoes, which is defined as the ratio of the largest echo to the smallest echo above noise level detected by the transducer, is very large—on the order of 100 to 120 dB. Typical display units or cathode ray tube (CRT) monitors can only display signals with adynamic range up to 40 dB at best. The horizontal axis of the CRT monitor is synchronized or triggered by pulses generated by the pulse the vertical axis or vertical deflection of the electron beam is driven by the output of the signal processing unit, which is the demodulated and log-compressed echo amplitude or simply the video signal.

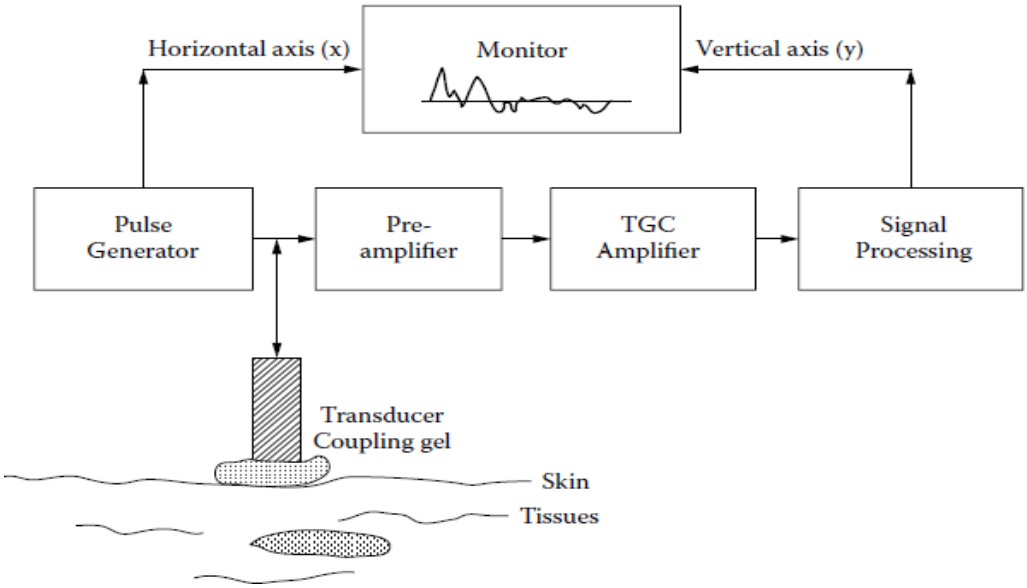


FIG: Block diagram of A-mode scanner

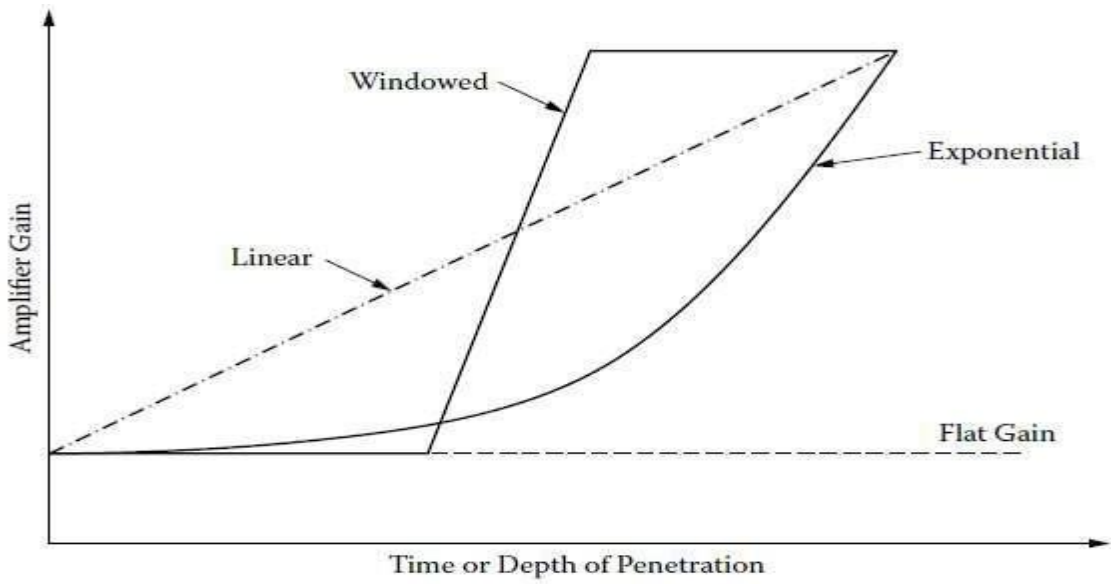


FIG: 6 Time–gain–compensation curves frequently used in ultrasonic imaging

The type of information obtained by an A-mode instrument, called an A-line.

B mode scanner:

A majority of commercial scanners on the market today are two-dimensional B-mode scanners in which the beam position is also monitored. Figure 7 shows a static B-scanner in which the position of the transducer in the *x–y* plane is encoded. The positional information of the beam, plus the video signal representing echoes returned from the *z*-direction, is converted into a format compatible with a CRT monitor in a device, called a scan-converter, and is almost invariably digital today. If the transducer is scanned in the *x*-direction, the image formed represents an image of structures in the *x–z* plane. Images can also be formed by superposition of multiple images after translating and rotating the transducer at a fixed *x*-position within a sector angle, as illustrated in Figure 8. This is called compound B-scan. The advantages of doing this are to make the image look smoother or suppress the speckle pattern and to average out the specular echoes due to flat interfaces. The disadvantage is that it slows down the image acquisition rate. Static B-scanners are no longer used today because of poor image quality due to the lack of dynamic focusing and low image acquisition rate except for high-frequency (higher than 20 MHz) applications. Modern B-mode scanners can acquire images faster than 30 frames per second to allow monitoring of organ motion.

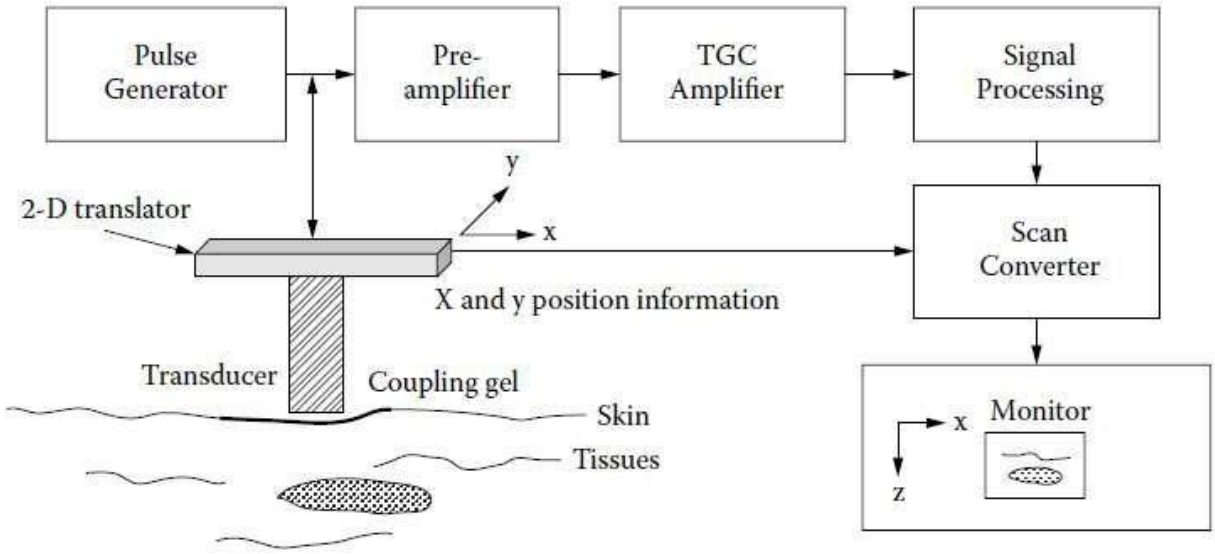


FIG: Block diagram of B-mode scanner

Depending upon the mechanisms used to drive a transducer, the real-time scanners are classified into mechanical-sector and electronic-array scanners. Because electronic array systems generally produce images of better quality, modern ultrasonic scanners are almost exclusively array-based systems.

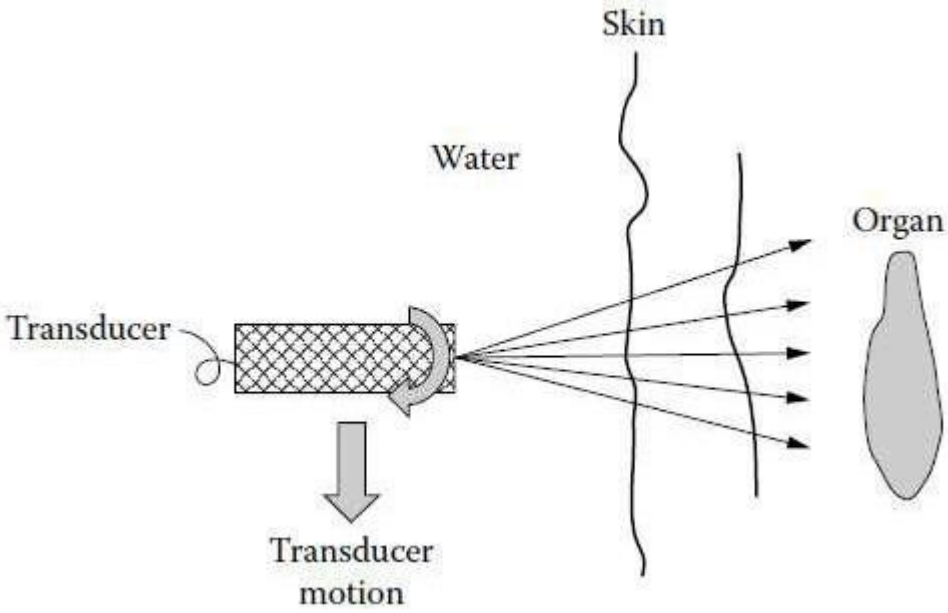


FIG: 8 Compound scan is performed by combining two different modes of motion of the transducer in forming one image.

Several components in a B-mode scanner perform the same functions as those in the A-mode system. These include the TGC amplifier and signal processing units for signal compression,

demodulation, and filtering. Various forms of TGC from which the operator can choose are available on the console. The timing and control signals are all generated by a central unit. The image is displayed on a storage monitor.

Clinical Applications

B-mode ultrasound has numerous applications because it is noninvasive and can display two dimensional
cross-sectional images of anatomical structures in real time. Some of the many applications of B-mode ultrasound include:

- Obstetrics for monitoring the status of the fetus.
- Gynecology for diagnosing problems in the ovary.
- General radiology for diagnosing liver tumors and gall bladder diseases.
- Vascular surgery for detecting arterial stenosis and deep vein thrombosis and for characterizing
atherosclerotic plaques.
- Cardiology for diagnosing valvular diseases and monitoring the integrity of cardiac wall functions.

M mode scanner:

In M-mode display, one intensity-modulated A-line or one B-line is swept across the monitor as a function of time at a rate much slower than the pulse repetition frequency (PRF) of the A-line, as illustrated in Figure 8. The sweep of the electron beam in the *x*-axis is controlled by a slow ramp generator; the triggering of the *y*-axis is synchronized with the pulser. The rest of the device is similar to the A-mode device. In this format, the ultrasound beam is fixed at a certain position or angle and the displacement of a target relative to the probe along the beam direction is displayed as a function of time.

The motion of a swinging pendulum at positions a, b, and c can be clearly discerned on the display. This type of display is most useful for monitoring the motion of anatomical structure.

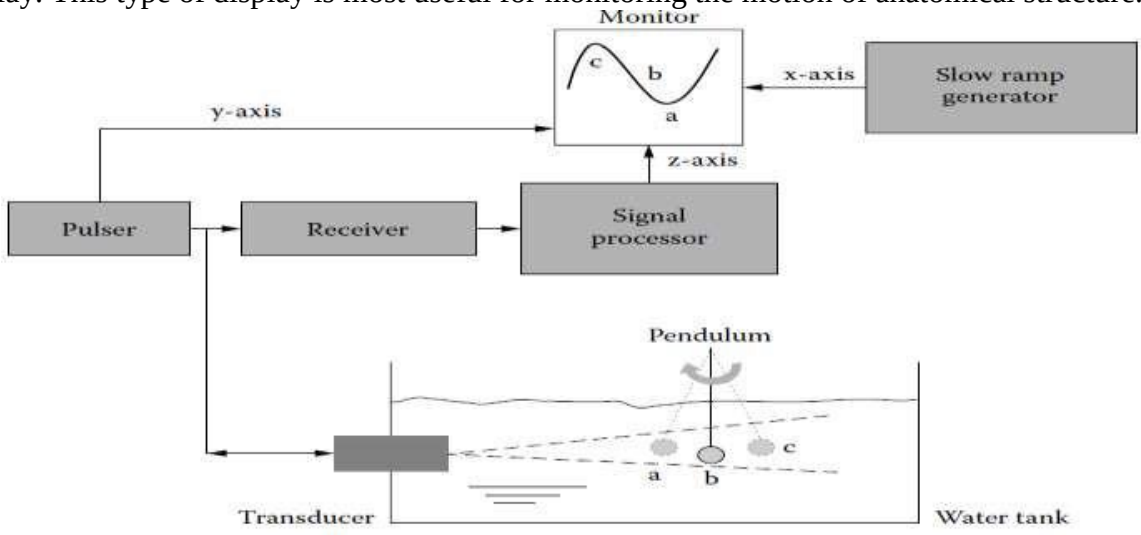
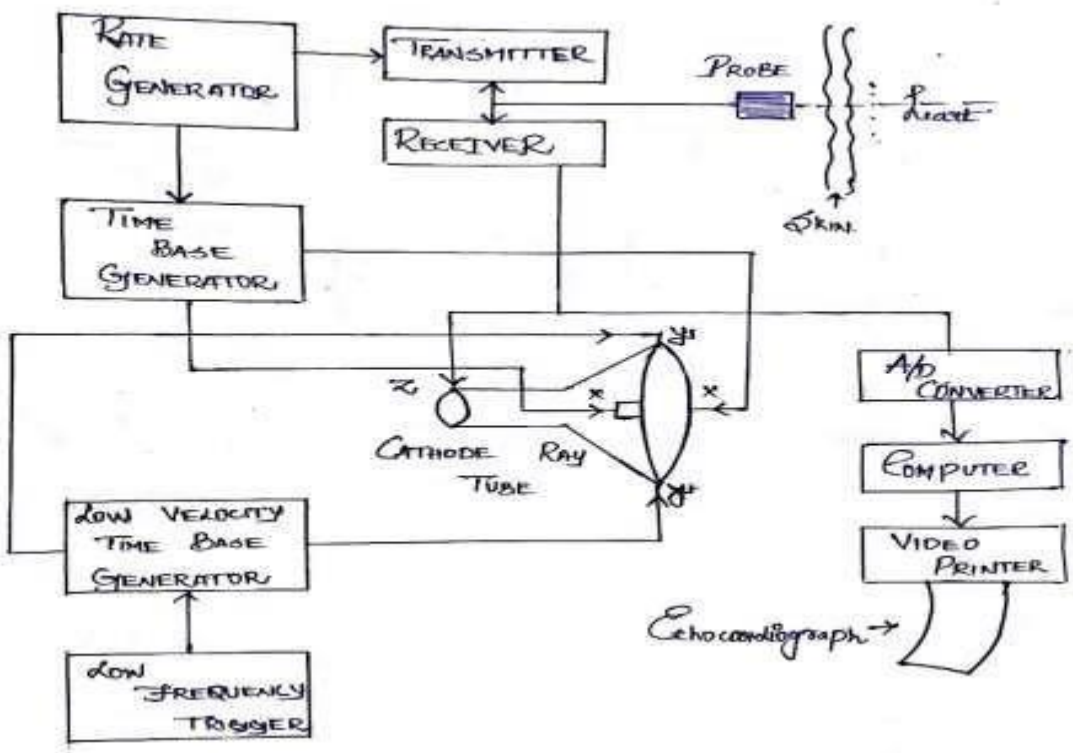


FIG: 9 Block diagram of M-mode scanner

4. Describe the working of echocardiograph with M- mode scanners.(MAY 17)(MAY 16)

Echocardiography:

Echocardiography has become routinely used in the diagnosis, management, and follow-up of patients with any suspected or known heart diseases. It is one of the most widely used diagnostic tests in cardiology. It can provide a wealth of helpful information, including the size and shape of the heart, pumping capacity, and the location and extent of any tissue damage. An Echocardiogram can also give physicians other estimates of heart function, such as a calculation of the cardiac output, ejection fraction, and diastolic function. Echocardiography can help detect cardiomyopathies, such as hypertrophic cardiomyopathy, dilated cardiomyopathy, and many others. The use of stress echocardiography may also help determine whether any chest pain or associated symptoms are related to heart disease. The biggest advantage to echocardiography is that it is not invasive (does not involve breaking the skin or entering body cavities) and has no known risks or side effects.



Not only can an echocardiogram create ultrasound images of heart structures, but it can also produce accurate assessment of the blood flowing through the heart by Doppler echocardiography, using pulsed- or continuous-wave Doppler ultrasound. This allows assessment of both normal and abnormal blood flow through the heart. Color Doppler, as well as spectral Doppler, is used to visualize any abnormal communications between the left and right sides of the heart, any leaking of blood through the valves and estimate how well the valves open.

Figure 11 shows the block diagram of an echocardiograph. Several circuit blocks are common to the general echo measuring instrument, except for the addition of a slow sweep circuit and recording arrangement.

Since the advent of 2D echocardiography, ultrasonic examinations of the heart have been

primarily recorded and stored on video tape. However, many problems have arisen with video tape when used for recording echocardiogram. The major problem is that video tape technology limits the availability to quickly review the echocardiograms. Digital echocardiography which involves recording, displaying and storing an echocardiogram digitally has, therefore, largely replaced the video tape recording procedure.

