Physics of Ultrasound

Seventh lecture

The ultrasound image: generation and display

Dr. Nasma Adnan

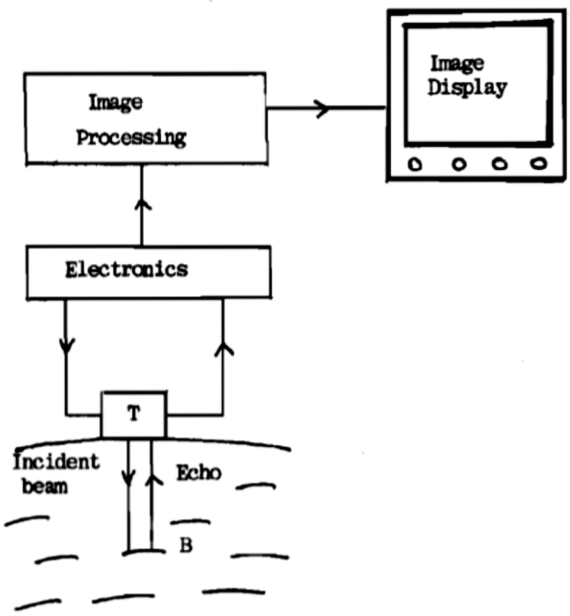
Third Stage

Department of medical physics

Al-Mustaqbal University-College

2021- 2022

1. *Basic principle of the ultrasonic image*



- An ultrasonic transducer, T, sends a beam of ultrasound into the subject over a selected area of interest.
- At an acoustic boundary such as B within tissue, some of the ultrasound energy is reflected, either specularly or by scattering.
- Under suitable conditions, some of the reflected ultrasound will go back towards T.
- At the transducer, the returning echo will interact with the piezoelectric crystal and generate an electric signal.
- This signal will be electronically processed and measured.
- The basic parameters to be determined in ultrasonic imaging are:
  - (i) the size of an echo
  - (ii) the distance of echo origin from the transducer.
- The ultrasound beam is built by scanning with the beam on the subject. For each position of the ultrasound beam, a set of signals will be recorded along the beam path, corresponding to reflecting boundaries lying at different distances from the transducer.

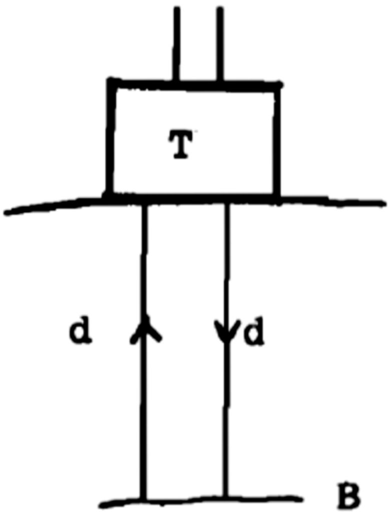
- The set of signals produced along one beam path may be referred to as a "scan line". It represents single-dimensional information along the beam path.
- By sweeping the ultrasound beam across the subject ("scanning") in a selected direction, many other scan lines are generated to build a two-dimensional (2-D) image of a plane in the subject.

2. Electronic processing of signals.

- The signals generated by the returning echoes at the transducer are electronically processed and organized in computer memory before being displayed on a cathode ray oscilloscope.
- First, the signals are amplified to increase their sizes. The intensity of an echo may be a tiny fraction of the original output intensity of the transducer, hence the piezoelectric voltage it generates at the transducer may be very small.
- Secondly, echoes returning from different tissue depths must be subjected to compensation for attenuation differences.
- Time gain compensation (TGC) is a process of applying differential amplification to signals received from different tissue depths.
- with echoes originating from longer distances being amplified to a greater extent than those from shorter distances in such a way that similar tissue boundaries give equal sized signals regardless of their depth in tissue. Because the dynamic range of signal sizes may be very wide, the range of signal sizes is compressed by using logarithmic amplifiers.
- Finally, signal sizes which are extremely small can be electronically rejected. The accepted signals are organized in computer memory before being presented to a cathode ray oscilloscope (CRO) for display.

3. Echo ranging

- One of the essential parameters to be determined in ultrasonic imaging is the distance between the transducer and a reflecting interface. This is done by measuring the time interval between the transmission of a pulse from the transducer and the reception of its echo back at the transducer.
- To achieve this, two events are electronically "marked", the moment the transducer is pulsed, and the moment it receives the returning echo from the tissue boundary.
- If d is the distance of a reflecting boundary (B) from the transducer (T), and t is the measured time interval between pulsing and reception, then the ultrasound beam will have travelled a distance equal to 2 d (to-and-fro journey) in the time t.



