EEE/INSTR F432
Medical Instrumentation
28th Mar'25

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.

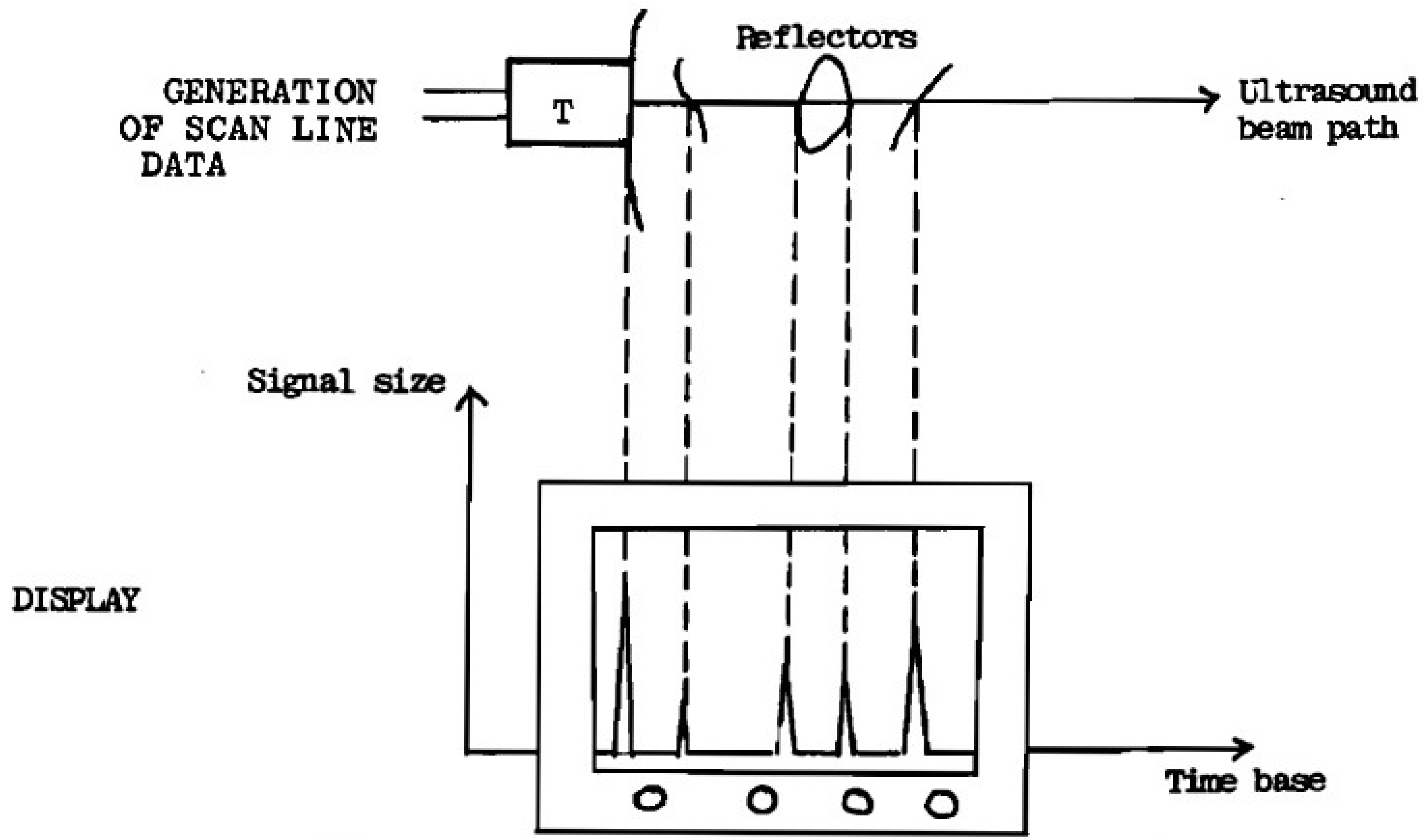
1. A-mode
2. B-mode
3. M-mode
4. Real time

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.

