Alberto Ardon M.D.

BASICS OF ULTRASONOGRAPHY

Preparatory Work

- Ultrasound Physics
  - http://www.nysora.com/mobile/regional-anesthesia/foundations-of-us-guided-nerve-blocks-techniques/index.1.html
- Basic Ultrasound Handling
  - https://www.youtube.com/watch?v=q2OtUKHrrUc
  - https://www.youtube.com/watch?v=Q9Tt83BNboI
- Supraclavicular Block
  - https://www.youtube.com/watch?v=ztOIvfjsB-U
- Popliteal Block
  - https://www.youtube.com/watch?v=kzhSiQBPE7s

Physics

- Frequency
  - Number of cycles of a sound wave per unit of time; cycles/sec ---Hertz.
  - F = propagation velocity / wavelength
  - Reciprocal of the *period (time between successive specific reference points). F=1/P*
- Audio frequencies: 20-20000Hz (range of human hearing).
- Ultrasonic frequencies are above 20.000Hz.
- Ultrasounds machines utilizes frequencies in the range of 2-10 MHz some intracardiac probes use 30 MHz.

Physics

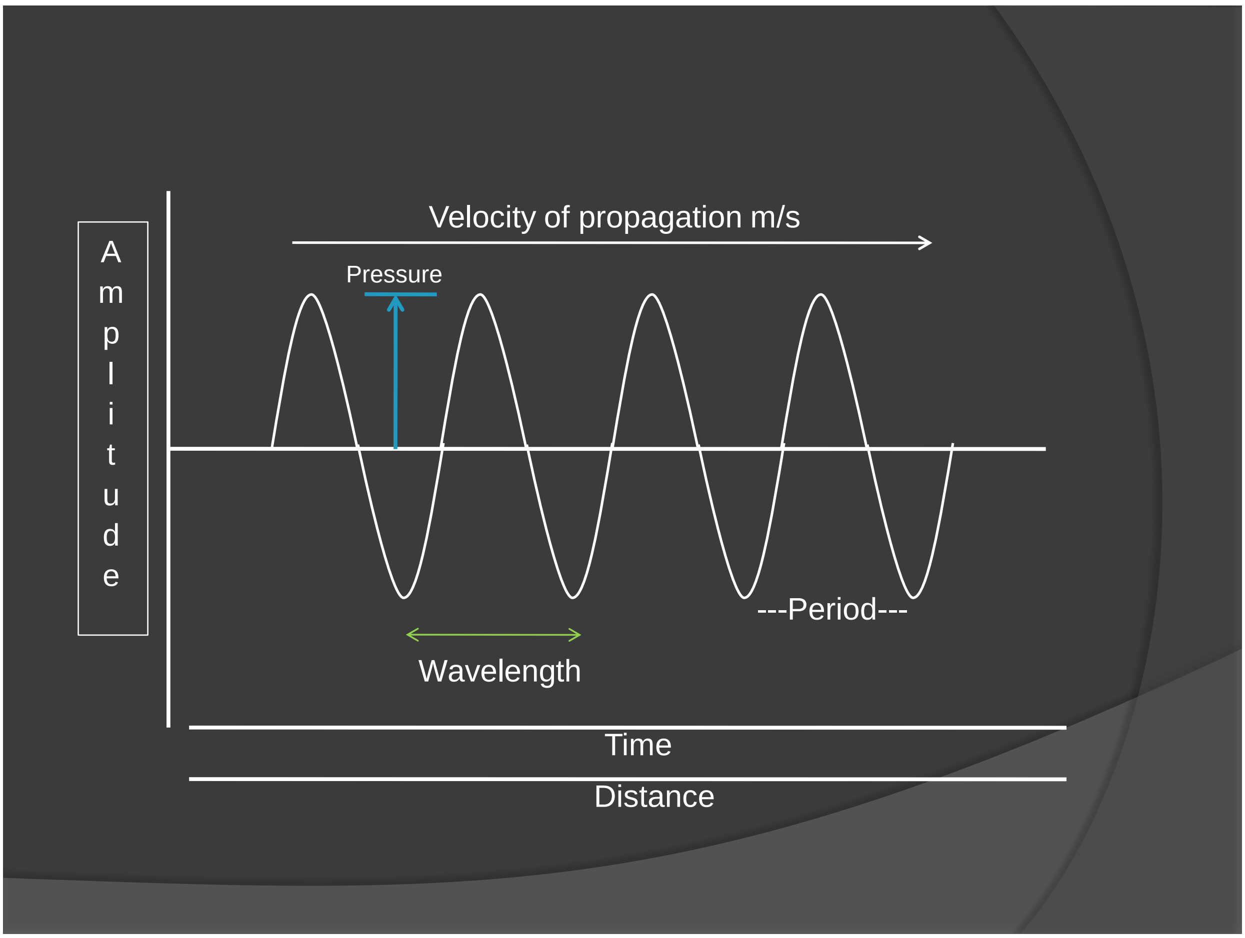
- Wavelength
  - Distance between corresponding reference points (peaks or valleys) on adjacent cycles of a sound wave.
  - Frequency and wavelength are related when defining velocity of propagation of a sound wave in a medium by the following equation: Vp = Frequency x Wavelength.
  - Amplitude is the distance from the baseline to the peak and is defined in units of pressure