- To determine the distance d of the reflector, we use the simple relationship.

  Distance = velocity x time

  or 2 d = v. t

  where v = velocity of ultrasound in the transmitting medium.
- Ultrasound systems use the average soft tissue velocity value of 1,540 m/s to calibrate distance measurements.

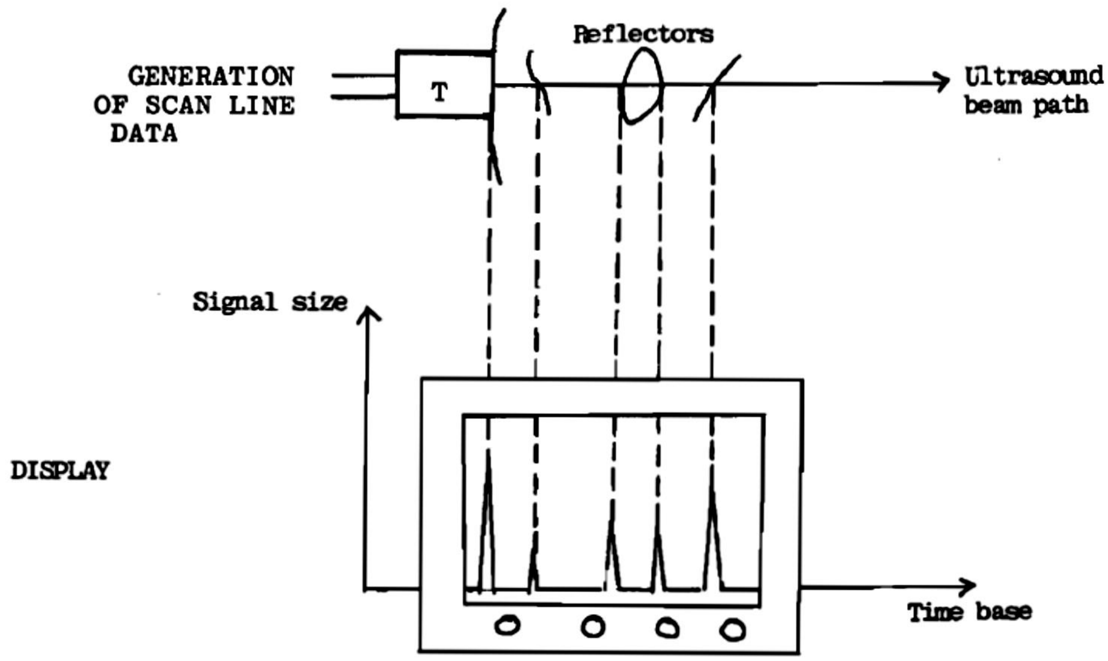
- Echo ranging is possible only when ultrasound is used in the pulsed mode, in which the transducer operation is made to alternate between transmission and reception. with continuous wave ultrasound, ranging is not possible because the time interval between pulsing and echo reception cannot be determined.

4. Display modes

Once the diagnostic information has been acquired and electronically processed, it has to be displayed for viewing and recording. Different methods are used to display the information acquired from ultrasound examinations.

4.1 The amplitude mode (A-mode)

In the amplitude mode, the signals from returning echoes are displayed in the form of spikes on a cathode ray oscilloscope (CRO), traced along a time base.



- On one axis (vertical axis) the amplitude of the signal (magnitude of the voltage pulse) is displayed, and on the other axis (horizontal), the position of the signal on a time scale is represented.

- The amplitude of a spike is a relative measure of echo size. Because of the relationship between the distance of a reflector and the time of echo reception, the position of a spike along the time base is a measure of the distance of the associated reflecting boundary from the transducer. The A-mode suffers from the limitation of displaying only l-D information, representing the echoes lying along the beam path. The information does not constitute an image. Additionally, the display has the disadvantage of taking up a lot of space on the CRO in relation to the amount of information that it provides.

4. 2 The brightness mode (B-mode)

In the brightness mode, signals from returning echoes are displayed as dots of varying intensities. The spike of the A-mode is replaced by a small dot which occupies much less space on the CRO. The intensity of a dot (the brightness) is a relative measure of echo size, with large echoes appearing as very bright dots, while at the other extreme non-reflectors appear totally dark. As in A-mode, the signals are presented along a time base on the CRO. The position of a dot along the time base is a measure of the distance of the associated reflector from the transducer. For any given position of the beam direction (scan line), a line of dots is displayed on the CRO, corresponding to the 1- D information of reflectors lying along the scan line. When the beam is swept across a selected section of the subject (the process of scanning), different dot lines are created for each scan line. These different dot lines are displayed at different positions on the CRO, displaced laterally from one another, in relation to their corresponding beam positions. The combined information from different scan lines provides a 2-D image of the cross-section through which the beam sweeps. One dimension represents depth information, while the other represents lateral variations in the direction of beam sweep.