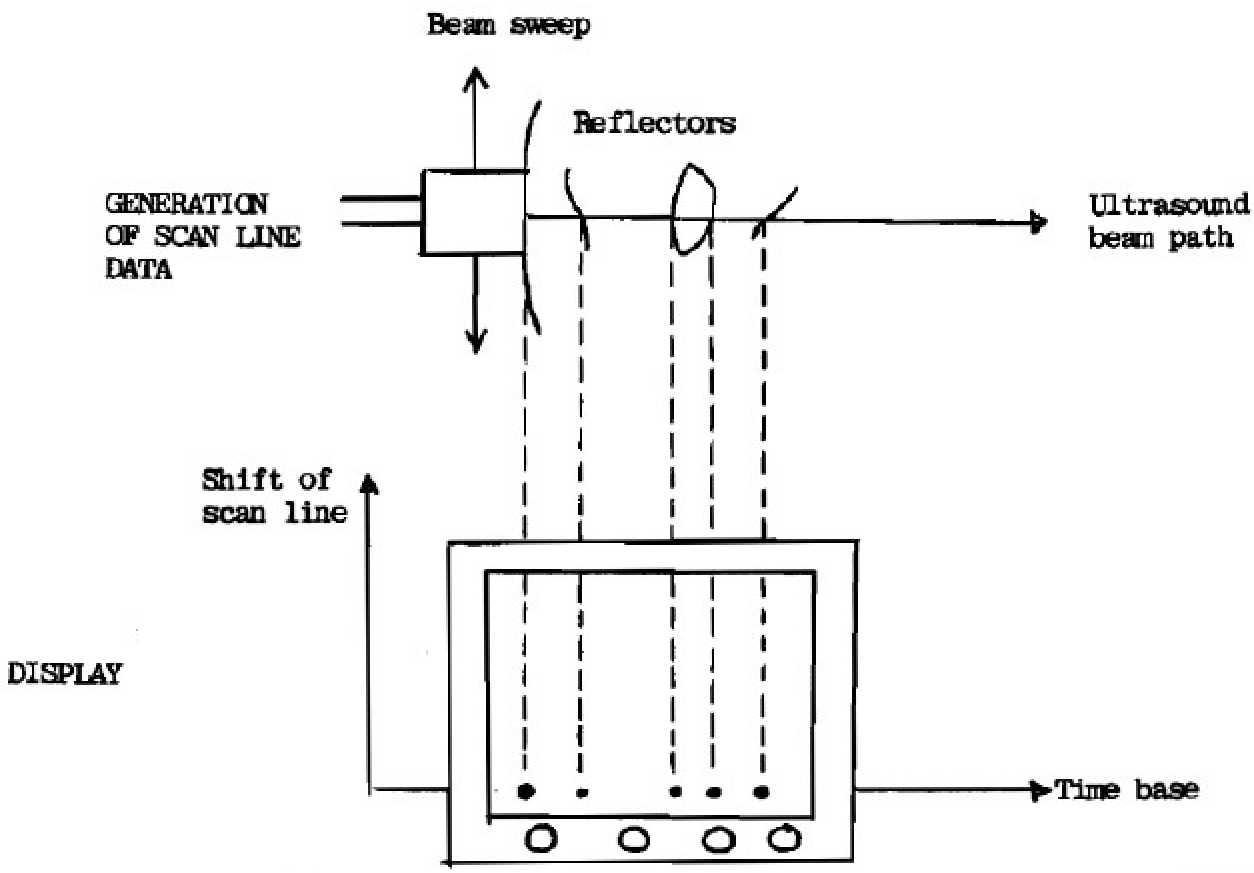
Amplitude Mode

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



Brighter Mode

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

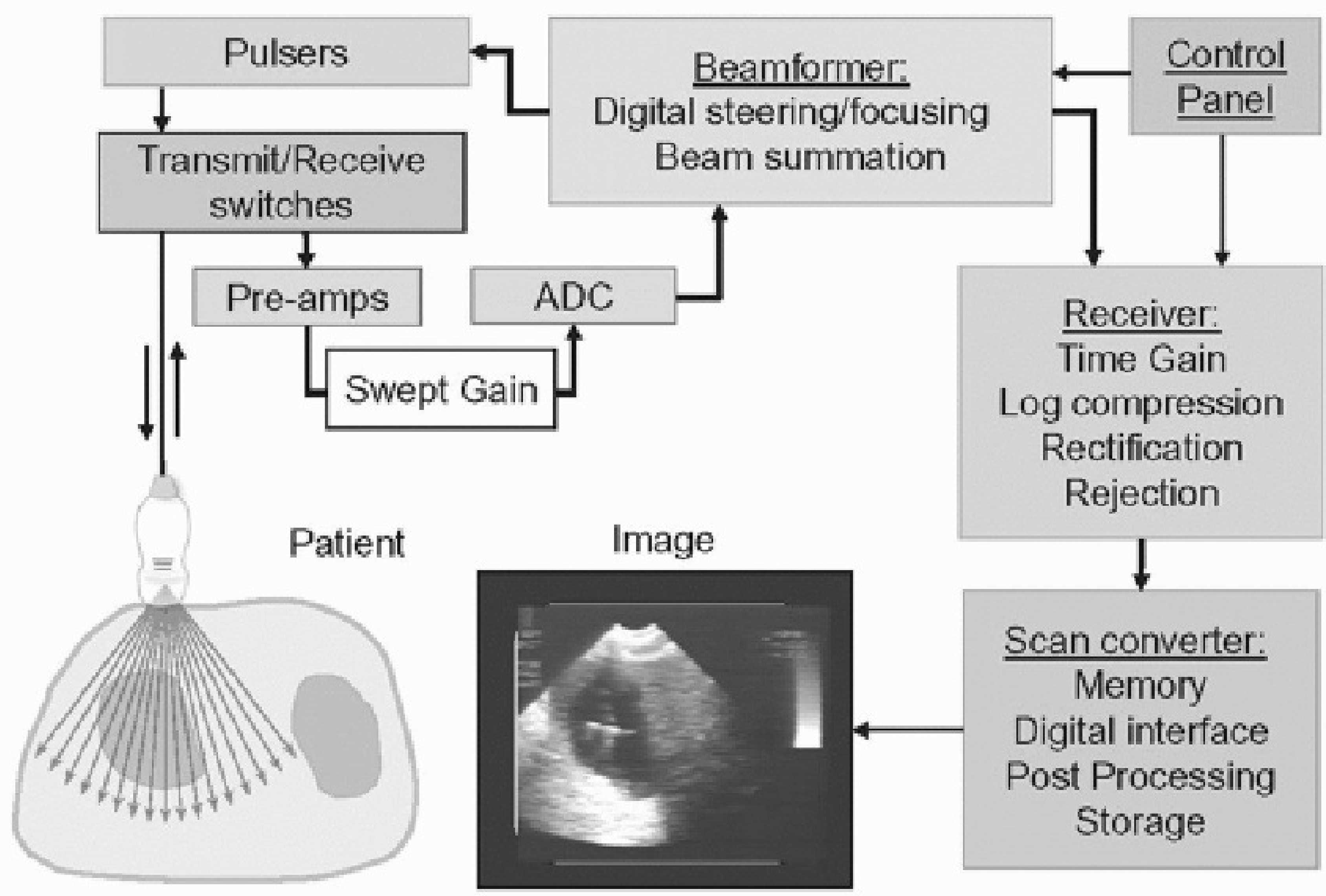


Motion Mode

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.

Schematic Diagram of US System



Ultrasound Resolution

1. Axial Resolution
2. Lateral Resolution
3. Image resolution

Axial Resolution

The resolution in the direction of the travel of the ultra sound. It depends on length of ultrasound pulse. For optimum axial resolution highest frequency possible must be used.

