\[ f = \frac{1}{T} \]

\[ \lambda \cdot f = c \]
graphic
A MODE

REAL TIME (B-MODE)  
2D  
3D

M - MODE

GATED MODE  
CW  
PW

DOPPLER MODE:  
COLOR (2D - 3D)  
ENERGY / POWER (2D - 3D)  
DTI (2D - 3D)
TRANSDUCER = Device converting an energy type in another

ELECTRICAL ENERGY → MECHANICAL ENERGY

EMITTER

MECHANICAL ENERGY → ELECTRICAL ENERGY

RECEIVER
INTERACTION US - TISSUE

• REFLECTION

• REFRACTION

• DIFFUSION

• ATTENUATION

IMAGING

ABSORPTION OR DIFFUSION OF ENERGY
CLINICAL USE OF US frequency 1-20 MHz in tissue

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Period (μs)</th>
<th>Wavelength (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1,54</td>
</tr>
<tr>
<td>2</td>
<td>0,5</td>
<td>0,77</td>
</tr>
<tr>
<td>3,5</td>
<td>0,29</td>
<td>0,44</td>
</tr>
<tr>
<td>5</td>
<td>0,2</td>
<td>0,31</td>
</tr>
<tr>
<td>10</td>
<td>0,1</td>
<td>0,15</td>
</tr>
<tr>
<td>20</td>
<td>0,05</td>
<td>0,08</td>
</tr>
</tbody>
</table>
\[ \frac{C}{1/sqrt(\rho)} \]

\[ C \div 1/sqrt(\text{compressibility}) \]

\[ C = C(f) \quad \text{dispersion} \quad (<1\%) \]

\[ C = C(\text{Temp.}) \quad (<1\%) \]
<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>DENSITY Kg / m³</th>
<th>US SPEED m / s</th>
<th>Z Kg / m² · s · 10⁻⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR</td>
<td>1,2</td>
<td>330</td>
<td>0,0004</td>
</tr>
<tr>
<td>WATER (20 °C)</td>
<td>1000</td>
<td>1480</td>
<td>1,48</td>
</tr>
<tr>
<td>MERCURY</td>
<td>13600</td>
<td>1450</td>
<td>20</td>
</tr>
<tr>
<td>TISSUE (AVG)</td>
<td>1060</td>
<td>1540</td>
<td>1,63</td>
</tr>
<tr>
<td>LIVER</td>
<td>1060</td>
<td>1550</td>
<td>1,64</td>
</tr>
<tr>
<td>MUSCLE</td>
<td>1080</td>
<td>1580</td>
<td>1,70</td>
</tr>
<tr>
<td>FAT</td>
<td>952</td>
<td>1459</td>
<td>1,38</td>
</tr>
<tr>
<td>BONE</td>
<td>1912</td>
<td>4080</td>
<td>7,8</td>
</tr>
<tr>
<td>PZT</td>
<td>7650</td>
<td>3791</td>
<td>29</td>
</tr>
</tbody>
</table>
ACOUSTIC IMPEDANCE

$$Z = \rho \cdot c$$
\[ \begin{align*}
I_r &= I_i \cdot \alpha \\
I_t &= I_i - I_r = (1 - \alpha) I_r \\
\alpha &= \left( \frac{Z_1 - Z_2}{Z_1 + Z_2} \right)^2
\end{align*} \]
show
<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>DENSITY Kg / m³</th>
<th>US SPEED m / s</th>
<th>Z Kg / m² · s · 10⁻⁶</th>
</tr>
</thead>
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<tr>
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<td>0,0004</td>
</tr>
<tr>
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<td>1000</td>
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<td>1,48</td>
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</tr>
<tr>
<td>PZT</td>
<td>7650</td>
<td>3791</td>
<td>29</td>
</tr>
</tbody>
</table>
Nonspecular reflection. The scattered wave is emitted in all directions, shown here in two dimensions only.
# ABSORPTION

\[ I = I_0 e^{-\alpha x} \]

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>1 MHz</th>
<th>2 MHz</th>
<th>5 MHz</th>
<th>10 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIW</td>
<td>0,25</td>
<td>0,06</td>
<td>0,01</td>
<td>-</td>
</tr>
<tr>
<td>WATER</td>
<td>1360</td>
<td>340</td>
<td>54</td>
<td>14</td>
</tr>
<tr>
<td>BLOOD</td>
<td>17</td>
<td>8,5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>BONE</td>
<td>0,2</td>
<td>0,1</td>
<td>0,04</td>
<td>-</td>
</tr>
<tr>
<td>BRAIN</td>
<td>3,5</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>FAT</td>
<td>5</td>
<td>2,5</td>
<td>1</td>
<td>0,5</td>
</tr>
<tr>
<td>LIVER</td>
<td>3</td>
<td>1,5</td>
<td>0,5</td>
<td>-</td>
</tr>
<tr>
<td>MUSCLE</td>
<td>1,5</td>
<td>0,75</td>
<td>0,3</td>
<td>0,15</td>
</tr>
<tr>
<td>TISSUE (AVG)</td>
<td>4,3</td>
<td>2,1</td>
<td>0,86</td>
<td>0,43</td>
</tr>
</tbody>
</table>