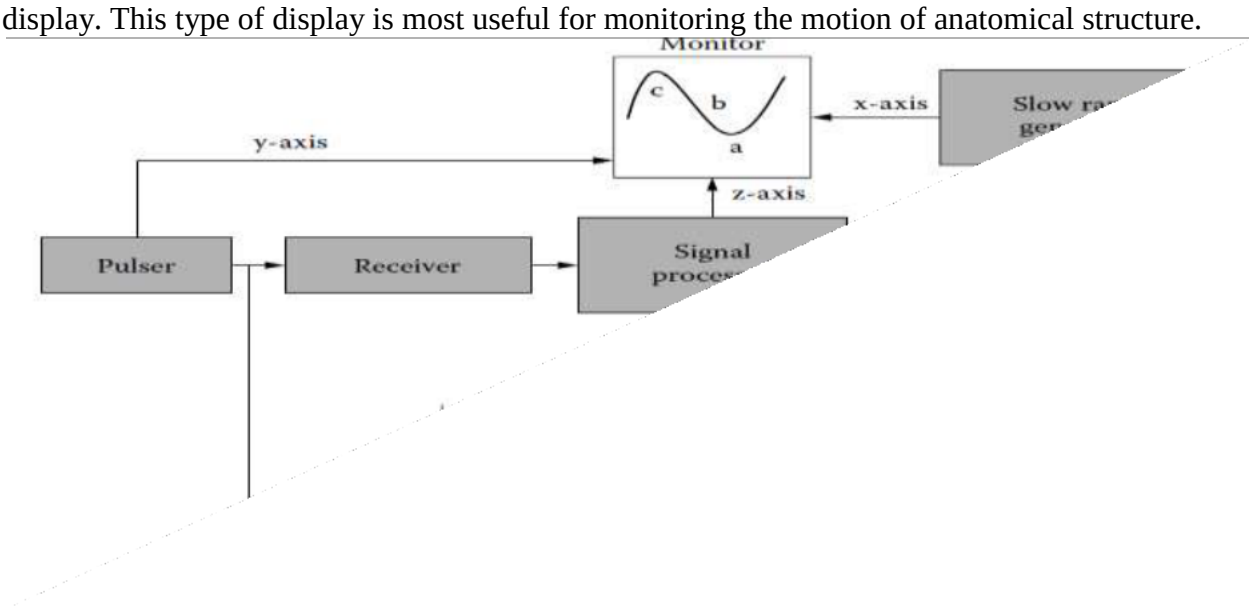
For echocardiography, the transducer is placed between the third and fourth ribs on the outer chest wall where there is no lung between the skin and heart. From this probe, a low intensity ultrasonic beam is directed toward the heart area and echo signals are obtained. The probe position is manipulated to obtain echoes from areas of interest in the heart.

The system operates on the principle of reflected ultrasound and senses flow velocity within a small 2X4mm tear drop shaped volume, referred to as the sample volume. The sample volume is specifically selectable within the heart and great vessels by means of a depth control settings and is subject to a variety of components of blood flow velocity; laminar, turbulent and motional Components like wall motion and wave motion.

M mode scanner:

In M-mode display, one intensity-modulated A-line or one B-line is swept across the monitor as a function of time at a rate much slower than the pulse repetition frequency (PRF) of the A-line, as illustrated in Figure 8. The sweep of the electron beam in the *x*-axis is controlled by a slow ramp generator; the triggering of the *y*-axis is synchronized with the pulser. The rest of the device is similar to the A-mode device. In this format, the ultrasound beam is fixed at a certain position or angle and the displacement of a target relative to the probe along the beam direction is displayed as a function of time.

The motion of a swinging pendulum at positions a, b, and c can be clearly discerned on the display. This type of display is most useful for monitoring the motion of anatomical structure.



5. Explain in detail the pulse echo technique of ultrasound.

Ultrasonic transducers:

The vast majority of medical ultrasound imaging systems use the same transducer for both generation and reception of ultrasound; this is the so-called pulse-echo mode of operation. The transducer is coupled to the body using an __acoustic gel,‘‘ and a brief pulse-like acoustic wave is

generated. This wave propagates into the body, where it encounters reflecting surfaces and small scatterers. These objects reflect or scatter the sound, a part of which returns to the transducer. The transducer then converts the acoustic wave sensed at its face to an electrical signal that can be amplified, stored, and displayed. In this section, we will describe each of the components required to carry out this basic imaging paradigm. This sets the stage for the development of an imaging equation, the analysis of image quality, and an introduction to pulsed Doppler and three-dimensional imaging systems in subsequent sections.

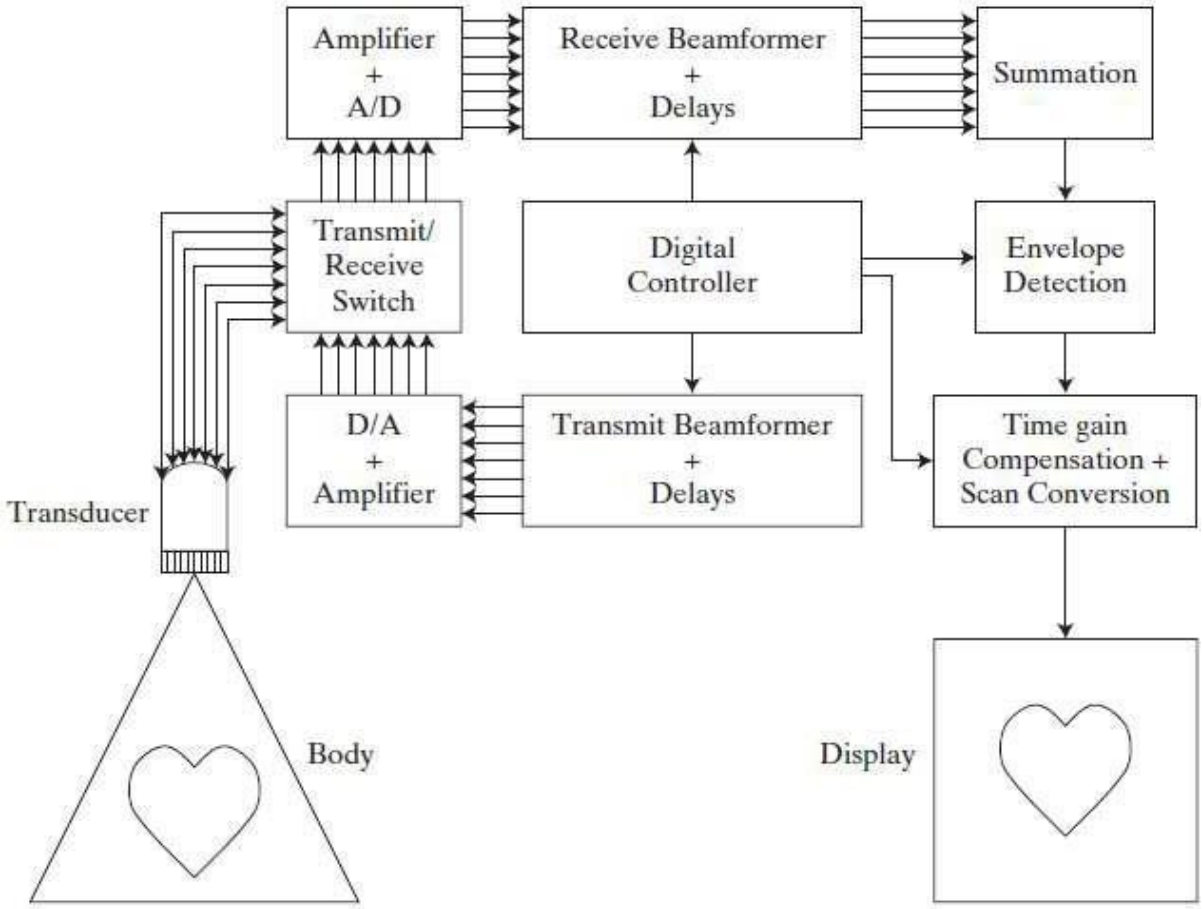


FIG: 2 Block diagram of an ultrasound imaging system

Piezoelectric

i. Piezoelectric Transducers:

Medical transducers use piezoelectric crystals to both generate and receive ultrasound. These crystals have the property that an induced electric field produces a strain (mechanical displacement), which in turn causes an acoustic wave. They also satisfy the reciprocal property that a mechanical displacement creates an electric potential, which means that they can also sense an acoustic wave. Lead zirconate titanate, or PZT, is the piezoelectric material used in nearly all medical ultrasound transducers. It is a ceramic ferroelectric crystal exhibiting a strong piezoelectric effect. These crystals can be manufactured in nearly any shape, and their axes of polarization can be oriented in nearly any direction. The most common transducer shapes are the circle, for single-crystal transducer assemblies found in Doppler monitoring systems, and the rectangle, for multiple-transducer assemblies such as those found in linear and phased arrays. An ideal transducer material, when used in pulse-echo

mode, should be both an efficient producer and sensitive receiver of ultrasound waves. The transmitting constant d of a transducer is the strain produced by a unit electric field and has units of meters per volt. The receiving constant g is the potential produced by a unit stress and has units of volt-meters per Newton.

ii. Resonance Transducers:

Transducer crystals exhibit resonance that is; they tend to vibrate sinusoidally after electrical excitation has ended. The frequency of this vibration is called the fundamental resonant frequency fT of a transducer. In most systems, different transducers having resonant frequencies in the range 1–20 MHz can be __plugged‘‘ into the ultrasound scanner. The difference in resonant frequency between the different transducers has a profound influence on image quality. The resonant frequency of a transducer is largely determined by the thickness of its piezoelectric crystal. When the front face of the transducer is moved forward (by the electrically induced strain, for example), an acoustic wave is initiated forward into the medium (perhaps a human body) and backward into the transducer crystal itself. The backward-traveling wave will hit the back face of the transducer and reflect toward the front face again. Resonance is set up when the returning wave strikes the front face at the time when the wave reaches a __crest,‘‘ thus reinforcing the wave. This condition occurs when

$$f_T = \frac{c_T}{}$$

Where, C_T and d_T are the speed of sound in the transducer and the thickness of the transducer, respectively. Since $\lambda_T = c_T/f_T$, the resonance condition is equivalently given by,

$$\lambda_T = 2d_T$$

Transducer Arrays:

Arrays are transducer assemblies with more than one element. Transducer arrays mainly classified based on,

- Linear sequential array (switched array)
- Linear phased array (vector, sector)
- Curved sequential array (curvilinear sequential array).
- Curved phased array (curvilinear phased array).
- Annular array

i. Linear Arrays

Linear array transducers typically contain 256 to 512 elements; physically these are the largest transducer assemblies. In operation, the simultaneous firing of a small group of approximately 20 adjacent elements produces the ultrasound beam. The simultaneous activation produces a synthetic aperture (effective transducer width) defined by the number of active elements. Echoes are detected in the receive mode by acquiring signals from most of the transducer elements. Subsequent ―A-line‖ acquisition occurs by firing another group of transducer elements displaced by one or two elements. A rectangular field of view (FOV) is produced with this transducer arrangement. For a curvilinear array, a trapezoidal FOV is produced.

ii. Phased Arrays

A phased-array transducer is usually comprised of 64 to 128 individual elements in a smaller package than a linear array transducer. All transducer elements are activated nearly simultaneously to produce a single ultrasound beam. By using time delays in the electrical activation of the discrete elements across the face of the transducer, the ultrasound beam can be steered and focused electronically without physically moving the transducer on the patient. During ultrasound signal reception, all of the transducer elements detect the returning echoes from the beam path, and sophisticated detection algorithms synthesize the data to form the image

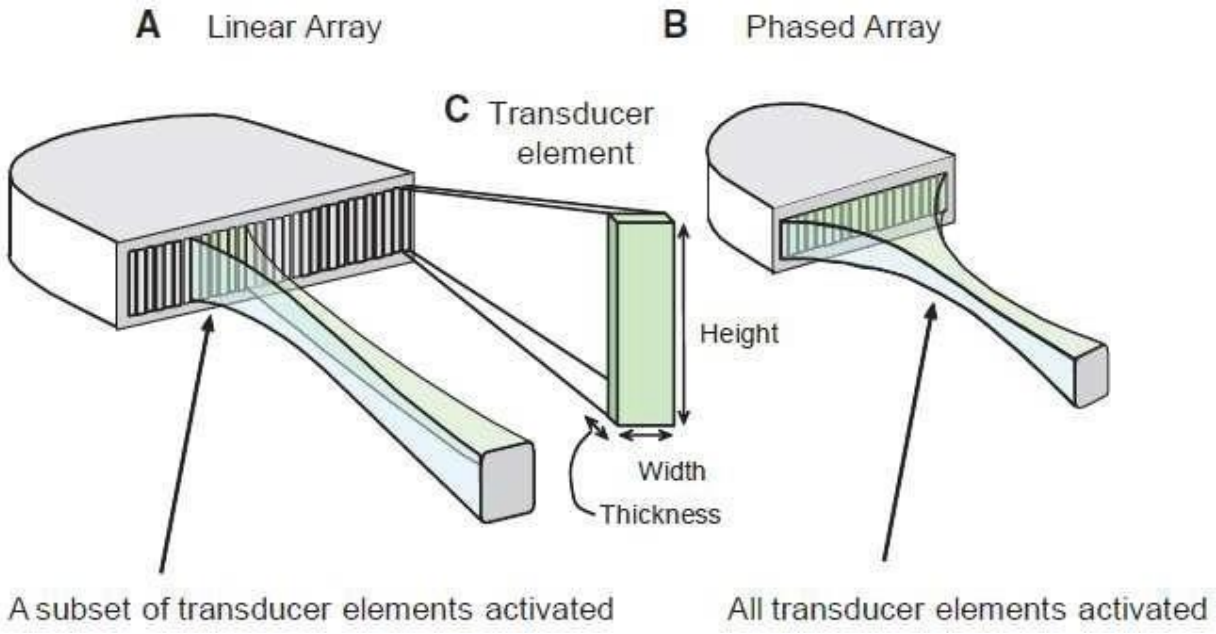


FIG: Multielement transducer arrays.

A. A linear (or curvilinear) array produces a beam by firing a subset of the total number of transducer elements as a group.

B. A phased array produces a beam from all of the transducer elements fired with fractional time delays in order to steer and focus the beam.

C. The transducer element in an array has a thickness, width, and height; the width is typically on the order of ½ wavelength and the height depends on the transducer design and slice-thickness requirements

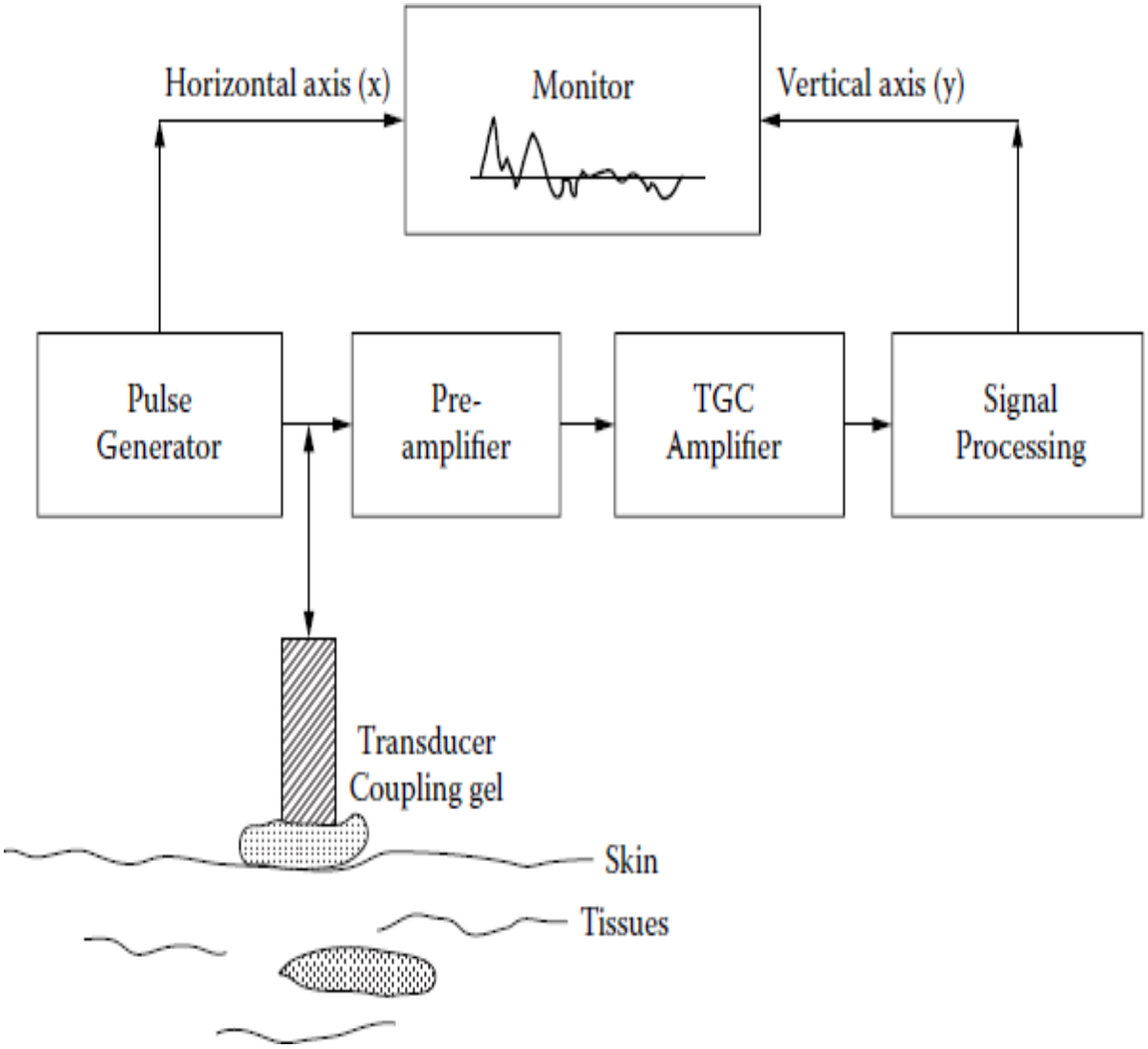
A mode scanner:

A-mode is the simplest and earliest mode of ultrasonic imaging. A block diagram for A-mode instruments is shown in Figure 5. A signal generator that produces high-intensity short pulses or a pulser is used to excite a single-element transducer. The returned echoes from the tissues are detected by the same transducer, amplified, and processed for display. A coupling medium in the form of an aqueous gel or oil is used to couple the transducer to the body because of the mismatch in acoustic impedance between the body and the transducer. Without the gel, very little energy can be transmitted into the body. The

echoes returned from various structures due to large interfaces between organs or small in homogeneities

in the organ, such as cells, small blood vessels, ducts, etc. are first amplified by a preamplifier. The preamplifier that provides the initial state of signal amplification with a gain of a few

decibels is an amplifier with high input electrical impedance and low noise. A second-stage amplification is provided by the time–gain–compensation (TGC) amplifier that may have a gain greater than 40 db. TGC is needed because ultrasound energy is attenuated by tissues as it penetrates deeper into the body. Energy loss is affected not only by tissue attenuation that is exponentially related to the depth of penetration (as previously discussed) but also by beam diffraction. Therefore it is quite difficult to compensate for the energy loss accurately. A variety of TGC curves, shown in Figure 6, has been used and are usually available in an ultrasonic scanner for the operator to select. The amplified signal is then demodulated, involving envelope detection and filtering, and logarithmically compressed. Logarithmic compression is needed because the dynamic range of the received echoes, which is defined as the ratio of the largest echo to the smallest echo above noise level detected by the transducer, is very large—on the order of 100 to 120 dB. Typical display units or cathode ray tube (CRT) monitors can only display signals with a dynamic range up to 40 dB at best. The horizontal axis of the CRT monitor is synchronized or triggered by pulses generated by the pulser the vertical axis or vertical deflection of the electron beam is driven by the output of the signal processing