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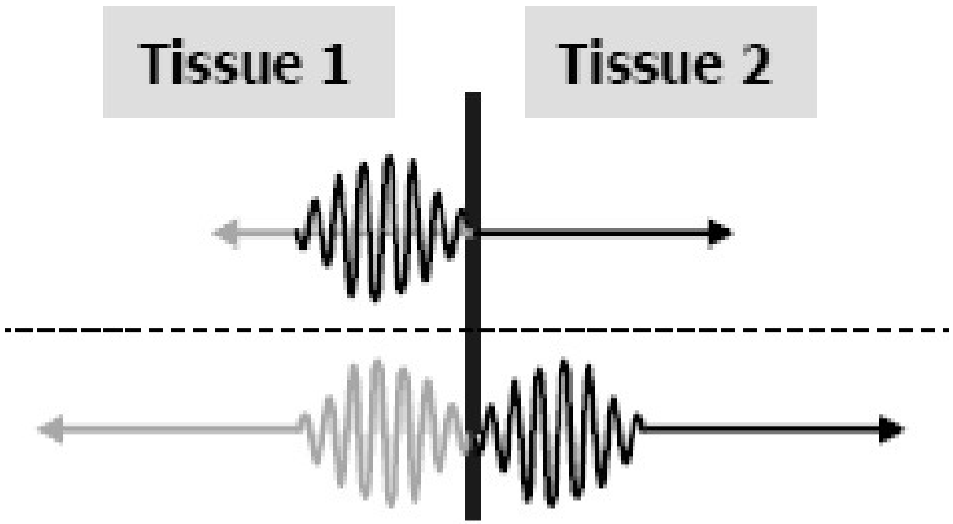

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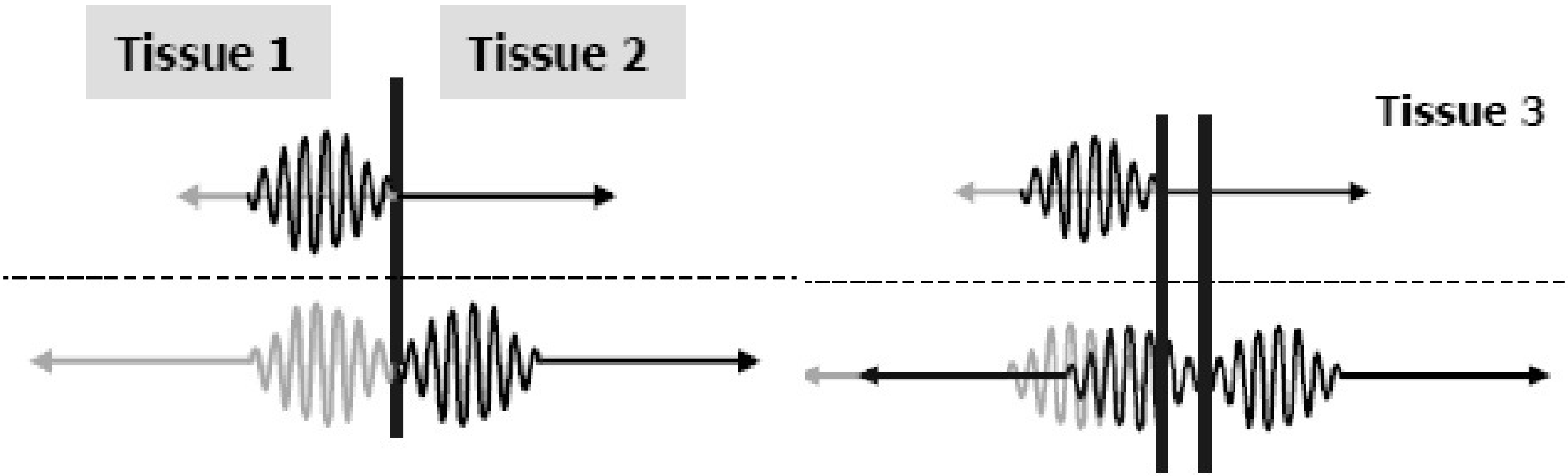