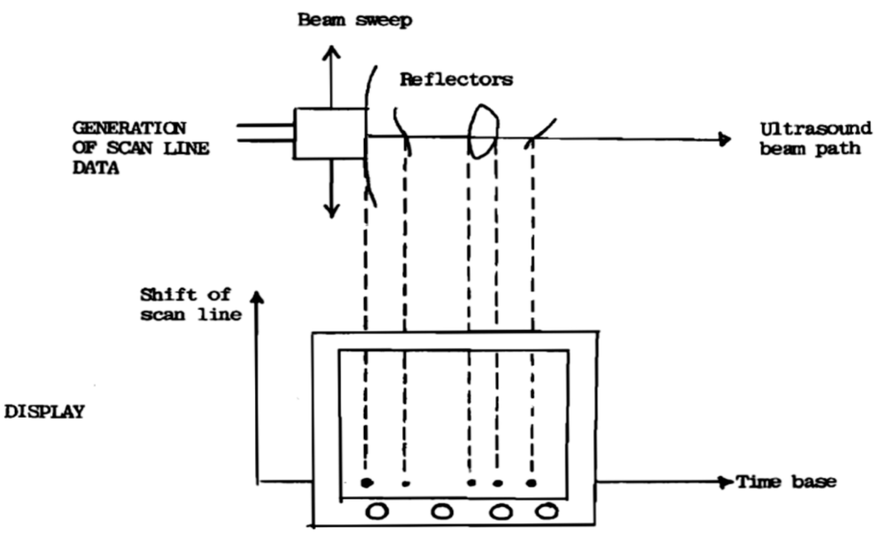
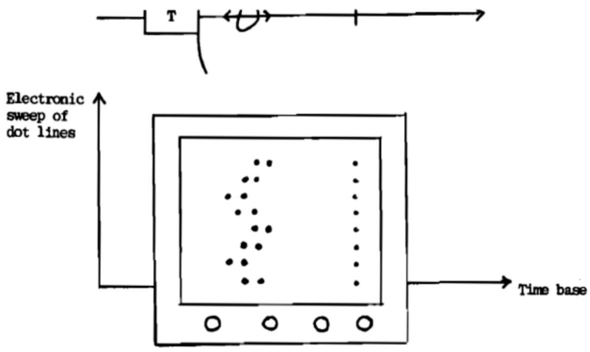


Fig illustrates the relationship between the positions of scan lines and the display of dots on the CRO to build the 2-D image.

4. 3 The motion mode (M-mode)

The motion mode is used to generate an electronic trace of a moving object lying along the path of the ultrasound beam. The transducer is placed in one fixed position in relation to the moving structure. Returning echoes are displayed in the form of dots of varying intensity along a time base as in B-mode. Dots for stationary reflectors will remain in the same positions along the time base, but dots for reflectors which move in the direction of the scan line will change their positions along the time base, because their distances from the transducer will be changing with time. To capture the time variation of moving structures graphically, dot lines obtained at different moments are recorded at different lateral positions on the CRO. This is achieved by applying on the CRO an electronic sweep of the dot lines perpendicularly to the direction of the time base. A time trace of the dot lines along the beam path is thus obtained. It should be noted that the sweep of dot lines on the CRO is achieved by purely electronic means. Results: Stationery structures whose dots do not shift positions will trace straight lines perpendicularly to the time base, while moving structures will trace zig-zag or sinusoidal patterns.

