EEE/INSTR F432
Medical Instrumentation
27th Mar'25

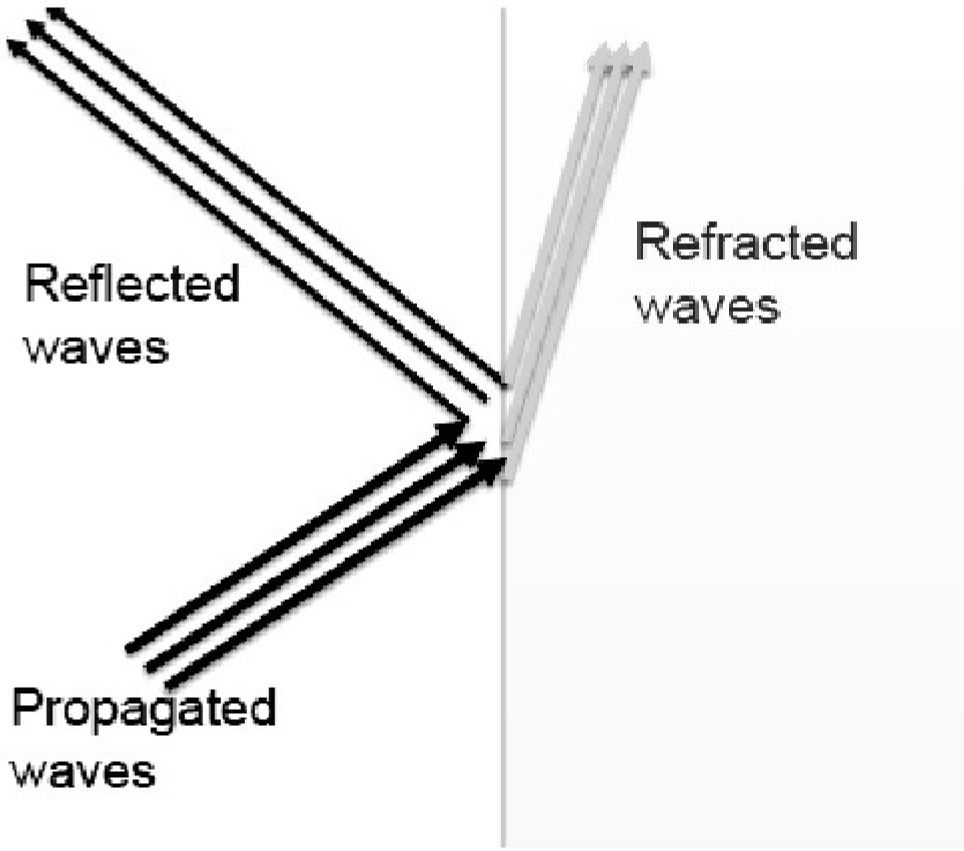
Ultrasound Imaging

Ultrasound imaging is a non-invasive imaging methodology which provides real time information about tissue anatomy and function.

The sound waves penetrate the body and encounter different tissues and tissue planes. Part of the wave is reflected back at varying speeds, depending on the density of the tissues. As the sound waves echo from different tissues, the sensitive microphone records tiny changes in the sound's pitch and direction

Physics of Ultrasound

Ultrasound is reflected and refracted by an interface between two medium of different acoustic impedance.



Physics of Ultrasound

The sound waves travel through a medium is measured by its " Acoustic impedance".

Acoustic Impedance (Z) = density x velocity

Acoustic impedance is considered in terms of density. A density change will cause reflection or refraction at interfaces having different densities. It is very important because largest reflections occur between tissues with great differences in acoustic impedance.

Physics of Ultrasound

Different tissue interfaces cause signature reflective patterns. For example, when the sound wave encounters a dense object such as bone, most of the sound is bounced back to the probe and little is allowed to pass through the tissue.

Physics of Ultrasound

Image contrast in ultrasound imaging is based on the difference of adjacent tissue impedances, with a large difference of impedance producing a higher amplitude ultrasound wave that is reflected and therefore detected.

Physics of Ultrasound

The size of object must be at least ¼ of the wavelength to reflect the ultrasound wave.

Ultrasound with higher frequency can reflect smaller objects so the high resolving power or resolution.

The penetration of wave in tissue decreases and the beam becomes more collimated.

Physics of Ultrasound

The reflected wave intensity is measured with respect to transmitted wave and expressed in dB.

Decibel is a relative measure used to compare relative intensities of two ultrasound beams i.e. transmitted and reflected beams.

$$dB = 10 \log \left(\text{reflected} / \text{transmitted} \right)$$

Physics of Ultrasound

Resolution and accuracy of an ultrasound imaging system are limited by the inherent characteristics of the ultrasound.