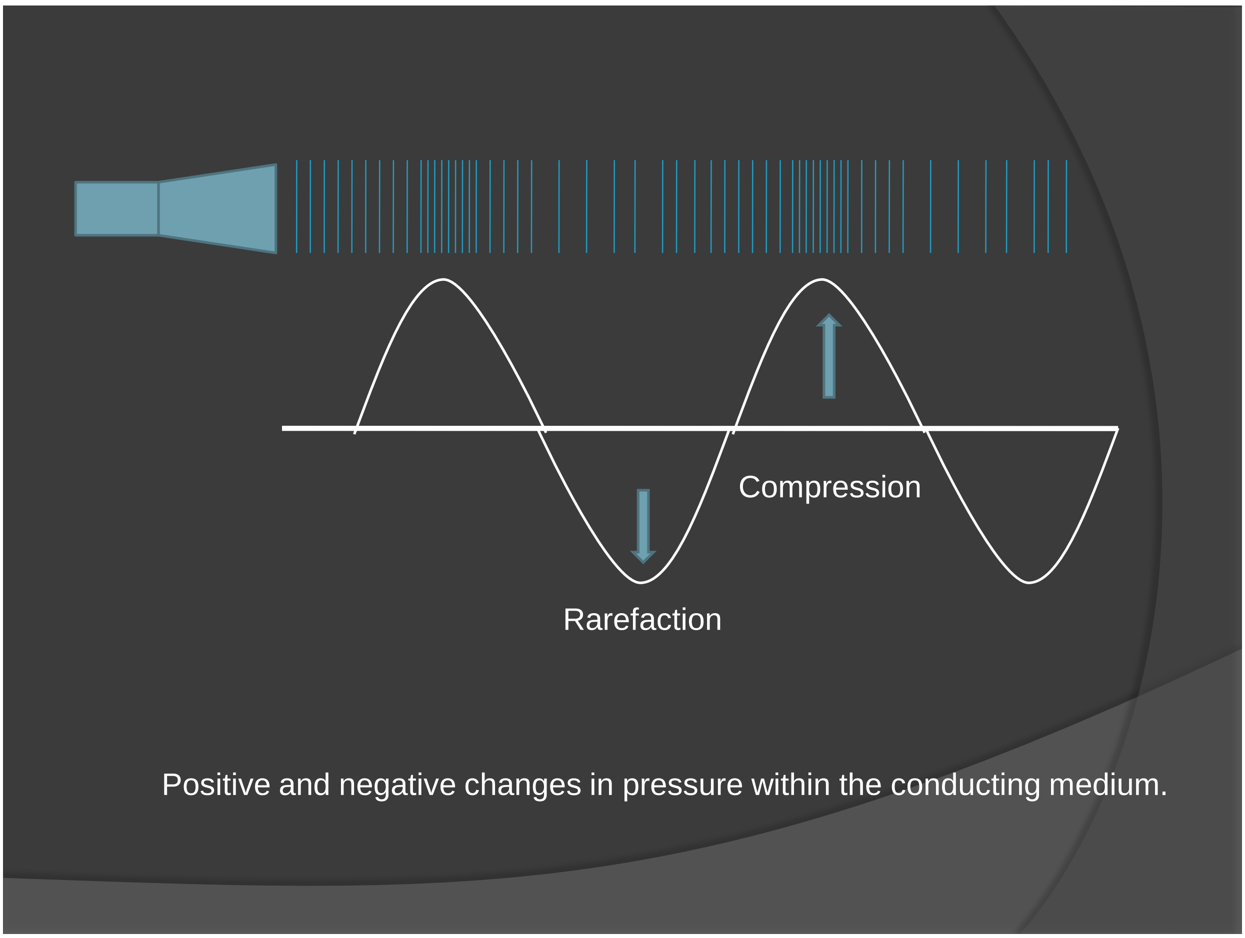
Physics

- Power of a sound wave is the rate of energy delivered and it is proportional to the pressure amplitude squared >>Watts
- Intensity is the power per unit area: watts/cm^2.
- The output of an ultrasound machine is specified as intensity.

- Power = Watts
- Intensity= Power/area ($watts/cm^2$)

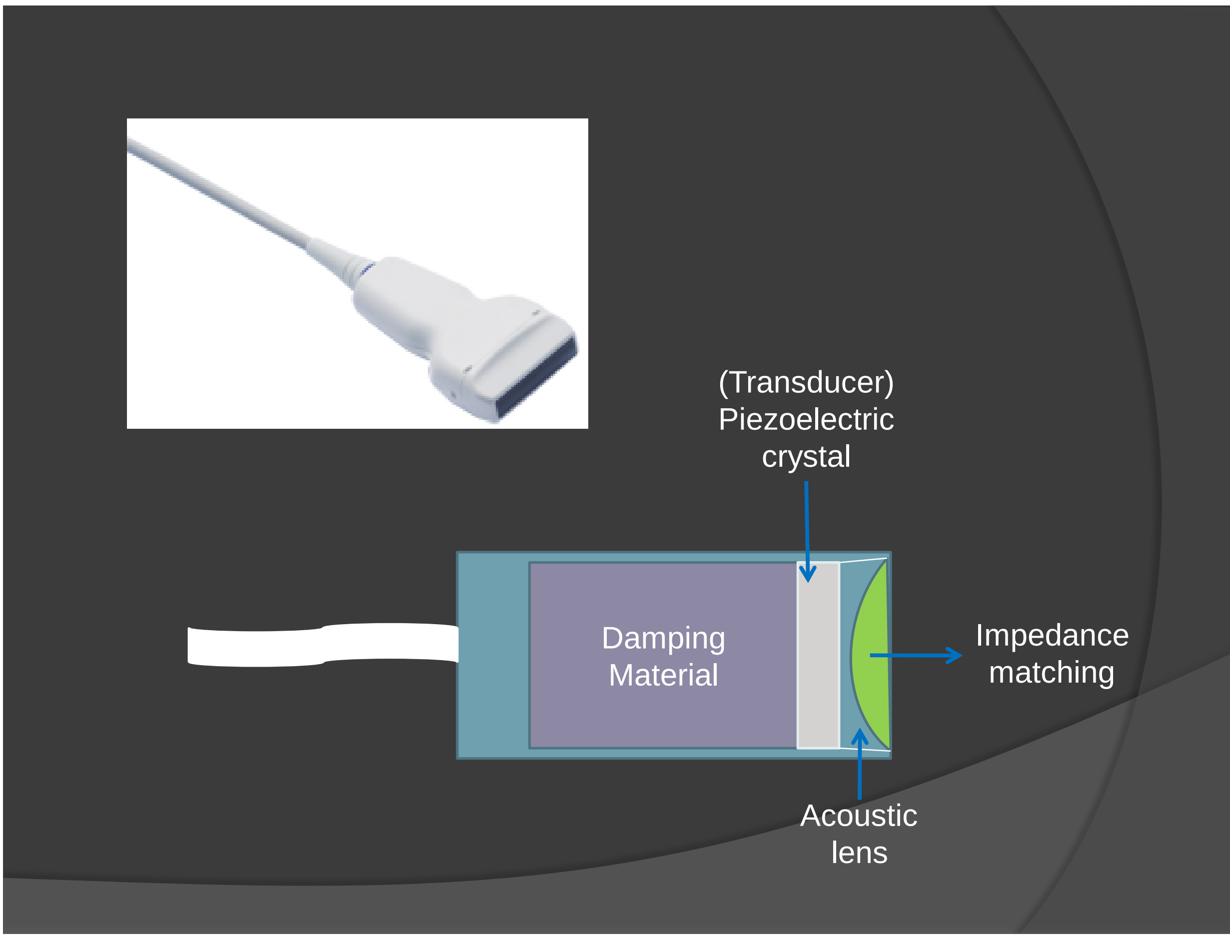
- Decrease of intensity= Attenuation
- Increase of intensity = Amplification

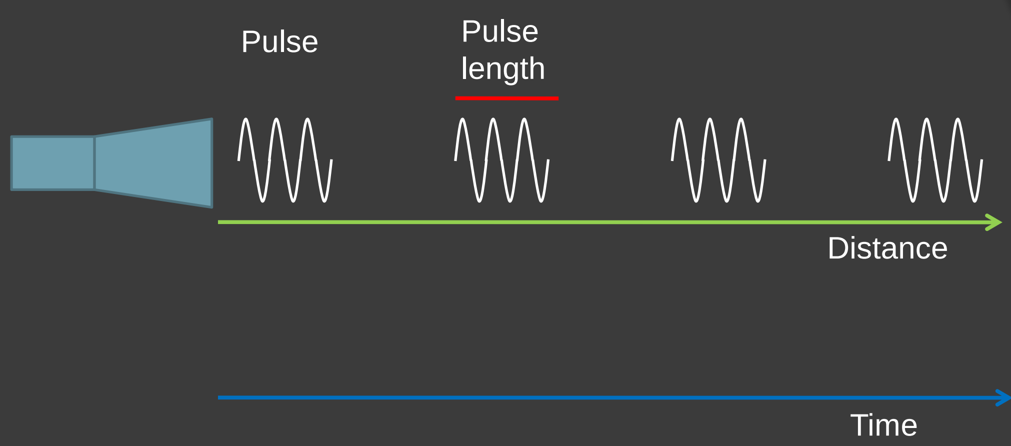

A m p l i t u d e
Velocity of propagation m/s
Pressure
---Period---
Wavelength
Time
Distance


Compression
Rarefaction
Positive and negative changes in pressure within the conducting medium.