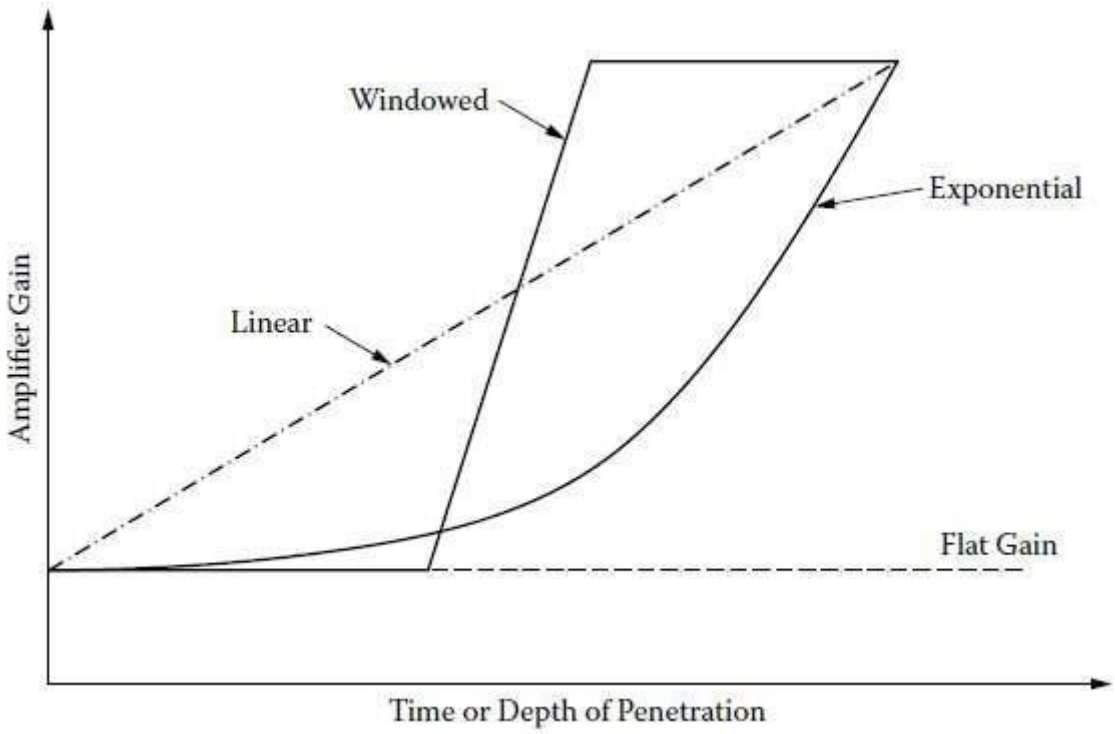


FIG: 6 Time–gain–compensation curves frequently used in ultrasonic imaging
The type of information obtained by an A-mode instrument, called an A-line

6. Describe about B – mode scan imaging in ultrasound.(NOV 18)(MAY 17)

B mode scanner:

A majority of commercial scanners on the market today are two-dimensional B-mode scanners in which the beam position is also monitored. Figure 7 shows a static B-scanner in which the position of the transducer in the *x*–*y* plane is encoded. The positional information of the beam, plus the video signal representing echoes returned from the *z*-direction, is converted into a format compatible with a CRT monitor in a device, called a scan-converter, and is almost invariably digital today. If the transducer is scanned in the *x*-direction, the image formed represents an image of structures in the *x*–*z* plane. Images can also be formed by superposition of multiple images after translating and rotating the transducer at a fixed *x*-position within a sector angle, as illustrated in Figure 8. This is called compound B-scan. The advantages of doing this are to make the image look smoother or suppress the speckle pattern and to average out the specular echoes due to flat interfaces. The disadvantage is that it slows down the image acquisition rate. Static B-scanners are no longer used today because of poor image quality due to the lack of dynamic focusing and low image acquisition rate except for high-frequency (higher than 20 MHz)

applications. Modern B-mode scanners can acquire images faster than 30 frames per second to allow monitoring of organ motion.

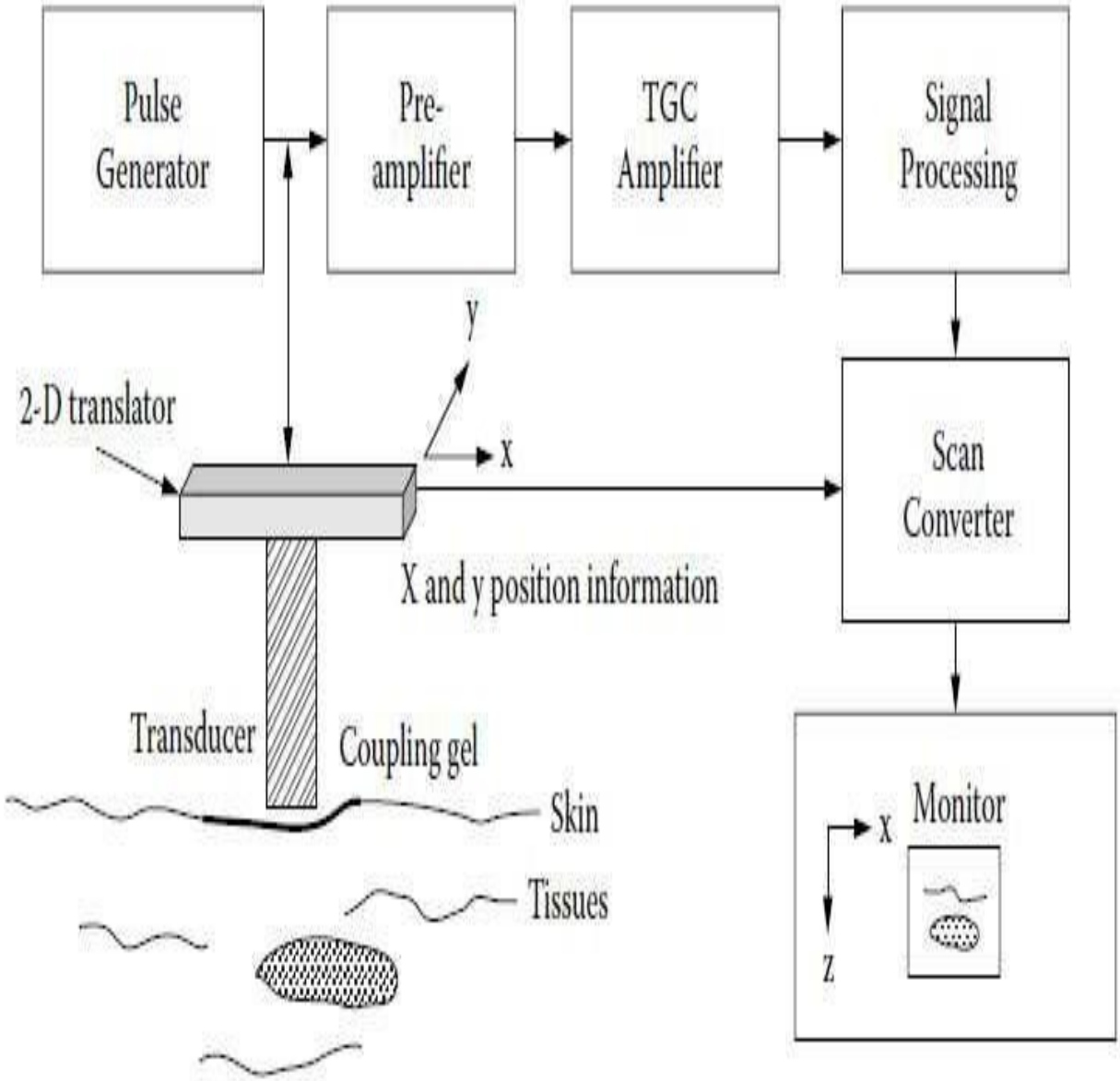


FIG: 7 Block diagram of B-mode scanner

Depending upon the mechanisms used to drive a transducer, the real-time scanners are classified into mechanical-sector and electronic-array scanners. Because electronic array systems generally produce images of better quality, modern ultrasonic scanners are almost exclusively array-based systems.

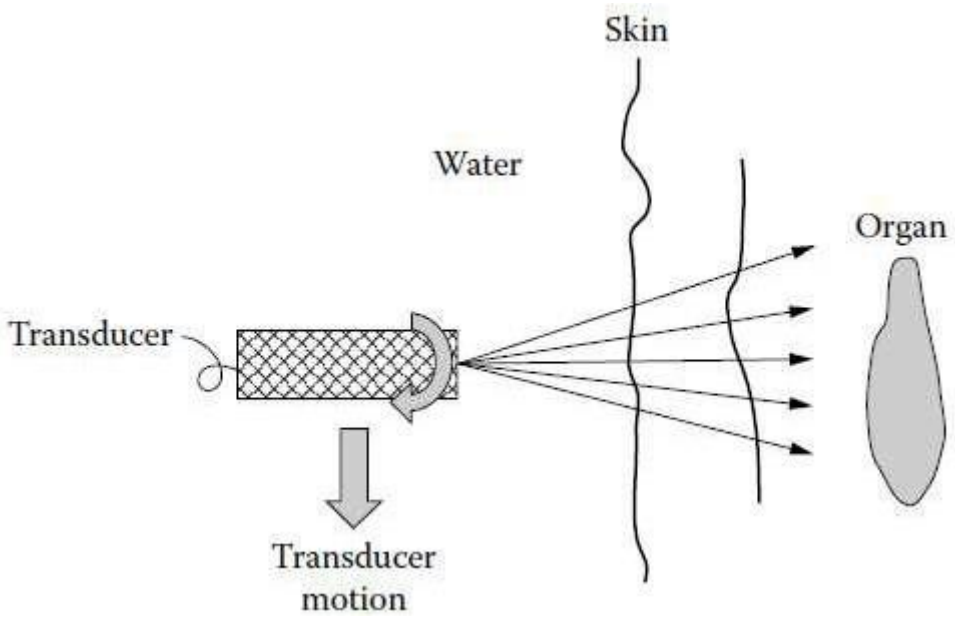


FIG: 8 Compound scan is performed by combining two different modes of motion of the transducer in forming one image.

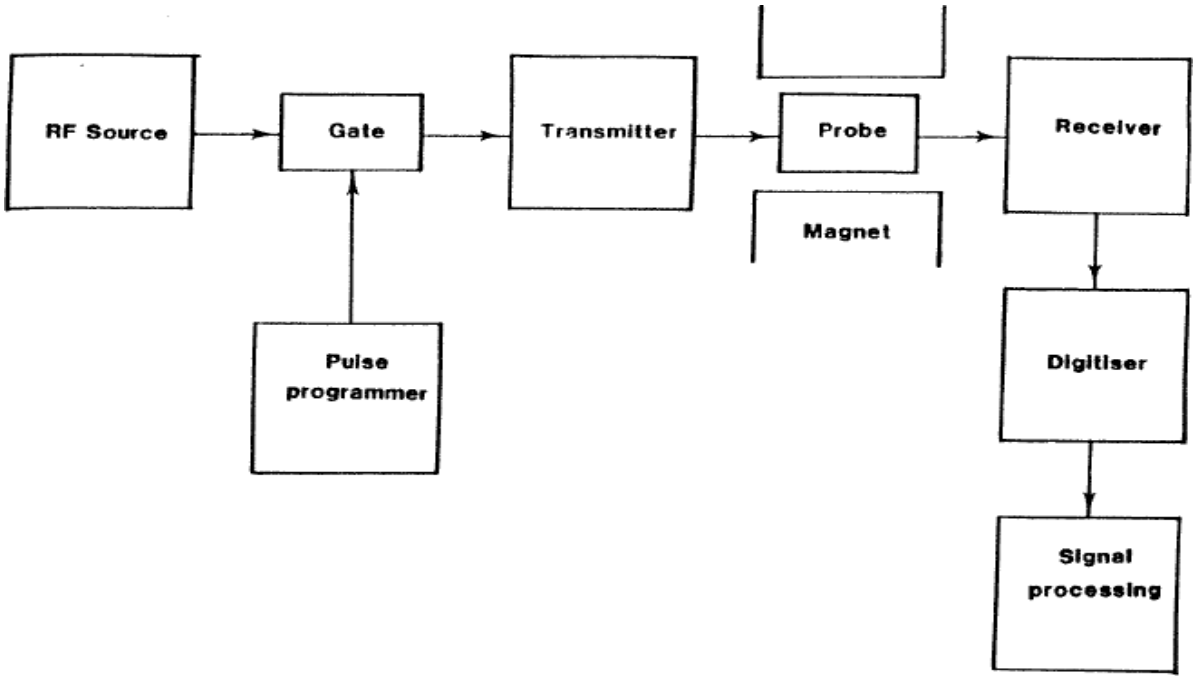
Several components in a B-mode scanner perform the same functions as those in the A-mode System. These include the TGC amplifier and signal processing units for signal compression, Demodulation and filtering. Various forms of TGC from which the operator can choose are available on the console. The timing and control signals are all generated by a central unit. The image is displayed on a storage monitor.

Clinical Applications

B-mode ultrasound has numerous applications because it is noninvasive and can display two dimensional cross-sectional images of anatomical structures in real time. Some of the many applications of B-mode ultrasound include:

- Obstetrics for monitoring the status of the fetus.
- Gynecology for diagnosing problems in the ovary.
- General radiology for diagnosing liver tumors and gall bladder diseases.
- Vascular surgery for detecting arterial stenosis and deep vein thrombosis and for characterizing atherosclerotic plaques.
- Cardiology for diagnosing valvular diseases and monitoring the integrity of cardiac wall functions.

7. With a neat block diagram of gradient system.(MAY 14)



8. Write detailed notes on generic pulse sequence used in MRI.(MAY 14)

MRI pulse sequence is a programmed set of changing magnetic gradients. Each sequence will have a number of parameters, and multiple sequences grouped together into an MRI protocol.

Parameters

A pulse sequence is generally defined by multiple parameters, including:

- time to echo (TE)
- time to repetition (TR)
- flip angle
- field of view and matrix size
- inversion pulse(s)
- spoiler gradient(s) (crusher gradients)
- echo train length (ETL)
- the spatial acquisition of k-space
- 3D acquisition vs. 2D acquisition vs. multiple overlapping slab acquisition

- post contrast imaging with gadolinium contrast agents
- diffusion weighting (b values)

Different combinations of these parameters affect tissue contrast and spatial resolution.

Parameters are discussed more fully in a separate article: MRI parameters.

Sequences

MRI sequences can be grouped in a number of ways. Probably most accurately they are grouped according to the type of sequence (e.g. spin echo, or inversion recovery etc..) however for non radiologists another way of grouping sequences is by general image weighting (e.g. T1 or T2) and additional features (e.g. fat suppressed or gadolinium enhanced). This simplified approach is described in a separate article: MRI sequences (basic).

Pulse sequences can be broadly grouped as follows:

- spin echo sequences
- inversion recovery sequences
- gradient echo sequences
- diffusion weighted sequences
- saturation recovery sequences
- echo-planar pulse sequences
- spiral pulse sequences

Protocols

Multiple sequences are usually needed to adequately evaluate a tissue, and the combination of sequences is referred to as a MRI protocol. The radiologist tailors the pulse sequences to try to best answer the clinical question posed by referring physician.

Protocols are discussed more fully in a separate article: MRI protocols.

References

Related Radiopaedia articles

Imaging technology

- imaging technology
- imaging physics
  - electronvolt
  - nuclear shell model
  - photoluminescence

- K-absorption edge
- electron binding energy
- linear attenuation coefficient
- mass attenuation coefficient

- imaging in practice
- x-ray
  - x-ray physics
  - x-ray in practice
    - radiation risk factor
  - x-ray production
    - high voltage generator
      - ripple
    - cathode
      - thermionic emission
      - filament circuit
      - space charge effect
    - anode
      - focal spot
      - anode angle
      - heel effect
      - off focus radiation
    - line focus principle
    - radiographic distortion
    - kilovoltage peak
    - milliamperage-seconds (mAs)
  - x-ray tubes
    - rotating envelope x-ray tube
  - tube rating
  - filters
    - compensating filter
  - automatic exposure control (AEC)
  - beam collimators
  - grids
    - bucky factor
  - air gap technique

- cassette
- intensifying screen
- x-ray film
  - developer solution
  - fixing solution
  - silver recovery
- image intensifier
  - entrance phosphor
  - photocathode
  - output phosphor
- digital radiography
  - computed radiography
  - direct digital radiography
    - flat panel detector (FPD)
    - charge-coupled device (CCD)
- digital image
  - radiographic contrast
  - signal to noise ratio
- mammography
- x-ray artifacts
  - external foreign body artifact
    - clothing artifact
    - hair artifact
    - jewelry artifact
  - grid cut off
- radiation units
  - absorbed dose
    - gray
  - equivalent dose
    - sievert
  - effective dose
    - tissue weighting factor
  - exposure
    - entrance skin dose
    - coulomb per kilogram

        - legacy units
            - curie
            - rad
            - rem
            - roentgen
            - rutherford
    - radiation safety
        - as low as reasonably achievable (ALARA)
        - radiation protection
        - background radiation
        - background radiation equivalent time
        - deterministic effect
        - dose limits
        - inverse square law
        - lead apron
        - radiation damage (biomolecular)
        - radiation damage (skin injury)
        - stochastic effect
            - radiation-induced carcinogenesis
                - radiation-induced lung cancer
    - radiation detectors
        - ionization chambers
        - dosimeters
            - thermoluminescent dosimeter
            - film dosimeter
- fluoroscopy
    - fluoroscopy vs fluorography
    - automatic brightness control (ABC)
- computed tomography (CT)
    - CT physics
    - CT in practice
    - CT technology
        - generations of CT scanners
            - helical CT scanning
            - step and shoot scanning

- CT x-ray tube
- CT fluoroscopy
- cone beam CT
- dual energy CT
  - clinical applications of dual energy CT
    - virtual non-contrast imaging
    - abdominal
    - vascular
    - urinary system
    - musculoskeletal
    - neuroimaging
- CT image reconstruction
  - filtered back projection
  - Hounsfield unit
  - iterative reconstruction
  - kernels
  - maximum intensity projection (MIP)
  - minimum intensity projection (MinIP)
  - metal artifact reduction algorithm
  - windowing
- CT image quality
  - CT spatial resolution
  - CT contrast discrimination
  - pitch
  - noise in CT
  - signal to noise ratio
- CT dose
  - CT dose index (CTDI)
  - dose length product (DLP)
  - size specific dose estimate (SSDE)
  - tube current modulation
- CT contrast media
- CT artifacts
  - patient-based artifacts
    - motion artifact

        - transient interruption of contrast
        - blur
            - motion blur
    - physics-based artifacts
        - beam hardening
        - partial volume averaging
        - quantum mottle (noise)
        - photon starvation
        - aliasing in CT
        - truncation artifact
    - hardware-based artifacts
        - ring artifact
        - tube arcing
        - out of field artifact
        - air bubble artifact
        - helical and multichannel artifacts
            - windmill artifact
            - cone beam effect
            - MPR artifact
                - zebra artifact
                - stair-step artifact
  - CT safety
  - history of CT
    - Godfrey N Hounsfield
- MRI
  - MRI physics
  - MRI in practice
  - MRI hardware
    - coils
        - gradient coil
        - phased array coil
        - radiofrequency coil
        - volume coil
        - surface coil
    - electronics and data processing

- magnets
  - quenching
  - magnetic field
- radiofrequency receiver
- radiofrequency transmitter
- 1.5 T vs 3 T
- ultrahigh field MRI

