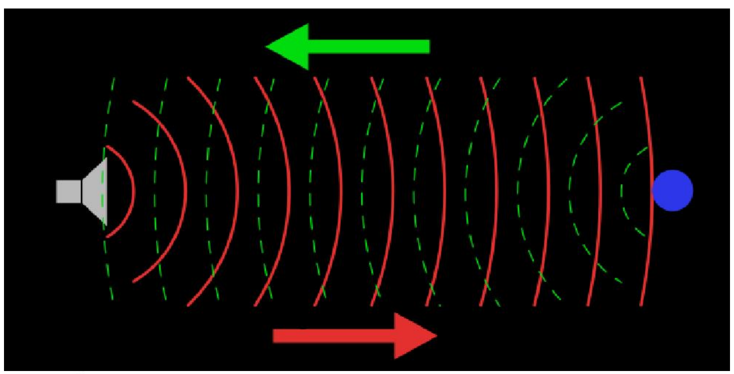
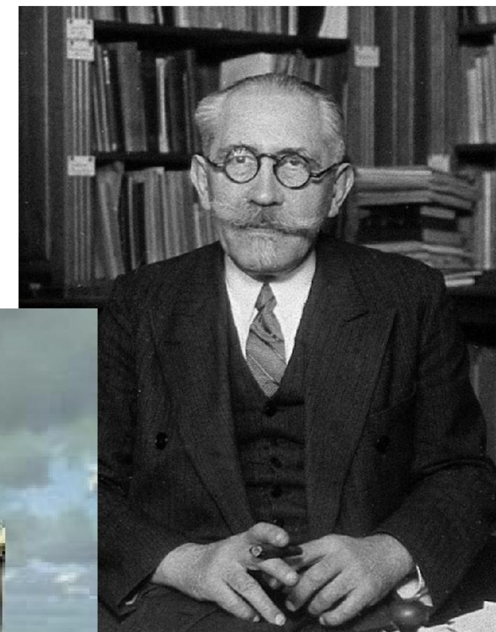
Fizikaultrazvucnemedicine

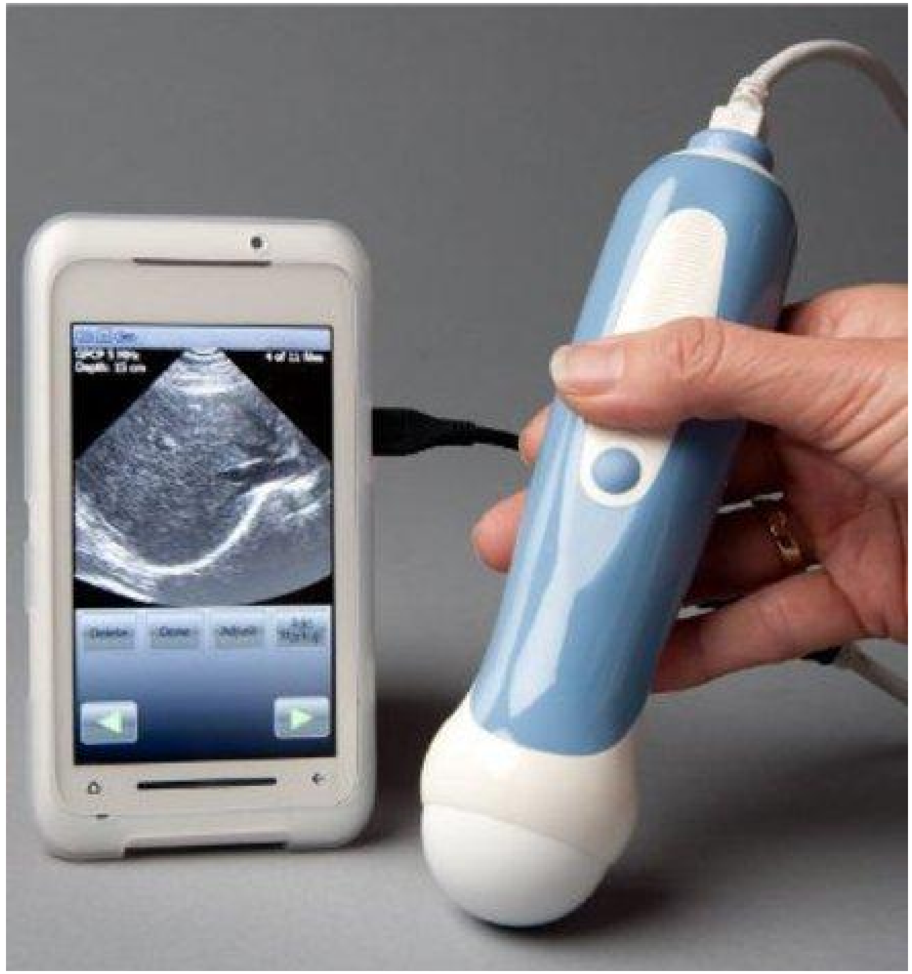
POVIJEST ULTRAZVUKA

- Iako je ultrazvuk otkriven 12 godina prije X-ray zraka (1883. god), njegova prva praktična primjena zabilježena je tijekom Prvog svjetskog rata.

- 1915 godine, potaknuti potonućem Titanika fizičar Paul Langevin dobio je nalog da osmisli način detektiranja objekata na dnu mora.







RAZVOJ ULTRAZVUKA

- neinvazivan
- dobra vizualizacija
- relativno jednostavno rukovanje

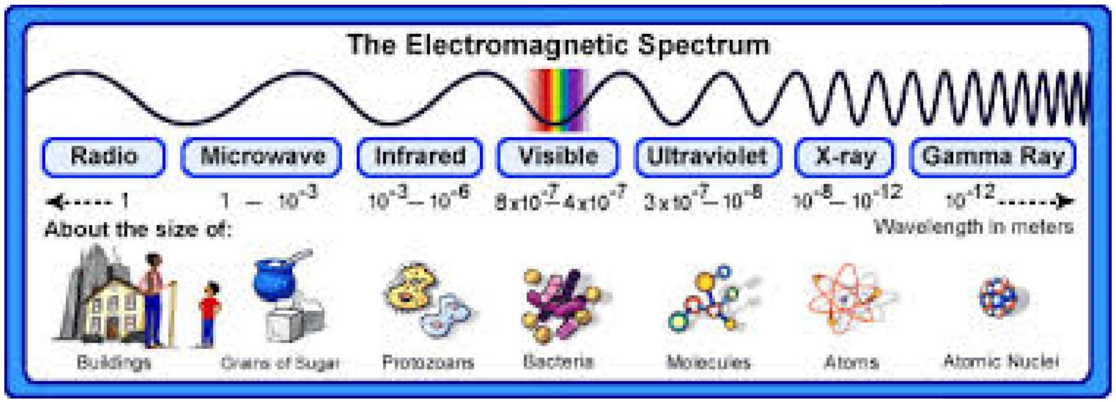
Što je ULTRAZVUK?

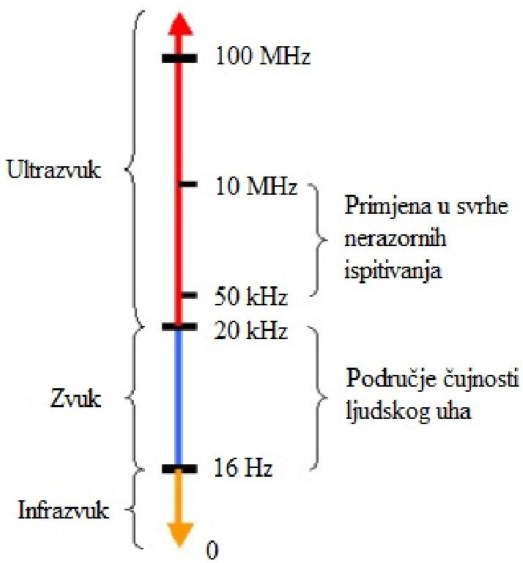
- Zvuk sa frekvencijama iznad gornje granice čujnosti za ljudsko uho – 20kHz do 10GHz

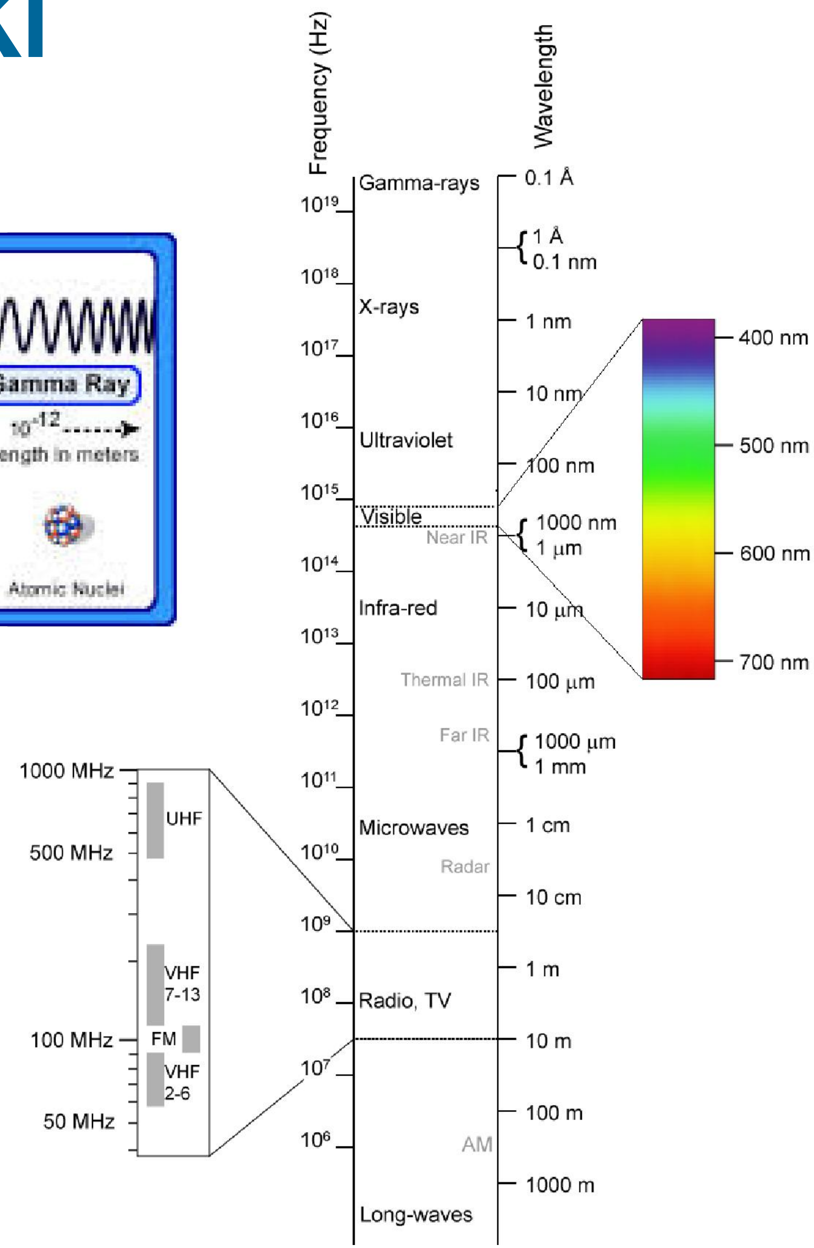
- NDT ispitivanja – 0,5 MHz - 10MHz (20MHz)

- MEDICINSKA DIJAGNOSTIKA – od 2MHz do 10MHz

ELEKTROMAGNETSKI SPEKTAR







Što je ULTRAZVUK?

Vrsta mehaničkih valova koji se šire od izvora kroz homogene materijale koji se kontrolira (ispituje).

Za širenje mehaničkih valova potrebno je sredstvo tj. MEDIJ kroz koji će pripagirati.

Ultrazvučni valovi se odbijaji ukoliko dođu na granicu dva materijala koji imaju različita AKUSTIČKA SVOJSTVA.

Što je VAL?

Akustički poremećaj koji se širi prostorom i prenosi energiju!

- Karakteristične veličine vala su:
  - ❖FREKVENCIJA ... *f*
  - ❖VALNA DULJINA ... *ʎ*
  - ❖BRZINA PROPAGACIJE ... *v*
  - ❖AMPLITUDA ... *A*

v=*ʎ·f*

VALOVI

- LONGITUDINALNI VAL - čestice titraju u smjeru propagiranja vala a može se širiti kroz:
  - Čvrsta tijela
  - Tekućine
  - Plinovi

Medicinska dijagnostika

NDT ispitivanja

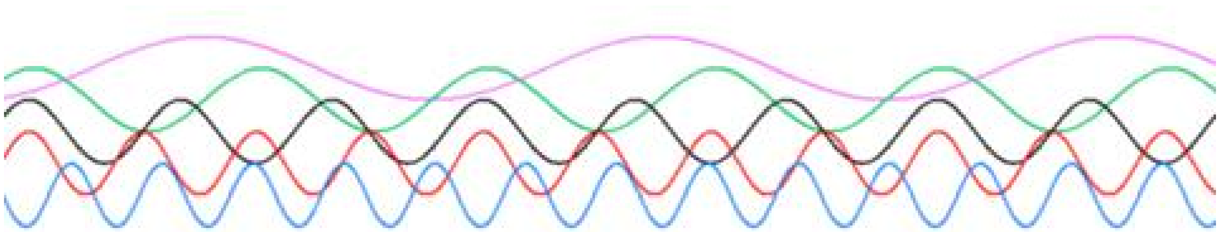
- TRANSVERZALNI VAL - čestice titraju okomito na smjer propagiranja vala:
  - Čvrsta tijela

Medicinska dijagnostika ✗

NDT ispitivanja

FREKVENCIJA

- Za određivanje frekvencije događanja broj događaja koji promatramo u određenom vremenskom intervalu se podijeli s trajanjem tog vremenskog intervala.
- Prema SI sustavu definira se kao broj titraja u jednoj sekundi [Hz]



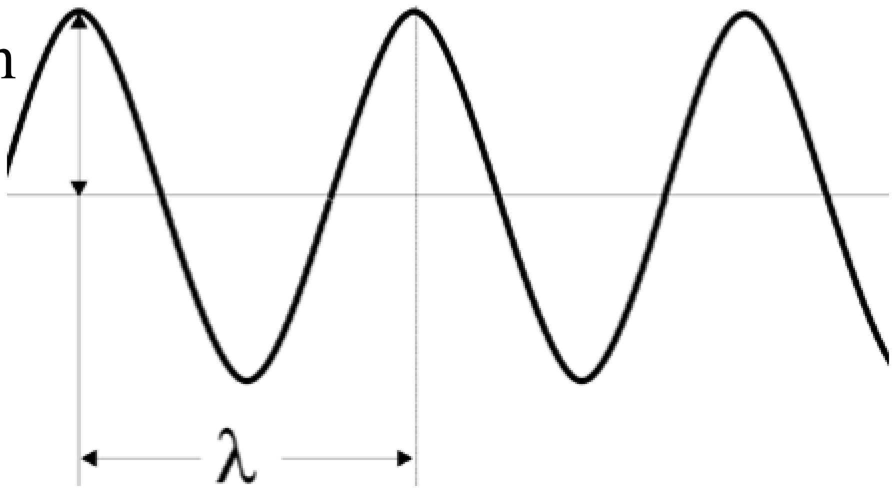
Frekvencija ima INVERZNU vezu prema pojmu valne duljine.

VALNA DULJINA

- Udaljenost dviju najbližih točaka vala koje titraju u istoj fazi.

Ljudsko uho čuje zvukove u području valnih duljina 20m-1,7cm

$$\lambda = \frac{v}{f}$$



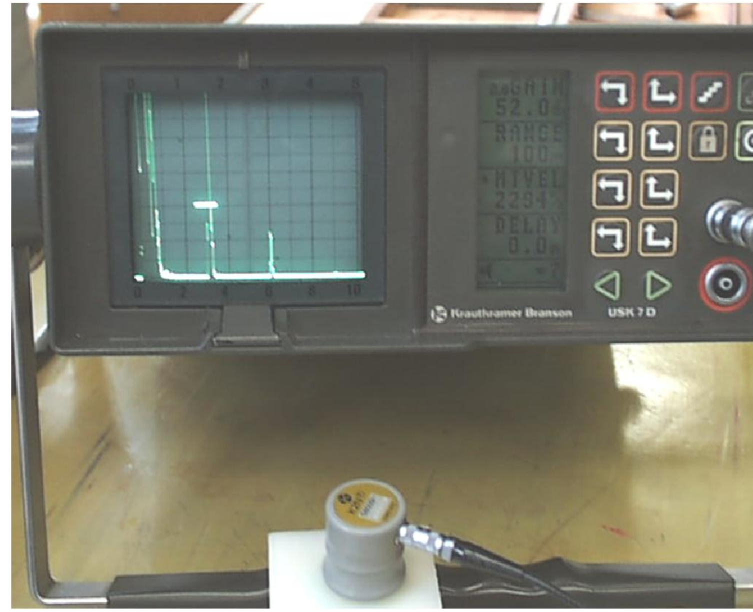
BRZINA PROPAGACIJE

- Brzina širenja ultrazvuka različita je za različite tvari, a ovisi i elastičnim svojstvima materijala, te se mijenja sa promjenom temperature.
- Brzina propagacije ne ovisi o frekvenciji ultrazvuka

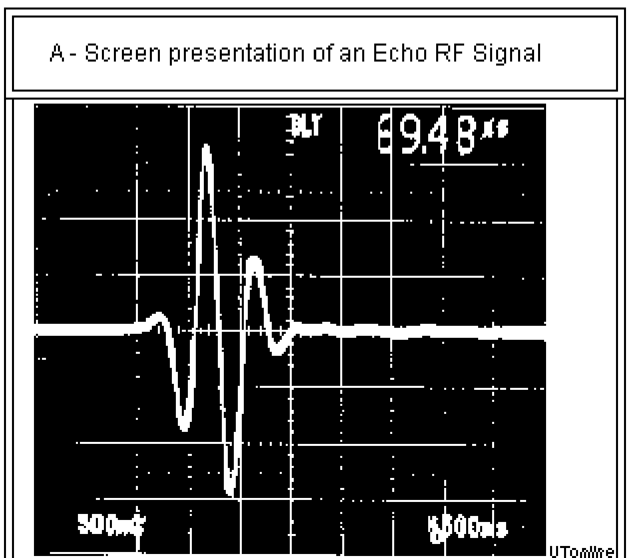
MATERIJAL	v [m/s]
Zrak pri nirmalnom tlaku	330
Voda (20°C)	1430
Ricinusovo ulje	1500
Polietilen	2000
Mjed	4490
Aluminij	6400
Čelik	5980

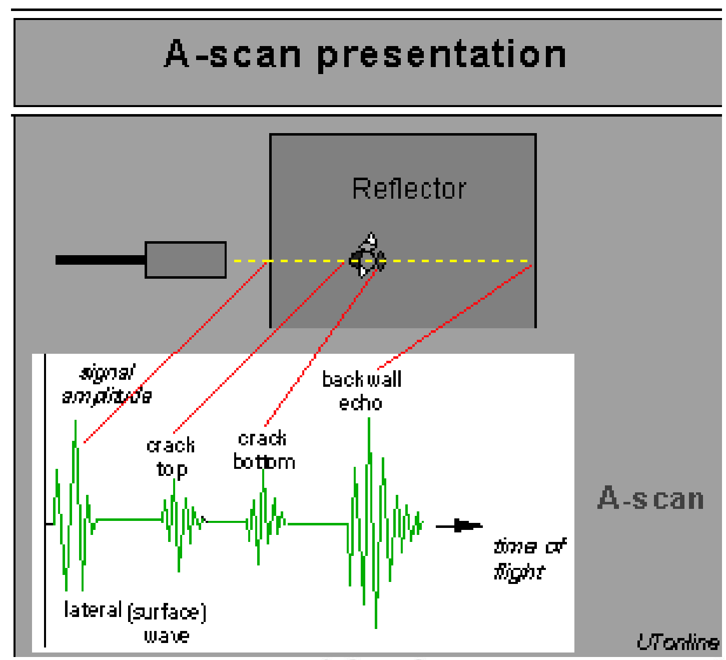
Ultrazvučni sustav

Odziv ultrazvučnih impulsa od granice dvaju sredstava različitih akustičkih impedancija.