HVL in cm
\[ I_r = I_i \cdot \alpha \]

\[ I_t = I_i - I_r = (1 - \alpha) I_r \]

\[ \alpha = \left( \frac{Z_1 - Z_2}{Z_1 + Z_2} \right)^2 \]
pression

PRF = \frac{1}{PRP} = \frac{c}{2d}
show
time = space / speed

t = \frac{2d}{c}

PRP \text{ min} = \frac{2d}{c}

PRF \text{ max} = \frac{c}{2d}
show
trasduttore

fascio

fascio
Stesso trasduttore per emettere US e ricevere gli echi
Damping

dynamic by backing
Dynamic damping
Q = mechanical coefficient

\[ Q = \frac{\text{Energy stored per cycle}}{\text{Energy lost per cycle}} \]

\[ Q = \frac{\text{Center frequency}}{\text{bandwidth}} \]
High Q

Low Q
Narrow frequency band

Wide frequency band
Narrow frequency band

Wide frequency band

Diagram showing two curves: one representing a narrow frequency band with a sharp peak, and another representing a wide frequency band with a broader peak.
Point objects
Map3
170 dB/C 3
Persistenza Media
Ott. 2D:Ris
Freq Imm:Alta

zoom
Lateral resolution

Axial resolution

Lateral resolution
Poor Axial SR

Good Axial SR
\[ d = \frac{a^2}{4 \lambda} \]

\[ \sin \vartheta = \frac{0.6 \lambda}{\sqrt{a}} \]
show
tecnologia a banda larga

technologia a multifrequenza
show
pressione

intensità dell’eco

tempo → profondità
show
input to demodulator

rectifier output
rectifier output

(b)

full wave

V

V

t

t

half wave

filter output

(c)

V

V

t

t

Full-wave and half-wave demodulation.
4 A-scan instrument block diagram.
Some transducers → 1 line

How to obtain several lines?

PROBE
PROBES

linear
convex
sector
special (EE, EL, 3D..)
lineare
convex
sector
Mechanical Transducer

- Stiff rotating drive shaft
- External guidewire
- Mechanical design makes tracking difficult and limited
- Catheter vibration causes risk of arterial spasm

Solid-State Transducer

- No moving parts
- No rotating drive shaft
- Central guidewire lumen
- Coaxial design enhances trackability and pushability

Visions® Five-64 F/X Intravascular Ultrasound Catheter

Guide Wire 0.014 inches
Outer diameter 2.9F
High frequency sound waves echo off vessel walls and are sent back to system.

System electronics process the signal.
vector
intensità dell'eco

rumore

Amplificazione

TGC

profondità
Clipping. Signal before (a) and after (b) clipping.
Windowing (dynamic range control). Signal before (a) and after (b) windowing.
A-scan display with TGC off (a) and on (b).
Figure 5.7 Demodulated echo pulses from similar reflectors in an attenuating medium.
adjustable by operator
TGC block diagram and control voltage waveform.
A-scan display with TGC off (a) and on (b).
Guadagno

Profondità

guadagno generale
Zona in cui studiare l'uniformità
Uniformità non buona
Uniformità buona
Transducer elements

selected elements

beam
short focus

long focus
FOCALIZZAZIONE ELETTRONICA

Annular array

Multiple zone focussing
Electronic focusing in transmission—block diagram.
Electronic focussing in reception—block diagram.
Focussing by (a) lens, (b) transducer shaping and (c) concave mirror.
Resultant beam pattern from both mechanical width focusing and electronic length focusing.
Mechanical focusing of an array in the width direction using an acoustic lens or curved crystal elements.
FRAME RATE (FR)

FR = \frac{PRF}{\text{numero di linee} \times \text{numero di fuochi}}

PRF \quad \text{n. linee} \quad \text{n. fuochi} \quad \text{RISOLUZIONE} \quad \text{RISOLUZIONE} \quad \text{PROFONDITÀ’}
1 solo fuoco
2 fuochi
4 fuochi
show
The curvilinear array

field of view

The phased array probe

beam

limit of selector scan
show
<table>
<thead>
<tr>
<th>Reflecting/Scattering structure</th>
<th>Relative echo amplitude (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft tissue–gas</td>
<td>0</td>
</tr>
<tr>
<td>Soft tissue–bone</td>
<td>-20</td>
</tr>
<tr>
<td>Fat–muscle</td>
<td>-40</td>
</tr>
<tr>
<td>Liver</td>
<td>-65</td>
</tr>
<tr>
<td>Brain</td>
<td>-100</td>
</tr>
</tbody>
</table>
Block diagram of B-scanner with scan converter.
Additions to the circuit of a mechanical scanner to allow electronic focussing in transmission and reception.
Linear array scanner block diagram.
Phased array scanner block diagram.
La regolazione del TGC deve determinare un’immagine omogenea del target.
Scelta del numero di fuochi

Scelta posizione dei fuochi

Scelta della profondità max (PRF)

Zoom in tempo reale
- **trackball**
- **misure su immagine**
- **=“Enter”**
- **salva immagine**
  - (HD, magneto ottico, ecc)
- **stampa immagine**
  - (carta, pellicola, ecc)
- **freezing immagine**
- **softkeys**
Zona morta
<table>
<thead>
<tr>
<th>reflectors</th>
<th>reflector positions at successive transmitter pulses</th>
</tr>
</thead>
<tbody>
<tr>
<td>stationary</td>
<td>---</td>
</tr>
<tr>
<td>moving</td>
<td>---</td>
</tr>
<tr>
<td>stationary</td>
<td>---</td>
</tr>
<tr>
<td>pulse No.</td>
<td>1</td>
</tr>
</tbody>
</table>

M-mode display

- Stationary reflectors at successive transmitter pulses.
- M-mode display showing different positions for stationary and moving reflectors.
Display during sweep mode (a) and scroll mode (b).
M-mode scanner block diagram.