- signal processing
  - acquisition time
  - Fourier transformation
  - k-space
  - motion compensation
  - signal-to-noise ratio (SNR)
  - spatial resolution
  - trade-offs
  - zero filling interpolation
- MRI pulse sequences (basics | abbreviations | parameters)
  - T1 weighted image
  - T2 weighted image
  - proton density weighted image
  - chemical exchange saturation transfer
  - CSF flow studies
  - diffusion weighted imaging (DWI)
    - apparent diffusion coefficient (ADC)
    - b-values
    - diffusion tensor imaging and fiber tractography
  - echo-planar pulse sequences
  - fat-suppressed imaging sequences
  - gradient echo sequences
    - in-phase and out-of-phase
    - spoiled gradient echo MRI
    - steady-state free precession
  - inversion recovery sequences
    - short tau inversion recovery (STIR)
    - fluid attenuation inversion recovery (FLAIR)

        - turbo inversion recovery magnitude (TIRM)
        - double inversion recovery (DIR)
    - metal artifact reduction sequence (MARS)
    - perfusion-weighted imaging
        - techniques
            - dynamic susceptibility contrast (DSC) MR perfusion
            - dynamic contrast enhanced (DCE) MR perfusion
            - arterial spin labeling (ASL) MR perfusion
        - derived values
            - cerebral blood flow (CBF)
            - cerebral blood volume (CBV)
            - k-trans
            - mean transit time (MTT)
            - negative enhancement integral (NEI)
            - time to peak (TTP)
    - saturation recovery sequences
    - spin echo sequences
        - fast spin echo (FSE)
        - 3d fast spin echo
    - spiral pulse sequences
    - susceptibility-weighted imaging (SWI)
    - T1 rho
- MR angiography (and venography)
    - contrast-enhanced MRA
    - non-contrast-enhanced MRA
        - phase contrast imaging
        - time of flight angiography
        - TRICKS
- MR spectroscopy (MRS)
    - 2-hydroxyglutarate peak: resonates at 2.25 ppm
    - alanine peak: resonates at 1.48 ppm
    - choline peak: resonates at 3.2 ppm
    - citrate peak: resonates at 2.6 ppm
    - creatine peak: resonates at 3.0 ppm
    - functional MRI (fMRI)

        - BOLD imaging
    - gamma-aminobutyric acid (GABA) peak: resonates at 2.2-2.4 ppm
    - glutamine-glutamate peak: resonates at 2.2-2.4 ppm
    - Hunter's angle
    - lactate peak: resonates at 1.3 ppm
    - lipids peak: resonates at 1.3 ppm
    - myoinositol peak: resonates at 3.5 ppm
    - MR fingerprinting
    - N-acetylaspartate (NAA) peak: resonates at 2.0 ppm
    - propylene glycol peak: resonates at 1.13 ppm
  - MRI artifacts

MRI hardware and room shielding

central point artifact

herringbone artifact

inhomogeneity artifact

moiré fringes

RF overflow artifact

zebra stripes

zipper artifact

MRI software

cross-excitation

Fat-water swapping

Slice-overlap artifact a.k.a. cross-talk artifact

patient and physiologic motion

phase-encoded motion artifact

entry slice phenomenon

flow void

tissue heterogeneity and foreign bodies

black boundary artifact

chemical shift artifact

dielectric effect artifact

magic angle effect

magnetic susceptibility artifact

blooming artifact

Fourier transform and Nyquist sampling theorem

- aliasing (wrap around) artifact
- Gibbs (truncation) artifact
- zero-fill artifact

MRI CONTRAST AGENTS

gadolinium contrast agents

gastrointestinal MRI contrast agents

reticuloendothelial MRI contrast agents

tumor-specific MRI contrast agents

intravascular (blood pool) MRI contrast agents

chromium-labeled red blood cells

Gd-DTPA-labeled dextran

Gd-DTPA-labeled albumin

gadofosveset trisodium

hepatobiliary MRI contrast agents

gadoxetate disodium

extracellular MRI contrast agents

gadobenate dimeglumine

gadobutrol

gadodiamide

gadopentetate dimeglumine

BM E63 – MEDICAL IMAGING TECHNIQUES

UNIT- 4

PART-A

1. What is gamma camera? (April/May 2014)

- A gamma camera (γ-camera), also called a scintillation camera or Anger camera, is a device used to image gamma radiation emitting radioisotopes, a technique known as scintigraphy.
- The applications of scintigraphy include early drug development and nuclear medical imaging to view and analyse images of the human body or the distribution of medically injected, inhaled, or ingested radionuclides emitting gamma rays.

2. What are the parts of a detector of gamma camera? (April/May 2014)

There are three major components in a gamma camera:

- Collimator,
- Scintillation crystal, and
- Photomultiplier tube (PMT) array

3. Define Rectilinear scanner. (April/May 2016)

- A rectilinear scanner is an imaging device, used to capture emission from radiopharmaceuticals in nuclear medicine.
- The image is created by physically moving a radiation detector over the surface of a radioactive patient.

4. (a)Explain the use of gamma ray camera (May 2017)

(b) What is the function of gamma ray camera?(November/December 2019)

- Gamma rays are ionizing electromagnetic radiation, obtained by the decay of an atomic nucleus.
- Gamma rays are more penetrating, in matter, and can damage living cells to a great extent.
- Gamma rays are used in medicine (radiotherapy), industry (sterilization and disinfection) and the nuclear industry.

5. Name any two SPECT radionuclides . (May 2017)

The radionuclides typically used in SPECT to label tracers are

- Iodine-123,
- Technetium-99m,
- Xenon-133,
- Thallium-201, and
- Fluorine-18.

6. What is SPECT?(November/December 2017)

- Single-photon emission computed tomography (SPECT, or less commonly, SPET) is a nuclear medicine tomographic imaging technique using gamma rays.
- It is very similar to conventional nuclear medicine planar imaging using a gamma camera (that is, scintigraphy), but is able to provide true 3D information.
- This information is typically presented as cross-sectional slices through the patient, but can be freely reformatted or manipulated as required.

7. Give the basic principle of nuclear imaging technique. (November/December 2017,2019)

The underlying principles of nuclear medicine imaging involve the use of unsealed sources of radioactivity in the form of radiopharmaceuticals. The ionizing radiations that accompany the decay of the administered radioactivity can be quantitatively detected, measured, and imaged in vivo with instruments such as gamma cameras.

8. Define LINAC. (April/May 2018)

A linear accelerator (LINAC) is the device most commonly used for external beam radiation treatments for patients with cancer. It delivers high-energy x-rays or electrons to the region of the patient's tumor.

9. Write the principle of PET scanner. (November/December 2018)

PET works by using a scanning device (a machine with a large hole at its center) to detect photons (subatomic particles) emitted by a radionuclide in the organ or tissue being examined.

10. What are the types of isotopes used in SPECT?(September 2020)

The **radioisotopes** typically **used in SPECT** to label tracers are iodine-123, technetium-99m, xenon-133, thallium-201, and fluorine-18. These radioactive **forms** of natural elements will pass through your body and be detected by the scanner. Various drugs and other chemicals can be labeled with these **isotopes**.

11. What is the principle of rectilinear scanner? (September 2020)

A **rectilinear scanner** is an imaging device, used to capture emission from radiopharmaceuticals in nuclear medicine. ... The image is created by physically moving a radiation detector over the surface of a radioactive patient.

12. What is the function of a gamma ray camera ?(November/December 2019)

The gamma camera, also called scintillation camera, is the most commonly used imaging device in nuclear medicine. It simultaneously detects radiation from the entire FOV and enables the acquisition of dynamic as well as static images of the area of interest in the human **body.**

13. Give the basic principle of nuclear imaging techniques. (November/December 2019)

Nuclear medicine utilizes radioactive molecules (radiopharmaceuticals) for the diagnosis and treatment of disease. The diagnostic information obtained from imaging the distribution of radiopharmaceuticals is fundamentally functional and thus differs from other imaging disciplines within radiology, which are primarily anatomic in nature. Imaging using radiopharmaceuticals can be subdivided into single- and dual-photon modalities.

PART-B

1. (a)Explain in detail about the radio isotopes rectilinear scanners. (April/May2014)

(b) Write notes on Rectilinear scanner.(May 2017)

- The rectilinear scanner is a device for imaging the distribution of radioactive material within the body. It is a systematic point sampling device that forms its image by moving over (scanning) the field of interest.
- Basically, the rectilinear scanner is a rigid bar with a radiation detector at one end and a light and a stylus at the other end. When the detector detects radiation, the light flashes, exposing some film, and the stylus taps, marking some paper.

- The rigid bar provides position data linking the radiation detector and the flashing light. The motion is boustrophedonic,alternately left to right and right to left. Of course, this simple model of the rectilinear scanner becomes more and more complex as one introduces the ancillary devices necessary to make the scanner operate properly.
- A **rectilinear scanner** is an imaging device, used to capture emission from radiopharmaceuticals in nuclear medicine. The image is created by physically moving a radiation detector over the surface of a radioactive patient. It has become obsolete in medical imaging, largely replaced by the gamma camera since the late 1960s.
- Cassen's original rectilinear scanner used calcium tungstate ($CaWo_4$) crystal as the radiation detector. Later systems used a Sodium iodide (NaI) scintillator, as in a gamma camera. The detector must be connected by mechanical or elecronic means to an output system. This could be a simple light source over photographic film, dot matrix printer, oscilloscope or television screen.

Mechanism:

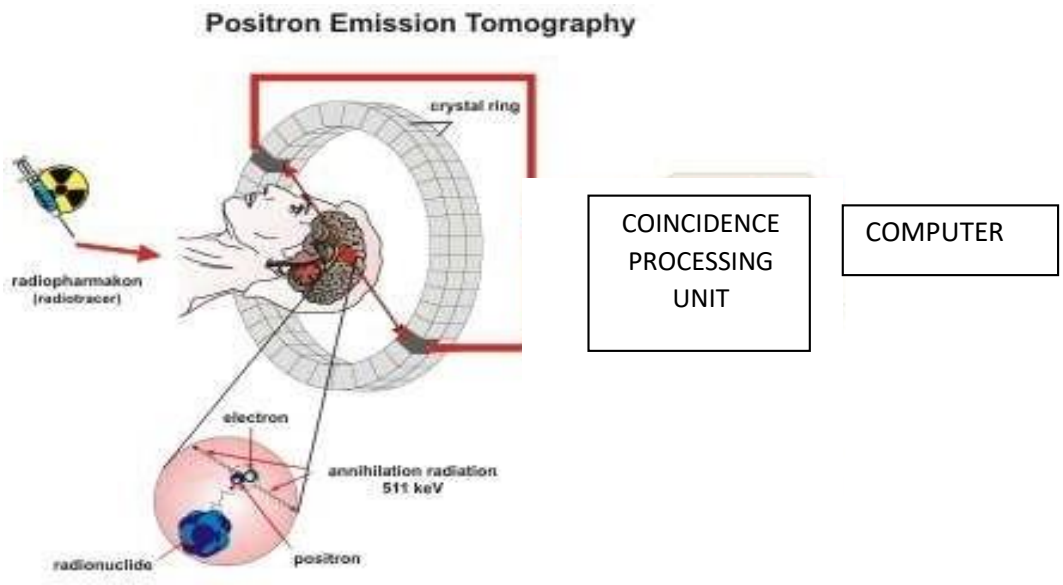
- The patient is administered with a radioactive pharmaceutical agent, such as iodine, which will naturally collect in the thyroid. The detector moves in a raster pattern over studied area of the patient, making a constant count rate. A collimator restricts detection to a small area directly below its position so that by the end of the scan emission from the whole study area has been detected.
- The output method is designed such that positional and detection information is maintained. For example when using a light source and film the light is moved in tandem with the detector, and the intensity of light produced increases with an increase in activity, producing dark areas on the film.
- Disadvantages include the very long imaging time (several minutes) due to the need to separately cover each target area, unlike a gamma camera which has a much larger field of view, and the motion artefacts this can result in.
- One of the first rectilinear scanners was developed by Benedict Cassen in 1950. Before then hand-held detectors had been used to locate radioactive materials in patients, but the Cassen system (designed for Iodine-131) combined a motor driven photomultiplier tube and printing mechanism. Subsequent developments improved the detection systems, movement, display and printing of images.

2. **(a)Elaborate on the data acquisition system of PET scanner with a simplified block diagram. (April/May2014)**
   (b)With neat diagram explain in detail the working of a PET machine. (April/May2016,November/December2019, September 2020)

PET is uses positron for imaging technique:

Positron-emission tomography (**PET**) is a nuclear medicine functional imaging technique that is used to observe metabolic activity (energy usage) and molecular function in the body.

CONSTRUCTION

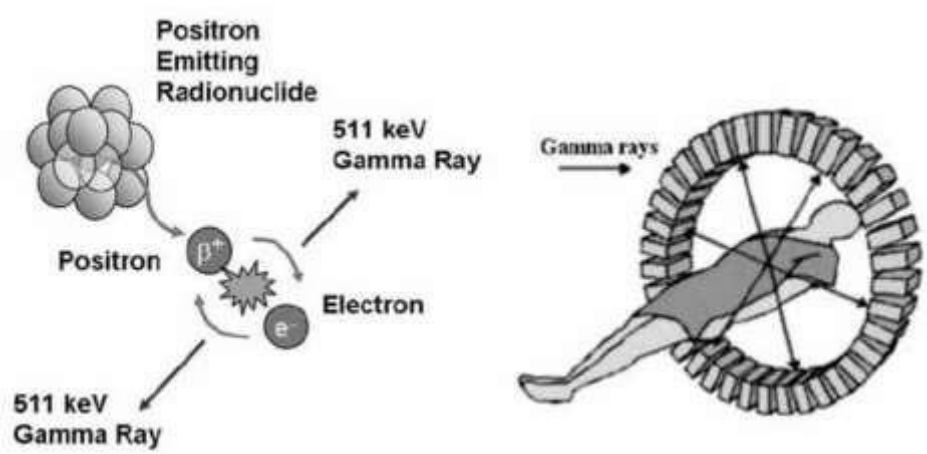


A PET scanner is provided with a patient table, array of detectors provided with scintillator crystal which collects the photons and a photo multiplier tube which converts these light photons to electrical signals, then a coincidence processing unit which provides the positional information and replaces the conventional collimator and computer for producing 3D images.

WORKING

- A small amount of biologically relevant material like oxygen or glucose (sugar) which have been labeled with radio nuclides such as carbon-11, nitrogen-13, oxygen-15 and fluorine-18 are to be introduced into the body through an I.V.
- These short lived tracer then travels through the body and is allowed to get absorbed which usually takes about 60 to 90 minutes to show differences between healthy tissue and diseased tissue.

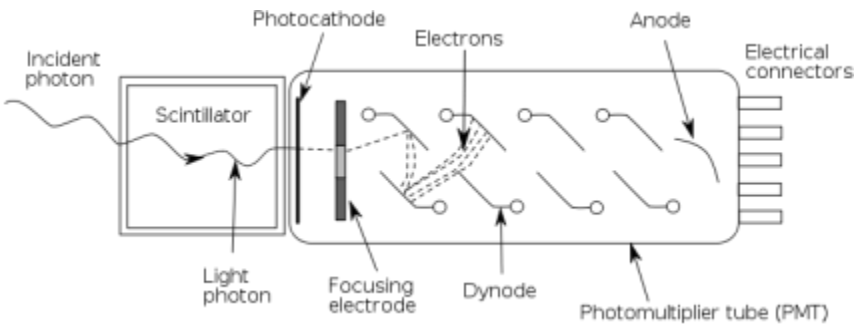
- The most commonly used tracer is [18F] 2-Fluoro-2-Deoxy-D-Glucose more commonly known as "FDG"(fluorodeoxyglucose), so the test is sometimes called an FDG-PET scan.
- The radioactive tracers becomes trapped in the cells that try to metabolize it. Its concentration in tissue is proportion to the rate of metabolism.
- Since cancer grows at a faster rate than healthy tissue, cancer cells absorb more of the radioactive tracers.



- As the isotope used in the radiolabeled oxygen or glucose undergoes radioactive decay, it emits high energy positrons (anti-matter) which collide with electrons resulting in bursts of γ-radiation (a photon pair) and this process is termed as positron – electron annihilation.

$$e^{+} + e^{-} \rightarrow \gamma + \gamma$$

- A photon detector for PET is typically made by a solid scintillating crystal for the detection of the γ rays, coupled to a light sensor such as a photomultiplier tube (PMT) or a photodiode, which absorbs the light emitted by the scintillator and produces an electrical signal.



- These electrical signals are produced as color-coded images of the body by image reconstruction techniques that show both normal and cancerous tissue where the cancerous cells appear as "hot spots" in PET images displayed on the computer monitor.
- A coincidence event is assigned to a line of response (LOR) joining the two relevant detectors. In this way, positional information is gained from the detected radiation without the need for a physical collimator.
- This is known as electronic collimation. Electronic collimation has two major advantages over physical collimation. They have improved sensitivity and improved uniformity of the point source response function.

APPLICATION

PET scanning is used to measure a range of activity of

- blood flow
- blood volume
- oxygen usage
- tissue pH (acidity)
- glucose (sugar) metabolism
- drug activity

3. Give an account on Scintillation detectors(April/May2016)

- A **scintillator** is a material that exhibits scintillation, the property of luminescence, when excited by ionizing radiation. Luminescent materials, when struck by an incoming particle, absorb its energy and scintillate (i.e. re-emit the absorbed energy in the form of light).
- Sometimes, the excited state is metastable, so the relaxation back down from the excited state to lower states is delayed (necessitating anywhere from a few nanoseconds to hours depending on the material).
- The process then corresponds to one of two phenomena: delayed fluorescence or phosphorescence. The correspondence depends on the type of transition and hence the wavelength of the emitted optical photon.

Principle of operation:

- Scintillation detector or scintillation counter is obtained when a scintillator is coupled to an electronic light sensor such as a photomultiplier tube (PMT), photodiode, or silicon photomultiplier.
- PMTs absorb the light emitted by the scintillator and re-emit it in the form of electrons via the photoelectric effect. The subsequent multiplication of those electrons (sometimes called photo-electrons) results in an electrical pulse which can then be analyzed and yield meaningful information about the particle that originally struck the scintillator.
- Vacuum photodiodes are similar but do not amplify the signal while silicon photodiodes, on the other hand, detect incoming photons by the excitation of charge carriers directly in the silicon. Silicon photomultipliers consist of an array of photodiodes which are reverse-biased with sufficient voltage to operate in avalanche mode, enabling each pixel of the array to be sensitive to single photons.

Applications:

- Scintillators are used by the American government as Homeland Security radiation detectors. Scintillators can also be used in particle detectors, new energy resource exploration, X-ray security, nuclear cameras, computed tomography and gas exploration.
- Other applications of scintillators include CT scanners and gamma cameras in medical diagnostics, and screens in older style CRT computer monitors and television sets.
- Scintillators have also been proposed as part of theoretical models for the harnessing of gamma-ray energy through the photovoltaic effect, for example in a nuclear battery.
- The use of a scintillator in conjunction with a photomultiplier tube finds wide use in hand-held survey meters used for detecting and measuring radioactive contamination and monitoring nuclear material.
- Scintillators generate light in fluorescent tubes, to convert the ultra-violet of the discharge into visible light. Scintillation detectors are also used in the petroleum industry as detectors for Gamma Ray logs.