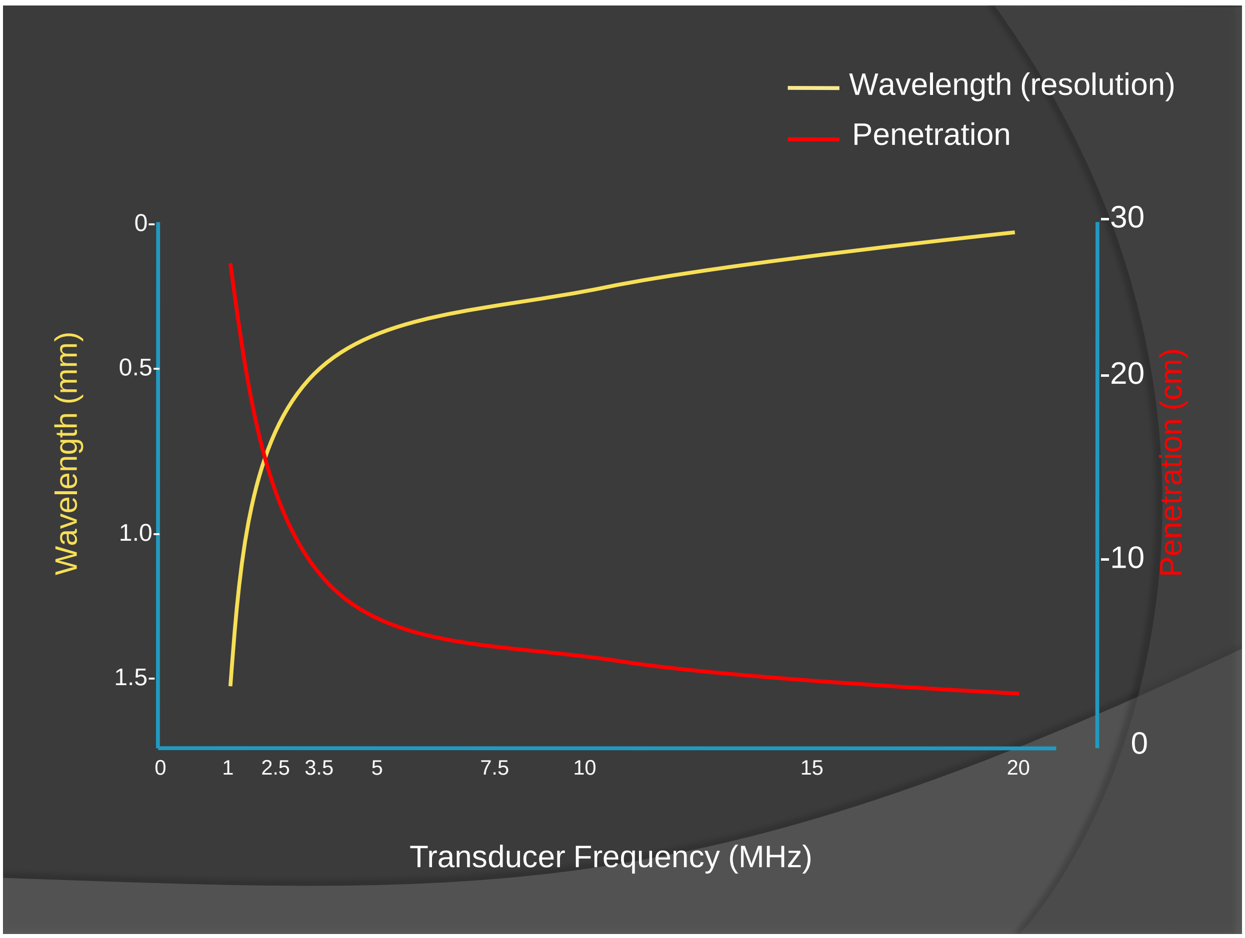
Physics

- Speed of propagation of sound in soft tissues and blood is approx = 1540 m/s (1.54 mm/usec).
- Speed of propagation of sound in air approx: 330 m/s)
- Speed of propagation changes inversely with density and directly with stiffness.
- Speed of propagation is higher in Solids>>Liquids>>Gases.
- Bone 4000 m/s blood:1540m/s lung: 500m/s


(Transducer)
Piezoelectric
crystal
Damping
Material
Impedance
matching
Acoustic
lens



PRF (Pulse Repetition Frequency): Number of pulses per unit of Time.

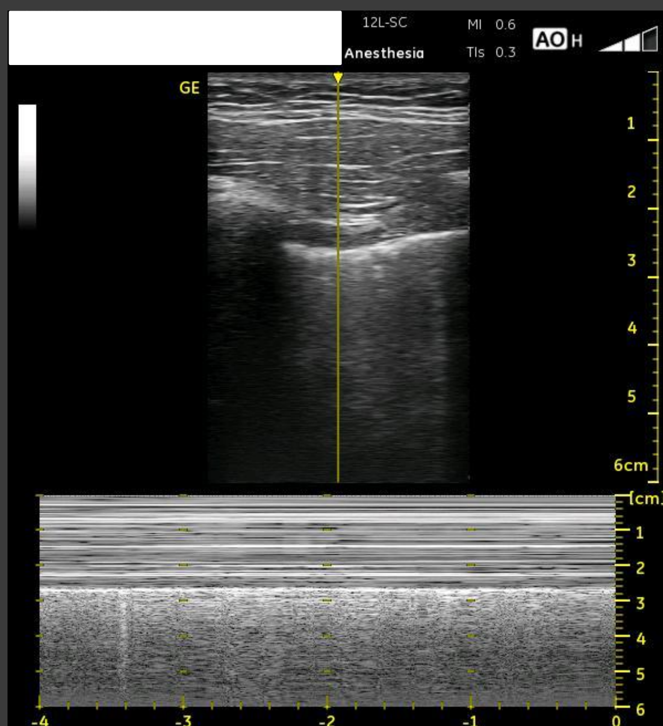


Wavelength (resolution)
Penetration
Wavelength (mm)
0-
0.5-
1.0-
1.5-
Penetration (cm)
-30
-20
-10
0
0
1
2.5
3.5
5
7.5
10
15
20
Transducer Frequency (MHz)

Ultrasound waves interaction with tissues

- Image formation depends on the wave reflections occurring at the interfaces between different media.
- Strength of the reflection depends on the difference of acoustic impedance between the 2 media.
- AI_{media} = $Density_{media}$ x Propagation $speed_{media}$
- Density differences is more important.
- **Blood fat** >>> *blood muscle*