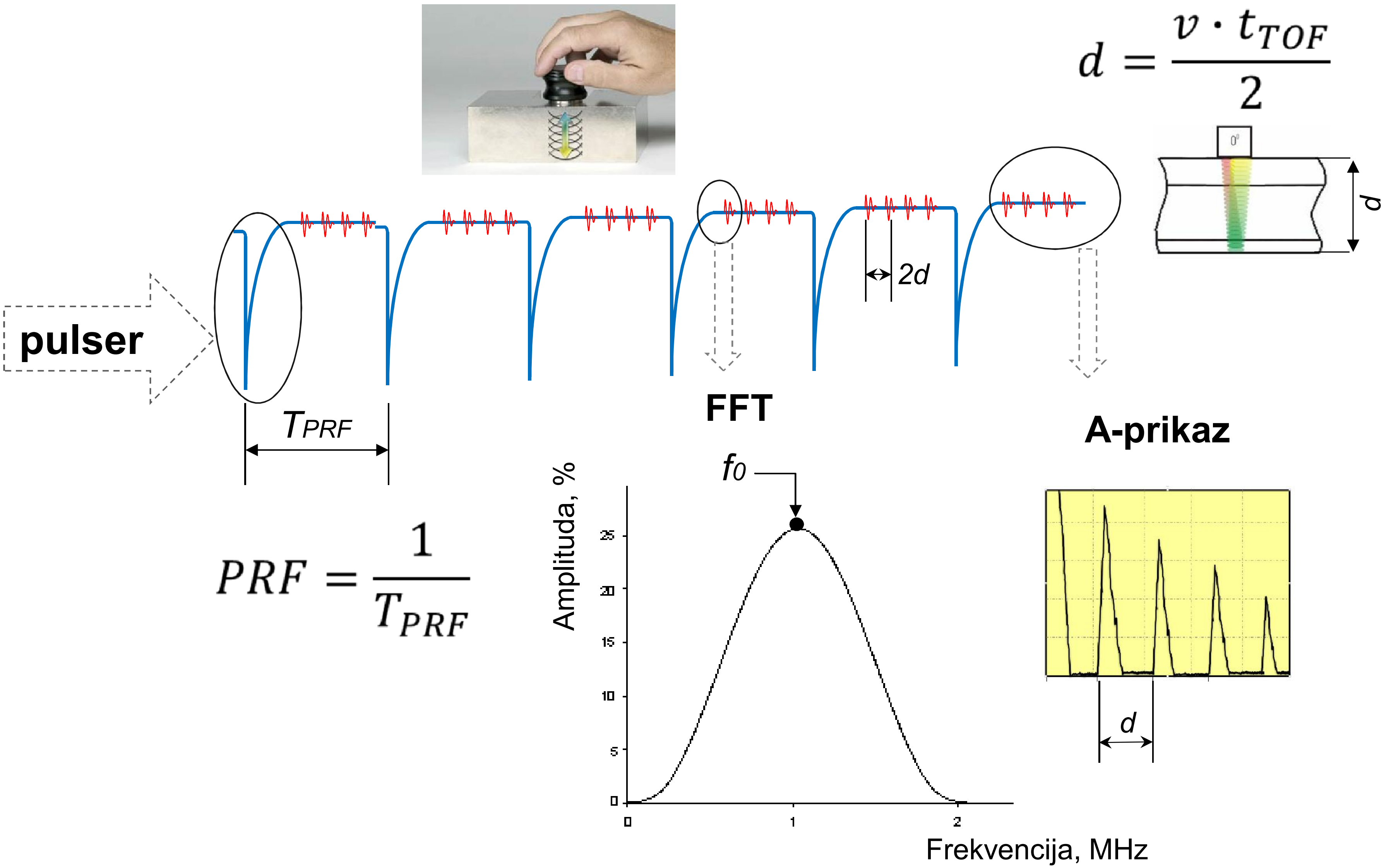


TERAPEUTSKI ULTRAZVUK





PRF i FREKVENCIJA



$$d = \frac{v \cdot t_{TOF}}{2}$$

$$PRF = \frac{1}{T_{PRF}}$$

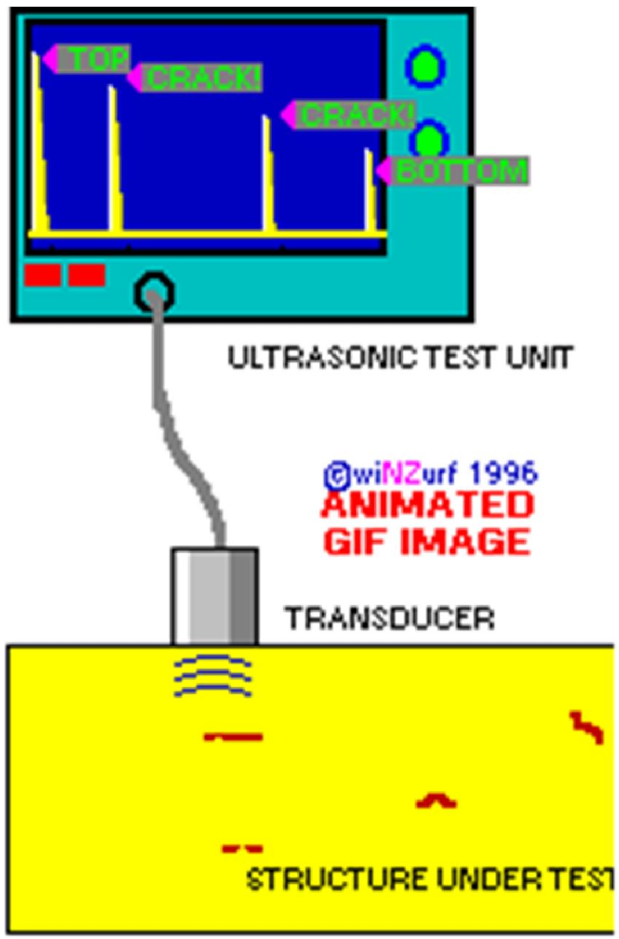
AKUSTIČNA IMPEDANCIJA

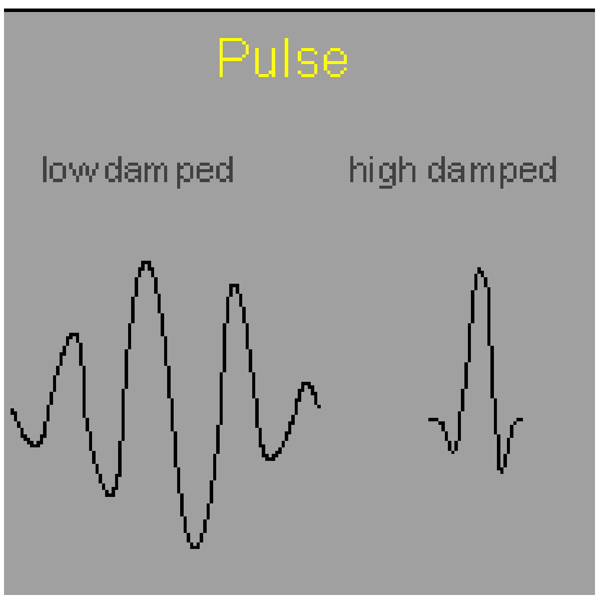
- Specifična akustična impedancija dolazi do izražaja pri širenju ultrazvuka kroz medij, pri prijelazu ultrazvuka iz izvora u pretvornik i obrnuto te pri prijelazu ultrazvuka iz jednog medija u drugi.
- Ovisi isključivo o svojstvima sredstva, gustoći materijala i brzini ultrazvučnih valova u određenom materijalu

MATERIJAL	Z Ns/m^3 10^6
zrak	0,0004
voda	1,49
mozak	1,58
kost lubanje	7,8
krv	1,61
jetra	1,65

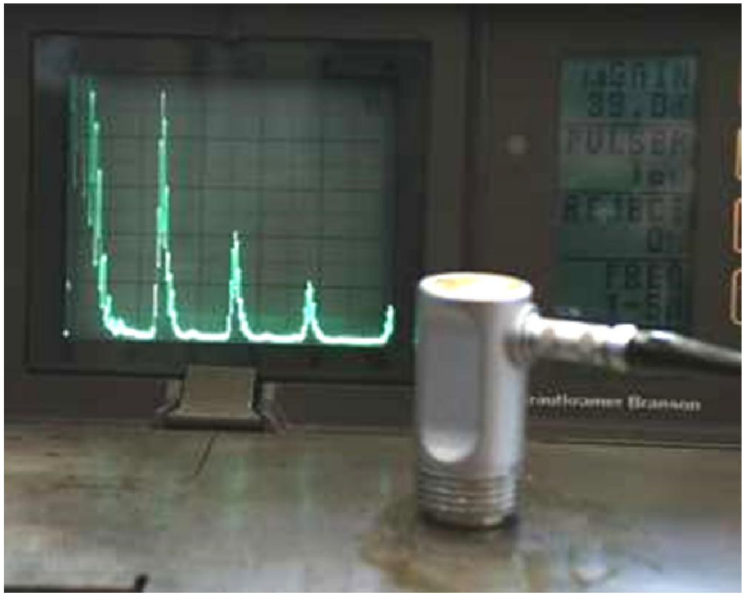
$$Z = \rho \cdot v$$

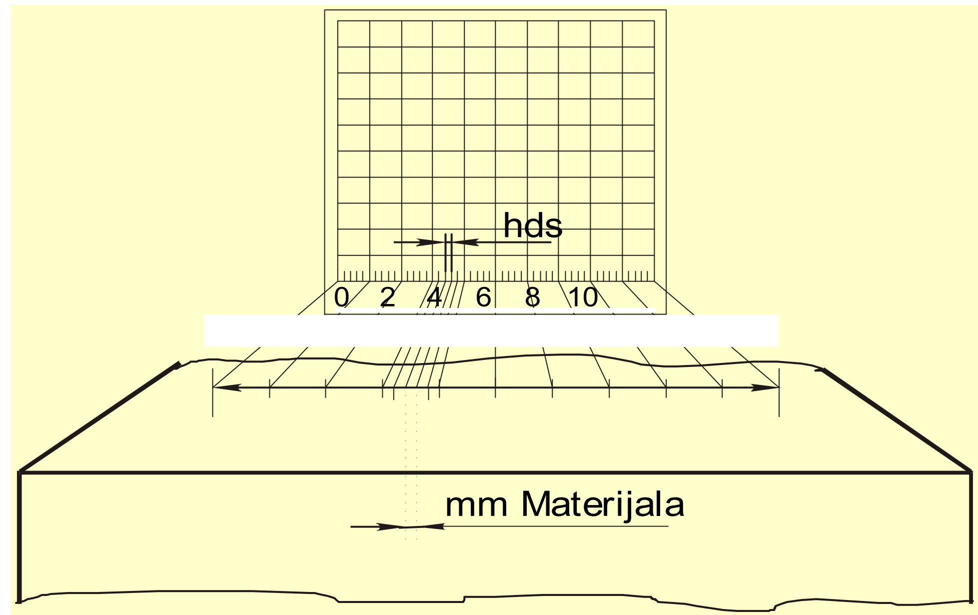
Ultrazvučna dijagnostika - načelo





Parametri ultrazvučnih odziva

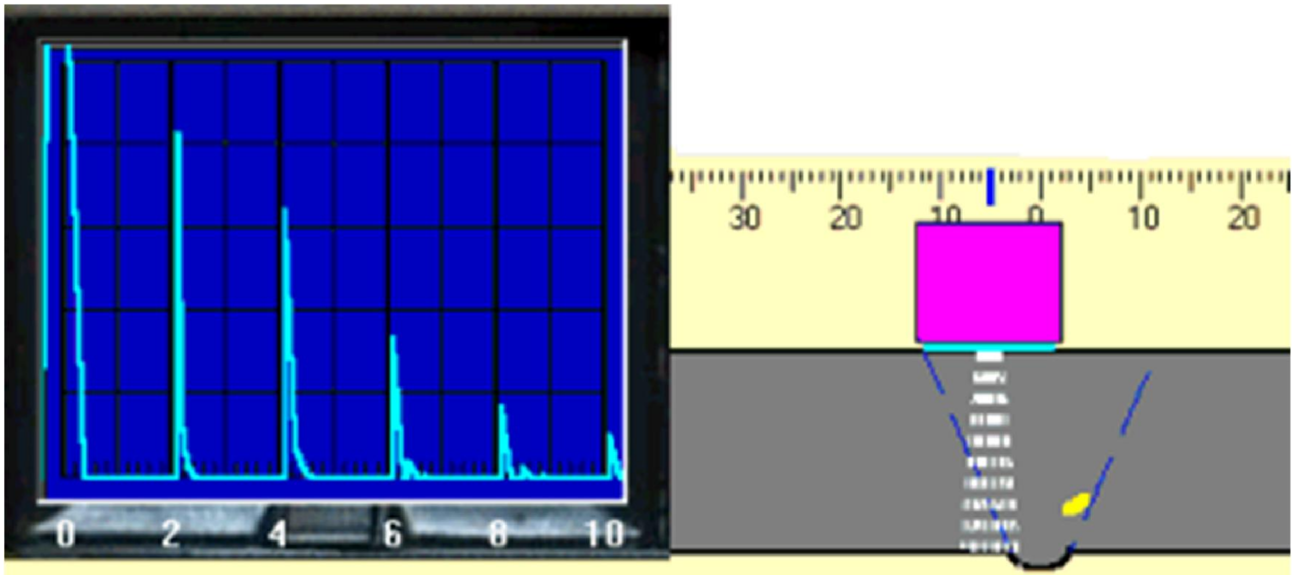




Uređaji s **A-prikazom**

- vremenska os ⇨ “vrijeme proleta” (TOF) ⇨ udaljenost reflektora
- amplituda signala ⇨ energija reflektiranog impulsa ⇨ veličina reflektora

„skeniranje” & odzivi

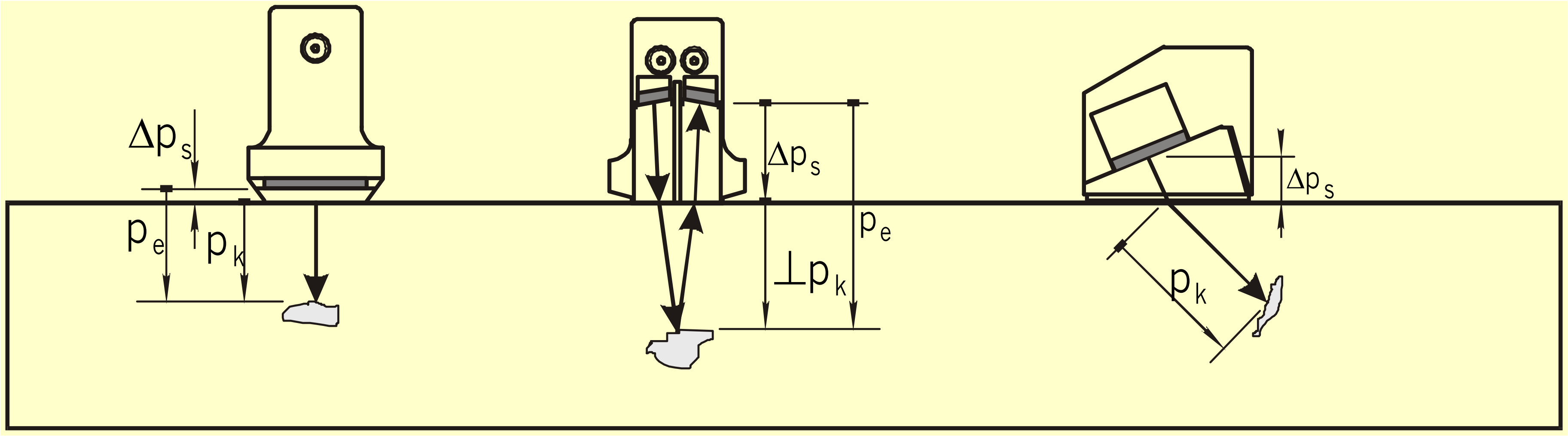


- “prolet” UZ impulsa ! … ultrazvučni snop - volumen
- pojave na površini reflektora ... refleksija, transmisija, geometrija (kutovi)

*

Vrste ultrazvučnih sondi

ravna sonda, **dvostruka sonda,** **kutna sonda**



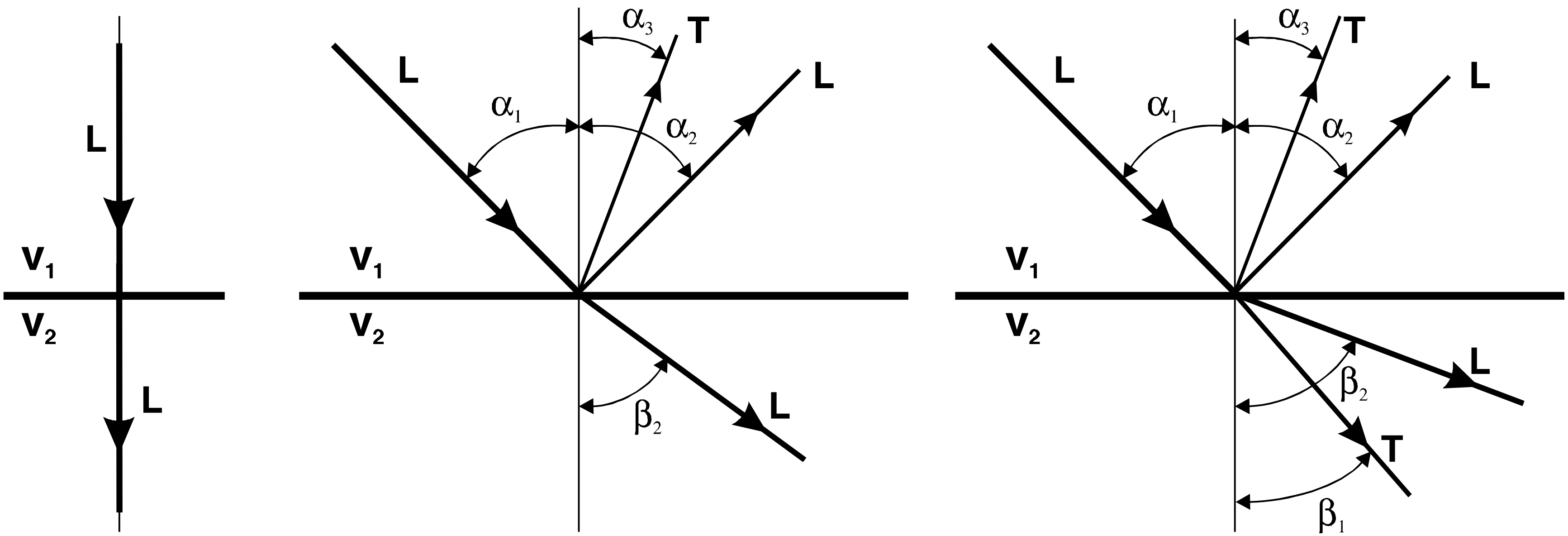
L-val
(T-val)