Properties:

- There are many desired properties of scintillators, such as high density, fast operation speed, low cost, radiation hardness, production capability and durability of operational parameters. High density reduces the material size of showers for high-energy γ-quanta and electrons.
- The range of Compton scattered photons for lower energy γ-rays is also decreased via high density materials. This results in high segmentation of the detector and leads to better spatial resolution.
- Usually high density materials have heavy ions in the lattice (e.g., lead, cadmium), significantly increasing the contribution of photoelectric effect ($\sim Z^4$). The increased photo-fraction is important for some applications such as positron emission tomography.
- High stopping power for electromagnetic component of the ionizing radiation needs greater photo-fraction; this allows for a compact detector. High operating speed is needed for good resolution of spectra.
- Precision of time measurement with a scintillation detector is proportional to $\sqrt{\tau_{sc}}$. Short decay times are important for the measurement of time intervals and for the operation in fast coincidence circuits. High density and fast response time can allow detection of rare events in particle physics.
- Particle energy deposited in the material of a scintillator is proportional to the scintillator's response. Charged particles, γ-quanta and ions have different slopes when their response is measured. Thus, scintillators could be used to identify various types of γ-quanta and particles in fluxes of mixed radiation.
- Another consideration of scintillators is the cost of producing them. Most crystal scintillators require high-purity chemicals and sometimes rare-earth metals that are fairly expensive.
- Not only are the materials an expenditure, but many crystals require expensive furnaces and almost six months of growth and analyzing time. Currently, other scintillators are being researched for reduced production cost.

Types:

1.Organic crystals

2.Organic liquids

3.Plastic scintillators

4.Inorganic crystals

5.Gaseous scintillators

6.Glasses etc..

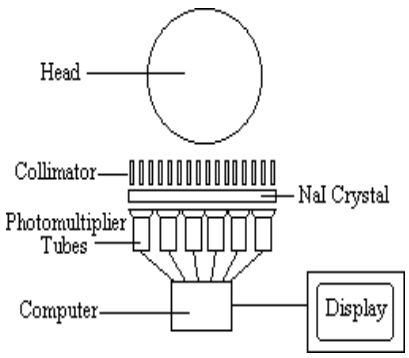
4. With a neat sketch explain the working of SPECT.(November/December2017)

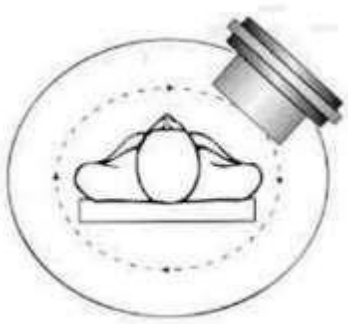
SPECT (SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY)

A Single Photon Emission Computed Tomography (SPECT) scan is a type of functional nuclear imaging test that is aimed to quantify the physiological processes taking place inside the human body without influencing them.

CONSTRUCTION

- The below figure shows a patient injected with radiopharmaceuticals and the gamma camera rotating around him absorbing the gamma radiations being emitted while decay of those radioisotopes.
- A SPECT camera consists of a gamma camera or a set of gamma cameras mounted on a gantry so that the detector can record projections from many equally spaced angular intervals around the body.





- The scintillation (gamma) camera consists of a lead collimator that allows photons travelling in given directions to pass through a large-area scintillator (commonly NaI (Tl) crystal) that converts the energy of γ-ray photons to lower-energy photons which are in turn converted to electric signals by photomultiplier tubes (PMTs).
- The signals from an array of PMTs are processed by electronic circuitry to provide information about the position at which a photon interacts with the crystal. The scintillation camera provides a two-dimensional projection image of the three-dimensional radioactivity distribution or radiopharmaceutical uptake within the patient.

WORKING PROCEDURE

- The technique requires delivery of a gamma-emitting radioisotope (a radionuclide) into the patient, normally through injection into the bloodstream which acts as radiation source.
- In SPECT scan the tracer stays in your blood stream rather than being absorbed by surrounding tissues.
- The radioisotopes typically used in SPECT to label tracers are iodine-123, technetium-99m, xenon-133, thallium-201, and fluorine-18. These radioactive forms of natural elements will pass safely through body.
- Most of the time, a marker radioisotope is attached to a specific ligand to create a radioligand. This allows the combination of ligand and radiopharmaceutical to be carried and bound to certain types of tissues, where the ligand concentration is seen by a gamma camera.
- These radioactive tracers used in SPECT emit gamma radiation that is measured directly.
- A gamma camera is used to acquire multiple 2-D projections, from multiple angles. A computer is then used to apply a tomographic reconstruction algorithm to the multiple projections, yielding a 3-D data.

DURATION

Total scan time is about 15 to 20 minutes for whole body scan.

APPLICATION

- This is used to view blood flow through arteries and veins.

- It is helpful in tumor imaging, infection (leukocyte) imaging, thyroid imaging.
- It is also useful in diagnosing stress fractures in the spine (spondylolysis), blood deprived (ischemic) areas of brain following a stroke, seizures and Alzheimer's disease.
- SPECT is also used to diagnose and track the progress of heart diseases, such as blocked coronary arteries.

5. Explain the principle behind PET and SPECT. (April/May2016, April/May2018)

- Photon emission computed tomography (SPECT, or less commonly, SPET) is a nuclear medicine tomographic imaging technique using gamma rays. It is very similar to conventional nuclear medicine planar imaging using a gamma camera.
- Positron emission tomography (PET) is a nuclear medicine, functional imaging technique that is used to observe metabolic processes in the body. The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer), which is introduced into the body on a biologica lly active molecule.

SPECT	PET
High sensitivity	Low sensitivity
A resolution limited by technology	A good resolution but with a physical limit
Single photon emission computed tomography (**SPECT**) imaging is routinely used and is the primary functional imaging tool used to evaluate the heart	Positron emission tomography (**PET**) has been applied to the study of the heart
SPECT scans measure gamma rays	**PET** scans produce small particles called positrons

6. Write notes on Molecular imaging(May 2017)

- NMR provides detailed information about molecular structure, dynamic processes and allows the direct observation of chemical reactions. It is also a primary quantitative method allowing the determination of concentration of molecules even in complex

mixtures. In addition to the well-known observation of hydrogen, carbon, fluorine and phosphorous it can be used on a large number of other elements.

- NMR is an indispensable tool in chemistry. From structure elucidation and verification to monitoring of reactions, organic chemistry cannot be imagined without this powerful analytical method. In other areas of chemistry NMR provides rare insight into such aspects as structure of catalysts, the state and reactions of electrolytes in batteries.
- Nuclear magnetic resonance (NMR) is a physical phenomenon in which nuclei in a strong constant magnetic field are perturbed by a weak oscillating magnetic field (in the near field) and respond by producing an electromagnetic signal with a frequency characteristic of the magnetic field at the nucleus.
- This process occurs near resonance, when the oscillation frequency matches the intrinsic frequency of the nuclei, which depends on the strength of the static magnetic field, the chemical environment, and the magnetic properties of the isotope involved; in practical applications with static magnetic fields up to ca. 20 tesla, the frequency is similar to VHF and UHF television broadcasts (60–1000 MHz). NMR results from specific magnetic properties of certain atomic nuclei.
- Nuclear magnetic resonance spectroscopy is widely used to determine the structure of organic molecules in solution and study molecular physics and crystals as well as non-crystalline materials. NMR is also routinely used in advanced medical imaging techniques, such as in magnetic resonance imaging (MRI).
- All isotopes that contain an odd number of protons and/or neutrons have an intrinsic nuclear magnetic moment and angular momentum, in other words a nonzero nuclear spin, while all nuclides with even numbers of both have a total spin of zero. The most commonly used nuclei are h and c, although isotopes of many other elements can be studied by high-field NMR spectroscopy as well.
- A key feature of NMR is that the resonance frequency of a particular sample substance is usually directly proportional to the strength of the applied magnetic field.
- It is this feature that is exploited in imaging techniques; if a sample is placed in a non-uniform magnetic field then the resonance frequencies of the sample's nuclei depend on where in the field they are located. Since the resolution of the imaging technique depends on the magnitude of the magnetic field gradient, many efforts are made to develop increased gradient field strength.

The principle of NMR usually involves three sequential steps:

- The alignment (polarization) of the magnetic nuclear spins in an applied, constant magnetic field B_0.
- The perturbation of this alignment of the nuclear spins by a weak oscillating magnetic field, usually referred to as a radio-frequency (RF) pulse. The oscillation frequency required for significant perturbation is dependent upon the static magnetic field (B_0) and the nuclei of observation.
- The detection of the NMR signal during or after the RF pulse, due to the voltage induced in a detection coil by precession of the nuclear spins around B_0. After an RF pulse, precession usually occurs with the nuclei's intrinsic Larmor frequency and, in itself, does not involve transitions between spin states or energy levels.

The two magnetic fields are usually chosen to be perpendicular to each other as this maximizes the NMR signal strength.

The frequencies of the time-signal response by the total magnetization (M) of the nuclear spins are analyzed in NMR spectroscopy and magnetic resonance imaging.

Both use applied magnetic fields (B_0) of great strength, often produced by large currents in superconducting coils, in order to achieve dispersion of response frequencies and of very high homogeneity and stability in order to deliver spectral resolution, the details of which are described by chemical shifts, the Zeeman effect, and Knight shifts (in metals).

The information provided by NMR can also be increased using hyperpolarization, and/or using two-dimensional, three-dimensional and higher-dimensional techniques.

NMR phenomena are also utilized in low-field NMR, NMR spectroscopy and MRI in the Earth's magnetic field (referred to as Earth's field NMR), and in several types of magnetometers.

7. **With neat diagram explain the working of nuclear radiation detectors. (November/December2017, November/December2019, September 2020)**

- Radiation detector or a particular detector is a **device used to detect, track, or identify ionizing particles** , such as those produced by cosmic radiation, nuclear decay, or reactions in a particle accelerator. Radiation detectors can measure the particle energy

and other attributes such as momentum, spin, charge, particle type, in addition to merely registering the presence of the particle.

- A radiation detector is a device for measuring nuclear, electromagnetic or light radiation. A nuclear radiation detector identifies nuclear radiation by measuring the emission of ionizing radiation of alpha particles, beta particles and gamma rays.
- A radiation Detector or particle detector is a device that measures this ionization of many types of radiation, like- beta radiation, gamma radiations, and alpha radiation with the matter. Thus, creating electrons and positively charged ions.
- Radiation Detector is an instrument used to detect or identify high-energy particles, such as those produced by nuclear decay, cosmic radiation, or reactions in a particle accelerator.
- Earlier, photographic plates were used to identify tracks left by nuclear interactions. Sub-nuclear particles are discovered by using cloud chambers which needed photographic recordings and a tedious measurement of tracks from the photographs.
- Electronic detectors developed with the invention of the transistor. Modern detectors use calorimeters to measure the energy of the detected radiation. They may also be used to measure other attributes such as momentum, spin, charge, etc. of the particles.

Type of Detectors

Scintillator

When excited by ionizing radiation, a scintillator exhibits scintillation which is nothing but the property of luminescence. When a scintillator is coupled to an electronic light sensor such as a photomultiplier tube (PMT), photodiode, or silicon photomultiplier, a scintillator detector. Scintillator-type detectors first convert light into electrical pulses. They use vacuum tubes to perform so.

Gaseous Ionization Detectors

A radiation detection instrument used in particle physics to detect the presence of ionizing particles, and in radiation protection applications to measure ionizing radiation is called Gaseous ionization detectors.

Geiger Counter

- Geiger-Mueller counter, commonly called the Geiger counter is the most commonly used detector.
- A central wire in between a gas-filled tube at high voltage is used to collect the ionization produced by incident radiation.
- Although it cannot distinguish between them, it can detect alpha, beta, and gamma radiation.

Types of radiations

The types of radiation detected by these detectors are Alpha, Beta, and Gamma radiation.

Alpha radiation

- Alpha particles or double ionized helium nuclei are the fast-moving helium atoms.
- They have high energy ranging in MeV.
- They have low penetration depth; typically a few cms of air or skin due to their large mass.

Beta radiation

- They are fast-moving electrons.
- Their energy ranges from hundreds of KeV to several MeV.
- They have better penetration depth due to their comparatively lighter mass. Typically, several feet of air, several millimeters of lighter materials.

Gamma radiation

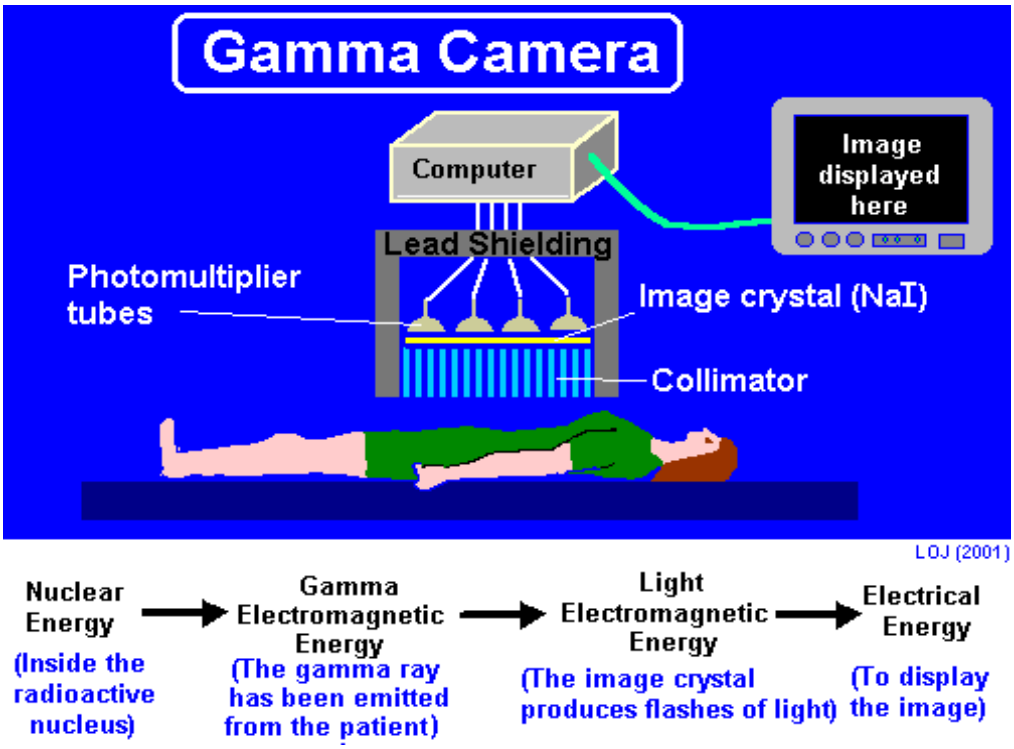
- They are the stream of photons.
- Typical energy ranges from Several KeV to Several MeV.
- They have comparatively very low mass. Thus, possess good penetration depth. Typically, a few inches of lead.

8. **Draw a labelled block diagram of gamma camera and explain its working. (November/December2017,May2019)**

GAMMA CAMERA:

- Is a device used to image gamma radiation radioisotopes this technique is called also scintillation camera.
- Gamma camera is used to view and analyse images of the human body or the distribution of the medically ingested, injected or inhaled radionuclides.

Gamma Camera Components:



Collimators:

The collimator provides an interface between the patient and the scintillation crystal by allowing only those photons traveling in an appropriate direction.

Types of collimators:

A) By the accepted energy.

B) By the geometric shape.

C) By the resolution

Light pipe:

- This sits between the scintillation crystal and the photomultiplier tubes
- Silicone grease is used to ensure good contact between the scintillation crystal, the light pipe and the photomultiplier tubes.

Crystal:

- Any damage to the crystal results in an inoperable scintillation camera and requires costly replacement of the crystal.
- The large surface area, as well as the hygroscopic and brittle nature of the crystal, calls for constant care to avoid puncturing the housing or otherwise damaging the crystal.
- The chosen material for the crystal is Na-I (Tl).
- The Na-I (Tl) crystal is stationary.
- The crystal transform the gamma-ray photon ------> Light photon

Photomultiplier Tubes:

- The Photocathode transform the light photon ---→ electron.
- The PMT multiplies the electron to be a significant detected signal.
- Photomultiplier tubes (photomultipliers or PMTs for short), members of the class of vacuum tubes, and more specifically vacuum phototubes, are extremely sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum. These detectors multiply the current produced by incident light by as much as 100 million times (i.e., 160 dB), in multiple dynode stages, enabling (for example) individual photons to be detected when the incident flux of light is low

Pre-amplifier:

This converts the current produced at the anode of the PMT to a voltage pulse. The amplitude of the voltage pulse is directly proportional to the charge produced at the anode and, therefore, the amount of light received by the PMT, which is proportional to the number of gamma photons that hit the scintillation crystal.

Energy calculation:

For each scintillation formed, the calculated absorbed energy (Z value) that caused it depends on the energy of the gamma photon that was emitted from the patient and the proportion of the energy that was absorbed into the crystal.The gamma photon energy absorbed by the

scintillation crystal depends on its interaction with that photon which results in a spectrum of Z values.

- All energy absorbed: gamma photon interacts with crystal via photoelectric effect.
- Part of the energy absorbed: photon undergoes one or more Compton interactions.

Scatter rejection:

If a gamma photon scatters within the patient's body (via Compton scatter) it will change direction and, therefore, will not hit the detector at a location corresponding to its location of origin. It is important to reject these scattered photons as they degrade the image contrast and spatial resolution. This cannot be done by the collimator and is, therefore, done electronically by a process called **energy discrimination**.

Image formation:

Each PMT corresponds to a coordinate on the scintillation crystal. This is then mapped out onto a matrix. Each time a gamma photon that falls within the acceptable energy window is detected it is mapped on to its corresponding coordinate within the image.

Image acquisition is controlled by the user and may be terminated when:

- Preset number of counts obtained
- Preset time passed

Image display:

The digital image is displayed upon a monitor with each pixel corresponding to a memory location in the matrix and the brightness / colour scale corresponding to the count number in that location.

Advantages:

- The imaging time is only 1-2min.
- It can distinguish 2 sources about 5mm apart.