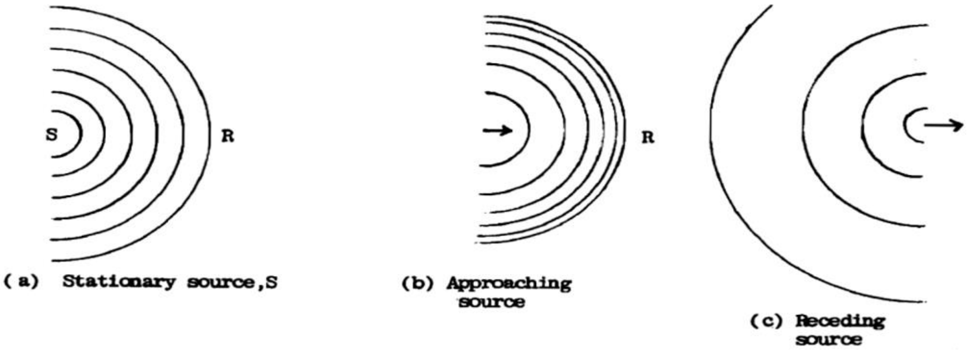


4.4 Real-time mode

Real-time imaging is rapid B-mode scanning to generate images of a selected cross-section within the subject repetitively at a rate high enough to create the motion picture impression. A rapid succession of images of the same plane are generated and viewed as they are acquired. Although in reality each image in the series represents an independent static image, the effect of rapid acquisition and viewing at rates exceeding about 25 image frames per second creates the impression of continuity in time. This impression arises due to limitations in human perception. We are unable to distinguish in time between events occurring at intervals shorter than about 40 milliseconds - they appear to us to occur "at the same time"

4. 5 The Doppler mode

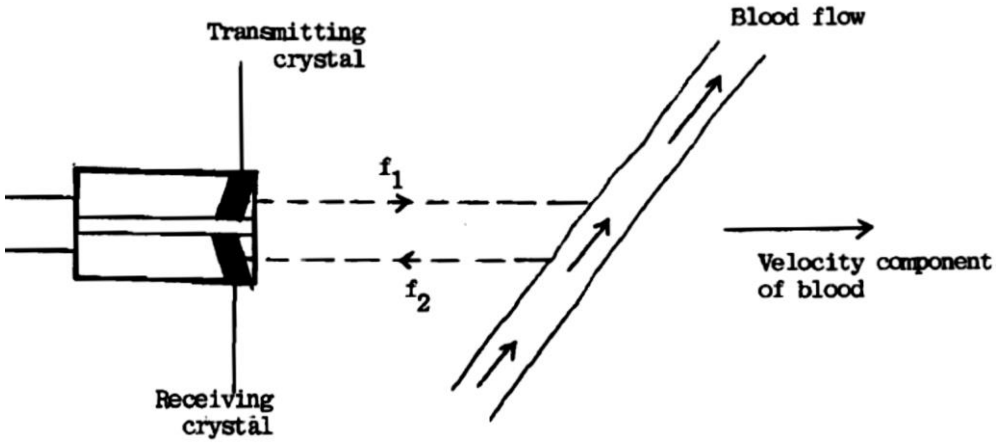
The Doppler effect is observed in the behavior of sound as well as light. In acoustics, it is associated with relative motion between the source of sound and the receiver, resulting in an apparent difference in frequency between that emitted by the source and that perceived by the receiver. An approaching sound source is perceived to be emitting sound at a higher frequency than it actually is, while a receding source appears to emit at a lower frequency. This situation arises because the wave fronts in the pressure wave of an approaching source are pushed closer together, while the wave fronts in a receding source are pulled further apart.



The apparent difference in frequency is called the Doppler shift. For a stationary source, the wave fronts are neither compressed nor stretched, hence no shift of frequency is observed. The Doppler shift can be measured and used to:

1. detect motion
2. determine the direction of motion
3. determine the velocity of a moving structure.

In clinical ultrasound, the Doppler mode is used in studies of blood flow and cardiac movements. When a beam of ultrasound emitted by a transducer at constant frequency interacts with a moving acoustic boundary, the boundary will, through the echoes it sends back to the transducer, act as a secondary source of ultrasound for the transducer (effectively, the reflecting boundary becomes the source, while the transducer serves as the observer). Because the boundary is moving, the transducer will detect the echoes with a Doppler shift in frequency, being of higher frequency if the interface is approaching, or of lower frequency if the interface is moving away. Both continuous wave (CW) and pulsed wave (PW) techniques are used in Doppler ultrasound. In CW Doppler units, the transducer assembly has separate crystal elements for producing the ultrasound beam and for detecting the echoes. continuously emits and the other continuously receives, it is not possible for one and the same crystal to transmit and detect ultrasound at the same time. By comparing the frequency of the echoes with that of the transmitted beam, it is possible to study motion (see Fig 6.7). The shift of frequency is related to the velocity of the moving reflector, and to the direction of motion. The greater the Doppler shift, the higher the velocity of the moving structure, and a higher detected frequency implies relative motion towards the transducer, while a lower detected frequency implies a receding reflector.



The distance of a moving structure from the transducer cannot be determined by CW ultrasound, since the go-return time for the ultrasound beam will not be known. Determination of range requires the use of pulsed beams. More sophisticated Doppler shift equipment utilizes PW ultrasound in conjunction with B-mode scanning to detect movement and determine range, and to produce images of regions of movement.