Depending on frequency and propagation speed of the ultrasound, the wavelength determines the minimum duration of an ultrasound pulse and the thickness of an ultrasound beam.

The high frequency brings high resolution but results in a low sensitivity due to the increase in absorption with the frequency.

Physics of Ultrasound

The depth of tissue penetration is dependent on the frequency of the ultrasound being used.

The typical example:

In abdominal ultrasound a 40 dB loss is seen when imaging tissue 10 cm deep.

Ultrasound Imaging

The UI system is portable, real-time, inexpensive, and does not use ionizing radiation. It is highly specialized method and require expert operator. It has a small field of view and is limited by the large impedance difference of bone and air compared to other soft tissues.

There are various ultrasound imaging modes, but the prevalent ones are B-mode ultrasound imaging, Doppler imaging, and contrast-enhanced ultrasound imaging.

Ultrasound Imaging

Ultrasound is a quantitative medical imaging biomarkers to better diagnose, treat, and monitor the health of patients.

Quantitative imaging is the extraction of quantifiable features from medical images for the assessment of normal conditions or the severity, degree of change, or status of a disease, injury, or chronic condition relative to normal.

Quantitative imaging validate the accuracy and precision of anatomically and physiologically relevant parameters, including treatment response and outcome, and the use of such metrics in research and patient care.

Ultrasound Technique

Ultrasound imaging uses sound waves to capture anatomy and anatomical function. Ultrasound can also be used to detect blood flow, anatomic movement (heart valves, for example), and anatomical structures.

It is frequently chosen as an imaging modality because it does not use radiation and carries less risk to the patient. Ultrasound uses high-frequency sound waves (1–20 MHz) that are projected into the body.

Ultra sound Imaging

The wavelength of ultra sound wave is

$$\lambda = f/c,$$

where the sound frequency is f, and c is the speed of sound in the tissue (typically 1540 m/sec in “soft tissue”). Medical ultrasound frequencies range from 1 to 50 MHz.

The wavelength λ for 10 MHz ultrasound (in vivo) is 154 μm, and for 50 MHz ophthalmological ultrasound, λ is 30.8 μm.

While pixel resolution increases with increasing frequency, so does energy absorption by the biological tissue ensonified.

Ultrasound Imaging

The waves hit an object, bounce back, and are detected with a piezoelectric crystal sensor. The distance from the transmitter probe and the anatomical structure can be calculated, and this data is used to produce an image. Computers can manipulate the transducer data to present three-dimensional or moving images.

Instrumentation and Operation

The ultrasound source is based on Piezoelectric effect. Piezocrystal contracts and expands according to the polarity of electric field and generates sound waves. When electric field oscillates at high frequency, piezoelectric crystal generates sound waves at high frequency.

The detector is based on reverse of the generation. When sound waves strike the crystal, the crystal oscillates to form electrical signals. The intensity of these electrical signals is proportional to the intensity of the incoming wave.

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Transducer Probe

UI transducer probes, which contain both the transmitter and the sensor, come in many shapes and sizes. Some are designed to enter body cavities such for better imaging quality. Most commonly, probes are placed on top of the skin and transmit into soft tissues. Ultrasound waves are blocked by air and bone. This can be a problem since air is contained in the lungs and there are bones surrounding some organs like the brain and heart.

Ultrasound Probe

A gel is often used to help block any air between the probe and the skin. This ensures effective transmission of the waves and unobstructed images.

Because of the inherent safety of this type of imaging, women often undergo ultrasound imaging to evaluate the progress of pregnancy. Another common application of ultrasound is echocardiography. The anatomy and function of the heart can be examined.

Ultrasound Doppler Imaging

It is also used to measure blood velocity at the same time the image by combining Doppler effect.

Because of the speed of the blood, speed of the reflected sound waves change” means “increased or decreased frequency of the reflected sound waves”

Higher frequency = blood toward transducer
Lower frequency = blood away from transducer.

Doppler ultrasonic imaging is invaluable in diagnosing kidney failure, coronary stenoses, pulmonary embolisms, and strokes.

Doppler Imaging

Measures speed of blood in parallel direction (to scan line)

It is based on shift in frequency in an US wave caused by a moving reflector (blood cells)

Object moving towards the transducer– higher frequency and shorter wavelength.

Object moving away from the transducer– lower frequency and longer wavelength.

If object moving perpendicular to the transducer, no change in the observed frequency or wavelength.

Example

The fetal heart beat is monitored by Ultrasound. If transmitting frequency is 2MHz ,the velocity of sound v=1540m/s and velocity of interface m=20 cm/s what is the Doppler shift?

Doppler shift = (fx 2m) / v

= 2 MHz (2x20cm/s) / 1540m/s

= 519 Hz

This value is in the audible range so you can actually hear the heart beat. This is called “Ultrasound stethoscope”.