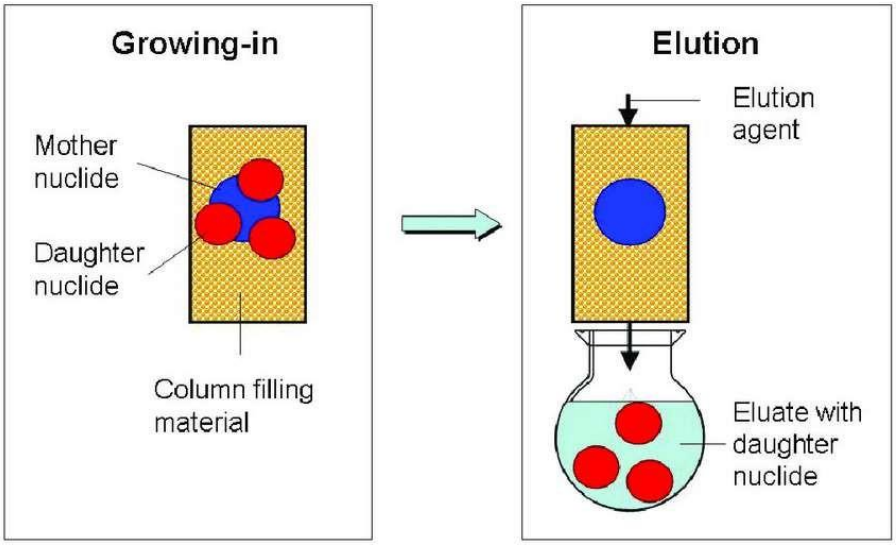
Disadvantages:

- When gamma rays pass through the human body, they ionize the tissue.
- Ionization from gamma rays can cause three different reactions in living cell tissues.

- If a gamma ray burst hit the Earth at high intensity, it would negatively interact with the upper atmosphere, creating nitrogen oxides that would lead to the destruction of the Earth's ozone layer.

9. Give an account on Radionuclide generators(April/May2016, April/May2018)

- Radionuclide generators are made possible by the occurrence of radioactive decays where the daughter is also radioactive. Commonly a radioactive decay proceeds from a radioactive parent to a daughter that is stable.
- For example when ^{32}P decays by beta emission the daughter is ^{32}S, which is not radioactive. In some decays however the daughter is itself radioactive and will undergo a decay process.
- There are many examples of this type of situation and in some of these useful generators can be constructed. In general the generators will allow isolation and utilization of the radioactive daughter.
- A radionuclide generator (these are sometimes referred to as "cows") will contain a long-lived radionuclide (also called "parent"), which then decays into a short-lived radionuclide (also known as "daughter") of interest.
- There are a number of useful isotopes that can be obtained from generator systems that have applications in medical diagnosis (imaging) and therapy as well as applications in radionuclide tracer work.
- There are generally two types of parent-daughter generator systems. The first one is "transient equilibrium generator" where the parent radionuclide half-life is somewhat greater than the daughter's.
- For example, the basic concept of the $^{99}Mo/^{99m}Tc$ generator relies on the availability of a relatively long-lived parent radionuclide that decays to a relatively short-lived daughter radionuclide that has useful physical and decay properties.
- In a generator the parent is adsorbed strongly on a suitable material; whereas the daughter will have different physical and chemical properties and can be eluted from the parent-daughter mixture. Although the $^{99}Mo \rightarrow {}^{99m}Tc$ radionuclide generator is the most common and best-known radionuclide generator, there are a variety of other examples of generators that fit this description (Other generators).



- The daughter radionuclide is a different element than the parent and will therefore often be in a quite different chemical form than the parent. With this difference in chemical characteristics between parent and daughter radionuclides, the latter can usually be separated by an elution method (this process is commonly called “milking” the generator or "cow").
- The concept of "transient equilibrium" is described in Equilibrium concepts and equations (This site is not yet available) but briefly we find that the daughter radionuclide after some time has passed will grow to a maximum and then appear to have a half-life that parallels the parent.
- Once the activity of the daughter is eluted there is a growth of the daughter until it again reaches a maximum and is again in equilibrium with the parent. This elution and regrowth can be continued as long as there are useful amounts of the parent radionuclide available.
- Elution may be performed before equilibrium is reached, and the amount of daughter activity eluted will depend on the time elapsed since the last elution. Another type of generator is called the "secular equilibrium generator"; where the half-life of the parent is much longer than the half-live of the daughter.
- The parent will not decay noticeably during many daughter half-lives. This situation is called "secular equilibrium".
- This example of a secular equilibrium generator has the parent / daughter system $^{81}Rb \rightarrow {}^{81m}Kr$ (the rubidium / krypton generator) where the parent ^{81}Rb has a $T_{1/2}$ = 4.58 hours and the daughter ^{81m}Kr has a $T_{1/2}$ = 13 seconds.

- Like the transient equilibrium generator, the rate of daughter production initially is greater than its rate of decay and the daughter activity will continue to increase until it reaches a state where the rate of production equals the rate of decay.
- At this point the daughter appears to decay with the parent half-life. There are a wide variety of generator systems that have been developed or proposed as shown in GEN-11 but very few have been widely available due to the availability of the parent radionuclides and the technical complexity of most separation techniques.

10. Discuss in detail about construction and working of LINAC. (November/December2017)

Medical linacs are cyclic accelerators that accelerate electrons to kinetic energies from 4 to 25 MeV using microwave radiofrequency fields:

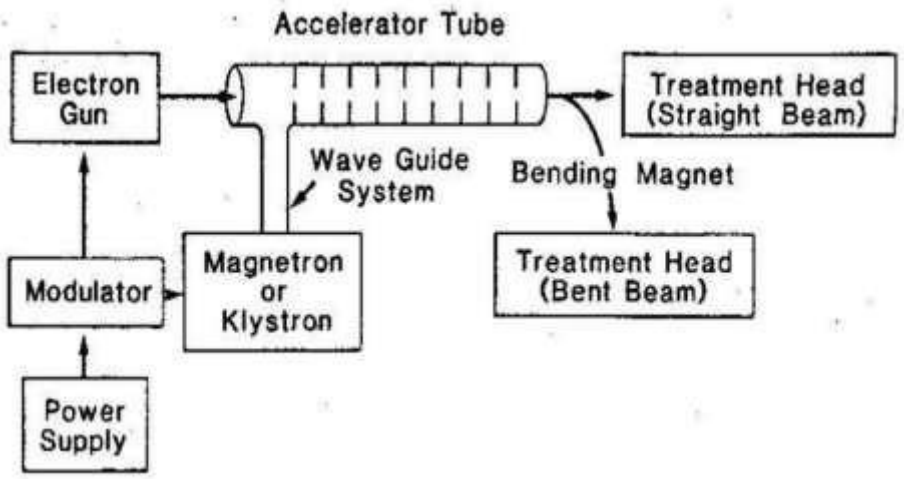
• 103 MHz : L band

• 2856 MHz: S band

• 104 MHz: X band

In a linac the electrons are accelerated following straight trajectories in special evacuated structures called accelerating waveguides.

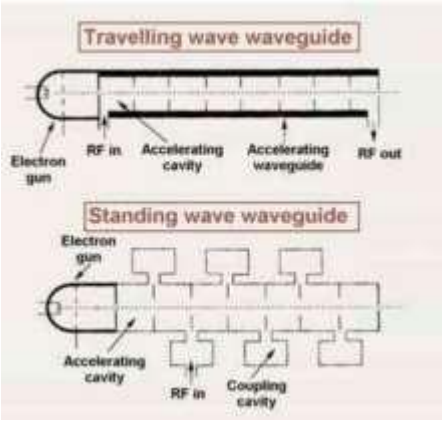
Block diagram of Linear Accelerator



Accelerating waveguide:

In the standing wave accelerating structure each end of the accelerating waveguide is terminated with a conducting disk to reflect the microwave power producing a standing wave in the waveguide.

Every second cavity carries no electric field and thus produces no energy gain for the electron (coupling cavities In the travelling wave accelerating structure the microwaves enter on the gun side and propagate toward the high energy end of the waveguide. Only one in four cavities is at any given moment suitable for acceleration.



Magnetron:

• A device that produces microwaves

• Functions as a high-power oscillator

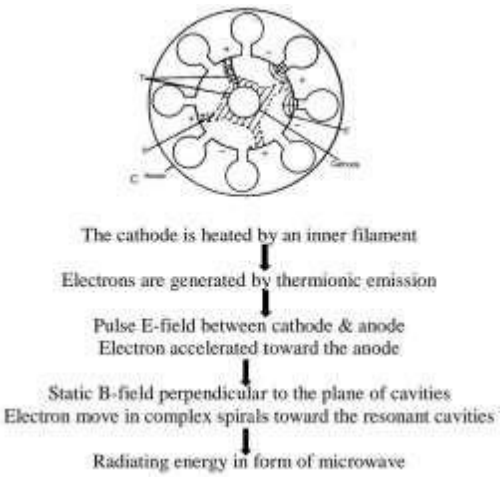
• Generating microwave pulses of several microseconds with repetition rate of several hundred pulses per second

• Frequency of microwave within each pulse is about 3000 MHz

• Peak power output:

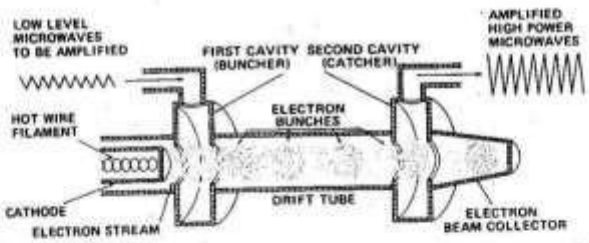
1. 2 MW (for low-energy linacs, 6MV or less)

2. 5 MW (for higher-energy linacs, mostly use klystrons)



Klystron:

• Not a generator of microwaves and it is a Microwave amplifier



Needs to be driven by a low-power microwave oscillator

Electrons produced by the cathode

↓

Electrons are accelerated by –ve pulse into buncher cavity

↓

Lower level microwave set up an alternating E field across the buncher cavity

↓

Velocity of e- is altered by the action of E-field (velocity modulation)

1. Some e- are speed up
2. Other are slowed down

↓

Passed in the drift tube (field-free space)

↓

Electrons arrive catcher cavity

1. Generate a retarding E-field
2. Electrons suffer deceleration
3. KE of electrons converted into high-power microwaves

Linac treatment head:

Components of a modern linac treatment head:

• Several retractable x-ray targets (one for each x-ray beam energy).

• Flattening filters (one for each x-ray beam energy).

• Scattering foils for production of clinical electron beams.

• Primary collimator.

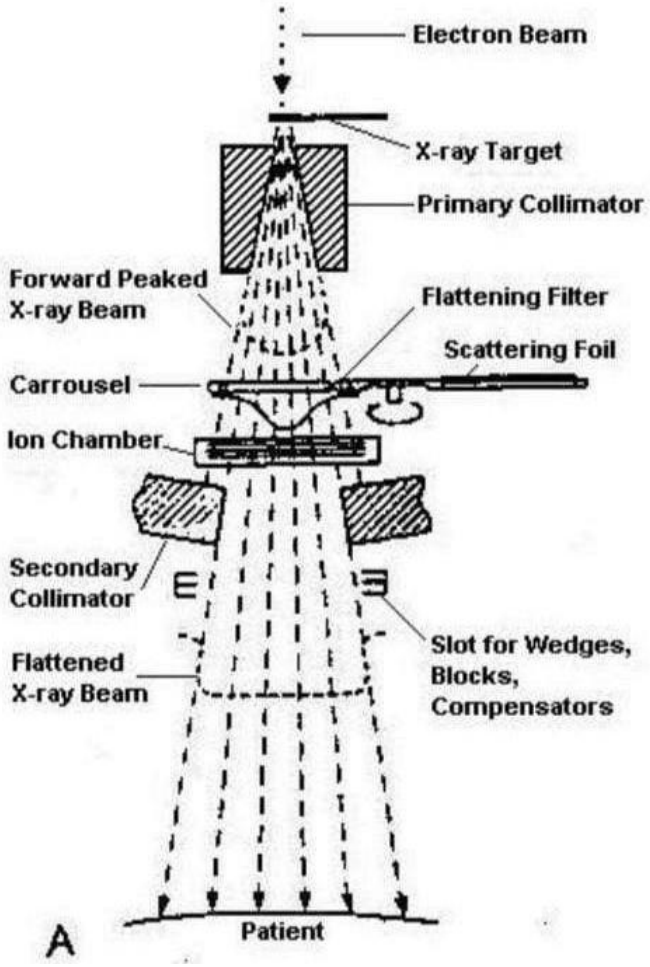
• Adjustable secondary collimator with independent jaw motion.

• Dual transmission ionization chamber.

• Retractable wedges.

• Multileaf collimator (MLC).

• Field defining light and range finder.



11. Discuss the different types of nuclear radiation with its characteristics and application in medical field.(May 2019)

Nuclear Radiation refers to processes whereby unstable nuclei become more stable by emitting energetic particles. The three types of nuclear radiation refer to alpha, beta, and gamma radiation. In order to become stable, a nucleus may emit an alpha particle (a helium nucleus) or a beta particle (an electron or a positron). Often, losing a particle this way leaves the nucleus in an excited state. Then, the nucleus releases the excess energy in the form of a gamma-ray photon.

A matter is ultimately made up of atoms. Atoms, in turn, are made up of **protons**, **neutrons** and **electrons**. Protons are positively charged and electrons are negatively charged. Neutrons are not charged. Protons and neutrons reside inside the **nucleus** of the atom, and protons and neutrons are together called **nucleons** . Electrons are found in a region around the nucleus, which is much larger than the size of the nucleus itself.

In neutral atoms, the number of protons is equal to the number of electrons. In neutral atoms, the positive and negative charges cancel each other, giving a zero net charge.

The Three Types of Nuclear Radiation:

Alpha Beta and Gamma Radiation

As we mentioned before, the three types of nuclear radiation are alpha, beta, and gamma radiation. In alpha radiation, a nucleus becomes more stable by emitting two protons and two neutrons (a helium nucleus). There are three types of beta radiation: beta minus, beta plus and electron capture. In beta minus radiation, a neutron can transform itself into a proton, releasing an electron and an electron antineutrino in the process. In beta plus radiation, a proton can transform itself into a neutron, giving off a positron and an electron antineutrino. In electron capture, a proton in the nucleus captures an electron of the atom, transforming itself into a neutron and releasing an electron neutrino in the process. Gamma radiation refers to the emission of gamma-ray photons by nuclei in excited states, in order for them to become de-excited.

Alpha Radiation:

Alpha radiation is another name for the alpha particles emitted in the type of radioactive decay called alpha decay. Alpha particles are helium-4 (^4He) nuclei.

- alpha radiation is the least penetrating (of alpha, beta, and gamma); typically it goes no more than a few cm in air

- like all kinds of radioactive decay, alpha decay occurs because the final state of the nucleus (the one decaying) has a lower energy than the initial one (the difference is the energy of the emitted alpha particle, both its binding energy and its kinetic energy)

- alpha decay involves both strong and electromagnetic interactions (or forces), unlike beta and gamma decay

Beta Radiation:

In beta radiation, a nucleus decays by emitting an electron or a positron (a positron is the antiparticle of the electron, having the same mass but the opposite charge). The nucleus does not contain electrons or positrons; so, first a proton or a neutron needs to transform, as we

will see below. When an electron or a positron is released, in order to conserve lepton number, an electron neutrino or an electron antineutrino is also released. The energy of beta particles (which refers to either electrons or positrons) for a given decay could take a range of values, depending on how much of the energy released during the decay process has been given to the neutrino/antineutrino. Depending on the mechanism involved, there are three types of beta radiation: **beta minus, beta plus and electron capture**.

Gamma Radiation:

Gamma rays or gamma radiation is a stream of high-energy electromagnetic radiation given off by an atomic nucleus undergoing radioactive decay.

UNIT –V

MAGNETIC RESONANCE IMAGING

TWO MARKS

1. **Illustrate the effects of motion in MRI system.(sep 2020)**

   Consequently MRI is sensitive to motion. Patient or subject motion during the acquisition can induce artefacts and reduce image quality and diagnostic or scientific relevance. Such motion artefacts manifest as ghosting, blurring, geometric distortion or decreased signal-to-noise ratio (SNR).

2. **Define Echo planar imaging (sep 2020)**

   Echo planar imaging is performed using a pulse sequence in which multiple echoes of different phase steps are acquired using rephasing gradients instead of repeated 180 degree radiofrequency pulses following the 90°/180° in a spin echo sequence.Each subsequent echo results in a progressively T2-weighted signal.

3. write the principle of MRI.(NOV 2019)

MRIs employ powerful magnets which produce a strong magnetic field that forces protons in the body to align with that field. When a radiofrequency current is then pulsed through the patient, the protons are stimulated, and spin out of equilibrium, straining against the pull of the magnetic field.

4. What are the biological effects of magnet field in MRI?(NOV 19)(MAY 18)

In addition to mild heating, there are other **biological effects** that may result during **MRI**. Some of these are routinely encountered (such as audible noise); others occur very infrequently (such as RF burns). Although extremely rare, improper MR procedures have resulted in serious injury or death.

5. Mention the safety consideration in MRI facility (MAY 19)

An MRI examination causes no pain, and the electromagnetic fields produce no known tissue damage of any kind. The MR scanner may make loud tapping, knocking, or other noises at times during the procedure. Earplugs are provided to prevent problems that may be associated with this noise.

6. Write the principle of NMR(MAY 2018)

Principle of Nuclear Magnetic Resonance (NMR) Spectroscopy

The principle behind NMR is that many nuclei have spin and all nuclei are electrically charged. If an external magnetic **field** is applied, an energy transfer is possible between the base energy to a higher energy level (generally a single energy gap)

.

7. a) What is larmour frequency (Nov/Dec2018)

b) Define larmour frequency (Nov/Dec2019, Nov/Dec2017)

The Larmor frequency is **independent of the polar angle between the applied magnetic field and the magnetic moment direction**. This is what makes it a key concept in fields such as nuclear magnetic resonance (NMR) and electron paramagnetic resonance (EPR), since the precession rate does not depend on the spatial orientation of the spins.

8. What are the characteristics needed for the radio to be used for imaging (Nov/Dec2018)

The radio imaging method (RIM), a technology used practically for geophysical surveys, was applied to biomedical measurements. The characteristics of a subject between a pair of simple loop antennas were measured by using a feeble electromagnetic wave of low frequency. Water distribution inside the human body was expected to be measured, as well as the original method imaged mineral distributions.

9. What are the different types of magnets used in MRI systems (Nov/Dec2019)

Magnets used for MRI are of three types:

- Permanent
- Resistive and
- Superconductive.

10 . What is spiral CT (May 2019)

A procedure that uses a computer linked to an x-ray machine to make a series of detailed pictures of areas inside the body. The x-ray machine scans the body in a spiral path. ... Spiral CT scan also creates more detailed pictures and may be better at finding small abnormal areas inside the body.

11. What are the advantages of MRI(May2019)

An MRI scanner can be used to take images of any part of the body (e.g., head, joints, abdomen, legs, etc.), in any imaging direction. MRI provides better soft tissue contrast than CT and can differentiate better between fat, water, muscle, and other soft tissue than CT (CT is usually better at imaging bones).

12. What is meant by T1 and T2 weighted imaging (Nov2016)

The most common MRI sequences are T1-weighted and T2-weighted scans. T1-weighted images are produced by using short TE and TR times. ... Conversely, T2-weighted images are produced by using longer TE and TR times. In these images, the contrast and brightness are predominately determined by the T2 properties of tissue.

13.Write the principle of MRI Technique (Nov2016, Nov/Dec2017)

Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body. MRI scanners use strong magnetic fields, magnetic field gradients, and radio waves to generate images of the organs in the body.