L i T-val

T-val
(L-val)

Snell-ov zakon loma

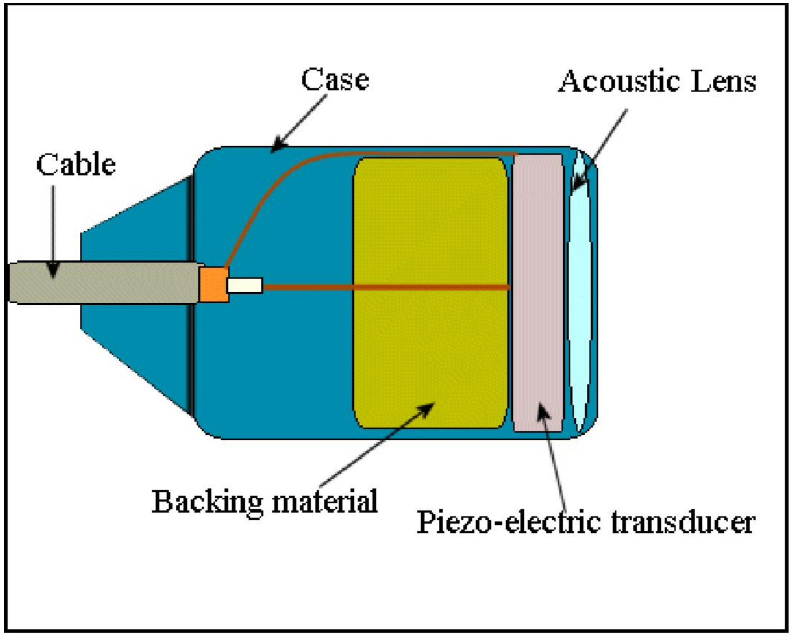
Konverzija: gornji i donji kritični kut

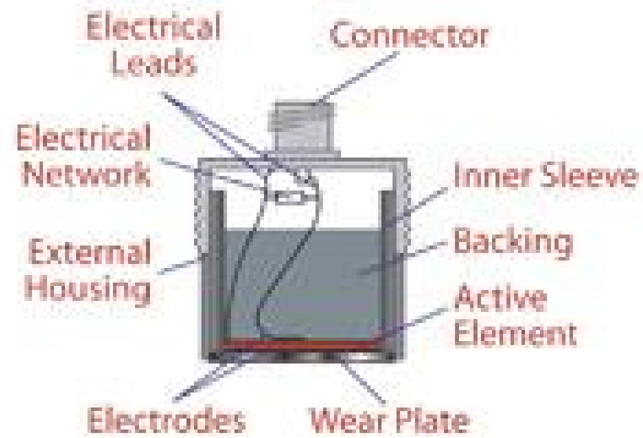


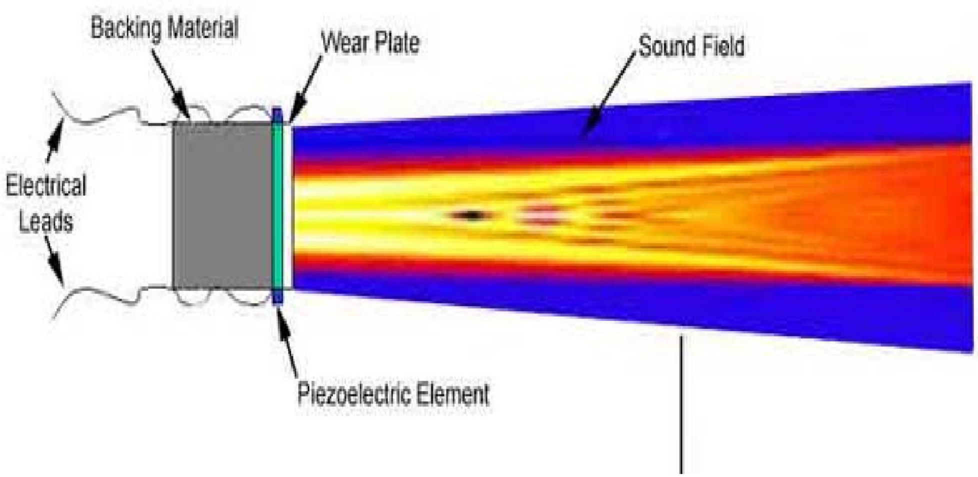
⇨ $$\frac{\sin\alpha_1}{v_{1L}} = \frac{\sin\alpha_2}{v_{1L}} = \frac{\sin\alpha_3}{v_{1T}} = \frac{\sin\beta_1}{v_{2T}} = \frac{\sin\beta_2}{v_{2L}}$$ ➲ $$\frac{\sin\alpha}{\sin\beta} = \frac{v_{1L,T}}{v_{2L,T}}$$

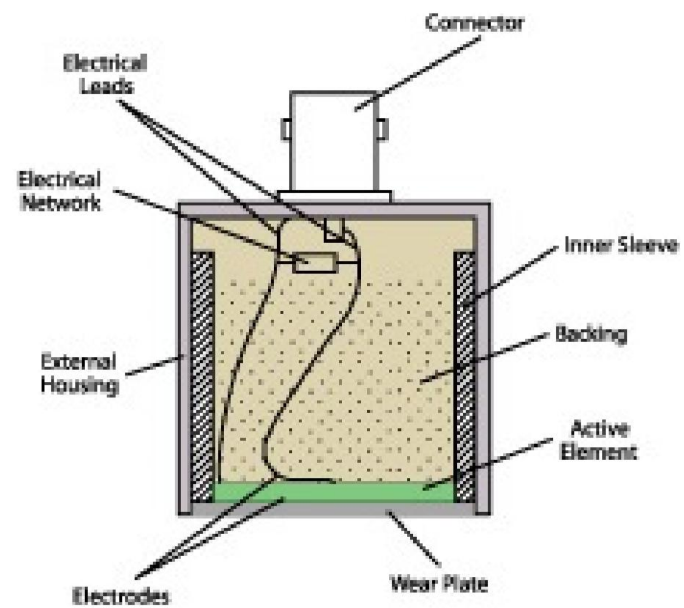
pri čemu je $v_1 \neq v_2$

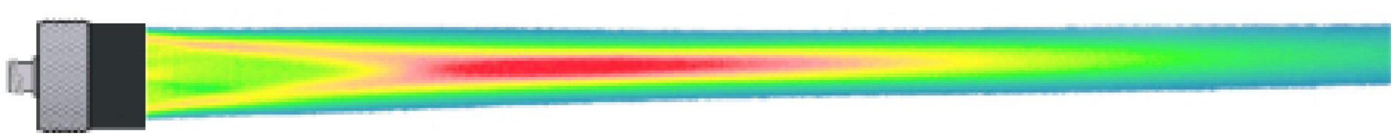
*


Case
Acoustic Lens
Cable
Backing material
Piezo-electric transducer


Electrical Leads
Connector
Electrical Network
Inner Sleeve
External Housing
Backing
Active Element
Electrodes
Wear Plate

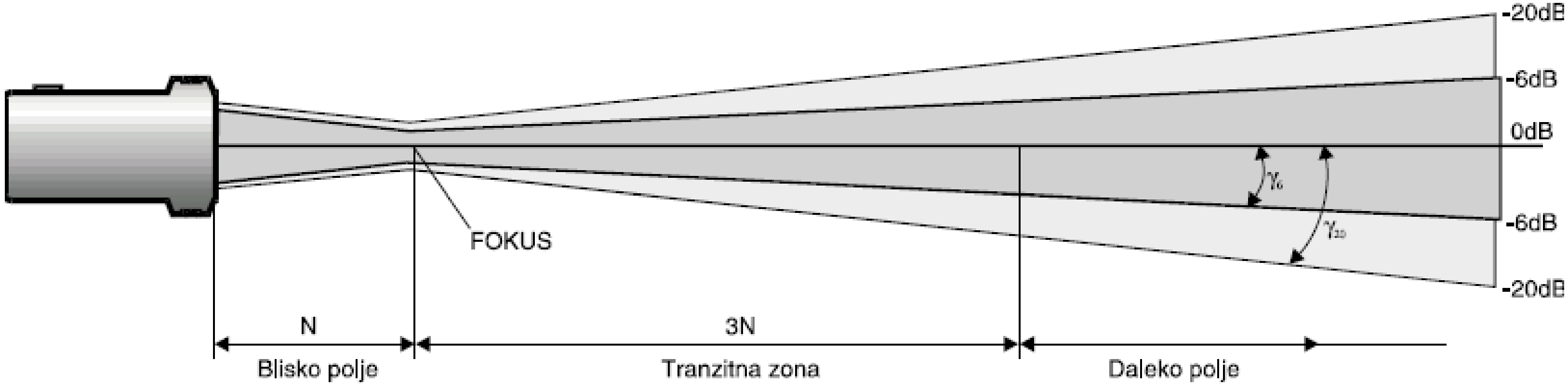

Backing Material
Wear Plate
Sound Field
Electrical Leads
Piezoelectric Element


Connector
Electrical Leads
Electrical Network
Inner Sleeve
Backing
External Housing
Active Element
Electrodes
Wear Plate



Ultrazvučne sonde - parametri

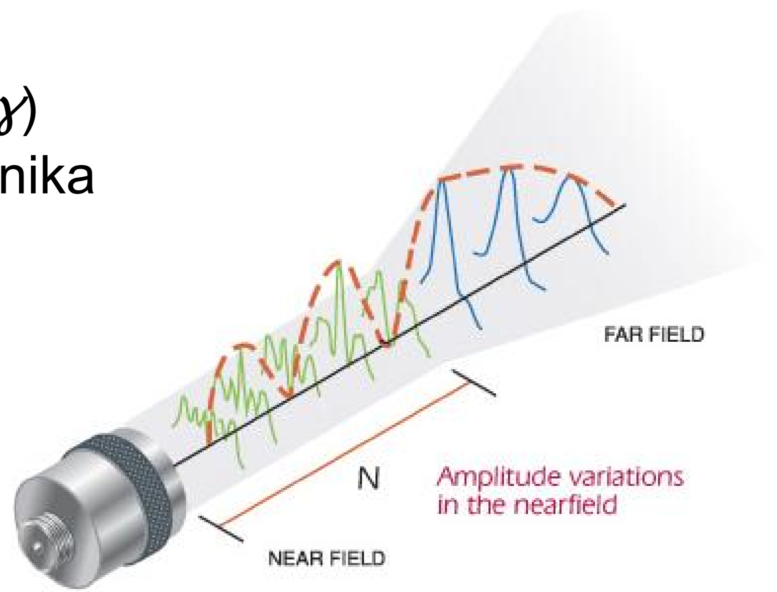
- prostorna distribucija UZ polja u mediju – gometrija UZ snopa



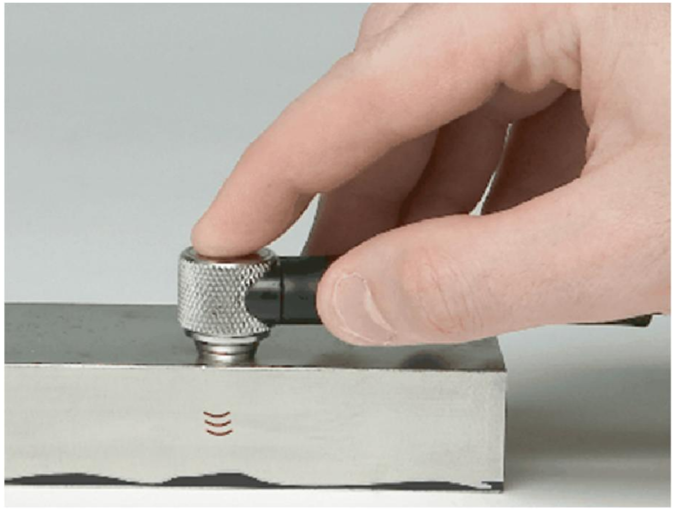
- blisko polje (N) i kut divergencije (γ) ovise o veličini i frekvenciji pretvornika

$$N = \frac{D^2}{4\lambda} \qquad N = \frac{D^2 f}{4v}$$

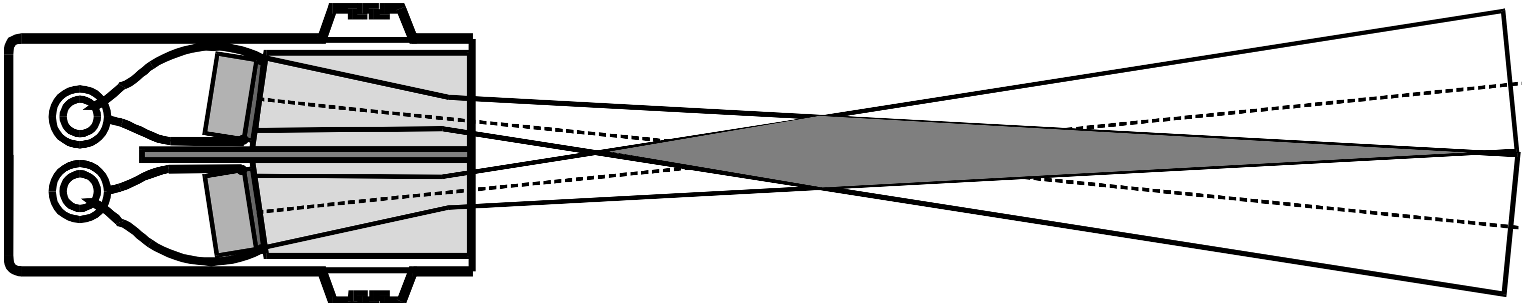
$$\sin\gamma_6 = 0{,}51\left(\frac{\lambda}{D}\right)$$