Operational Modes

1. Static Imaging Modes

A Mode for midline shift of the brain
B Mode for abdominal imaging

2. Dynamic Imaging Modes

M Mode for dynamic imaging of internal structures
Real Time for structures in motion
Doppler Ultrasound for blood flow and fetal heart beat measurements.

Imaging methods

Most ultrasound imaging is done with pulse-echo system.

1. A-mode
2. B-mode
3. M-mode
4. Real time

There is a timer which controls the duration and frequency of the beam. Commercial diagnostic echographs have a repetition rate of 1000/sec.

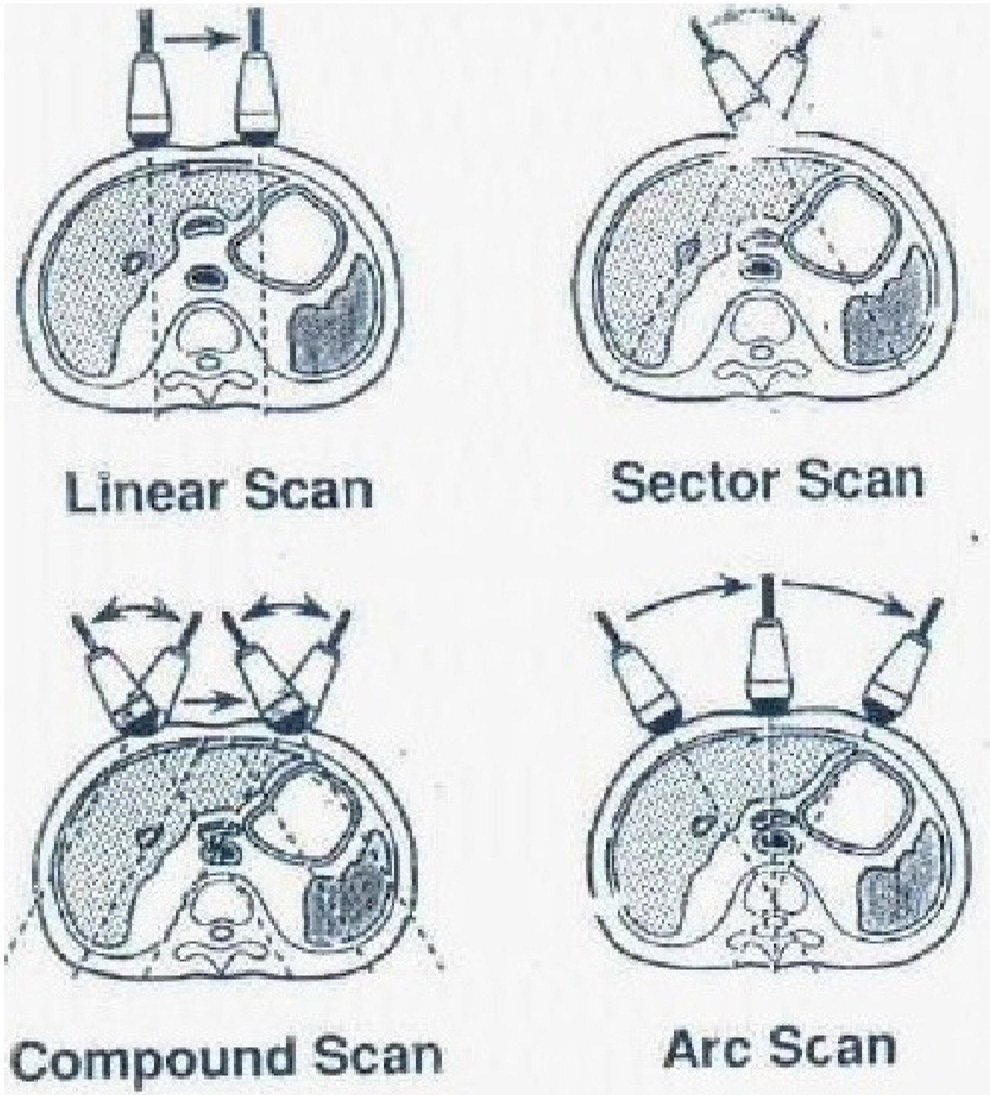
Typically 1- 5 ms pulse given and 995-999 ms detection.

Amplitude Mode

A-mode was the first ultrasound machine. It didn’t have ultrasound images, only a graph .

Distal reflections produce smaller blips than proximal reflections.

Brighter Mode



- The intensity of the reflected wave is displayed as a bright spot.
- The pulses are stored as the transducer is moved about the body.
- Summing all the pulses forms an image.

Motion Mode

Captures returning echoes in only one line of the B-mode image and display them over a time axis.

- This type of ultrasound is principally used for monitoring the heart and is called echocardiography.
- It can be synchronized with ECG for better evaluation of cardiac functions.