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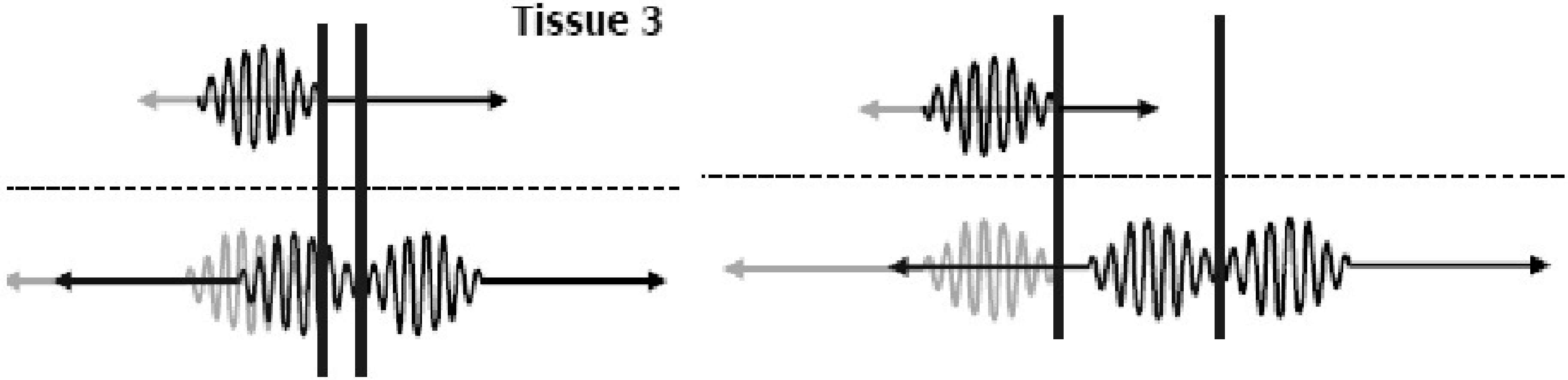
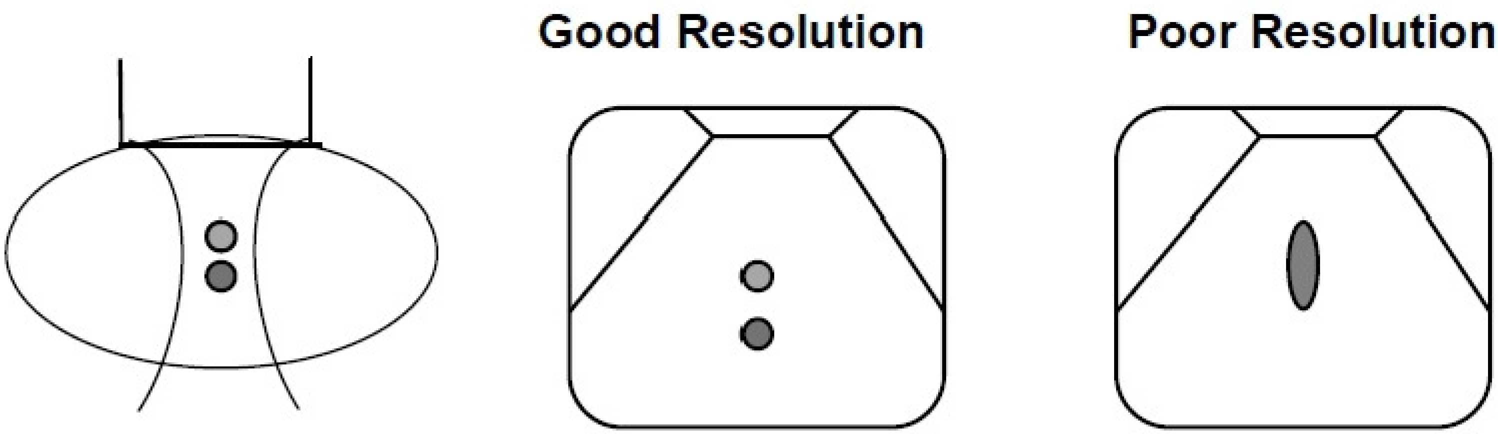


