Sound and Ultrasound

- **Sound**: It is the audible waves of frequency between 20 Hz to 20 kHz travels from a source with some definite velocity.
- **Infrasound:** refers to the sound of frequency below the normal hearing range (<20 Hz) and subsonic (0 to 20Hz), which cannot be heard.
- **Ultrasound:** It ranges above 20 kHz, which is also cannot be heard.

- **A sound wave** is a mechanical disturbance in a gas, liquid or solid cause local pressure increase (i.e. compression) and pressure decrease.

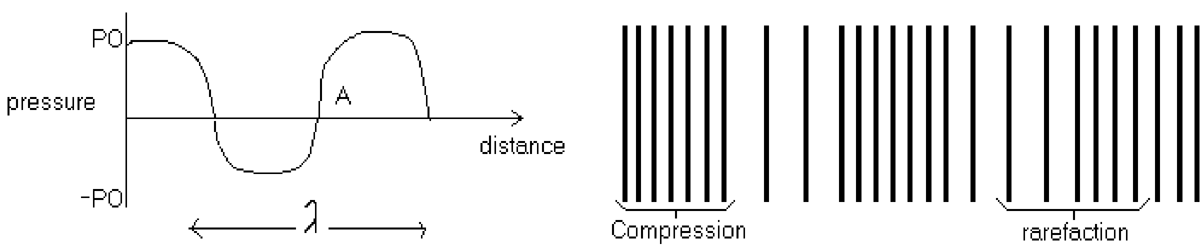


Figure (1) A sound wave vibrate at frequency f and produces compression and rarefaction**.**

. Sound wave spread outward as a longitudinal wave i.e. the pressure changes occurred in the same direction that the wave travels. The Velocity of the sound is given by :

$$V = \lambda f$$

f= frequency of vibration of the sound wave.

λ =wave length of the sound wave.

The velocity of sound in air is 344 m/sec

The higher the density, the higher is the velocity of the sound. Table below shows the velocity of sound in several substances of medical importance.

Velocity of ultrasound in several materials of medical interest	
Materials	**Velocity (m/s)**
Air	348
Aluminum	2700
Beryllium	12,890
Blood	1570
Bone	3360
Fat	1500
Liver	1550
Muscle	1580
Oil	1500
Polyethylene	920
Soft tissue	1540
Water	1480

Note that the velocity of ultrasound in bone is twice that in soft tissue and the velocity in soft tissue is five times that in air. The velocity of ultrasound does not depend on frequency, it is determined by the medium.i.e..

Speed in gas < speed in liquid < speed in solid

The frequencies from 1 to 15 kHz are used for medical application.

ACOUSTIC IMPEDANCE

Acoustic impedance (Z) is used to describe the reflection of sound at an interface. The compressibility is measured by the velocity of sound in the medium. , mathematically, acoustic impedance is described by:

$$\mathbf{Z = \rho V}$$

Where

ρ : is the density of the medium (Kgm/m3)

V : is the velocity of the sound in the medium (m/ s)

∴ Acoustic impedance therefore has unit (Kgm/m2.s)

In general, the higher the density, the greater is the acoustic impedance. Also , the higher the velocity of sound in the medium, the greater is the acoustic impedance.

Table below. Reports the acoustic impedance for several materials since the acoustic impedance is determined by the velocity of sound in the medium, it is not dependent on the frequency or wavelength of the ultrasound beam.

Acoustic impedance for several materials of diagnostic impedance	
Materials	Acoustic impedance kg/m2s (10-6)
Air	0.0004
Aluminum	17
Beryllium	1.61
Blood	7.80
Bone	1.58
Fat	1.38
kidney	1.62
Muscle	1.70
Oil	1.43
Polyethylene	1.88
Soft tissue	1.63
Water	1.48

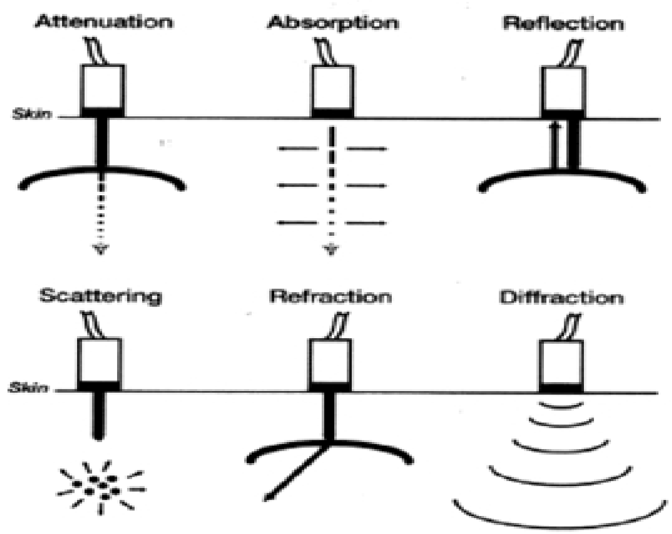
- The other two parameters constituting the wave equation-frequency and wavelength are inversely proportional**. As ultrasound frequency increases, the wavelength decreases.**