M Mode



Different tissue density

Ultrasound waves interaction with tissues

- Attenuation
- Reflection
- Scattering
- Refraction

Attenuation

- Energy loss – Amplitude of original signal decreases as it passes through tissues (depth of penetration).
- A big % of attenuation is due to absorption ---- Heat production, reflection and scattering.
- Measured in Decibels.
- Every tissue has its own Attenuation Coefficient.
- The higher the coefficient, the more attenuated the ultrasound wave is by the specific tissue.
- Bone>>>Muscle>Kidney>liver>Fat>Blood>Water

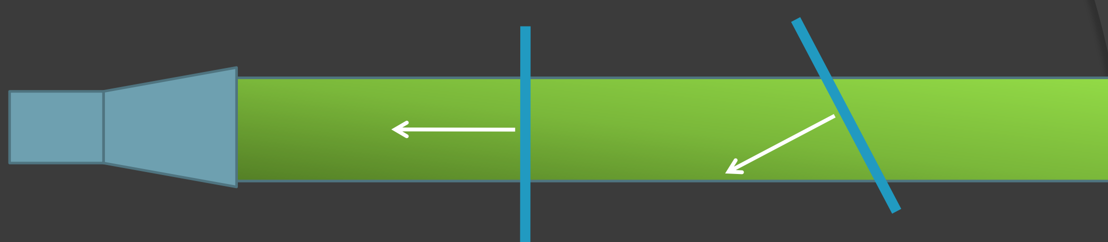
Attenuation

- Frequency dependent; lower U/S frequencies penetrate deeper and get less attenuated.
- The depth of penetration for adequate imaging is limited by aprox 200 wavelengsths.

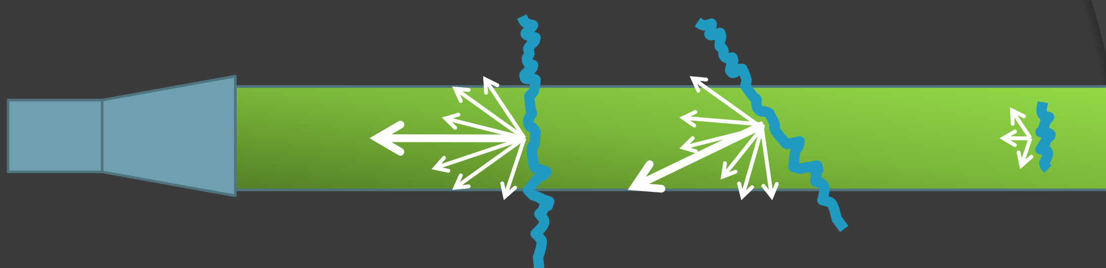
1 MHz	30 cm
5 MHz	6.0 cm
20 MHz	1.5 cm

Reflection

- Difference in Acoustic impedance between structures.
- Conducting gel is important!!!



Specular reflection: occurs at smooth, flat surfaces where the reflection is transmitted in a single direction and the surfaces is bigger than the wavelength.

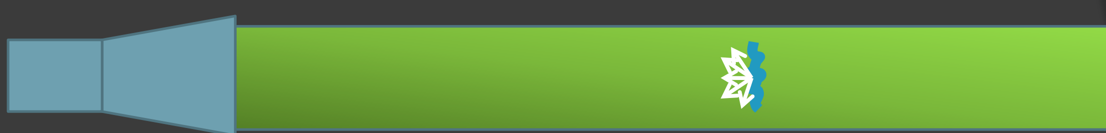


Diffused reflection: From reflectors that don't have a smooth surface (organs).

Decreased amplitude.

Scattering

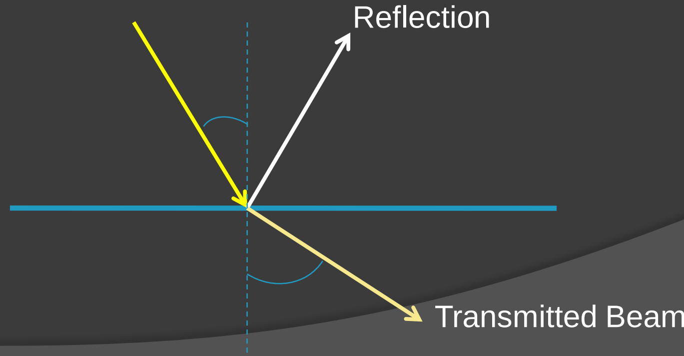
- Caused by structures with less than 1 wavelength of lateral dimension.
- Ultrasound energy is radiated in multiple directions.
- A small portion reaches the transducer, with amplitudes 100- 1000 times less (40-60 dB) than amplitudes from specular reflectors signals