14. Mention the limitations of photo timers (April/May 2018)

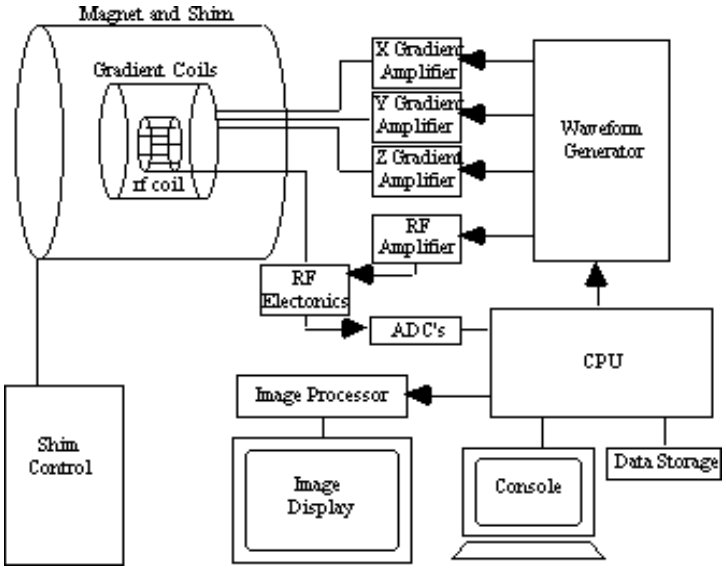
Photo-timers is for controlling x-ray exposure includes an array of x-ray sensors, and digital processing electronics for calculating x-ray exposure by selecting one or more signals from the x-ray sensors, and calculating the x-ray exposure from the selected signals.

14. What are the applications of photo timers? (April/May 2018)

Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body. MRI scanners use strong magnetic fields, magnetic field gradients, and radio waves to generate images of the organs in the body.

15. Draw the block diagram of MRI system and explain the principle behind MRI (April/May 2018)

Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to Form pictures of the anatomy and the physiological processes of the body. MRI scanners use strong magnetic fields, magnetic field gradients, and radio waves to generate images of the organs in the body.



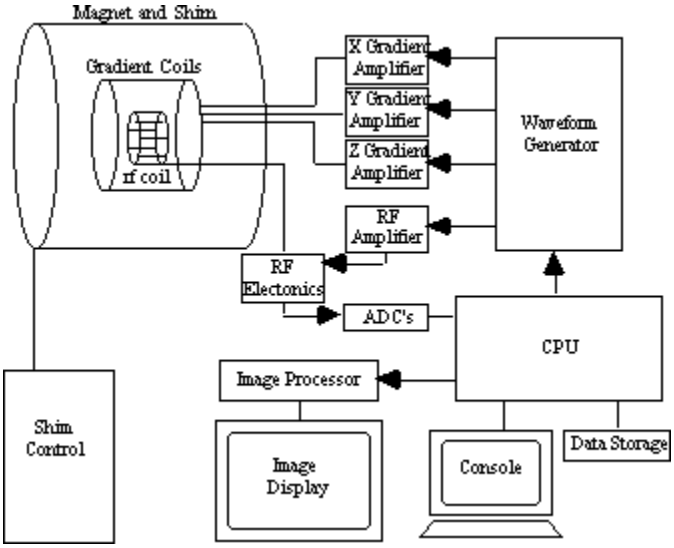
16. Write short notes about the three types of magnet used in MRI (April/May 2018)

- Permanent MRI magnets use permanently magnetized iron like a large bar magnet that has been twisted into a C-shape where the two poles are close together and parallel.
- Resistive (air core) MRI magnets operate at room temperature using standard conductors such as copper in the shape of a solenoid or Helmholtz pair coil.
- Superconductive MRI magnets use a solenoid-shaped coil made of alloys such as niobium/titanium or niobium/tin surrounded by copper.

11 Marks:

1. **Write down the working principle of magnetic resonance imaging (Nov/Dec 2018)**

   Magnetic Resonance Imaging (MRI) is a non-invasive imaging technology that produces three dimensional detailed anatomical images. It is often used for disease detection, diagnosis, and treatment monitoring. It is based on sophisticated technology that excites and detects the change in the direction of the rotational axis of protons found in the water that makes up living tissues.



Working Principle :

MRIs employ powerful magnets which produce a strong magnetic field that forces protons in the body to align with that field. When a radiofrequency current is then 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.

To obtain an MRI image, a patient is placed inside a large magnet and must remain very still during the imaging process in order not to blur the image. Contrast agents (often containing the element Gadolinium) may be given to a patient intravenously before or during the MRI to

increase the speed at which protons realign with the magnetic field. The faster the protons realign, the brighter the image.

The three magnets used in MRI are

- Permanent MRI magnets use permanently magnetized iron like a large bar magnet that has been twisted into a C-shape where the two poles are close together and parallel.
- Resistive (air core) MRI magnets operate at room temperature using standard conductors such as copper in the shape of a solenoid or Helmholtz pair coil.
- Superconductive MRI magnets use a solenoid-shaped coil made of alloys such as niobium/titanium or niobium/tin surrounded by copper.

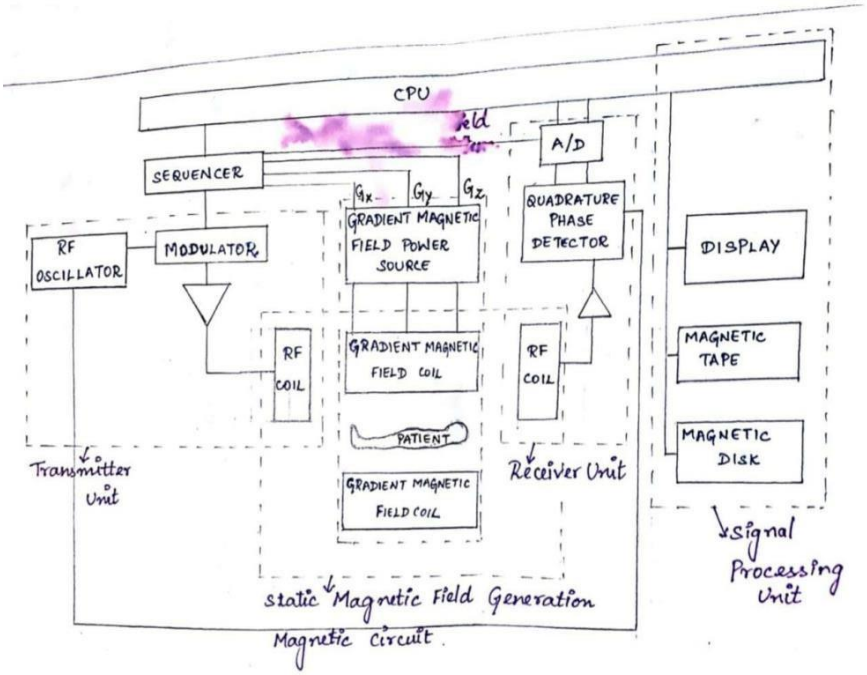
2. a) Give a detailed description of about generation of gradient magnetic field?(Nov 2016)

b) Explain in detail about the generation of gradient magnetic field(Nov/Dec2017)(SEP 2020)

c) Discuss the use of gradient coil in MRI (Nov/Dec2018)

GRADIENT MAGNETIC FIELD:

A magnetic field that changes in strength in a given direction. Such fields are used in magnetic Resonance Imaging (MRI) to select a region for imaging and to encode the location of MRI signals received from the object being imaged.



GENERATION OF GRADIENT MAGNETIC FIELD IN MRI.

Gradient coils:

- Gradient coils are used to spatially encode the positions of protons by varying the magnetic field linearly across the imaging volume.
- The larmour frequency will then vary function of position in the x y and z-axes.
- Scan speed is dependent on performance of the gradient system.
- Stronger gradients allow for faster imaging, for higher resolution.
- Types of Gradient:

  X Gradient -Frequency Encoding

  Y Gradient- Encoding Phase

  Z Gradient - Slice Selection

GENERATION OF GRADIENT MAGNETIC FIELD:

- The transmitter system radiates a radio frequency (RF) signals so as to cause nuclear of the atoms magnetic resonance in the atomic nucleus of the tissues of patient by the

RF magnetic pulse sent from the sequencer and comprises an RF oscillator, an RE coil modulator an RF amplifier and on the transmission side

- RF pulse from RF oscillator modulated by is amplitude modulated by the modulator in accordance with the instruction of the sequencer
- The amplitude modulated RF pulse in amplified & supplied to the RF coil disposed in proximity of patient / subject so that electromagnetic subject that waves can be irradiated the to the subject
- The receiver unit detects echo signals (NMR signals) emitted due to nuclear magnetic resonance of tissue of subject and comprises RF coil, ADC, amplifier & detector on the reception side.
- The NMR signals generated response to electromagnetic waves from the transmission side.
- Then it is fed to ADC to the digital signal processing unit.

3. a)Describe the MRI system with block diagram (Nov/Dec2018)

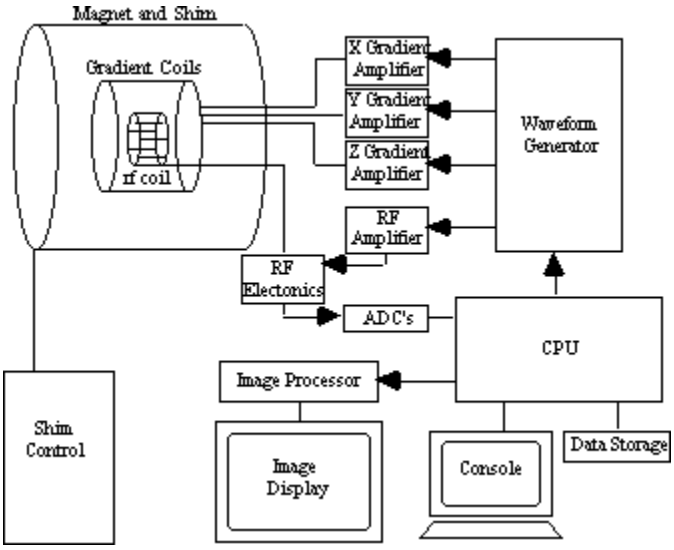
b) Describe about the basic components of MRI system using a neat diagram (Nov/Dec2017)

c) Explain the block diagram of MRI and explain in detail and give the medical applications (April/May 2018)

An MRI scanner is made up of four components: the magnet, gradient coils, r.f. transmitter and receiver, and the computer. In this section the general design and construction of these components is discussed.

The Magnet:The magnet is the most expensive part of the whole scanner. The earliest systems were based around water-cooled resistive magnets, and for particular applications it is possible to use permanent magnets, but the majority of modern scanners use superconducting magnets. The reason for this is the high fields now desirable for MRI. Whole body resistive and permanent magnets are limited to around 0.3 T field strength, before their weight becomes prohibitively large. Superconducting magnets are able to generate much larger fields, and there are a number of 4.0 T whole body scanners now available. These magnets are constructed from materials such as NbTi alloy, which below a critical temperature of about 9 K loses its resistivity. Once started

the current will flow in the coils indefinitely, provided that the temperature is kept below the critical temperature by cooling with liquid helium. The fields from such magnets are very stable with time, which is essential for an MRI system.



The Gradient Coils: The requirement of the gradient coils are twofold. First they are required to produce a linear variation in field along one direction, and secondly to have high efficiency, low inductance and low resistance, in order to minimise the current requirements and heat deposition.

R.f. Transmission and Reception: The third main component of an MRI scanner is the r.f. coil. There are many different designs of coils, but they fall into two main categories; surface coils and volume coils.As the name suggests, a surface coil rests on the surface of the object being imaged. In its simplest form it is a coil of wire with a capacitor in parallel. The inductance of the coil, and the capacitance form a resonant circuit which is tuned to have the same resonant frequency as the spins to be imaged. In practice, since the coil is connected to a power amplifier which will have an output impedance of 50W, and the coil will have an input impedance of the order of kilo-ohms, then on transmission a lot of the power will be reflected back.

Control and Processing: The scanning operation is controlled from a central computer. This specifies the shape of gradient and r.f. waveforms, and timings to be used, and passes this information to the waveform generator, which outputs the signals and passes them to be

amplified and sent to the coils. The NMR signal, once it has been phase sensitively detected, is turned to a digital signal by an analogue to digital converter. The digital signal is then sent to an image processor for Fourier transformation and the image is displayed on a monitor.

Applications:

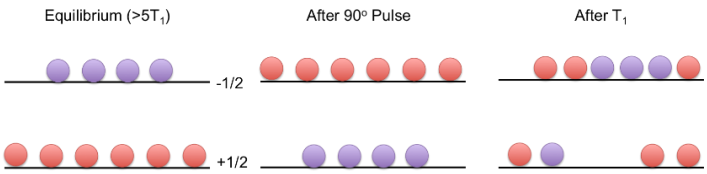
The following are examples in which an MRI scanner would be used:

- anomalies of **the brain** and **spinal cord**.
- tumors, cysts, and other anomalies in various parts of the body.
- breast cancer screening for women who face a high risk of breast cancer.
- injuries or abnormalities of the joints, such as the back and knee.

4. Explain in Detail about the T1 and T2 relaxation with diagram (Nov/Dec2019)

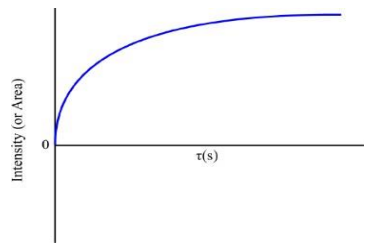
T_1 Relaxation: T_1 relaxation, also known as spin lattice or longitudinal relaxation is the time constant used to describe when ~63% of the magnetization has recovered to equilibrium. The T_1 of a given spin is dictated by field fluctuations (both magnetic and electric) that occur in the sample. Consequently, T_1 measurements can tell us important information regarding inter and intra molecular dynamics of the system. Several factor may cause this alternating field: molecular motion, J-Coupling, Dipolar Coupling, Chemical Shift Anisotropy, and quadrupole-phonon interactions.

We can also look at relaxation from the energy level standpoint. Initially, we have a Boltzmann distribution of spins in the (For I=1/2) in two energy levels, with the lower energy level slightly more populated than the higher energy level. After a pulse these spin populations are inverted and now the higher energy level has more spins in it. Eventually, these spins will go back to their lower energy state due to relaxation. The timescale on which this occurs is T_1.



From the Bloch Equations, we know that magnetization is along the Z-axis is

$$M_z = M_0(1 - \exp(-t/T_1))$$



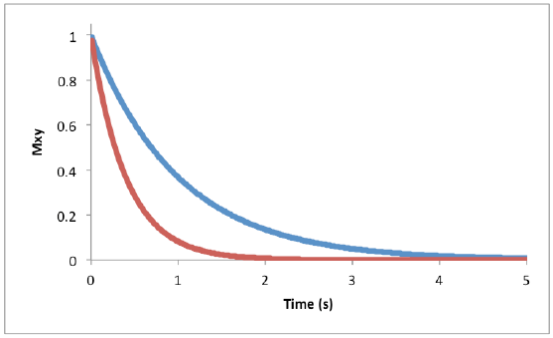
$T_{1\rho\rho}$ Relaxation: $T_{1\rho\rho}$ is the relaxation of the magnetization during a spin lock. This becomes particularly important in the cross-polarization.

T_2 Relaxation: T_2 relaxation is also known as spin-spin or transverse relaxation. T_2 relaxation involves energy transfer between interacting spins via dipole and exchange interactions. Spin-spin relaxation energy is transferred to a neighboring nucleus. The time constant for this process is called the *spin-spin relaxation time (T_2)***. The relaxation rate is proportional to the concentration of paramagnetic ions in the sample. This mechanism is largely temperature independent. T_2 values are generally much less dependent on field strength, B, than T_1 values.**

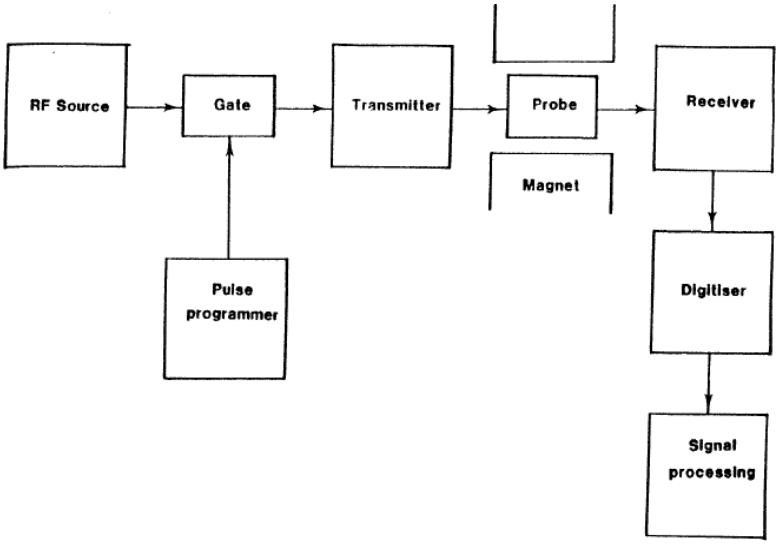
In the process of relaxation, the component of magnetization in xy-plane will become zero as M_0 returns to z-axis. Time constant T_2 is used here to describe spin-spin relaxation with the following function. This process involves energy changing between the spin-active and their adjacent nuclei.

$$M_{xy} = M_{xy0} \exp(-t/T_2)$$

T_2* Relaxation: In an ideal NMR spectrometer, the external magnetic field is completely homogeneous. However, all magnets have small inhomegneities in them. Consequently, nuclei experience different magnetic fields which changes the precessional frequency of each nucleus. The change in Larmor frequency results in dphasing in the transverse plane and is known as T_2*



5. Explain the principle of Nuclear MRI (May 2019)



Nuclear magnetic resonance (NMR) is a physical phenomenon in which nuclei in a strong constant magnetic field are perturbed by a weak oscillating magnetic field (in the near field) and respond by producing an electromagnetic signal with a frequency characteristic of the magnetic field at the nucleus. This process occurs near resonance, when the oscillation frequency matches the intrinsic frequency of the nuclei, which depends on the strength of the static magnetic field, the chemical environment, and the magnetic properties of the isotope involved; in practical applications with static magnetic fields up to ca. 20 tesla, the frequency is similar to VHF and UHF television broadcasts (60–1000 MHz). NMR results from specific magnetic properties of certain atomic nuclei. Nuclear magnetic resonance spectroscopy is widely used to determine the structure of organic molecules in solution and study molecular physics and crystals as well as non-crystalline materials. NMR is also routinely used in advanced medical imaging techniques, such as in magnetic resonance imaging (MRI).

All isotopes that contain an odd number of protons and/or neutrons have an intrinsic nuclear magnetic moment and angular momentum, in other words a nonzero nuclear spin, while all nuclides with even numbers of both have a total spin of zero. The most commonly used nuclei are h and c, although isotopes of many other elements can be studied by high-field NMR spectroscopy as well.

A key feature of NMR is that the resonance frequency of a particular sample substance is usually directly proportional to the strength of the applied magnetic field. It is this feature that is exploited in imaging techniques; if a sample is placed in a non-uniform magnetic field then the resonance frequencies of the sample's nuclei depend on where in the field they are located. Since the resolution of the imaging technique depends on the magnitude of the magnetic field gradient, many efforts are made to develop increased gradient field strength.