The ability to resolve small objects is directly related to the wavelength of the radiation involved.

- High –frequency ultrasound (short-wavelength) results in better resolution than the low frequency.
- High-frequency ultrasound results in shallow penetration.

REFLECTIVITY

When an ultrasound wave incident on a tissue interface, some of the sound will be reflected and some will be transmitted. The transmitted beam will leave the interface at an angle different from that of the incident beam. The deviation of the beam is called refraction.



The angle for total reflection is called t**he critical angle,** and it *depends* on the velocity of sound in each medium.

SCATTERING

The amount of the transmitted ultrasound beam that will be reflected if the roughness of the tissue interfaces *is large* compared to the wavelength of the ultrasound. Such a situation is normal in diagnostic ultrasound and is termed **specular reflection**. If the roughness of the tissue interface is small compared to the wavelength of the transmitted ultrasound, the specular reflection will not occur, in such a case, the ultrasound beam becomes diffuse and intense because of multiple scattering.

Highly irregular interfaces result in scattering, some of the ultrasound is scattered back to the transducer and contribute to image formation. This is call backscattered ultrasound.

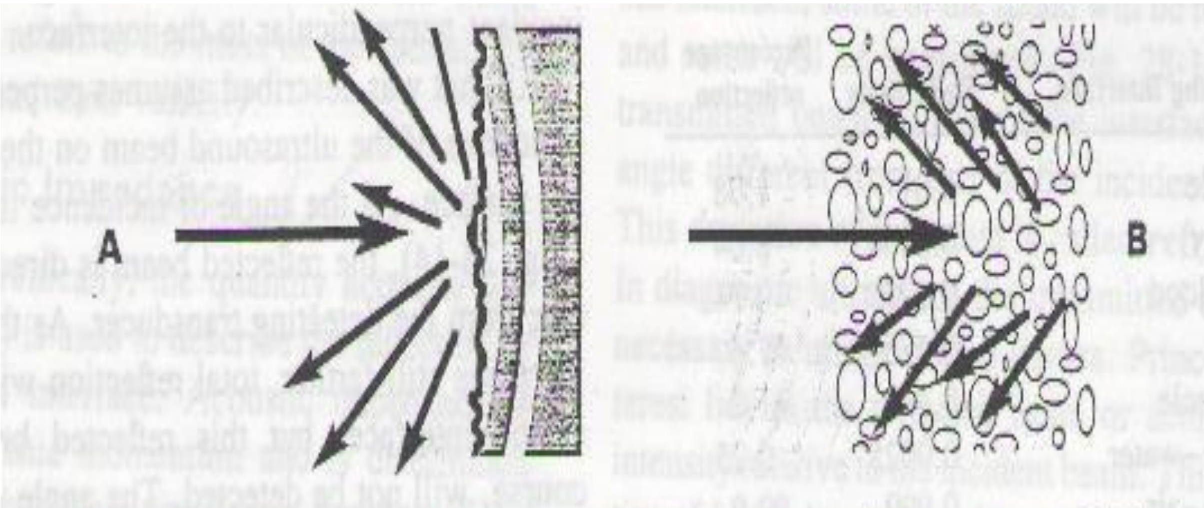


Fig.8-5. Scattering occurs when diagnostic ultrasound encounters a highly irregular or rough surface A, or heterogeneous tissue such as kidney and liver, B.

ABSORPTION

Attenuation refers to the reduction in the beam intensity with depth in tissue caused by *absorption*, scattering, and beam divergence.

NOTE:

Pulses of US are transmitted into the body by placing the vibrating crystal in close contact with the skin by using a jelly paste or water to :

1- Eliminate the air.

2- Give good coupling at skin.