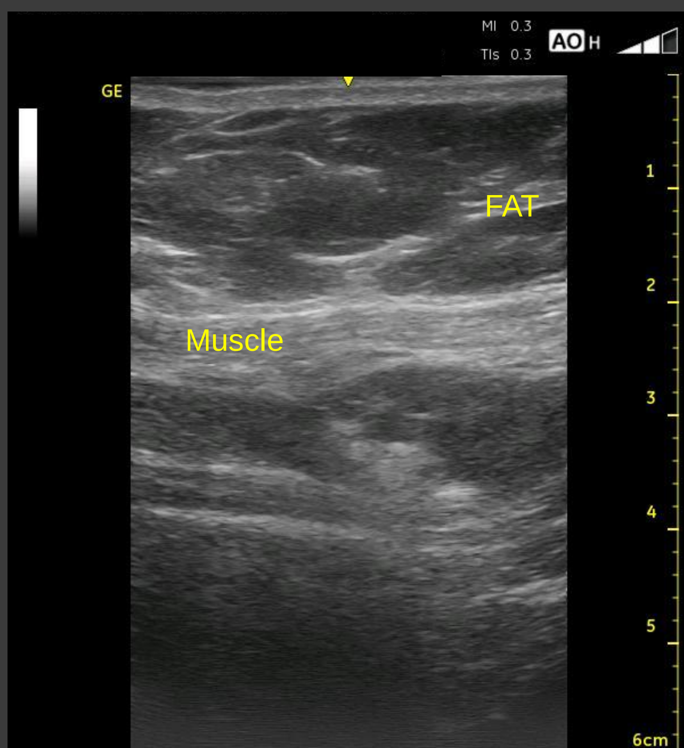


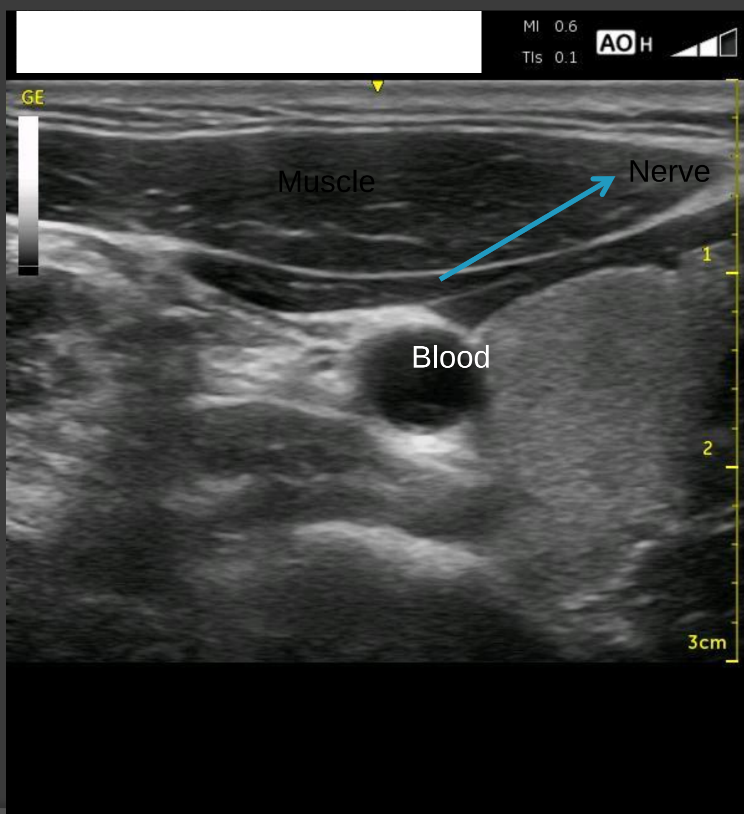
Scattering: Occurs when incident waves encounter structure that
Is not perfectly smooth.
Weaker returning signal.
Is the basis of Doppler ultrasonography --- Red cells

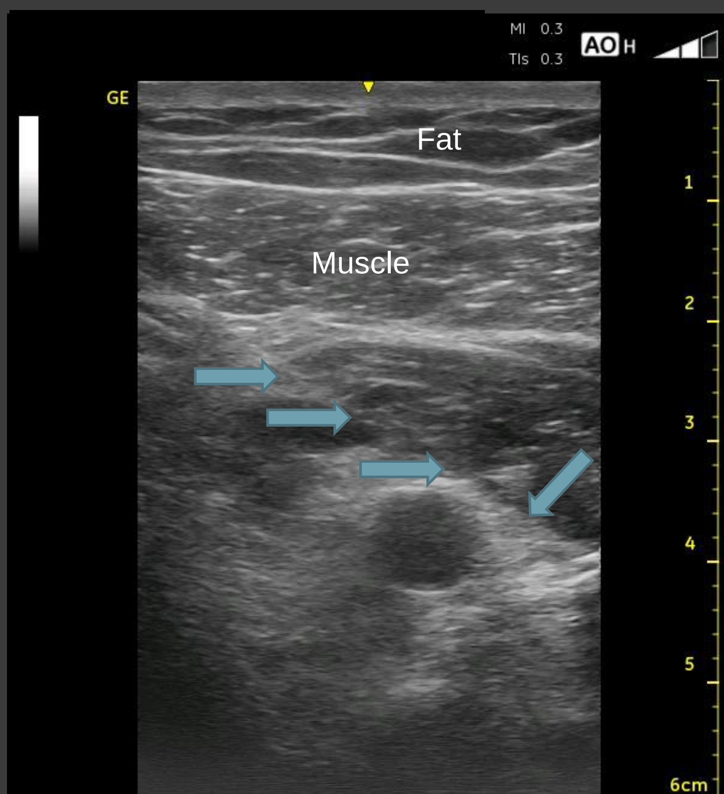
Refraction

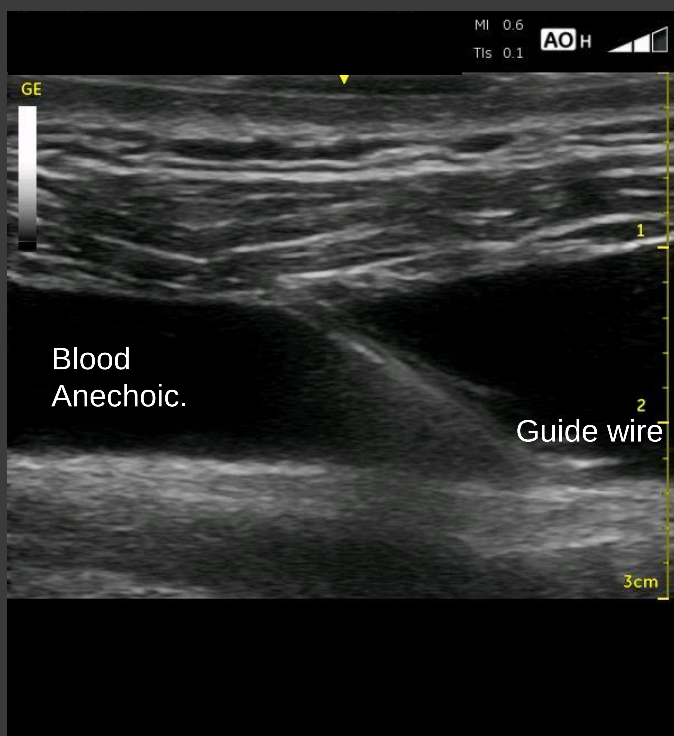
- Deflection or Bending of obliquely emitted ultrasound waves from a straight path as they pass through a medium with different propagation velocities.