The principle of NMR usually involves three sequential steps:

- The alignment (polarization) of the magnetic nuclear spins in an applied, constant magnetic field B_0.
- The perturbation of this alignment of the nuclear spins by a weak oscillating magnetic field, usually referred to as a radio-frequency (RF) pulse. The oscillation frequency required for significant perturbation is dependent upon the static magnetic field (B_0) and the nuclei of observation.
- The detection of the NMR signal during or after the RF pulse, due to the voltage induced in a detection coil by precession of the nuclear spins around B_0. After an RF pulse, precession usually occurs with the nuclei's intrinsic Larmor frequency and, in itself, does not involve transitions between spin states or energy levels.

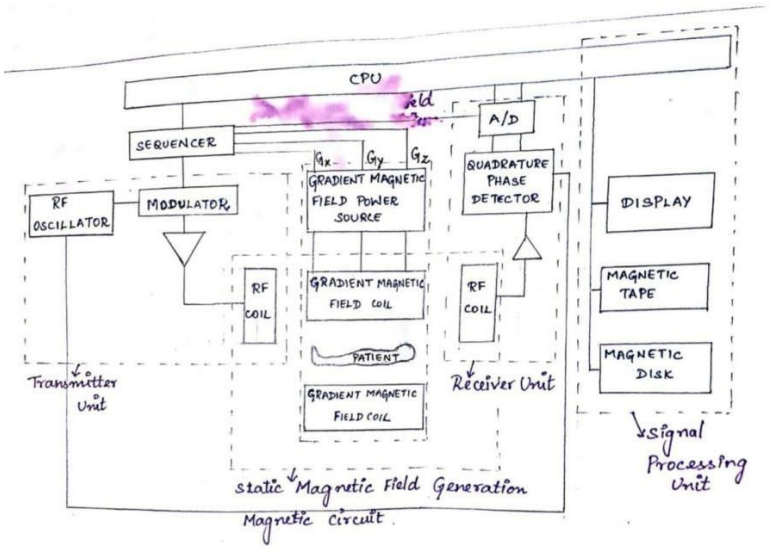
The two magnetic fields are usually chosen to be perpendicular to each other as this maximizes the NMR signal strength. The frequencies of the time-signal response by the total magnetization (M) of the nuclear spins are analyzed in NMR spectroscopy and magnetic resonance imaging. Both use applied magnetic fields (B_0) of great strength, often produced by large currents in superconducting coils, in order to achieve dispersion of response frequencies and of very high homogeneity and stability in order to deliver spectral resolution, the details of which are described by chemical shifts, the Zeeman effect, and Knight shifts (in metals). The information

provided by NMR can also be increased using hyperpolarization, and/or using two-dimensional, three-dimensional and higher-dimensional techniques.

NMR phenomena are also utilized in low-field NMR, NMR spectroscopy and MRI in the Earth's magnetic field (referred to as Earth's field NMR), and in several types of magnetometers.

6. Explain the following:

a) Use of Gradient GX coil in MRI



GENERATION OF GRADIENT MAGNETIC FIELD IN MRI.

GRADIENT MAGNETIC FIELD:

A magnetic field that changes in strength in a given direction. Such fields are used in magnetic Resonance Imaging (MRI) to select a region for imaging and to encode the location of MRI signals received from the object being imaged.

Gradient coils:

- Gradient coils are used to spatially encode the positions of protons by varying the magnetic field linearly across the imaging volume.
- The larmour frequency will then vary function of position in the x y and z-axes.
- Scan speed is dependent on performance of the gradient system.

- Stronger gradients allow for faster imaging, for higher resolution.
- Types of Gradient:

  X Gradient -Frequency Encoding

  Y Gradient- Encoding Phase

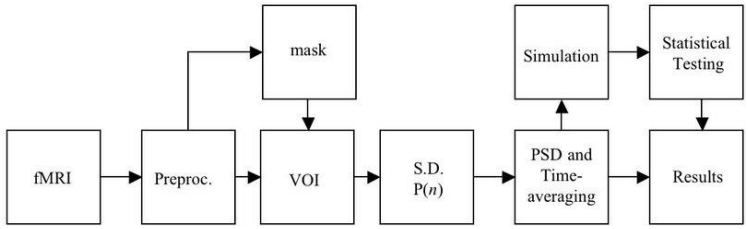
  Z Gradient - Slice Selection

GENERATION OF GRADIENT MAGNETIC FIELD:

- The transmitter system radiates a radio frequency (RF) signals so as to cause nuclear of the atoms magnetic resonance in the atomic nucleus of the tissues of patient by the RF magnetic pulse sent from the sequencer and comprises an RF oscillator, an RE coil modulator an RF amplifier and on the transmission side
- RF pulse from RF oscillator modulated by is amplitude modulated by the modulator in accordance with the instruction of the sequencer
- The amplitude modulated RF pulse in amplified & supplied to the RF coil disposed in proximity of patient / subject so that electromagnetic subject that waves can be irradiated the to the subject
- The receiver unit detects echo signals (NMR signals) emitted due to nuclear magnetic resonance of tissue of subject and comprises RF coil, ADC, amplifier & detector on the reception side.
- The NMR signals generated response to electromagnetic waves from the transmission side.
- Then it is fed to ADC to the digital signal processing unit.

b)FMRI (May 2019)

Functional magnetic resonance imaging or functional MRI (fMRI) measures brain activity by detecting changes associated with blood flow. This technique relies on the fact that cerebral blood flow and neuronal activation are coupled. When an area of the brain is in use, blood flow to that region also increases.



The primary form of fMRI uses the blood-oxygen-level dependent (BOLD) contrast, discovered by Seiji Ogawa in 1990. This is a type of specialized brain and body scan used to map neural activity in the brain or spinal cord of humans or other animals by imaging the change in blood flow (hemodynamic response) related to energy use by brain cells. Since the early 1990s, fMRI has come to dominate brain mapping research because it does not require people to undergo injections or surgery, to ingest substances, or to be exposed to ionizing radiation. This measure is frequently corrupted by noise from various sources; hence, statistical procedures are used to extract the underlying signal. The resulting brain activation can be graphically represented by color-coding the strength of activation across the brain or the specific region studied. The technique can localize activity to within millimeters but, using standard techniques, no better than within a window of a few seconds. Other methods of obtaining contrast are arterial spin labelingand diffusion MRI. The latter procedure is similar to BOLD fMRI but provides contrast based on the magnitude of diffusion of water molecules in the brain.

In addition to detecting BOLD responses from activity due to tasks/stimuli, fMRI can measure resting state fMRI, or taskless fMRI, which shows the subjects' baseline BOLD variance. Since about 1998 studies have shown the existence and properties of the default mode network (DMN), aka 'Resting State Network' (RSN), a functionally connected neural network of apparent 'brain states'.

fMRI is used in research, and to a lesser extent, in clinical work. It can complement other measures of brain physiology such as EEG and NIRS. Newer methods which improve both spatial and time resolution are being researched, and these largely use biomarkers other than the BOLD signal. Some companies have developed commercial products such as lie detectors based on fMRI techniques, but the research is not believed to be developed enough for widespread commercialization.

7. a) How do Nuclei Interacts with static magnetic field and radio frequency wave . Explain? (Nov 2016)

b) Explain about the interactions of nuclei with static magnetic field and radio frequency wave (April/May2018)

MRI uses the same physical effect as **N**uclear **M**agnetic **R**esonance (NMR) spectroscopy, in which the identity of an unknown compound (like a potential new drug) may be identified by the resonant properties (the jiggling of protons) of the atoms that comprise it. In fact, the only reason that the technique is called MRI and not NMR is because it premiered during the Cold War, during which patients were hesitant to undergo any sort of "nuclear" treatment!

NMR spectroscopy was originally developed to help chemists who had created strange compounds that they couldn't identify. In the technique (and just as in MRI), an unknown sample is placed in a static magnetic field, briefly excited with radio-frequency photons (light), and then allowed to re-emit those photons. NMR works because the characteristic frequency of the re-emitted photons varies very slightly based on the structure of the molecule. A proton all by itself may absorb and reemit 900 MHz photons, but when it gets near other charges (such as in a large hydrocarbon chain), the magnetic field around it is gets twisted and distorted and so its resonant frequency may shift to something like 906 MHz. This means that NMR may be used to generate "spectra" corresponding to the amount of resonance at various frequencies, which in turn reveals details of the structure of molecules. So if a chemist looks at the NMR spectrum of her unknown sample and sees a huge peak near 906 MHz, then she knows that her sample probably has at least one hydrocarbon chain somewhere on it.

The main difference between NMR spectroscopy and MRI imaging is that NMR generates information (a spectrum of light corresponding to chemical structure) based on the **frequency** of emitted radiation (which is related to the speed of the jiggling protons). MRI instead generates information (images of the body) using the **intensity** of radiation (the quantity of re-emitted photons) arriving from various parts of body. Protons in dense or solid structures tend to be more or less prone to misalignment when the disrupting radio waves are applied to the body's tissue, resulting in a lower number of re-emitted photons coming from that region and thus a darker area in the resulting image.

Generally, using stronger stationary magnetic fields results in nicer MRI images. Because the water molecules in the body are warm, they are constantly jiggling around and colliding with one another. This jiggling tends to knock the alignment of protons in random directions, and so if the stationary magnetic field is too weak, these thermal forces will prevent protons from lining up, resulting in a dimmer MRI image.

The images get even better when the radio waves are applied multiple times, with the images from each subsequent re-emission merged together to yield a final, combined image. It's like taking the same picture multiple times on your camera and blending them together in your favorite image editor to get a better exposed image. The main limitation of this method is ensuring that the patient lies still long enough that the image doesn't get blurry!

Sometimes there is not enough difference in structure between two tissues to see them using MRI. For example, a healthcare provider may want to check out an unusual blood vessel (such as a blood vessel with a blood clot), but such an image may be difficult to see because the neighboring fat and muscle tissue re-emit photons at a similar rate as the blood vessel. There just isn't enough contrast between the different structures. To solve this problem, the healthcare provider may inject a **contrast agent**, such as Gadolinium (III), into the patient's bloodstream. Atoms of Gd(III) have really unusual electrical properties that cause them to disrupt the effective magnetic field experienced by protons in the bloodstream, which in turn changes the amount of photons that the protons will absorb and emit. This causes the blood vessels to stand out from neighboring tissues in subsequent MRI images.

8. Write detailed notes on :

a) Automatic Exposure controls and

Automatic exposure control is a device incorporated into radiographic and mammographic imaging systems. Its function is to automatically terminate exposure when a preset amount of radiation has been detected.

Automatic exposure control systems help to provide a consistent optical density/signal-to-noise ratio, regardless of patient-centric factors such as size and density.

Automatic exposure control systems also help to reduce 'dose creep' that can occur with inadvertent radiation overexposure by the technologist.

The first generation of automatic exposure control systems are phototimers, which have now largely been superseded by ionization chambers.

In radiography, the automatic exposure control device is placed in front of the image receptor. In mammography, the automatic exposure control device is placed underneath the image receptor.

Automatic Exposure Control (AEC) is an X-ray exposure termination device. A medical radiography x-ray exposure is always initiated by a human operator but an AEC detector system may be used to terminate the exposure when a predetermined amount of radiation has been received. The intention of AEC is to provide consistent x-ray image exposure, whether to film, a digital detector or a CT scanner. AEC systems may also automatically set exposure factors such as the X-ray tube current and voltage.

OPERATION:

Projectional Radiography:

In projectionalradiography an AEC system uses one or more physically thin radiation ionization chambers (the "AEC detector") which is positioned between the patient being x-rayed and the x-ray film cassette. Where low energy x-rays are used such as in mammography the AEC detector is placed behind the image receptor to avoid creating a shadow.

In a simple AEC system a weak ionization signal from the AEC detector is integrated as a ramp shaped voltage waveform. This ramp signal rises until it matches a pre-set threshold. At this point the x-ray exposure is terminated. AEC devices are calibrated to ensure that similar exams have linearity in optical density.

Computed Tomography:

Modern computed tomography (CT) scanners have AEC systems which aim to maintain image quality for patients of varying sizes, whilst keeping doses as low as reasonably practicable. The systems are also designed to maintain quality with the varying size and attenuation of an individual patient over their length. Implementations vary between manufacturers, some systems are based on a desired noise level in the image, while others are based on a specified reference output (milliampere second, mAs).

CT AEC systems use the initial "scanogram", a fixed angle planning view, to determine the relative size of the patient, and variation over their length. The tube output is then adjusted for overall size. The output is also typically modulated for each rotation in response to changes in attenuation over patient length. Some systems adjust output during each rotation, which is known as rotational modulation, based on measured attenuation in the previous rotation.

b) Serial film chargers (April/May2018)

A serial radiograph system has an improved film changer featuring reusable film pack containers. An exposure station through which X-rays are directed is virtually free of X-ray absorbing material providing a "see through" station. As a consequence of the "see through" exposure station, an image intensification tube positioned under the exposure station provides an unobstructed fluoroscopic image with minimum X-ray dosage to a patient.

The film changer utilizes film packs, each of which has a semi enclosed, partially sealed, pouch. Each pouch contains a sheet of radiographic film between a pair of intensifying screens. A plurality of the film packs are stacked in a novel supply magazine and are sequentially transported to the exposure station by a transport system having a plurality of pinch roll pairs. An evacuator pinch roll pair causes uniform engagement of the screens with the film as the film pack is transported into the exposure station by exhausting the air from the pouch and creating a vacuum as it passes through the rolls. The rolls then clamp unsealed edges of the pouch in releasably sealing contact during X-ray exposure of the film for maintaining the engagement of the film and the screens by maintaining the vacuum.

The present invention relates generally to serial radiographic systems and more particular to an improved X-ray film changer and method for storing and transporting X-ray film packs.

In serial radiography, a series of radiographs are produced by sequentially feeding a series of X-ray films, one at a time, to an exposure station. The exposure station is aligned with a source of X-rays which directs a beam of X-rays through the exposure station for exposing the films.

High-speed X-ray systems expose films at frame rates of up to six per second. High speed in radiography is desirable not only for minimizing the duration of the examination during which the patient must be immobile, but more importantly, for assuring that a timely exposure will accurately record an event of short duration.

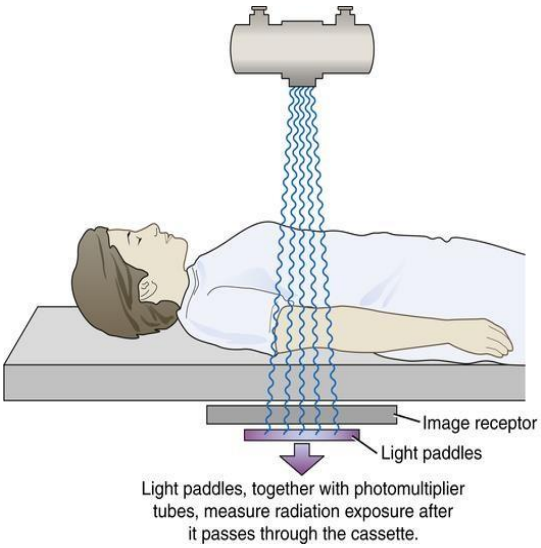
Certain vascular studies are examples of medical diagnostic techniques which require high-speed exposures at high frame rates. With such a study a fluid which is relatively opaque to X-rays is injected into a patient's blood stream. Rapid sequence radiographs produce diagnostically useful information about the patient's blood vessels. This radiographic sequence must be rapid because the opaque material passes very quickly through that portion of a patient that is under investigation.

This high-speed requirement has posed problems in developing an optimized system. Such a system should be characterized: (a) by a minimum of system vibration, (b) by a minimum of noise, (c) by a "see through" exposure station allowing unobstructed fluoroscopy, (d) generally as an efficiently compact system which does not require expensive and bulky vacuum generating apparatus or mechanisms for opening evacuated pouches, (e) by assurance that there is intimate film contact with a pair of intensifying screens which usually accompany the film, and (f) avoiding any possibility of a film being scratched or otherwise damaged during transport or exposure

9. **Discuss the types of photo timers with its characteristics and applications in medical field (April/May2018)**

   Phototimers use a fluorescent (light-producing) screen and a device that converts the light to electricity. A **photomultiplier (PM) tube** is an electronic device that converts visible light energy into electrical energy. A photodiode is a solid-state device that performs the same function. Phototimer AEC devices are considered exit-type devices because the detectors are positioned behind the image receptor so that radiation must exit the image receptor before it is measured by the detectors. Light paddles, coated with a fluorescent material, serve as the detectors, and the radiation interacts with the paddles, producing visible light. This light is transmitted to remote PM tubes or photodiodes that convert this light into electricity. The timer is tripped and the radiographic exposure is terminated when a sufficiently large charge

has been received. This electrical charge is in proportion to the radiation to which the light paddles have been exposed. Phototimers have largely been replaced with ionization chamber systems.



Two types of AEC systems have been used:

- Phototimers and
- Ionization chambers.

Phototimers represent the first generation of AEC systems used in radiography, and it is from this type of system that the term phototiming has evolved.

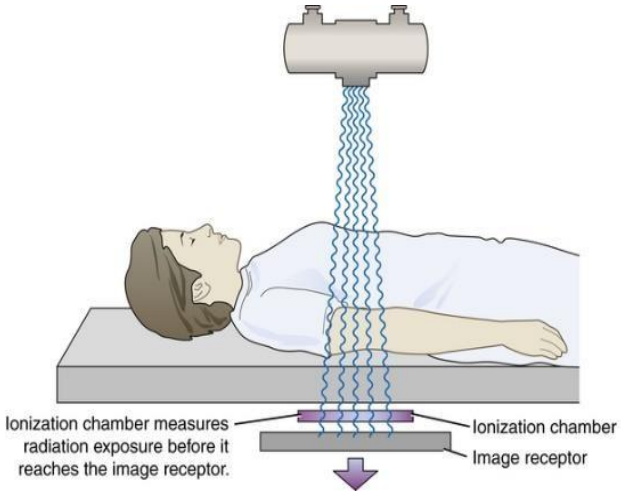
Phototimers:

Phototimers is for controlling x-ray exposure includes an array of x-ray sensors, and digital processing electronics for calculating x-ray exposure by selecting one or more signals from the x-ray sensors, and calculating the x-ray exposure from the selected signals.

Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body. MRI scanners use strong magnetic fields, magnetic field gradients, and radio waves to generate images of the organs in the body.

Ionization Chamber Systems:

An **ionization** or **ion chamber** is a hollow cell that contains air and is connected to the timer circuit via an electrical wire. Ionization-chamber AEC devices are considered entrance-type devices because the detectors are positioned in front of the image receptor so that radiation interacts with the detectors just before interacting with the image receptor. When the ionization chamber is exposed to radiation from a radiographic exposure, the air inside the



chamber becomes ionized, creating an electrical charge. This charge travels along the wire to the timer circuit. The timer is tripped and the radiographic exposure is terminated when a sufficiently large charge has been received. This electrical charge is in proportion to the radiation to which the ionization chamber has been exposed. Compared with phototimers, ion chambers are less sophisticated and less accurate, but they are less prone to failure. Most of today's AEC systems use ionization chambers.