3- Greatly increase the transmission of US. into the body and of the echoes to the detector (***Transducer)***

Diagnostic Ultrasound Instrumentation and Operation

Medical ultrasound is a diagnostic imaging technique based on the application of ultrasound wave. it is used to see internal body structures such as tendons, muscles, joints, vessels and internal organs. Its aim is often to find a source of a disease or to exclude any pathology. The practice of examining pregnant women using ultrasound is called obstetric ultrasound, and is widely used.

Ultrasound device **consists of** a transducer, transmitter pulse generator, compensating amplifiers, the control unit for focusing, digital processors and systems for display. It is used in many cases such as: abdominal, cardiac, maternity, gynecological, urological and cerebrovascular examination, breast examination, and small pieces of tissue as well as in therapeutically, pediatric and operational review

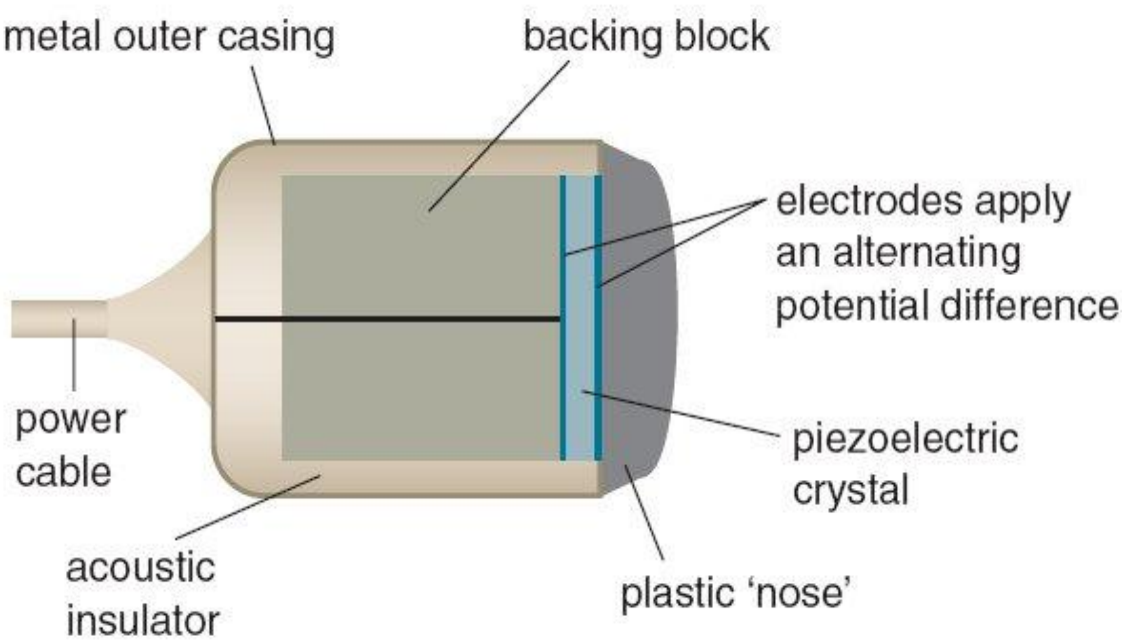
Benefits of Ultrasound

Ultrasounds offer many advantages:

1. They are generally painless and do not require needles or injections.
2. Patients aren't exposed to ionizing radiation, making the procedure safer than diagnostic techniques such as X-rays and CT scans
3. Captures images of soft tissues that don't show up well on X-rays.
4. Widely accessible and less expensive than other methods.
5.

Ultrasound Transducer

A transducer is any device that converts energy from one form to another. Ultrasound is produced and detected using an ultrasound transducer. Ultrasound transducers are capable of sending an ultrasound and then the same transducer can detect the sound and convert it to an electrical signal to be diagnosed.



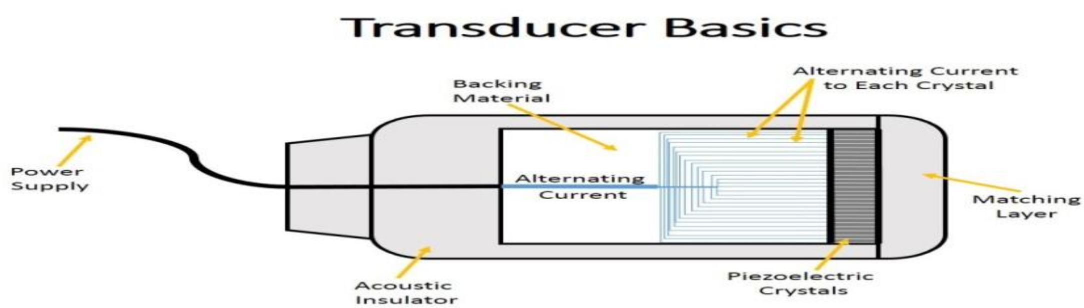
**** Operation of an ultrasound transducer is based on the piezoelectric effect.***

The piezoelectric effect

To produce an ultrasound, a piezoelectric crystal has a current applied across it. The piezoelectric crystal grows and expands depending on the voltage run through it. The current through it causes it to vibrate at a high speed and to produce an ultrasound.