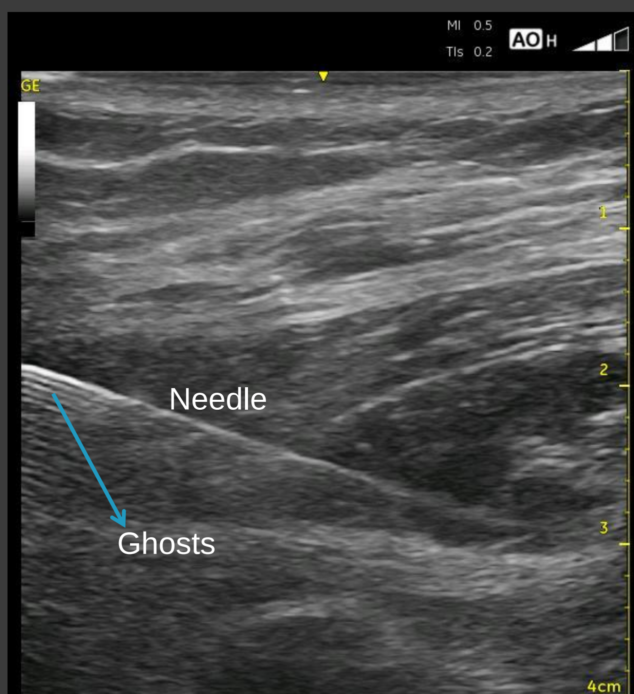


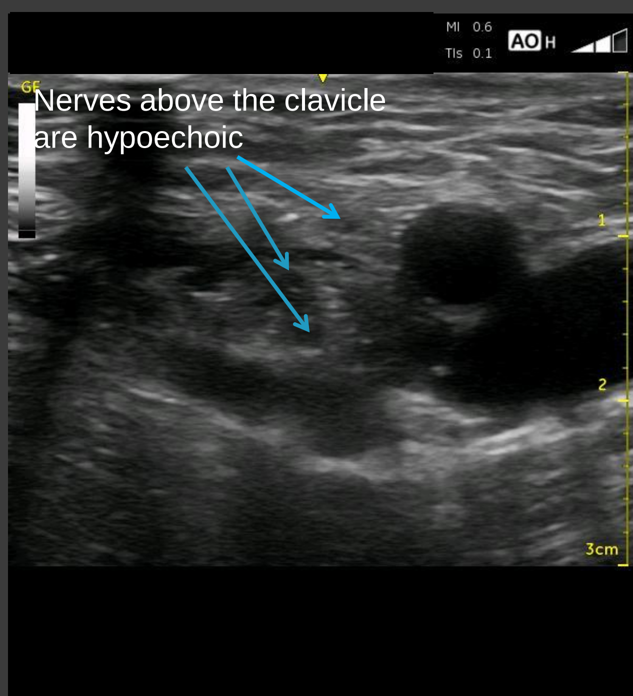

MI 0.3
TIs 0.3
AO H
GE
FAT
Muscle
1
2
3
4
5
6cm


MI 0.6
TIs 0.1
AO H
GE
Muscle
Nerve
Blood
1
2
3cm


MI 0.3
TIs 0.3
AO H
GE
Fat
Muscle
1
2
3
4
5
6cm


MI 0.6
TIs 0.1
AO H
GE
Blood
Anechoic.
1
2
Guide wire
3cm


MI 0.5
TIs 0.2
AO H
GE
1
2
3
4cm
Needle
Ghosts


MI 0.6
TIs 0.1
AO H
GE
Nerves above the clavicle
are hypoechoic
1
2
3cm

Transducers

- Electrical energy ⇄ Acoustic energy
- Piezoelectric effect (*piezein – tight. Squeeze)*
- Piezoelectric crystals/ceramics.
- Short pulse duration improves axial resolution.

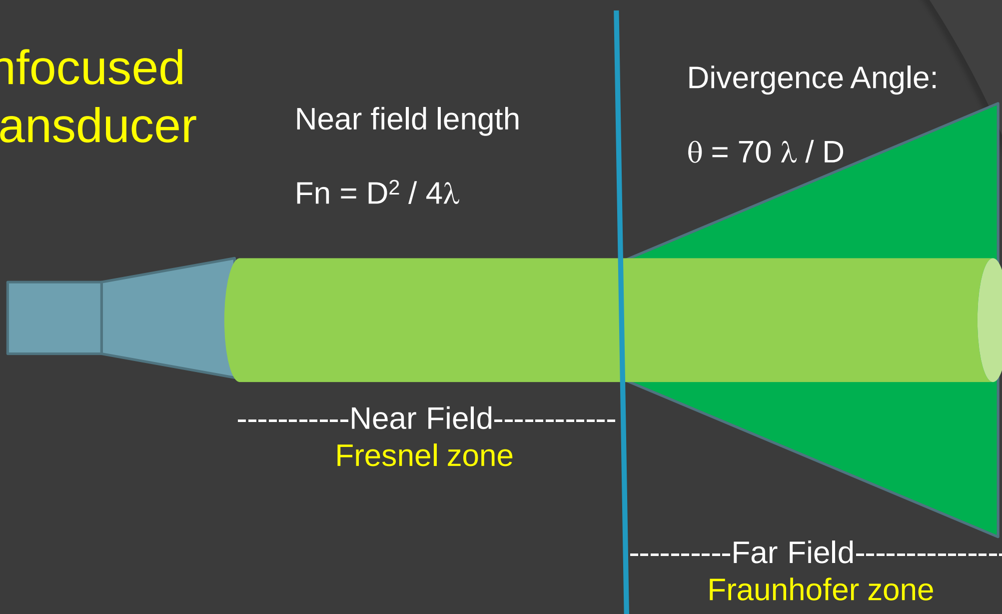
Unfocused Transducer

Near field length

Fn = $D^2 / 4\lambda$

Divergence Angle:

$\theta = 70\ \lambda / D$

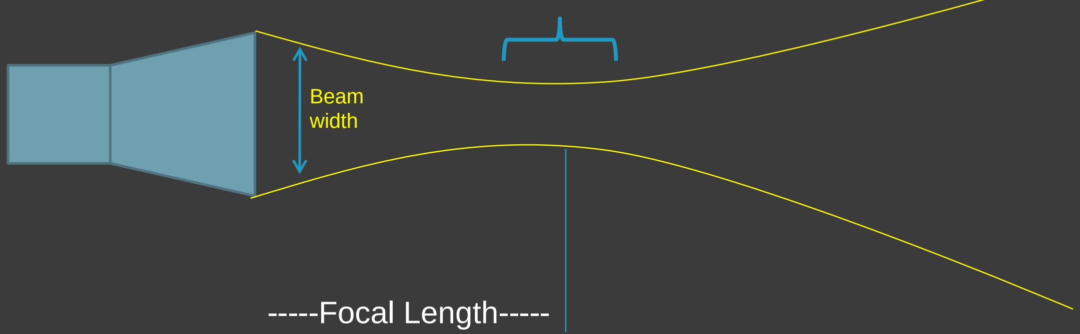


4 MHz transducer with a 5mm Diameter aperture:

Fn = 25 / 4 x 0.385
Fn = aprox 1.6 cm

Divergence Angle $\theta = 70 \times 0.385 / 5$
$\theta = 5.39$ degrees

Focused Transducer



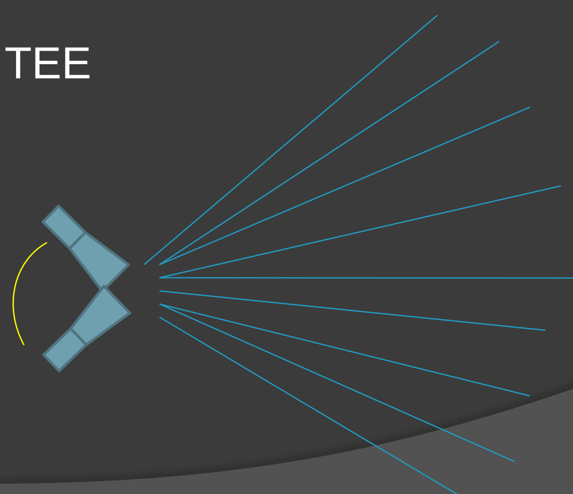
Transducers

- Mechanical sector scanner

- Phased Array / Vector Array
- Linear Array/Curvilinear array
- Annular Array

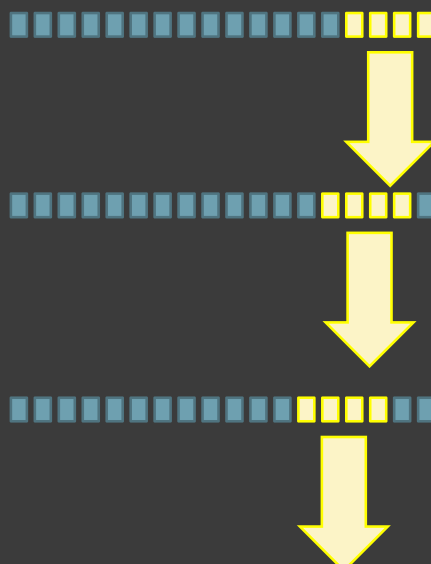
Mechanical sector scanners

- Mechanical steering – sector (pie shaped)
- Motor in transducer that rotates the beam line through an arc creating a sector shaped Field of view.
- Example: TEE