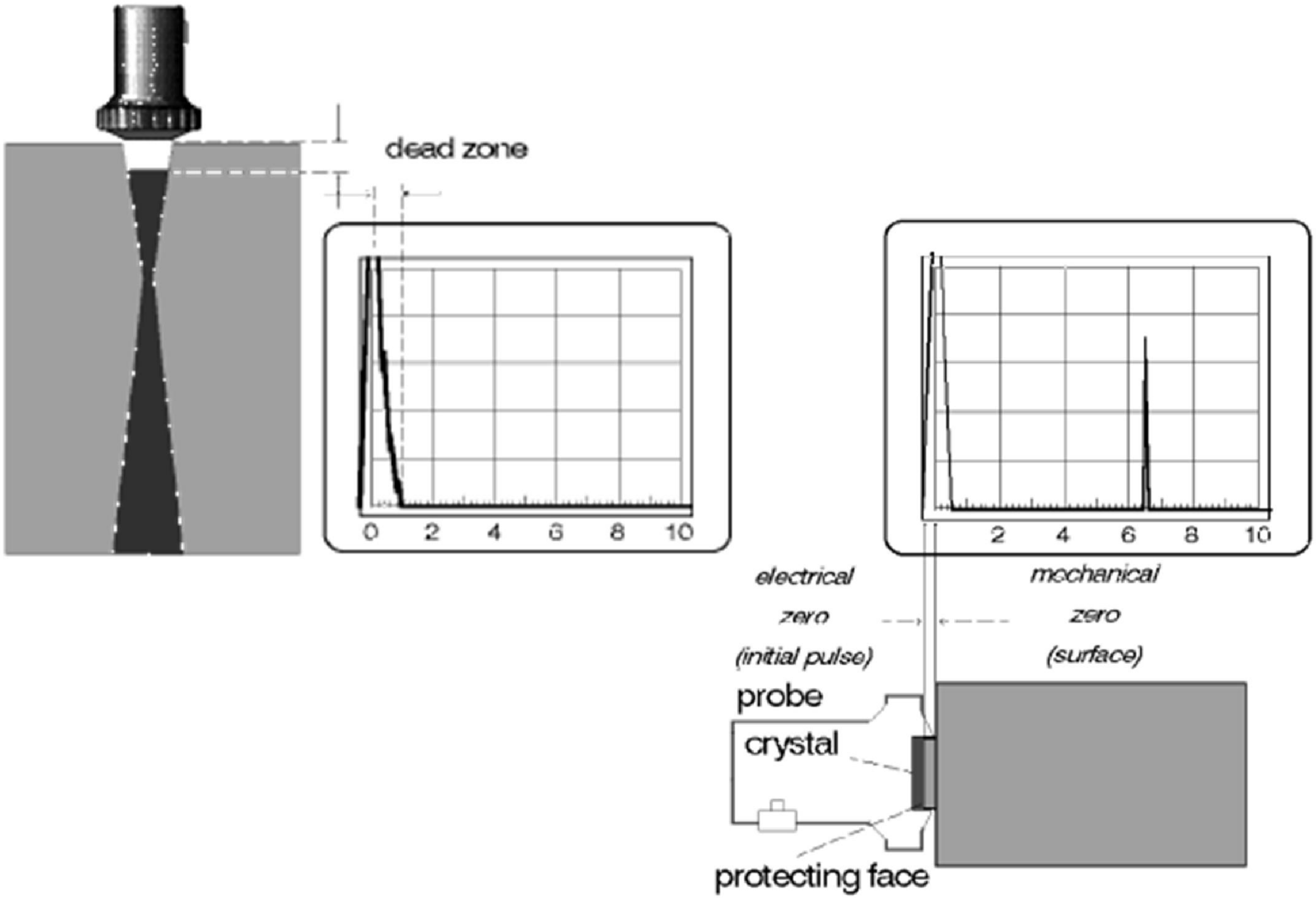


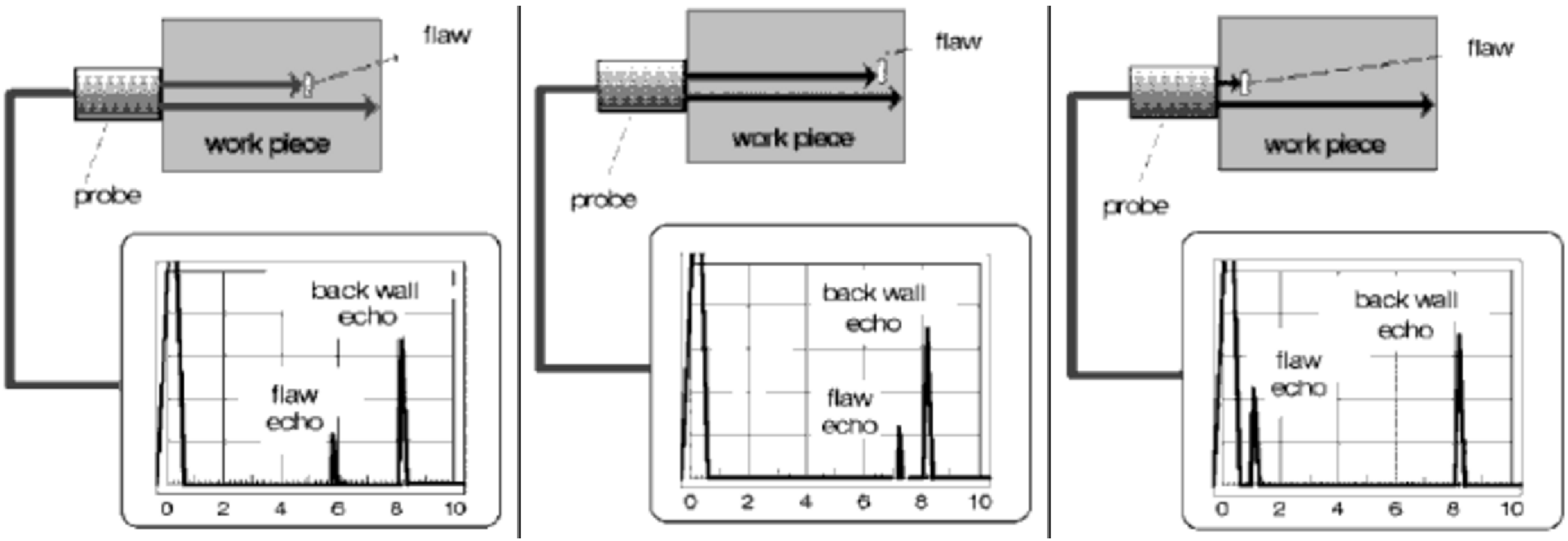
Ultrazvučne sonde - parametri

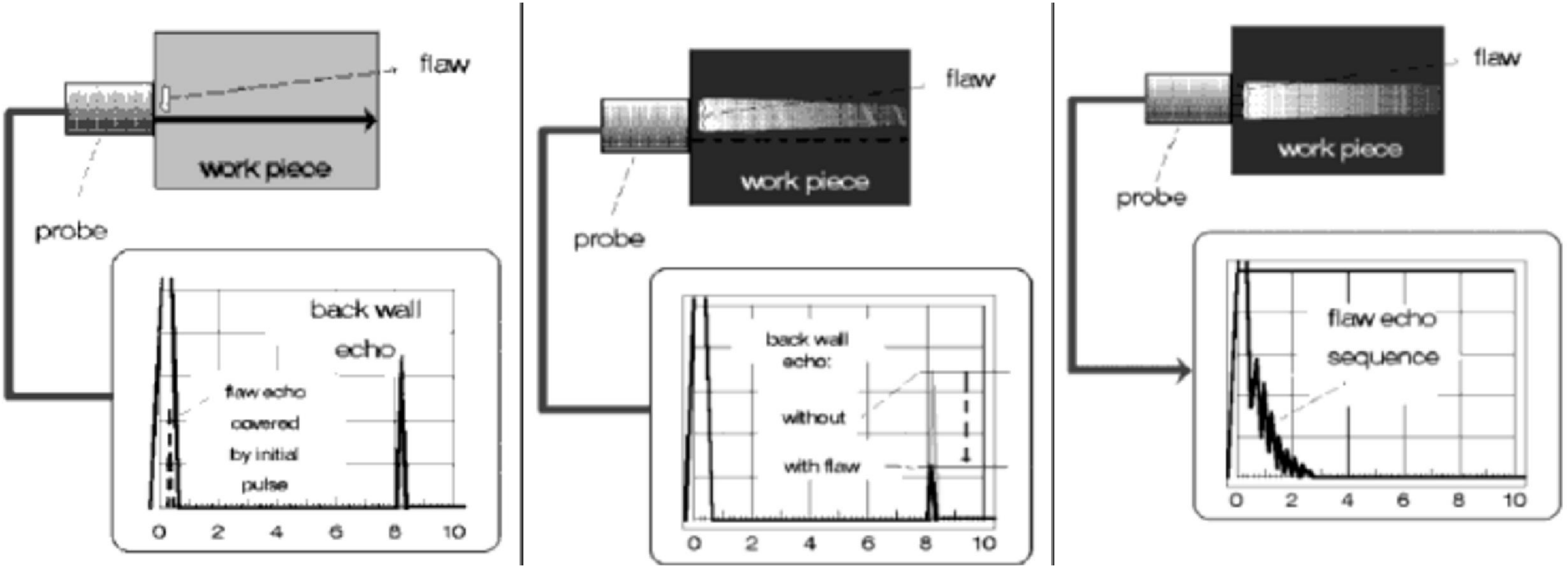


- prostorna distribucija UZ polja dvostruke sonde
- radno područje dvostruke sonde



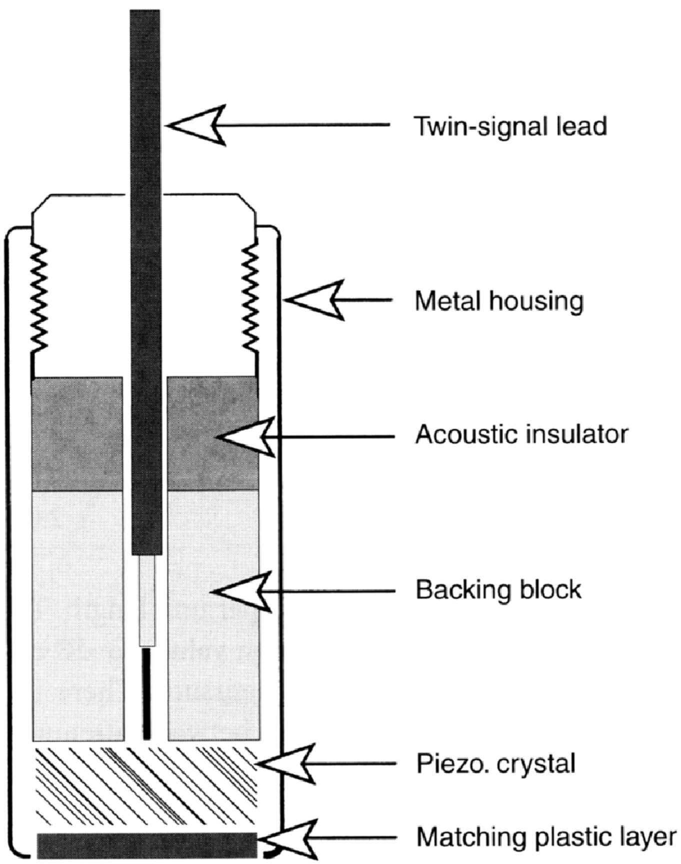

dead zone
0
2
4
6
8
10
2
4
6
8
10
electrical
zero
(initial pulse)
mechanical
zero
(surface)
probe
crystal
protecting face

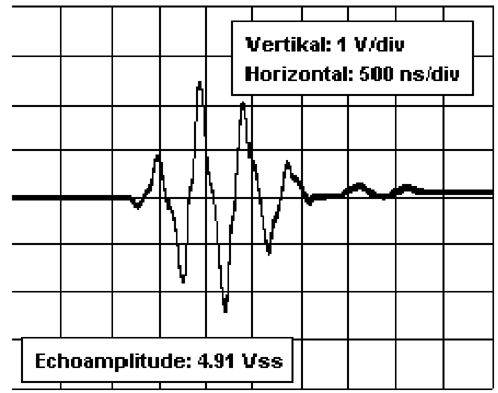

flaw
work piece
probe
back wall
echo
flaw
echo
0
2
4
6
8
10
flaw
work piece
probe
back wall
echo
flaw
echo
0
2
4
6
8
10
flaw
work piece
probe
back wall
echo
flaw
echo
0
2
4
6
8
10

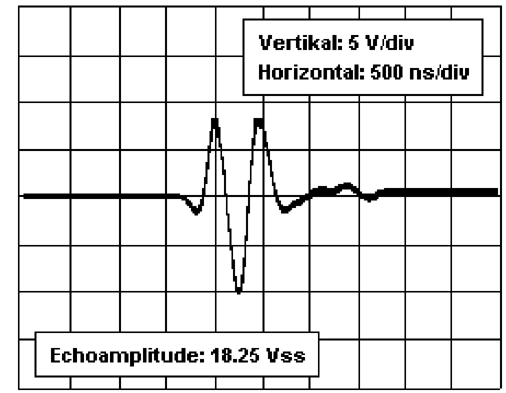


flaw
work piece
probe
back wall
echo
flaw echo
covered
by initial
pulse
0 2 4 6 8 10
flaw
work piece
probe
back wall
echo:
without
with flaw
0 2 4 6 8 10
flaw
work piece
probe
flaw echo
sequence
0 2 4 6 8 10

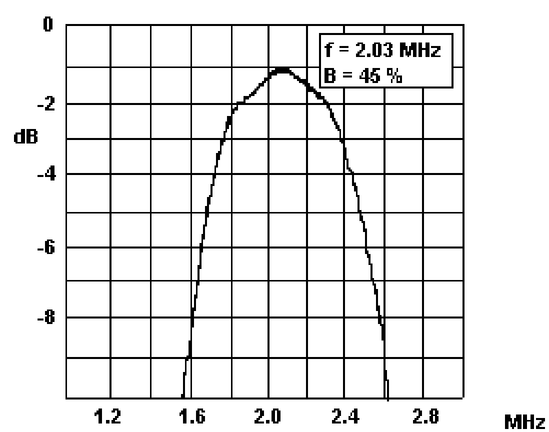
Frekvencijska karakteristika UZ impulsa, tj. sonde/pretvornika

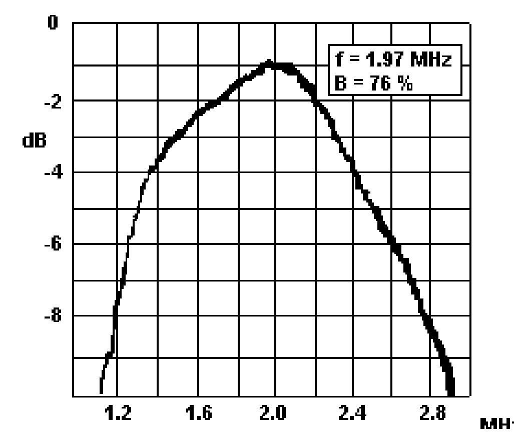


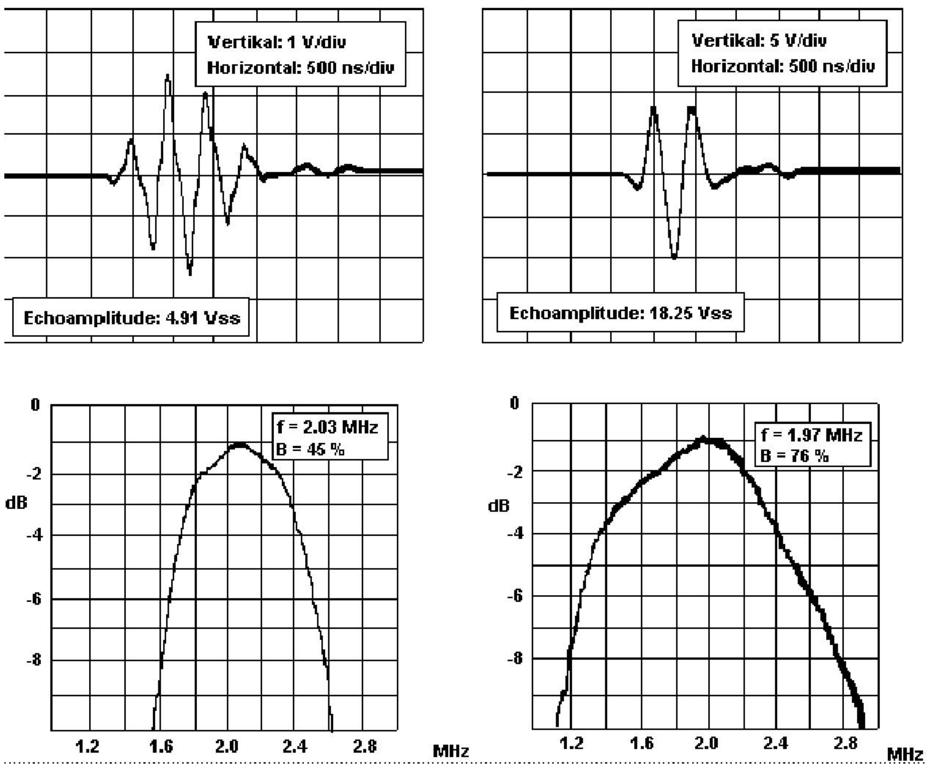


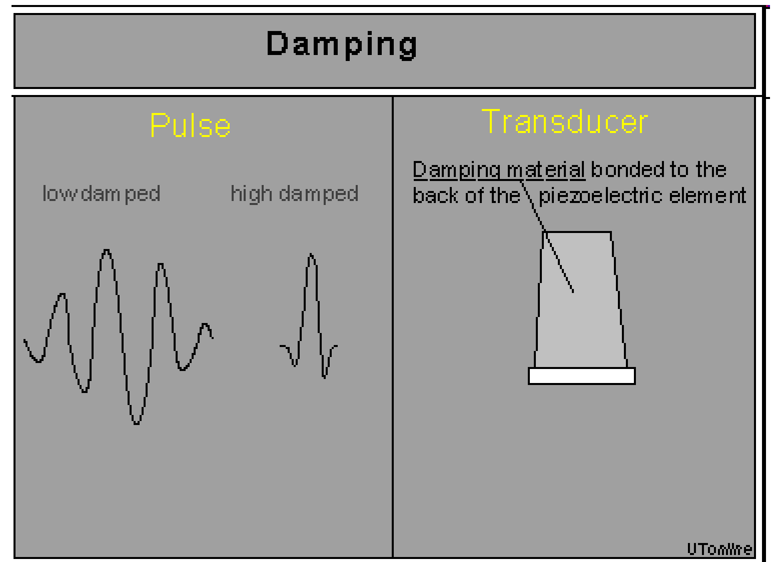


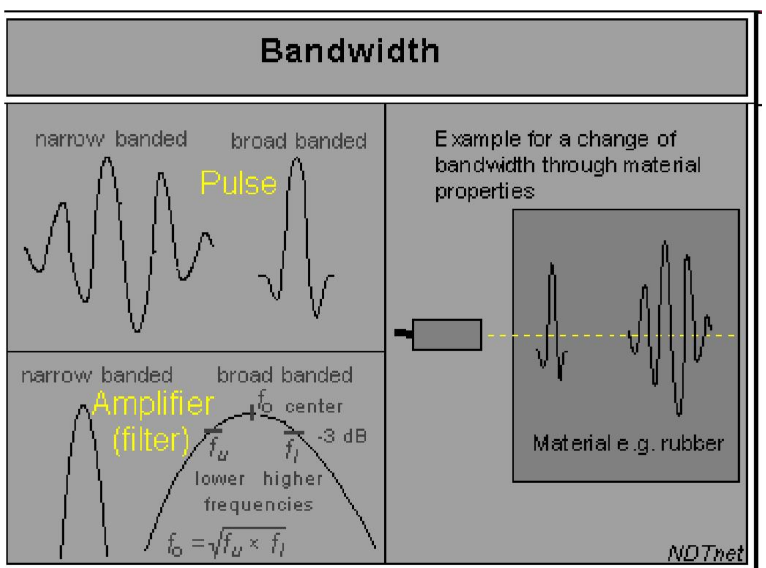
Koji je frekv. spektar uži ili širi?

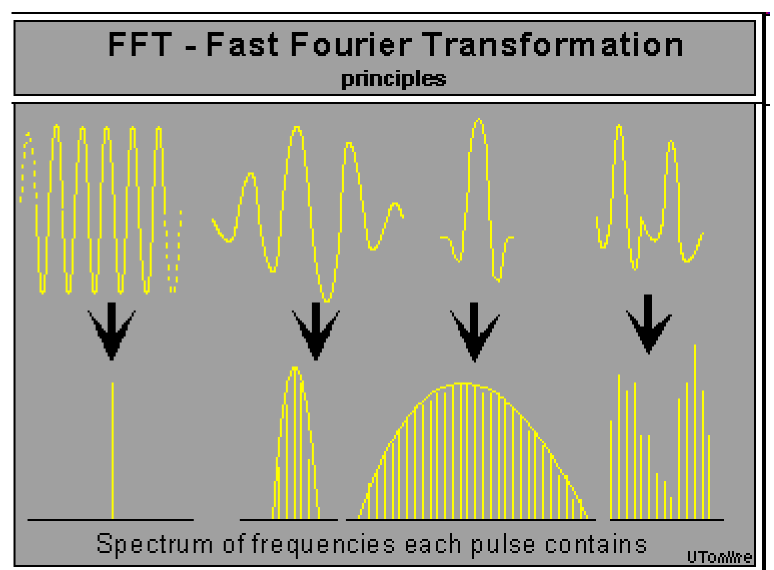


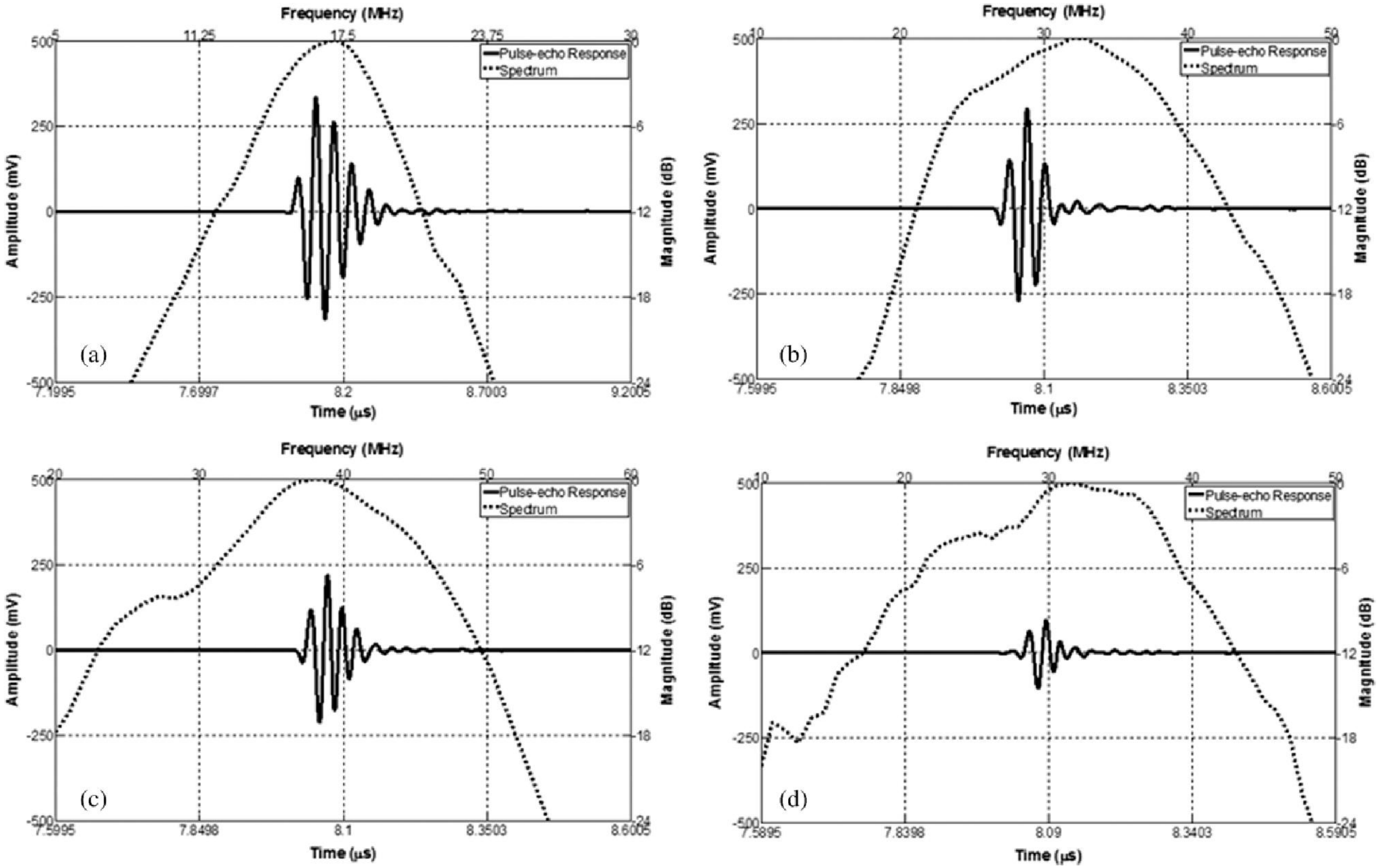


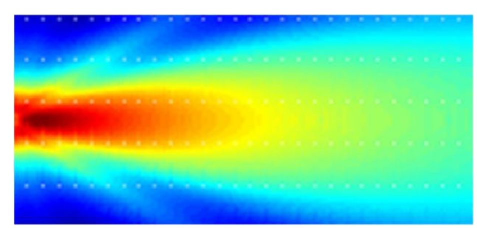

Vertikal: 1 V/div
Horizontal: 500 ns/div
Echoamplitude: 4.91 Vss
Vertikal: 5 V/div
Horizontal: 500 ns/div
Echoamplitude: 18.25 Vss
f = 2.03 MHz
B = 45 %
0
-2
dB
-4
-6
-8
1.2
1.6
2.0
2.4
2.8
MHz
f = 1.97 MHz
B = 76 %
0
-2
dB
-4
-6
-8
1.2
1.6
2.0
2.4
2.8
MHz