This conversion of electrical energy to mechanical energy is known as the **piezoelectric effect**. The sound then bounces back off the object under investigation. The sound hits the piezoelectric crystal and then has the reverse effect - causing the mechanical energy produced from the sound vibrating the crystal to be converted into electrical energy.

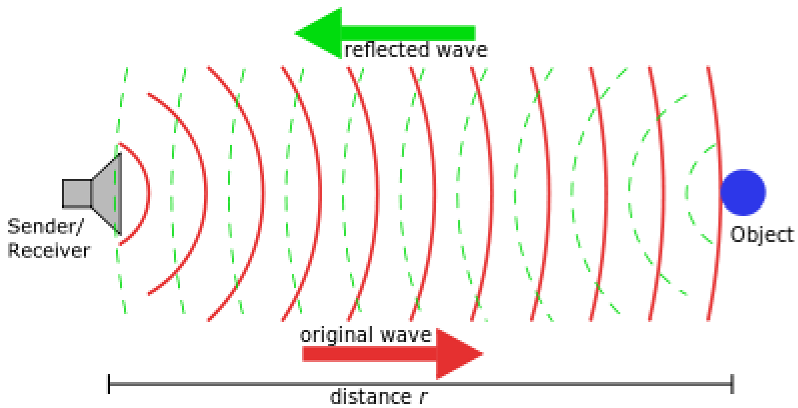
By measuring the time between when the sound was sent and received, the amplitude of the sound and the pitch of the sound, a computer can produce images, calculate depths and calculate speeds.



* The active element of the transducer is ***the piezoelectric crystal.*** The material most frequently used is *lead zirconate titanate* (**PZT**).

* The piezoelectric crystal is backed by material designed to damp the movement of the crystal so that, when the electric stimulus is removed, the crystal will cease motion immediately.

* The piezoelectric crystal and backing material are surrounded by acoustic insulation to further confine the ultrasound beam. Electric signals are transmitted through a connecter on the back of the transducer to each of the piezoelectric. The crystal faces are coated with electrically conducting material.