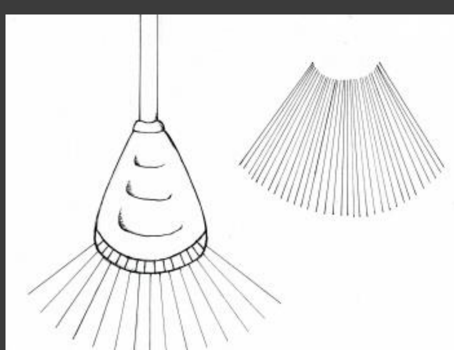


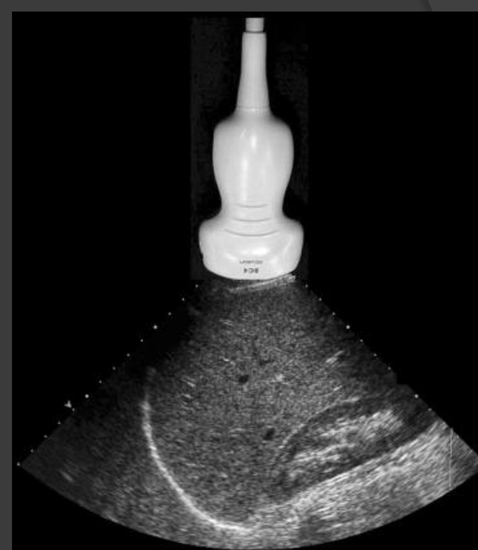
Linear array

- Elements are arranged in line.
- Electronically stimulates a subset of this elements at a time.
- Ultrasound pulse emitted perpendicular to array
- Successive beams are obtained by shifting the subsets of excited elements across the face of the array.
- Advance the beam laterally
- U/S beam is electronically swept across an entire rectangular field.



Hangiandreou, N. B-Mode US: Basic concepts and
new Technology. Radiographics 2003;23:1019-33





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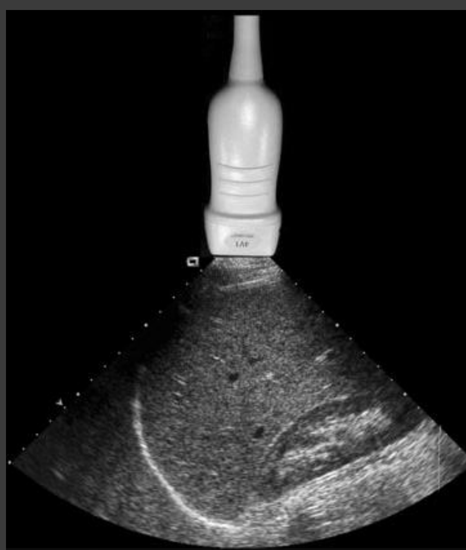
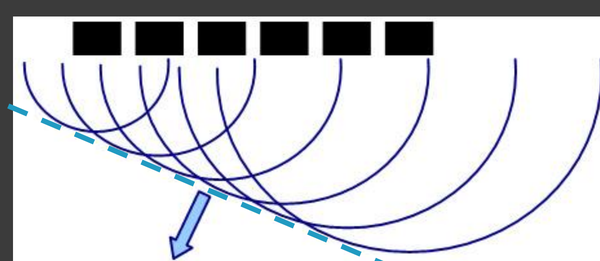
Curvilinear array.

Phased Array

- Multiple firing of the ultrasound elements achieving a lens like summation wavefront (curved).
- Imagine a “moving front” of narrow scanning along the length of the probe
- can be set to scan ahead of the actual probe position
- Most useful in TTE and TEE



Phased Array



Curvolinear Linear Phased Array

Image formation

- A Mode:
  - Amplitude vs Depth.
  - “Ice pick” view of tissues.
  - Limited use clinically—interpretation/movement/ calibration
- M Mode (Motion mode image):
  - “Ice pick” view of tissues.
  - Repetitive sampling over time (1800 times per second).

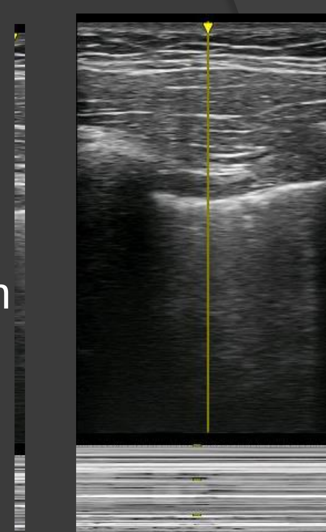
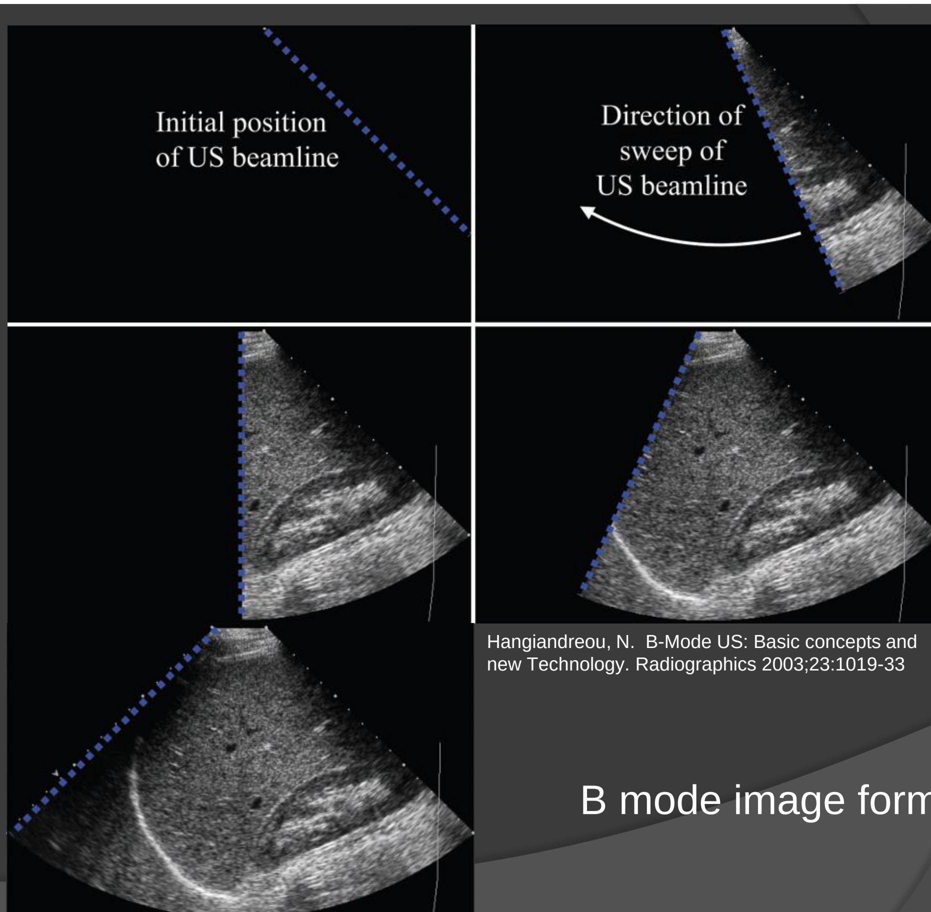


Image formation

- B Mode (Brightness mode):
  - Tomographic 2-D ultrasound image.
  - Scans U/S beam (mechanically or electronically), with (Linear or Phased array)
  - The strength of returned echoes are used to modulate the brightness of points in the image translating it to luminance, hence "Brightness mode" image display.