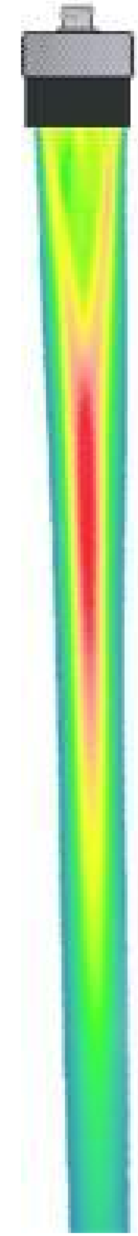

Damping
Pulse
low damped
high damped
Transducer
Damping material bonded to the back of the piezoelectric element
UTonline


Bandwidth
narrow banded
broad banded
Pulse
narrow banded
broad banded
Amplifier
(filter)
f_0 center
-3 dB
f_u
f_l
lower
higher
frequencies
$f_0 = \sqrt{f_u \times f_l}$
Example for a change of bandwidth through material properties
Material e.g. rubber
NDTnet


FFT - Fast Fourier Transformation
principles
Spectrum of frequencies each pulse contains
UTonline


Frequency (MHz)
5
11.25
17.5
23.75
30
500
250
0
-250
-500
0
-6
-12
-18
-24
Pulse-echo Response
Spectrum
Amplitude (mV)
Magnitude (dB)
(a)
7.1995
7.6997
8.2
8.7003
9.2005
Time (μs)
Frequency (MHz)
10
20
30
40
50
Pulse-echo Response
Spectrum
Amplitude (mV)
Magnitude (dB)
(b)
7.5995
7.8498
8.1
8.3503
8.6005
Time (μs)
Frequency (MHz)
20
30
40
50
60
Pulse-echo Response
Spectrum
Amplitude (mV)
Magnitude (dB)
(c)
7.5995
7.8498
8.1
8.3503
8.6005
Time (μs)
Frequency (MHz)
10
20
30
40
50
Pulse-echo Response
Spectrum
Amplitude (mV)
Magnitude (dB)
(d)
7.5895
7.8398
8.09
8.3403
8.5905
Time (μs)





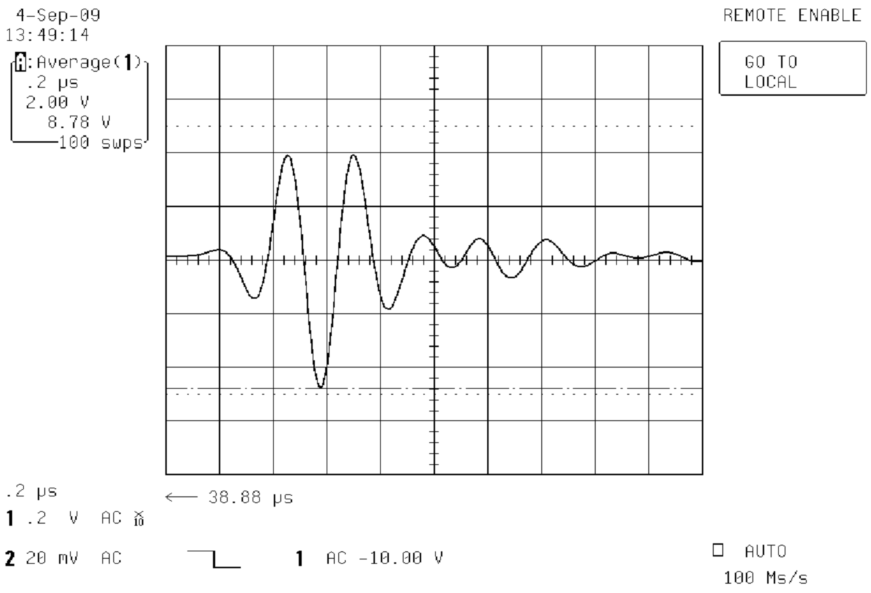
FOURIEROV RED

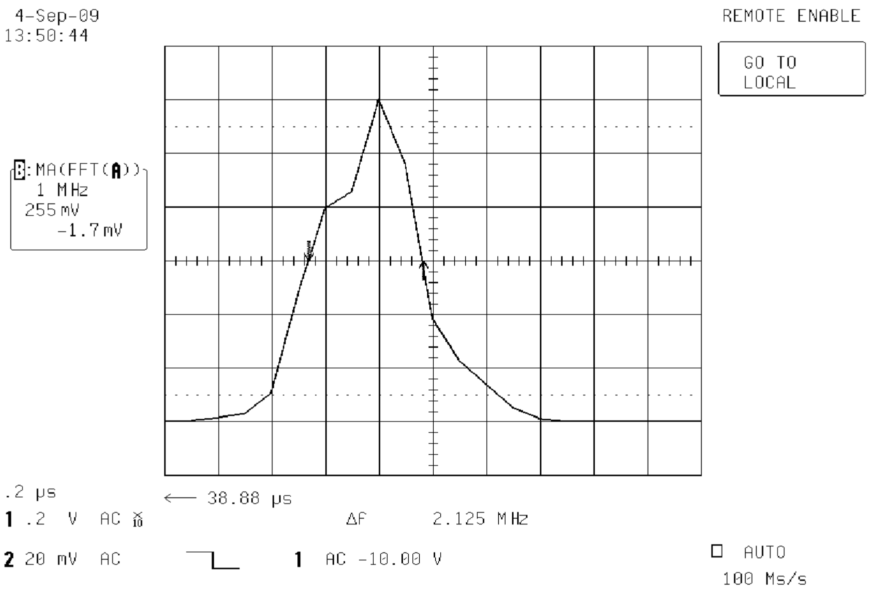
Složeni periodički signal može se prikazati kao suma jednostavnih oscilatornih funkcija.

- Opći oblik gibanja dobiva se superpozicijom više jednostavnih oblika.

ZAŠTO PRIKAZIVATI FUNKCIJU U OVAKVOM OBLIKU?

- Ako promatramo funkciju f(x)=f(t) kao neki vremenski promjenjivi električni signal, tada njezin prikaz u obliku Fourierovog reda zapravo prikazuje harmonike ili frekvencije tog signala gdje koeficijenti a_0 , a_n i b_n određuju amplitude a n red harmonika.





Koeficijente Fourierovog reda računamo prema relaciji:

- $a_0 = \frac{2}{L}\int_a^b f(x)dx$
- $a_n = \frac{2}{L}\int_a^b f(x)cos\frac{2\pi nx}{L}dx$
- $b_n = \frac{2}{L}\int_a^b f(x)sin\frac{2\pi nx}{L}dx$

Razvoj u Fourierov red zapisujemo kao:

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}\left(a_n cos\frac{2\pi nx}{L} + b_n sin\frac{2\pi nx}{L}\right)$$

PRIMJER

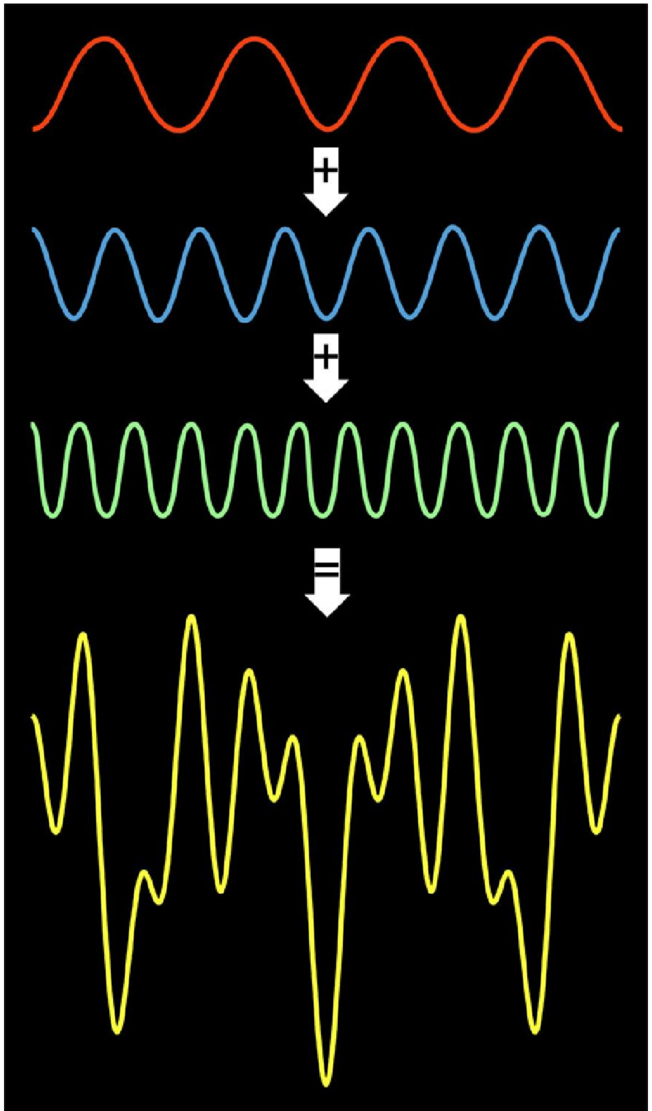
- Funkciju:

$$\mathbf{f(x)}= \begin{cases} 0 & x \in [0, \frac{1}{2}] \\ 1 & x \in [\frac{1}{2}, 1] \end{cases}$$

razvijte u Fourierov red!

*

Povezanost vremenske i frekvencijske domene



http://en.wikipedia.org/wiki/File:Fourier_series_and_transform.gif

PIEZOELEKTRIČNI MATERIJAL

Najznačajniji piezoelektrični materijali:

1. Kvarc (SiO_2) - kristalna struktura silicijevog dioksida
2. Seignettova sol i turmalin
3. PZT keramika (olovni cirkonat-titanat)

DIELEKTRICI

ANIZOTROPIJA

Materijal koji je loš vodič elektriciteta tako da može podnijeti znatan električni napon pri čemu primijenjeno električno polje dovodi samo do pomaka naboja ali ne i do njegova toka.

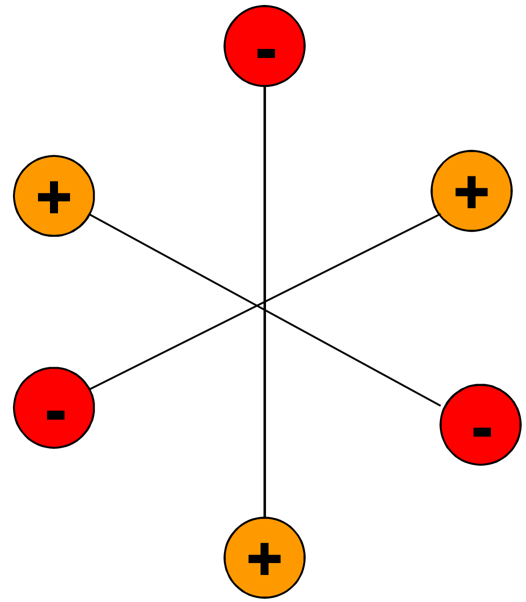
Osobina nekih tijela da u raznim smjerovima imaju različita fizikalna svojstva



PIEZOELEKTRIČNI EFEKT

- povezuje električne i mehaničke veličine.
- pojava stvaranja vezanih električnih naboja na površini nekih čvrstih tvari prilikom njihove mehaničke deformacije

The unit cell of crystal silicon dioxide

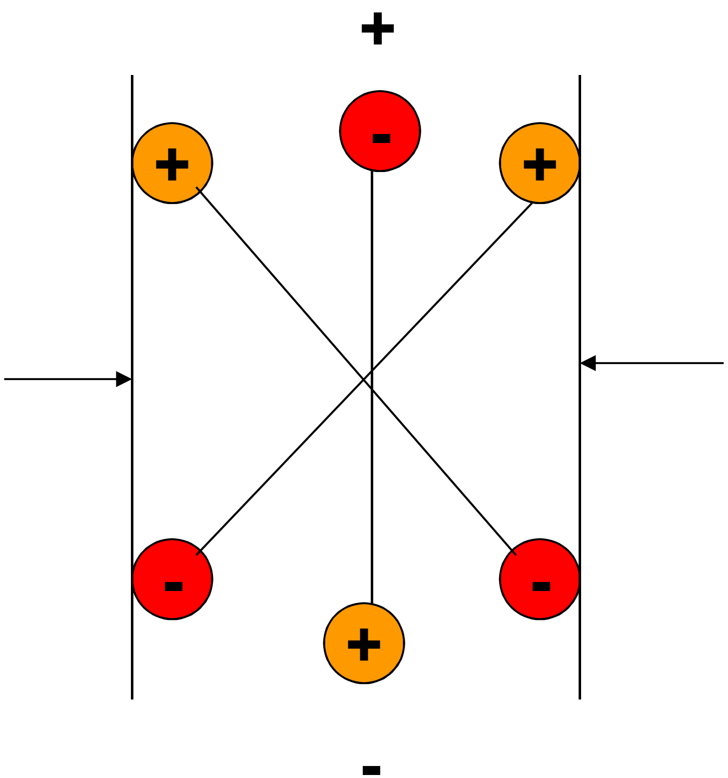


Predstavlja silicijev atom (kation)

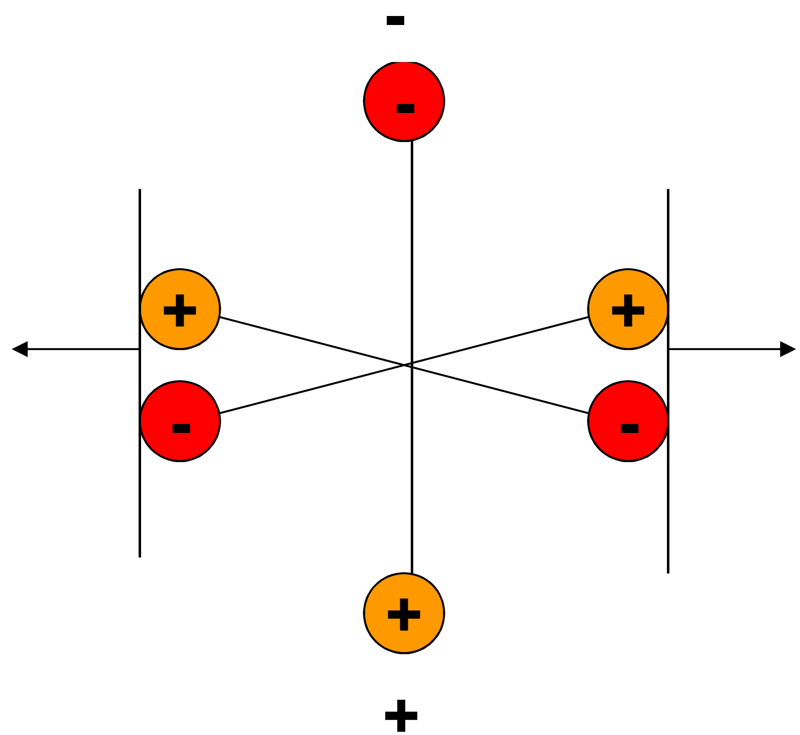
Predstavlja kisikov atom (anion)

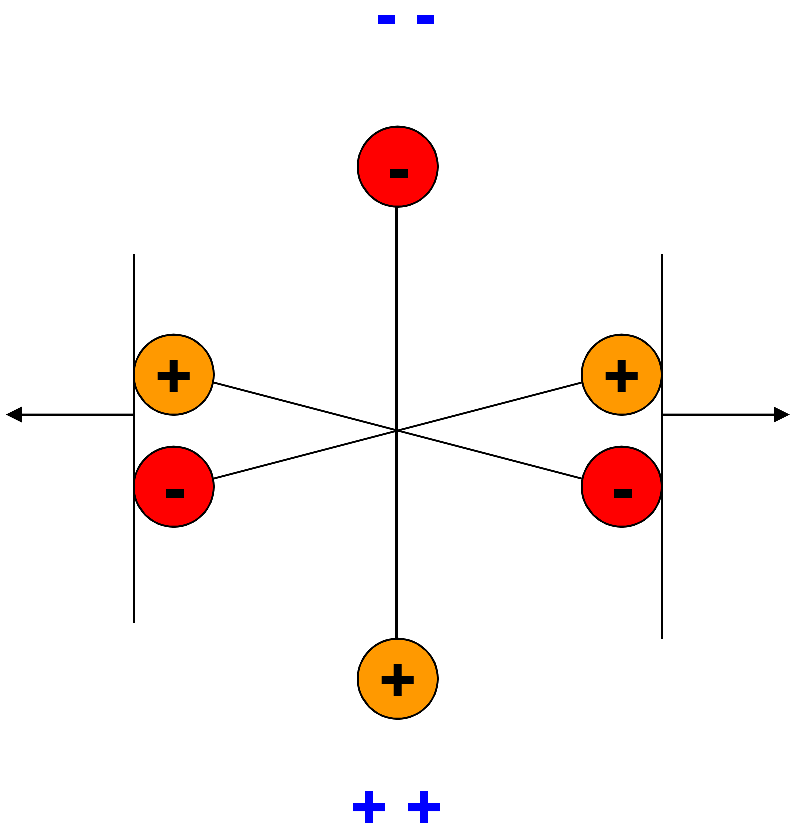
Električna i geometrijska ravnoteža

A pushing force:
(compression)