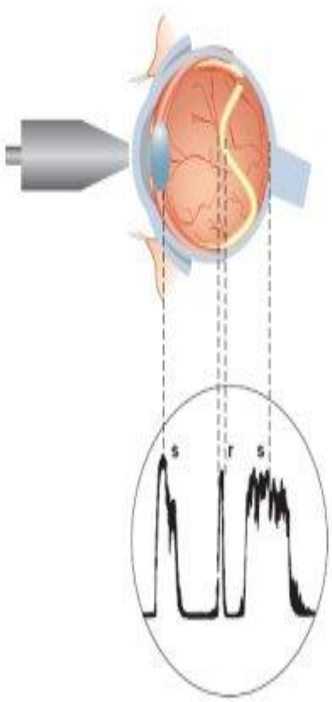


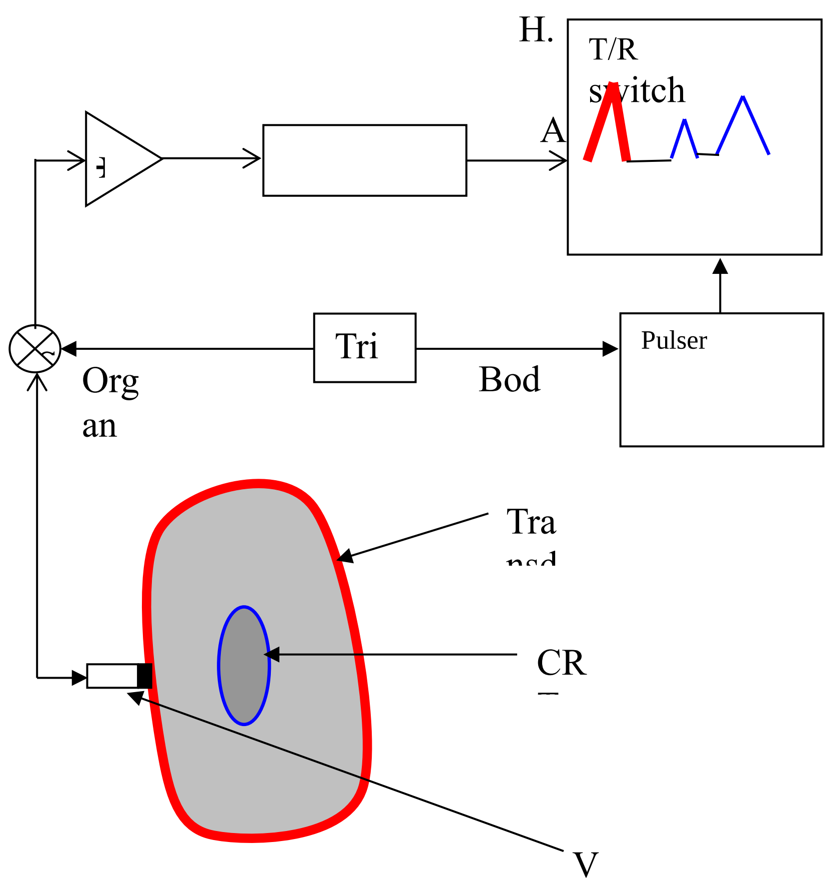
The nature of A-scans, B-scans, sector scans and phase scans

A Mode presents reflected ultrasound energy on a single line display. The strength of the reflected energy at any particular depth is visualized as the amplitude of the waveform

A-scans (A=amplitude)

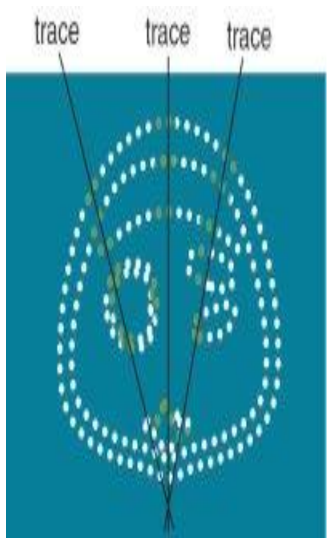
A-scans can be used in order to measure distances. A transducer emits an ultrasonic pulse and the time taken for the pulse to bounce off an object and come back is graphed in order to determine how far away the object is. A-scans only give one-dimensional information and therefore are not useful for imaging.

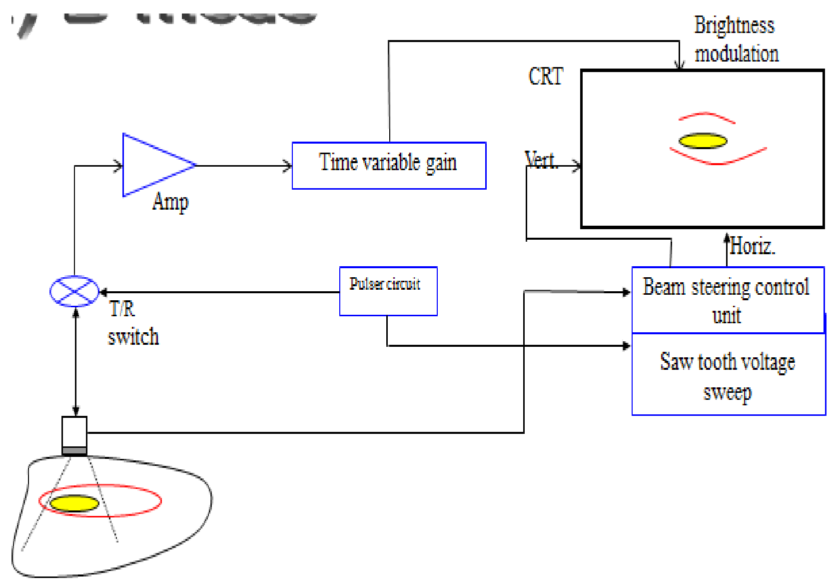




B-Scans (B=brightness) (2D in echocardiography)

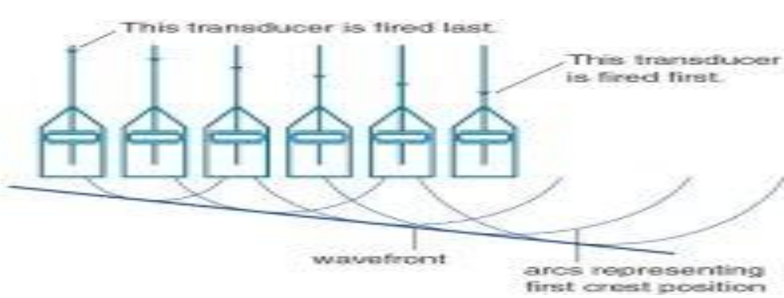
B-scans can be used to take an image of a cross-section through the body. The transducer is swept across the area and the time taken for pulses to return is used to determine distances, which are plotted as a series of dots on the image. B-Scans will give two-dimensional information about the cross-section.