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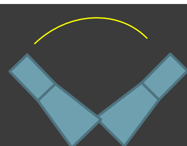
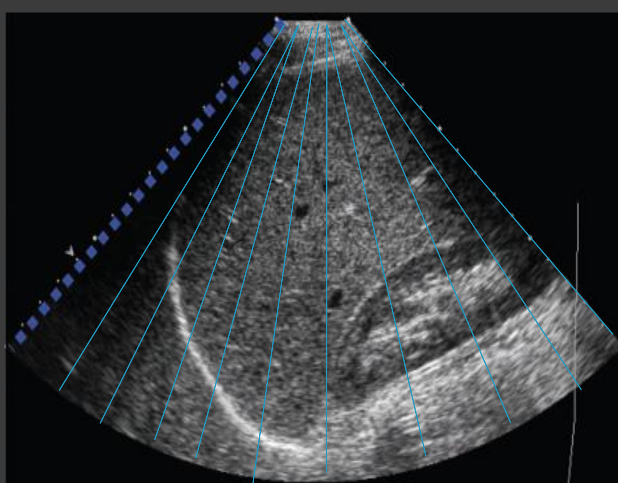
B mode image formation





128 lines are scanned to cover 90º = Sector

A complete scan of a sectors forms a Frame

Time to generate one frame

$$\frac{2 \times n \times d}{c}$$

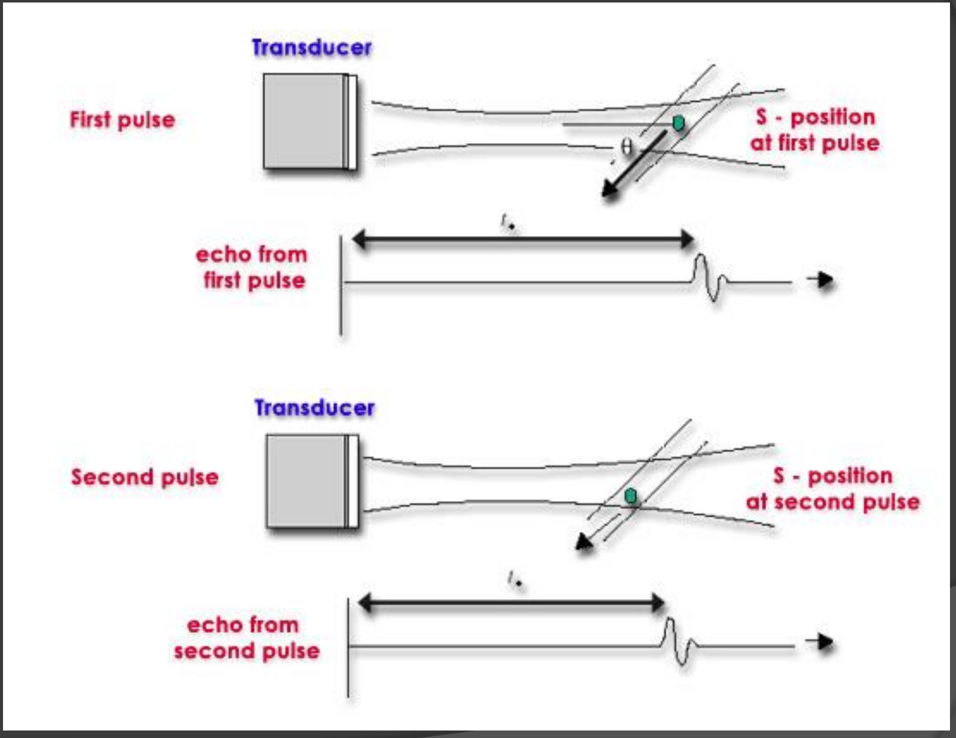
n= # of scan lines in frame
d= maximum depth of sector
c= velocity of propagation

N= 128, d= 8cm

$$t = \frac{2 \times 128 \times 80\text{mm}}{1.54\ us}$$

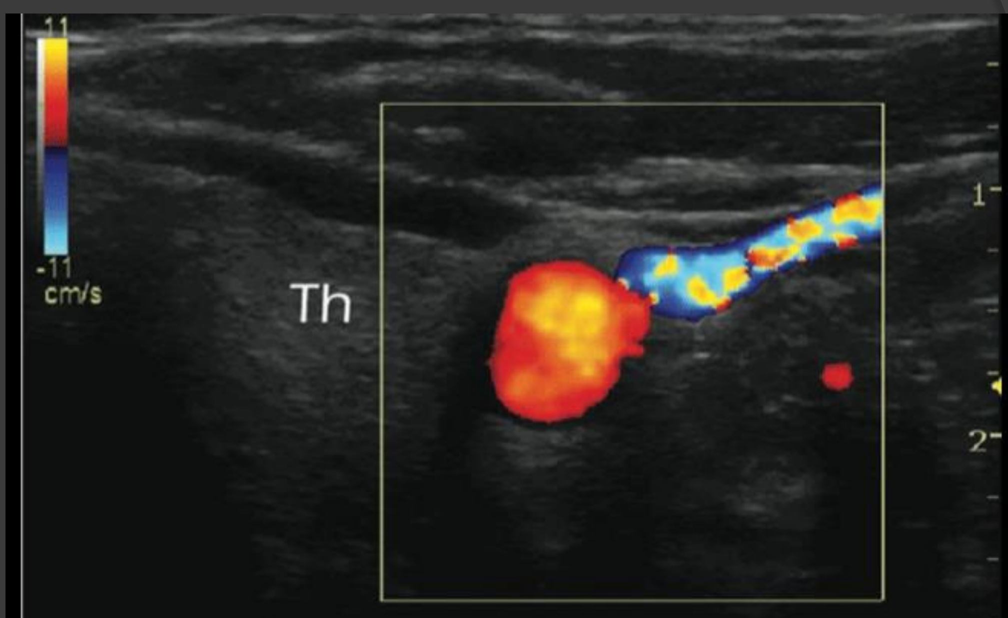
= aprox 13 ms ------- 76 frames per second

Color Flow Doppler



Color Flow Doppler

- Allows us to assess motion (ex: bloodflow) in real time
- Based on movement of RBC's or a moving fluid
- Red = toward transducer
- Blue = away from transducer


11
-11
cm/s
Th
1
2

Improving image quality