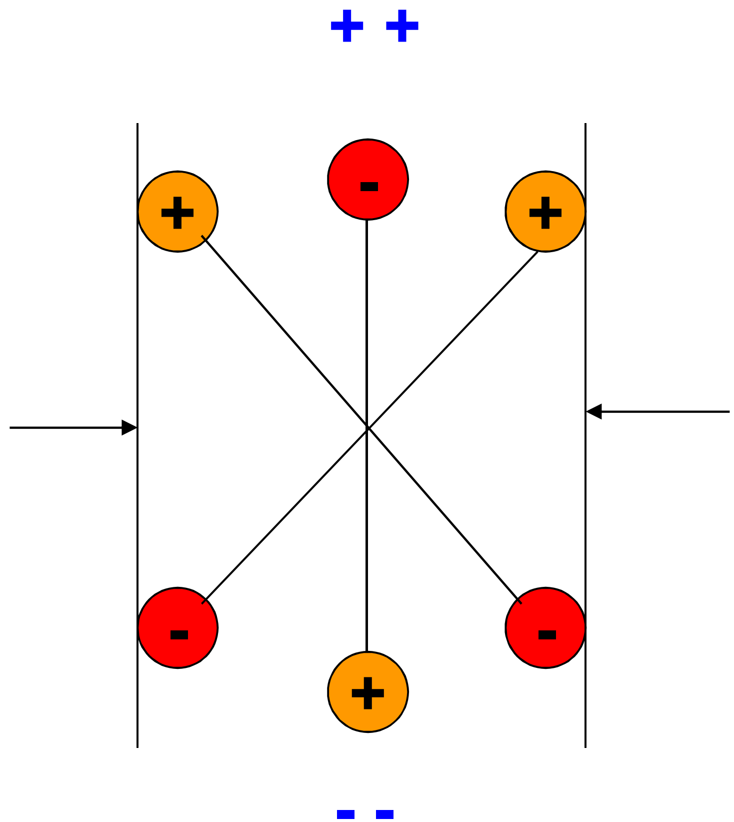


A pulling force:
(tension)





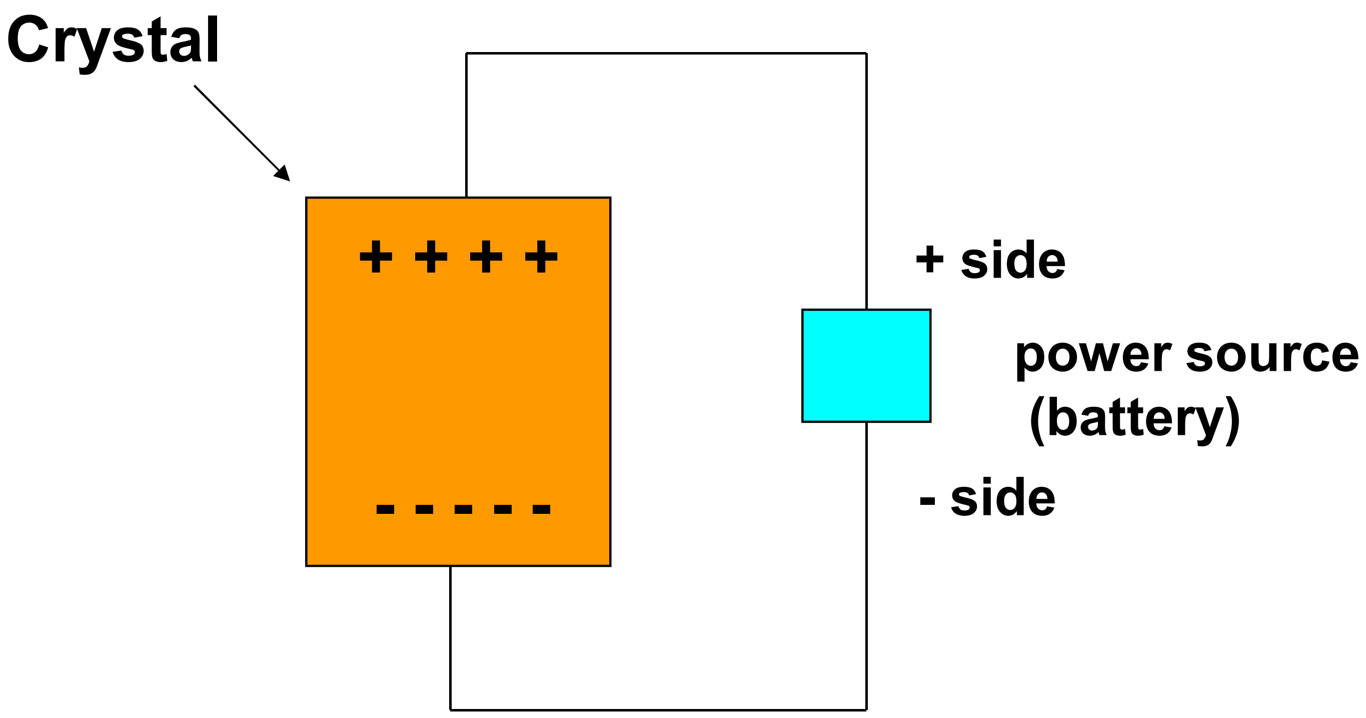
For example, a 1 cm^3 cube of quartz with 2 kN (500 lbf) of correctly applied force can produce a voltage of 12500 V.



For example, a 1 cm^3 cube of quartz with 2 kN (500 lbf) of correctly applied force can produce a voltage of 12500 V.

The electromechanical effect

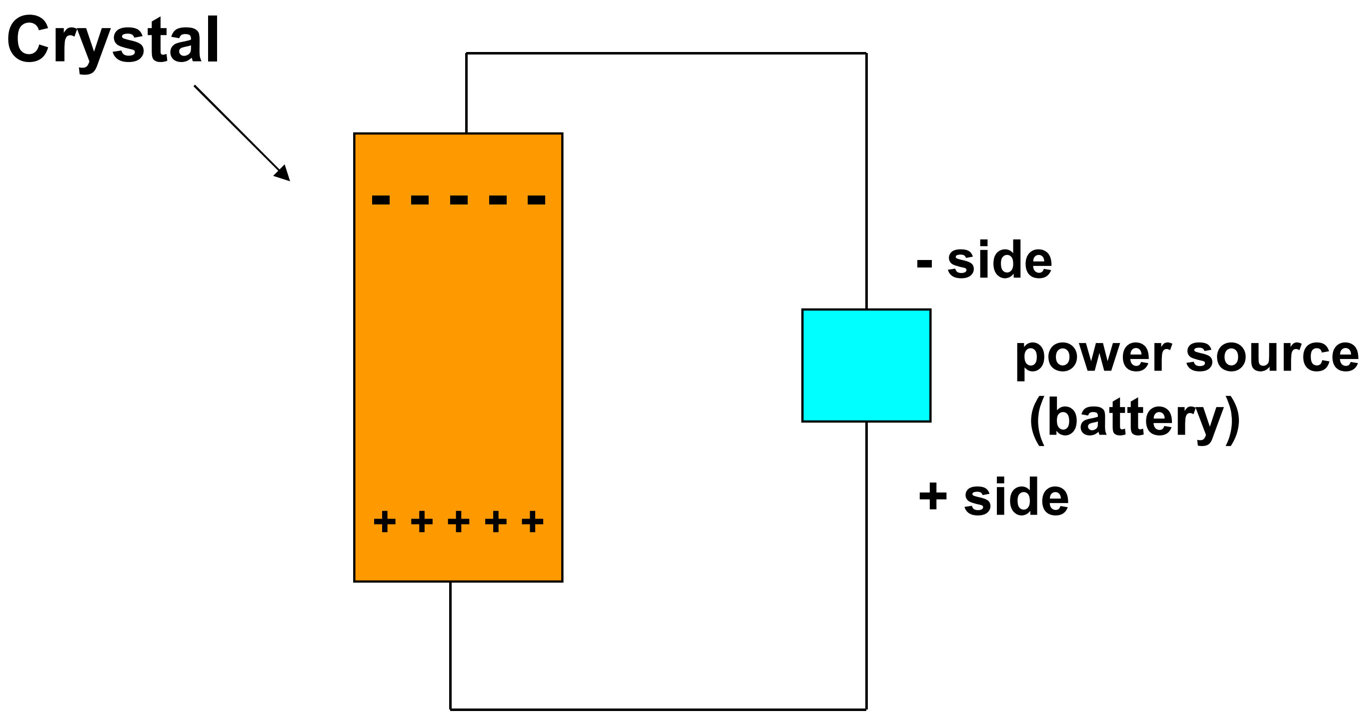
When the switch is closed, and you apply the exact amount of power to get the same current that resulted when you squeezed the crystal, the crystal should deform by the same amount ☺



…. and, the crystal should get shorter and fatter.

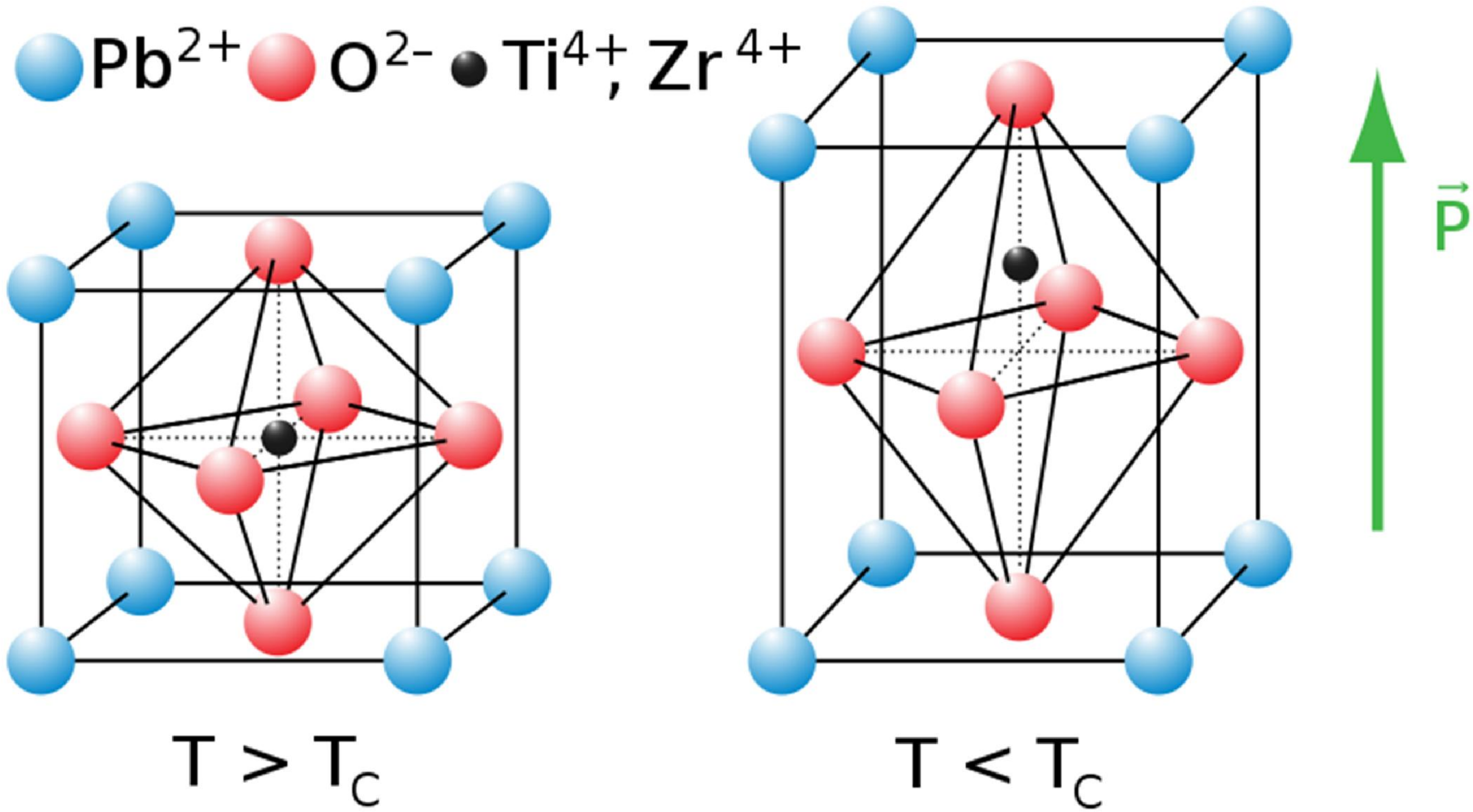
The electromechanical effect

What will happen if you switched the battery around?



…. the crystal should get longer and skinnier.

barijev titanat, $BaTiO_3$
kalcijevog titanida $CaTiO_3$
manji kationi : Ti, Zr, Sn, Nb…
veći kationi : Pb, Ba, Sr, Ca, Na...



Tetragonal unit cell of lead titanate

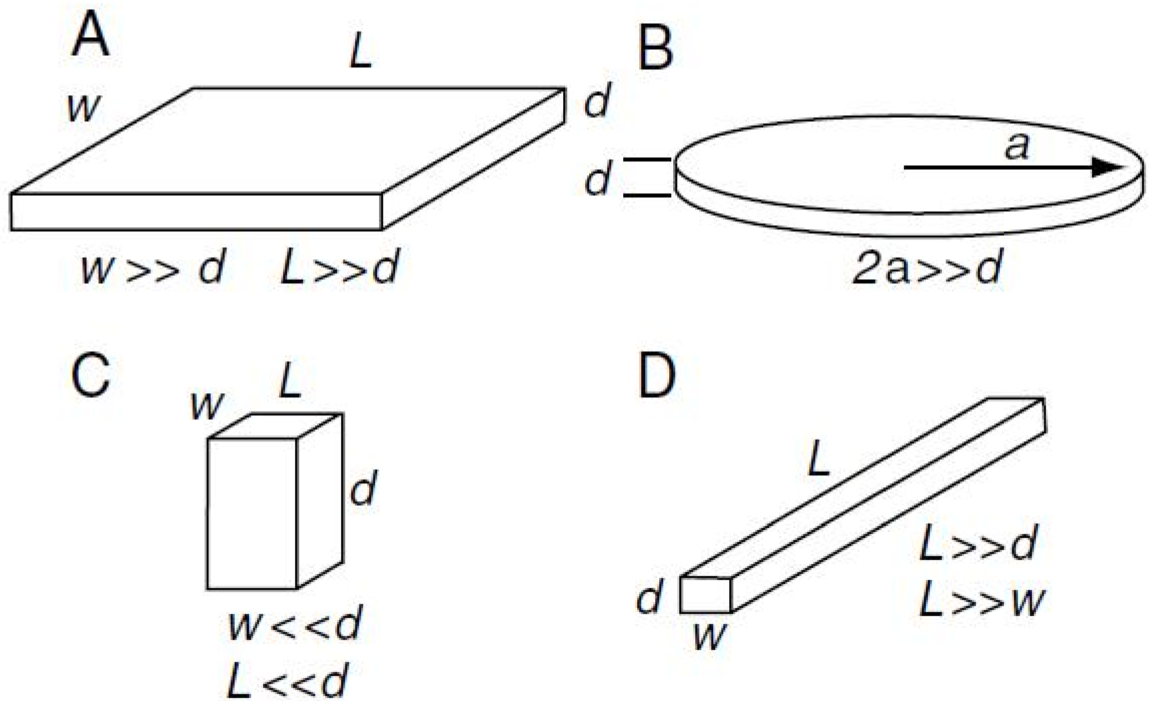
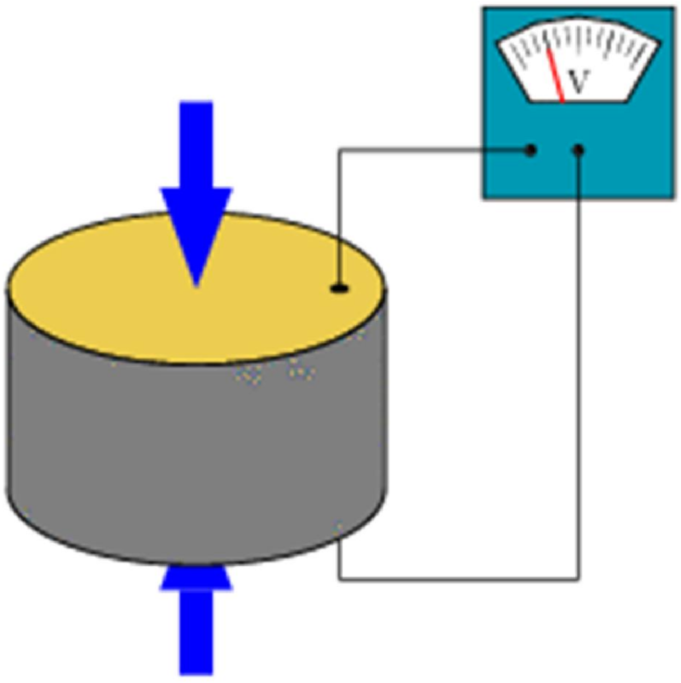
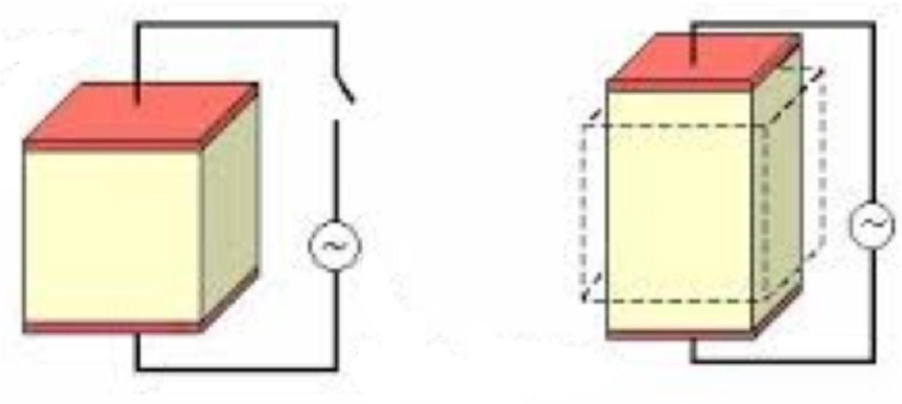


Figure 5.4 Resonator geometries for longitudinal vibration modes along the *z* axis. (A) Thickness-expander rectangular plate. (B) Thickness-expander circular plate disk. (C) Length-expander bar. (D) Width-extensional bar or beam plate.

Vrste aktuatora …. i druge aplikacije (*surgery*)


V

MATCHING LAYER



Debljina piezoelektričnog elementa uvjetovana je željenom frekvencijom ultrazvučne sonde.

Piezoelektrični element odašilje valnu duljinu koja je po iznosu jednaka njegovoj dvostrukoj debljini.

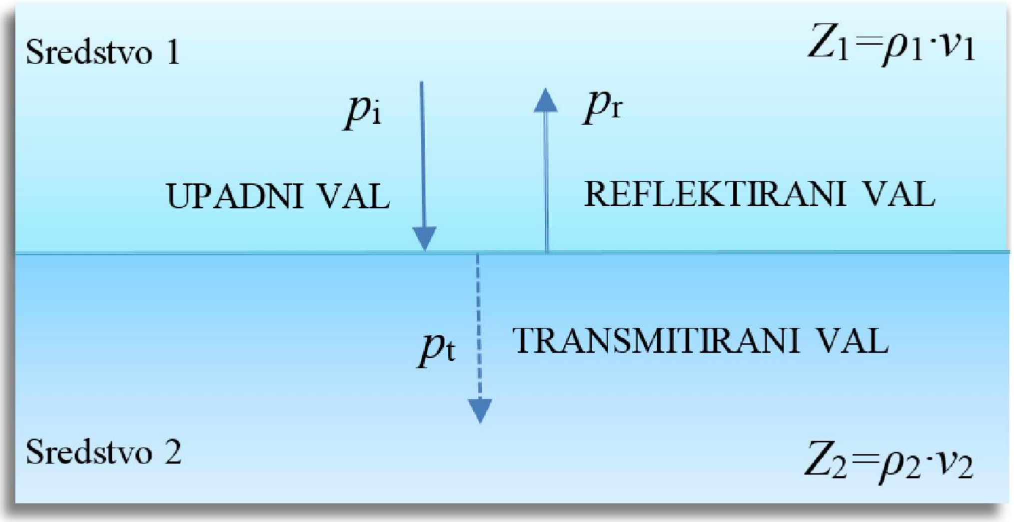
Piezoelektrični element rezan je na pola valne duljine.