Example

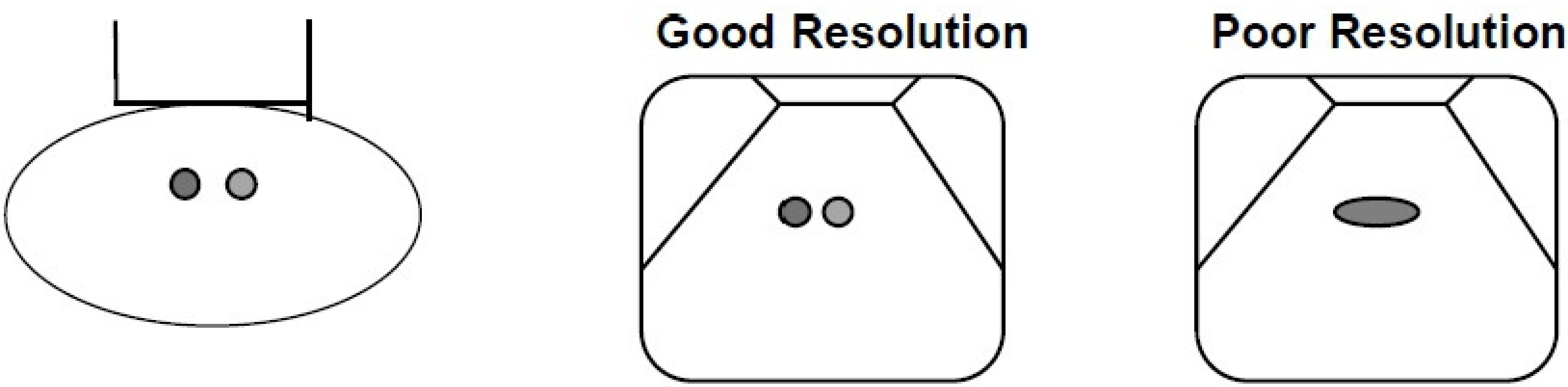


Lateral Resolution

The ability to resolve scatters at right angle to the direction of travel of the ultrasound. It is approximately equal to effective beam width. The smaller the size of transducer the better the lateral resolution. The higher the frequency the better the lateral resolution.

It means lateral resolution is more important for image quality.

Example:



Ultrasound Wave Characteristics

1. Attenuation
2. Absorption
3. Diffraction
4. Scattering
5. Reflection
6. Refraction

Attenuation: Absorption

US waves attenuate due to absorption, reflection and scattering, diffraction.

The 3dB loss is a 50% reduction in intensity.

Attenuation in soft tissue = 1dB/cm/MHz

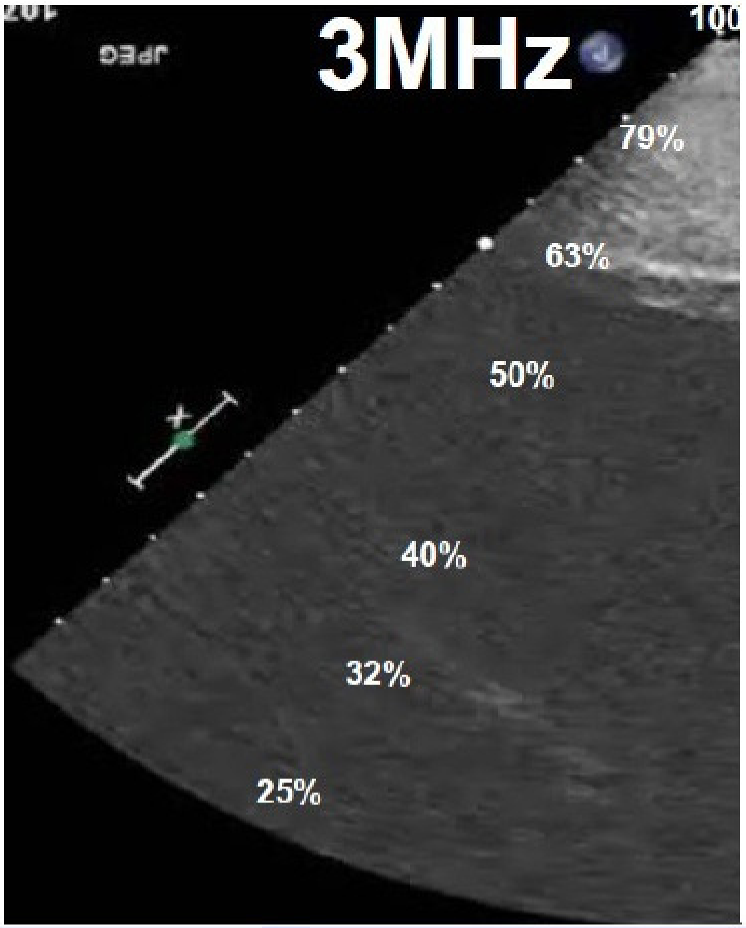
The high frequency ultrasound wave causes more molecular motion and loss more energy to absorption. Therefore at any given depth a high frequency wave will be weaker.