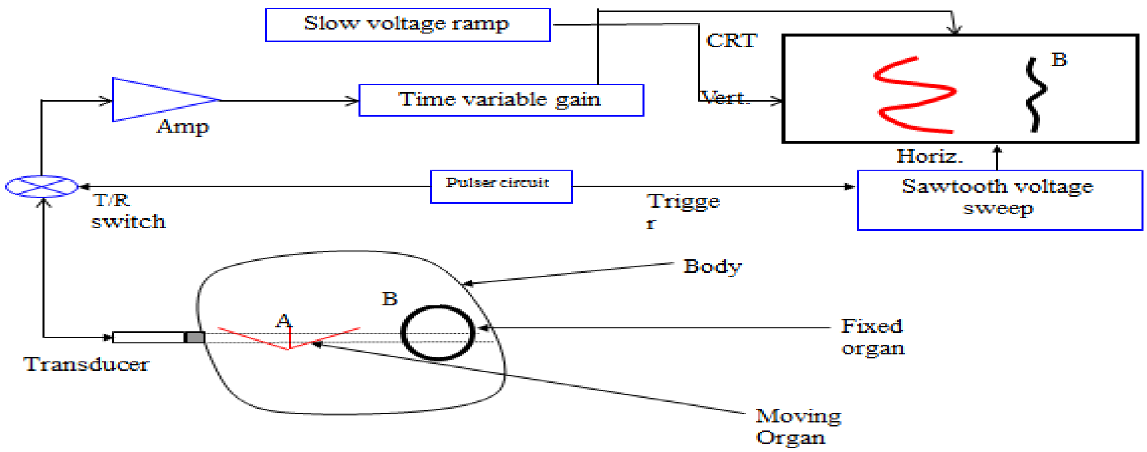
Phase scans

Phase scans have hundreds of transducers in the same probe in order to take a high resolution real-time scan. The angle of the wavefront can be altered by firing the transducers one after another, when this happens they are out of phase. By changing the angle of the wavefront, a three-dimensional image can be built up over a large area.



M-mode (M=motion)

It reflects a motion of the heart structures over time. Nowadays, the integration of 2D and M-mode images is possible. Due to its excellent temporal resolution (high sampling rate), M-mode is extremely valuable for accurate evaluation of rapid movements



D-mode(D=Doppler)

This imaging mode is based on the Doppler effect, ie. Change in frequency (Doppler shift) caused by the reciprocal movement of the sound generator and the observer. Diagnostic ultrasound uses the change in frequency of ultrasound signal backscattered from red blood cells. The frequency of the reflected ultrasound wave increases or decreases according to the direction of blood flow in relation to the transducer.

Review

- A sound wave is typically produced by a piezoelectric transducer. Strong, short electrical pulses from the ultrasound machine drive the transducer at the desired frequency.
- The frequencies can be anywhere between 1 and 18 MHz
- The sound is focused either by the shape of the transducer, or a complex set of control pulses from the ultrasound
- . The wave travels into the body and comes into focus at a desired depth.

- The sound wave is partially reflected from the layers between different tissues or scattered from smaller structures. Specifically, sound is reflected anywhere where there is acoustic impedance changes in the body

Receiving the echoes

The return of the sound wave to the transducer results in the same process as sending the sound wave. The returned sound wave vibrates the transducer and the transducer turns the vibrations into electrical pulses that travel to the ultrasonic scanner where they are processed and transformed into a digital image.

Forming the image

To make an image, the ultrasound scanner must determine two things from each received echo:

1. How long it took the echo to be received from when the sound was transmitted.
2. How strong the echo was.

Once the ultrasonic scanner determines these two things, it can locate which pixel in the image to light up and to what intensity.

The strength of the echo determines the brightness setting for that cell (white for a strong echo, black for a weak echo, and varying shades of grey for everything in between.) When all the echoes are recorded on the sheet, we have a greyscale image.

Displaying the image

Images from the ultrasound scanner are transferred and displayed using the DICOM standard. Normally, very little post processing is applied to ultrasound images.

Several modes of ultrasound are used in medical imaging.