Za visoke frekvencije potrebni su što tanje rezani piezoelektrični elementi.

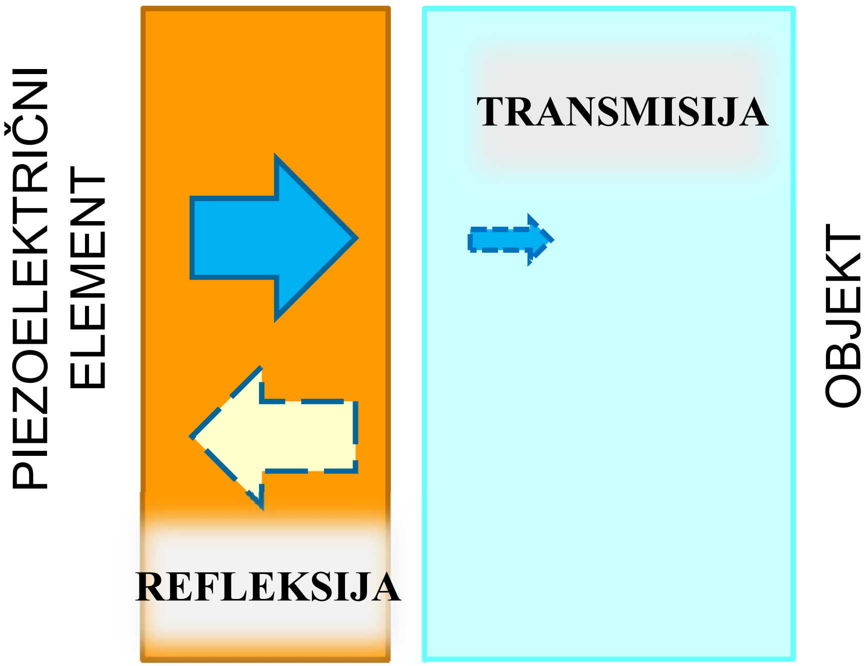
MATCHING LAYER

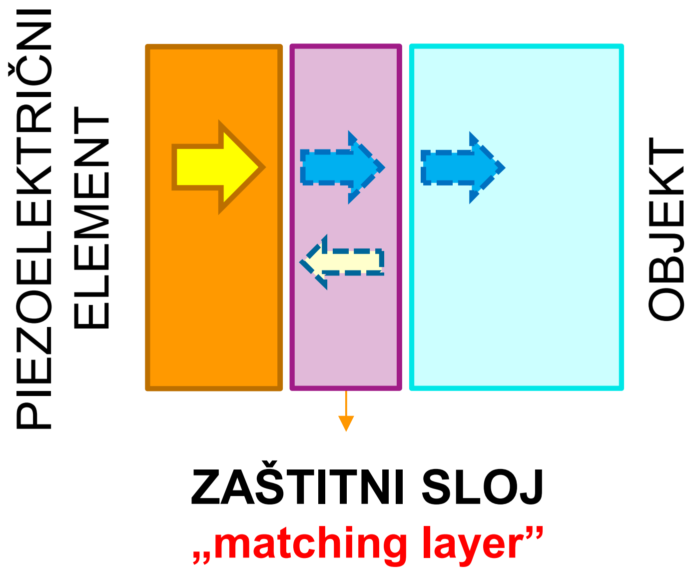
- POJAVE NA GRANICI SREDSTAVA

Nailaskom ultrazvučnih valova na granicu dvaju sredstava općenito dolazi do pojave REFLEKSIJE i TRANSMISIJE ultrazvučne

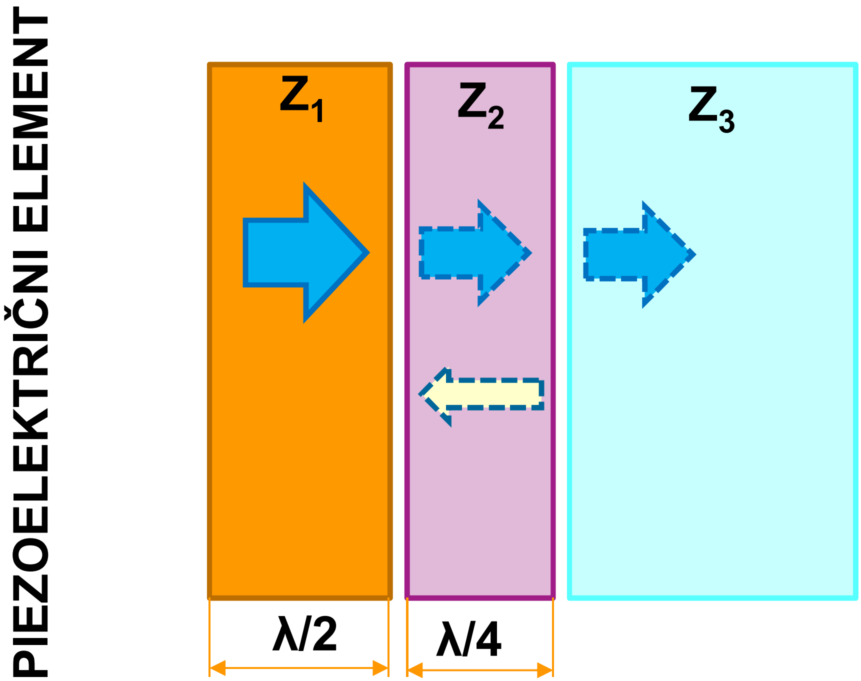


MATCHING LAYER





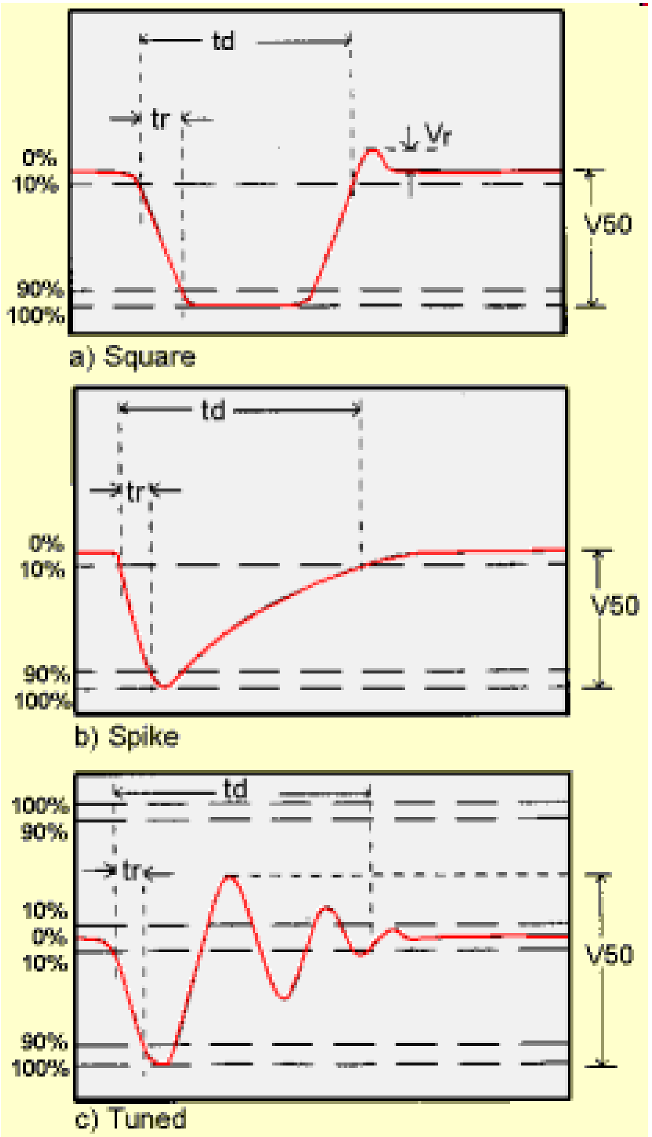
MATCHING LAYER

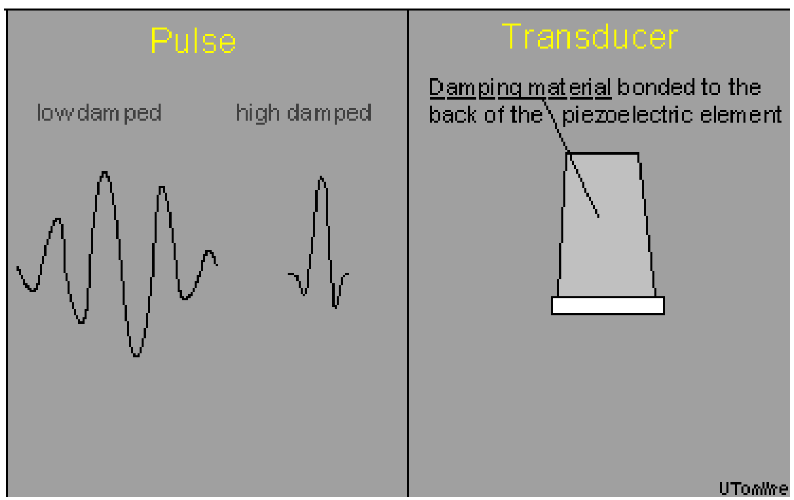


ZAŠTITNI SLOJ
„matching impedance layer"

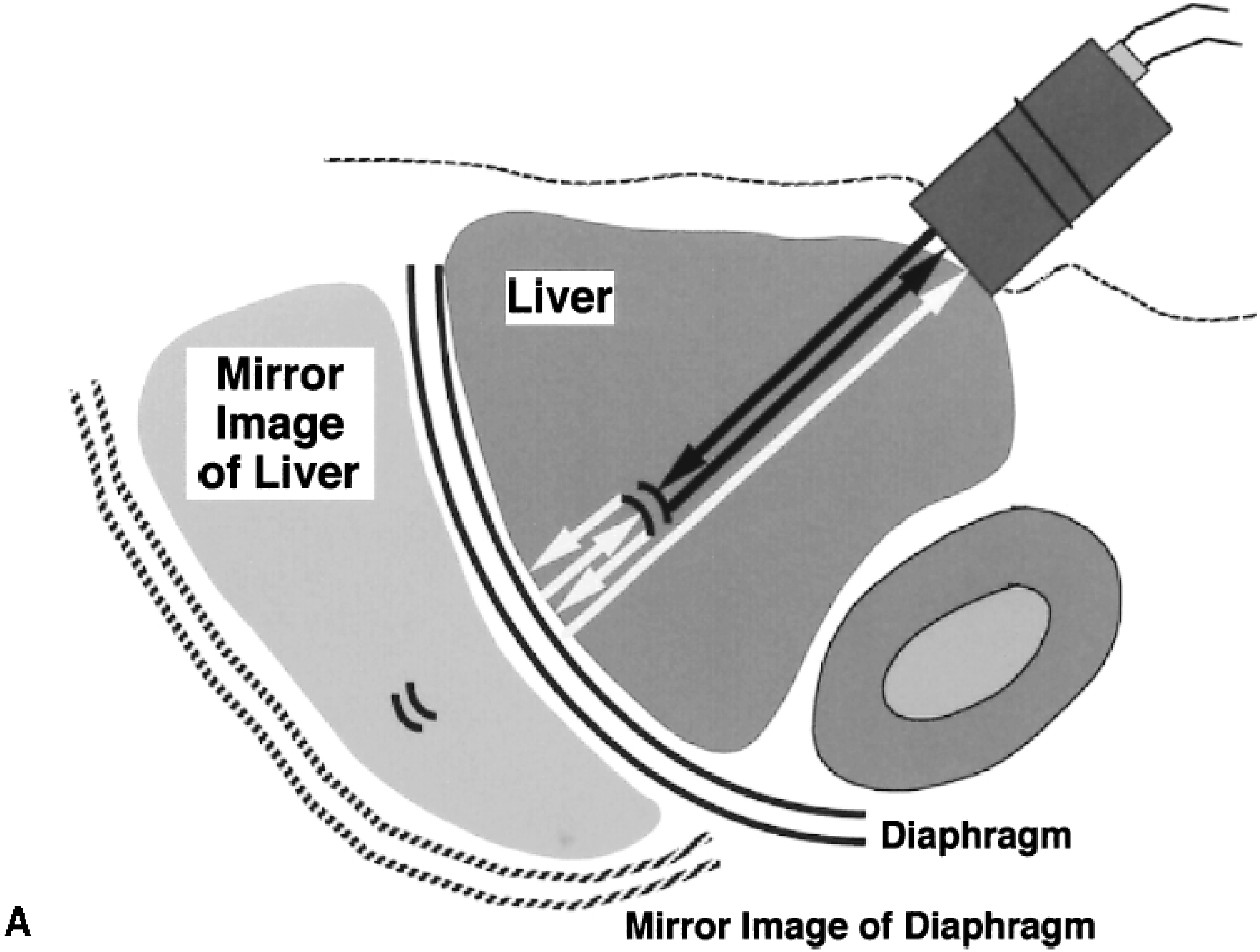
$Z_1 < Z_2 < Z_3$

Pobuda sonde/pretvornika







http://www.msdlatinamerica.com/ebooks/CoreCurriculumTheUltrasound/sid102252.html

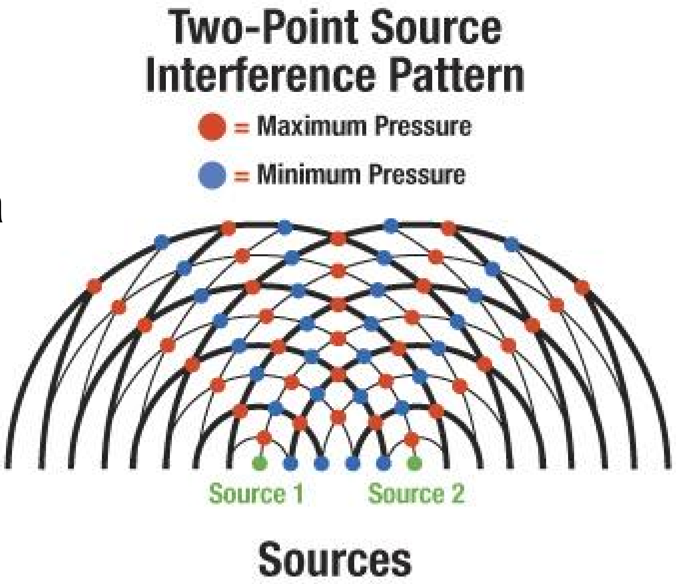
- http://www.olympus-ims.com/en/ndt-tutorials/transducers/characteristics/
- http://www.olympus-ims.com/en/ndt-tutorials/transducers/wave-front/

- http://www.olympus-ims.com/en/ndt-tutorials/transducers/inside/
- http://www.olympus-ims.com/en/ndt-tutorials/transducers/pa-definitions/
- http://www.olympus-ims.com/en/ndt-tutorials/transducers/generating/

Svaki površinski element doprinosi cijelom ultrazvučnom polju

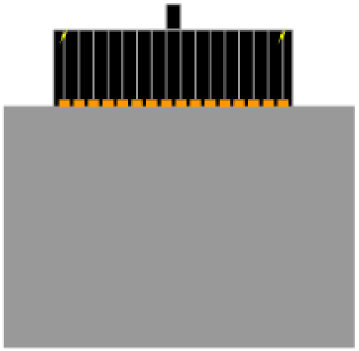
Ako je veličina pretvarača znatno manja od valne duljine – TOČKASTI IZVOR

valovi u obliku polukugle koji su međusobno identični s različitim mjestom izvora.

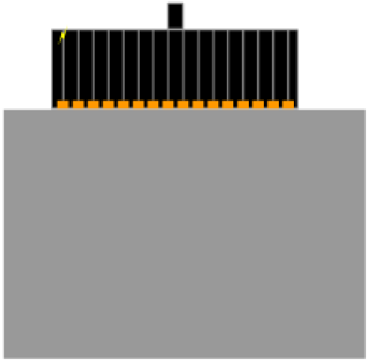


Upravljanje i oblikovanje UZ snopa (*Beam shaping & steering*)

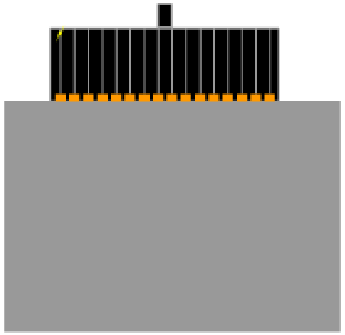
- http://www.olympus-ims.com/en/ndt-tutorials/transducers/generating/calculator/
- http://www.olympus-ims.com/en/ndt-tutorials/transducers/pa-beam/steering/
- http://www.olympus-ims.com/en/ndt-tutorials/transducers/focusing/



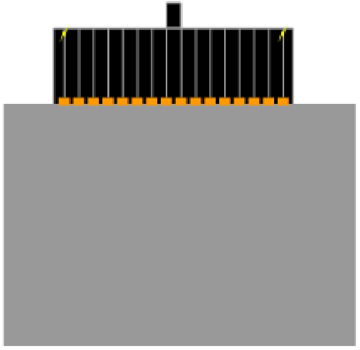
Beam Focusing



Beam Steering

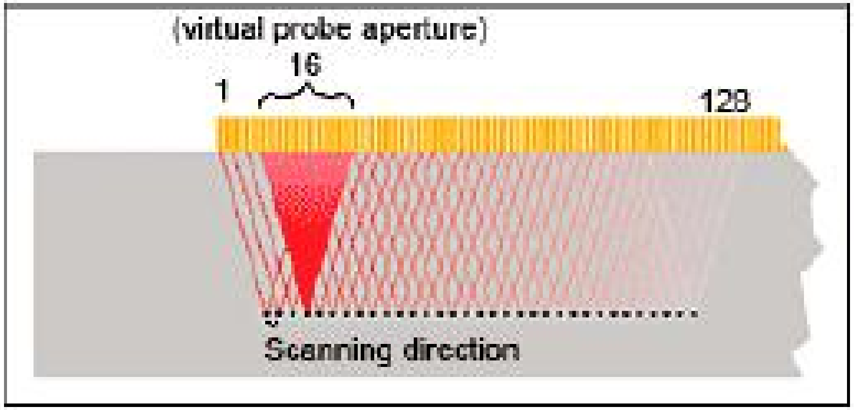


Beam Focusing and steering



Beam Re-forming

Linearno skeniranje (*normal beam*)