Attenuation: Absorption

Soft Tissue Type	Speed of Sound
Fat	1450m/sec
Liver	1550m/sec
Blood	1570m/sec
Muscle	1585m/sec
Bone	4080m/sec

Material	Speed of Sound
Air	330 metres/second
Metal	5000 m/sec
Pure Water	1430 m/sec

Increase the frequency, increase the rate of absorption.



Attenuation: Reflection

The strength of the reflected wave is related to the difference in acoustic impedance.

$$\text{Percentage reflected} = [(Z_2 - Z_1)/(Z_2 + Z_1)]^2 \times 100\%$$

Material	Acoustic Impedance (Z)
Air	0.0004
Lung	0.26
Soft-tissue (avg)	1.63
Bone	7.8

Reflection between air/soft tissue; Bone/soft tissues

Example

The velocity of ultrasound in a commercial preparation of lead zirconate titanate, a commonly used piezoelectric ceramic material, is 4,000 meter per second. If a vibration frequency of 5 MHz were desired, what would be the crystal thickness?

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Thickness ‘t’ = v/2f = 0.4 mm

Example

Calculate the angle of transmission for ultrasound striking the interface between fat and muscle at an incident angle of 25°.

Given the speed of sound for fat and muscle is 1450 ms^{-1} and 1590 ms^{-1}, respectively.

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According to Snell's Law,

$$\frac{\sin\theta_i}{\sin\theta_t} = \frac{1450}{1590}$$

$$\frac{\sin 25^{\circ}}{\sin\theta_t} = \frac{1450}{1590}$$

Angle of transmission, $\theta_t = 27.6^{\circ}$

Example

Calculate the intensity reflection coefficients and the intensity transmission coefficients when an ultrasound beam encounters the following tissue interfaces at an incident angle of 90°.

Explain the three conditions where the acoustic impedance, Z of the tissues at the interface are *Z1 >> Z2, Z1 ~ Z2, and Z1 < Z2.*

Case	Z_1, (g cm^{-2}s^{-1})	Z_2, (g cm^{-2}s^{-1})
$Z_1 >> Z_2$	Muscle, (1.7)	Air, (0.00043)
$Z_1 \sim Z_2$	Liver, (1.65)	Kidney, (1.62)
$Z_1 < Z_2$	Muscle, (1.7)	Bone, (7.8)

Example

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Intensity reflection coefficient,

$$R = \frac{I_r}{I_i} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

Intensity transmission coefficient,

$$T = \frac{I_t}{I_i} = 1 - R = \frac{4(Z_1 Z_2)}{(Z_2 + Z_1)^2}$$

Example

Calculate the intensity reflection coefficients and the intensity transmission coefficients when an ultrasound beam encounters the following tissue interfaces at an incident angle of 90°.

	Z_1, ($g\ cm^{-2}s^{-1}$)	Z_2, ($g\ cm^{-2}s^{-1}$)	R (%)	T (%)
$Z_1 >> Z_2$	Muscle, (1.7)	Air, (0.00043)	99.90	0.10
$Z_1 \sim Z_2$	Liver, (1.65)	Kidney, (1.62)	0.01	99.99
$Z_1 < Z_2$	Muscle, (1.7)	Bone, (7.8)	41.23	58.77