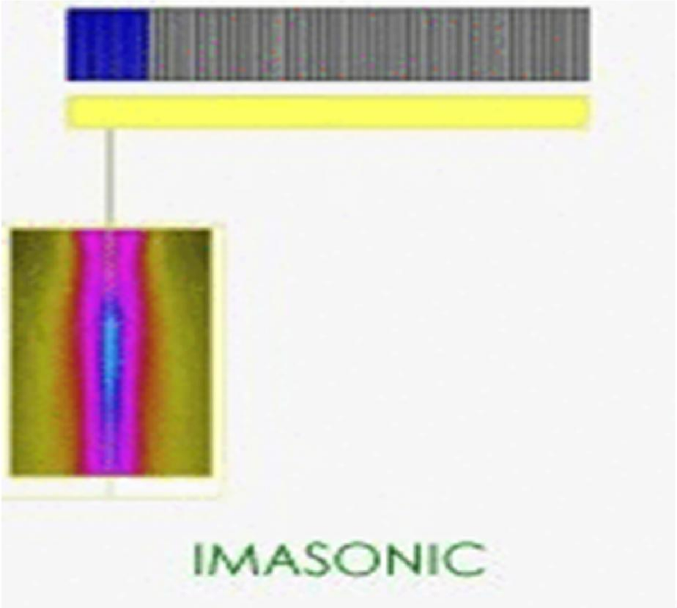
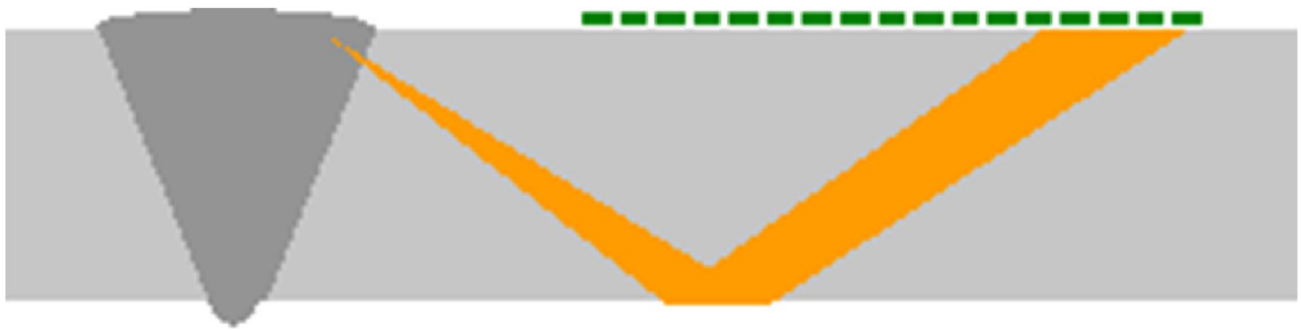
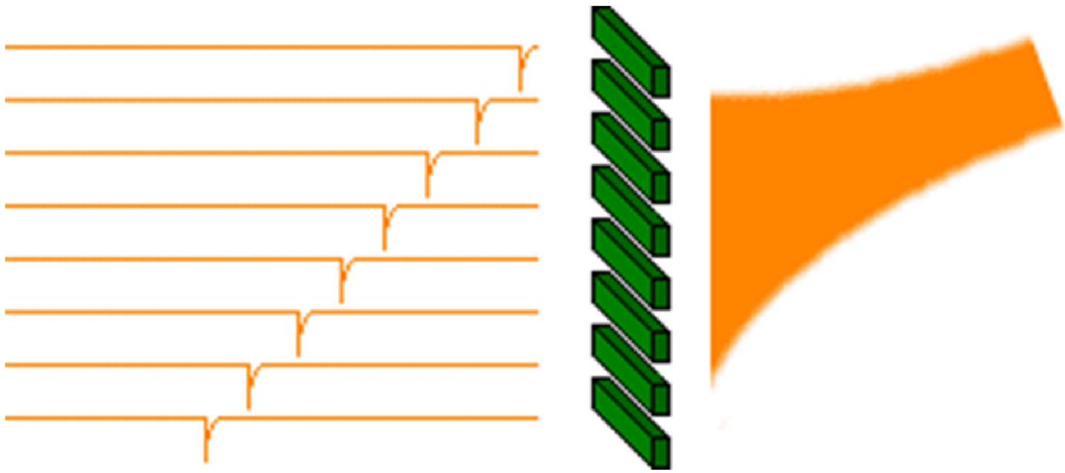


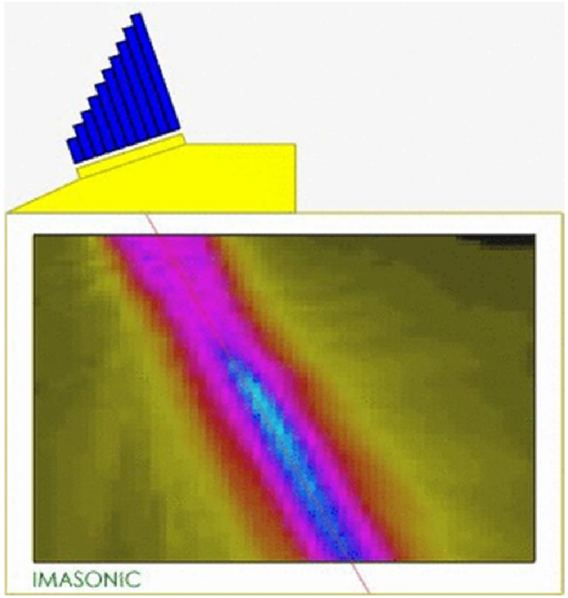
Fig.4. Electronic scanning with normal beam (virtual probe aperture = 16 elements)

Linearno skeniranje (*angle beam*)

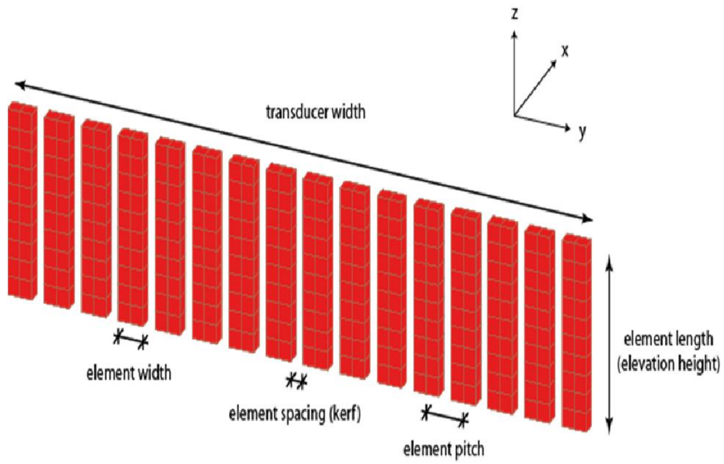


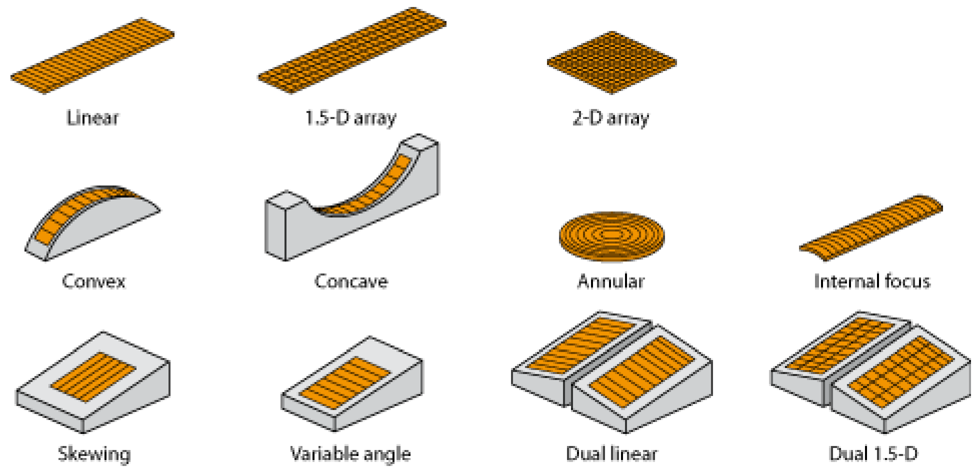
Sektorsko skeniranje (*sectorial scan*)
- upravljanje („njihanje”) kuta snopa -



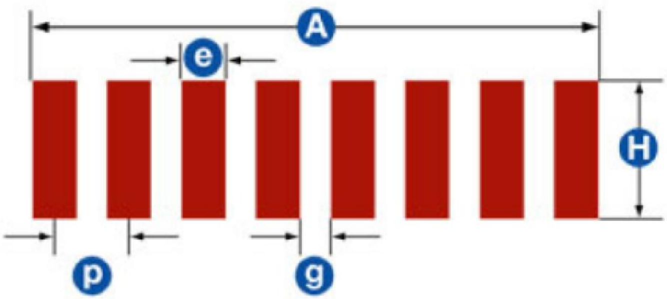


(oblici) „polja” pretvornika



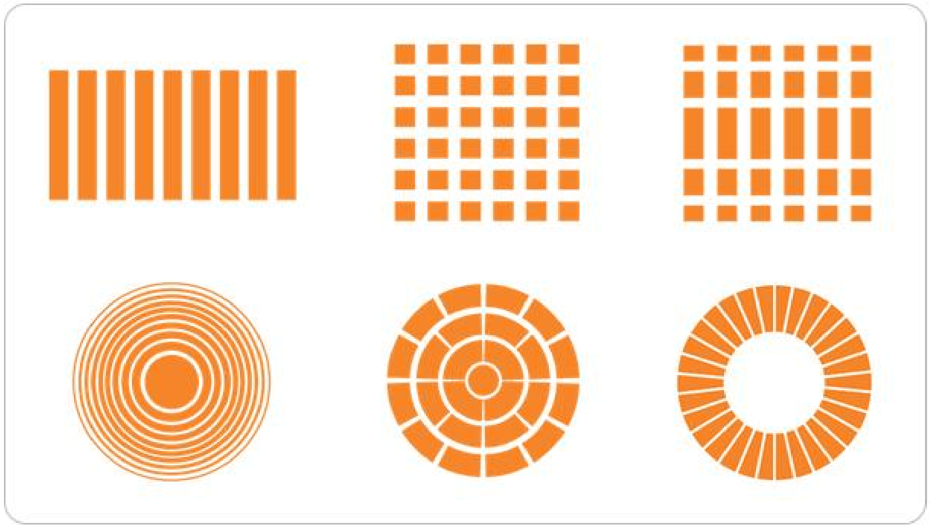


Dimensional Parameters of Phased Array Probe

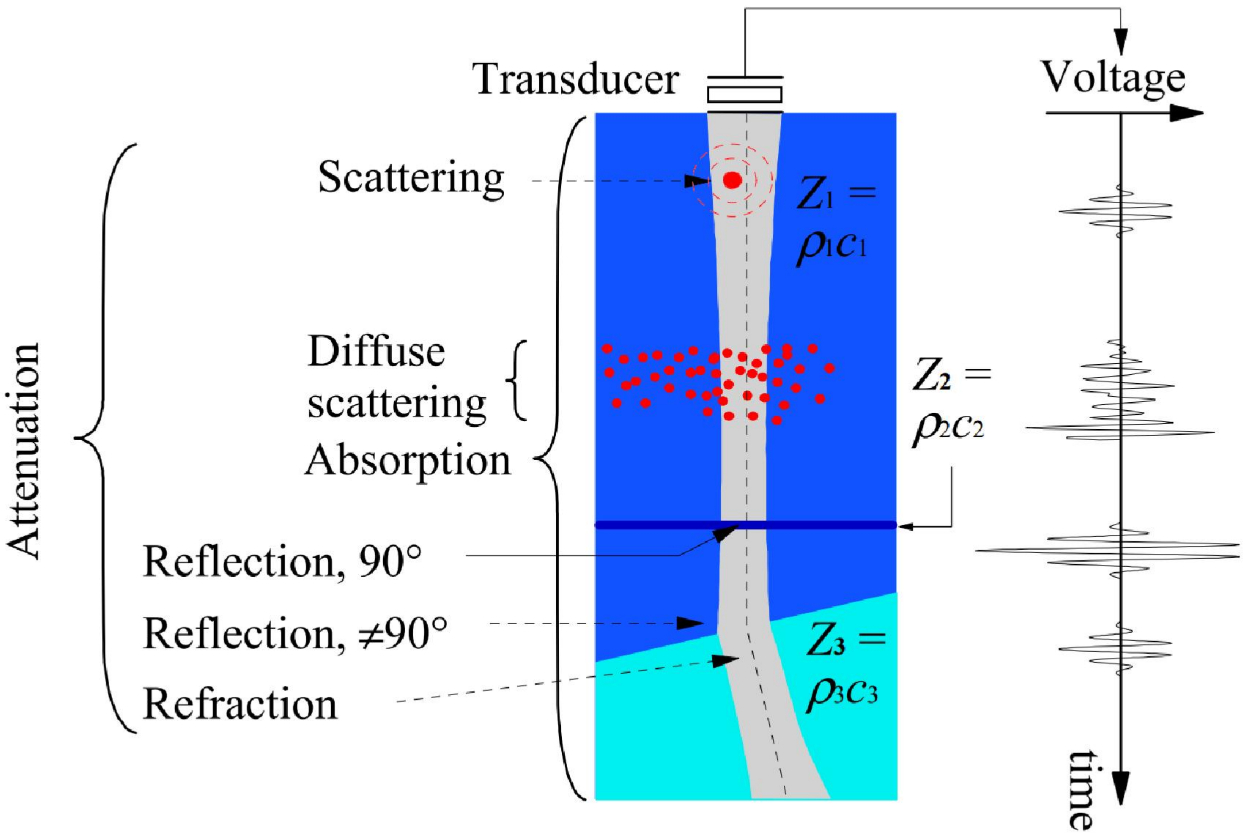


N = total number of elements in the array
A = total aperture in steering or active direction
H = element height or elevation. Since this dimension is fixed, it is often referred to as the passive plane.
p = pitch, or center-to-center distance between to successive elements
e = width of an individual element
g = spacing between active elements

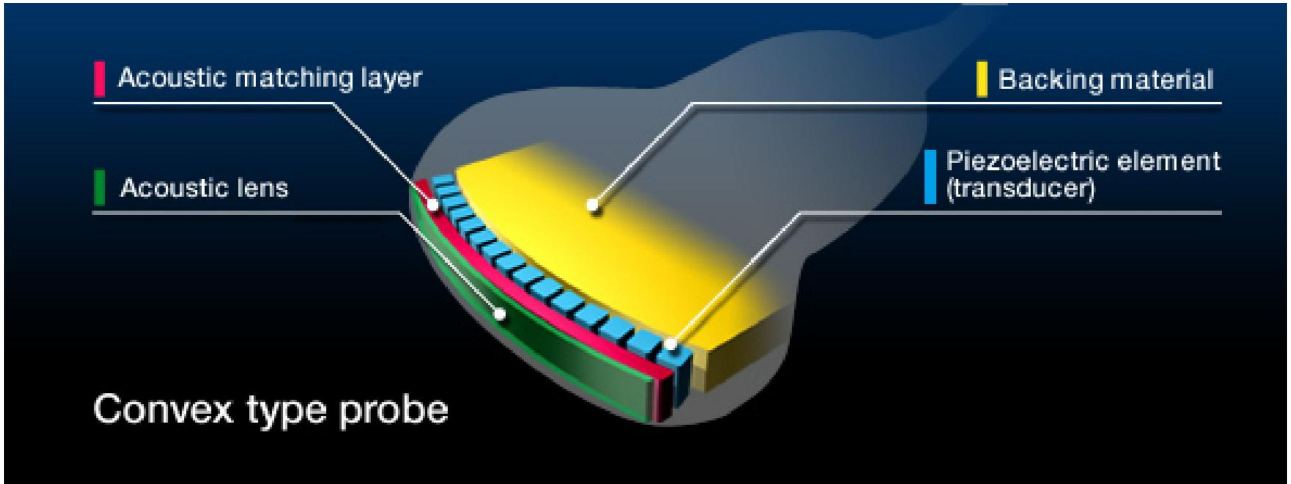
Element Patterns

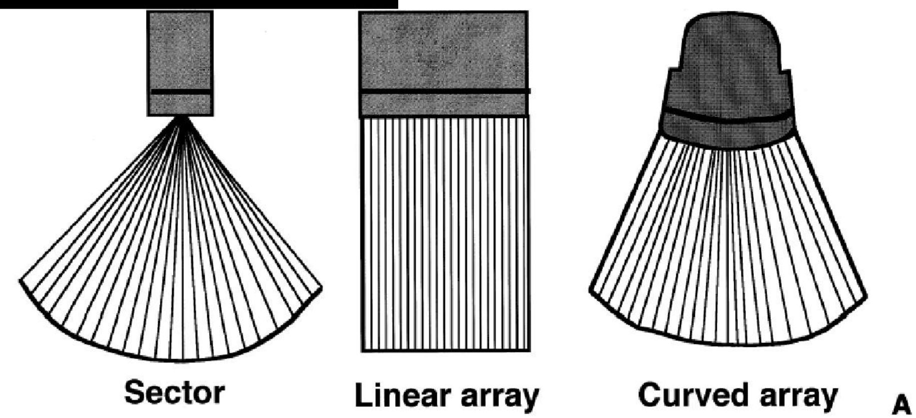


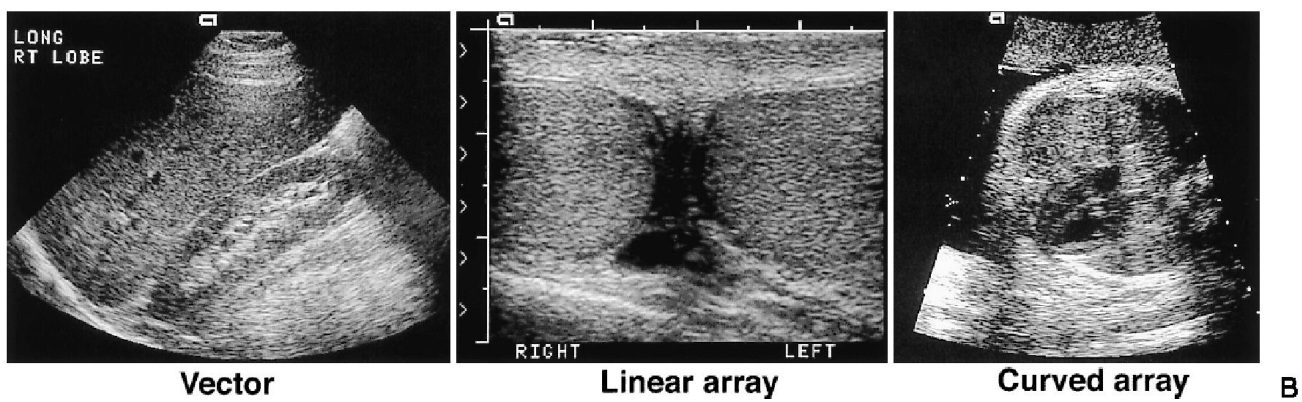

06/04/29 Saturday
Patient ID:
Doctor:



Transducer
Voltage
Scattering
$Z_1 = \rho_1 c_1$
Diffuse scattering
$Z_2 = \rho_2 c_2$
Absorption
Attenuation
Reflection, 90°
Reflection, ≠90°
$Z_3 = \rho_3 c_3$
Refraction
time


Acoustic matching layer
Backing material
Acoustic lens
Piezoelectric element
(transducer)
Convex type probe

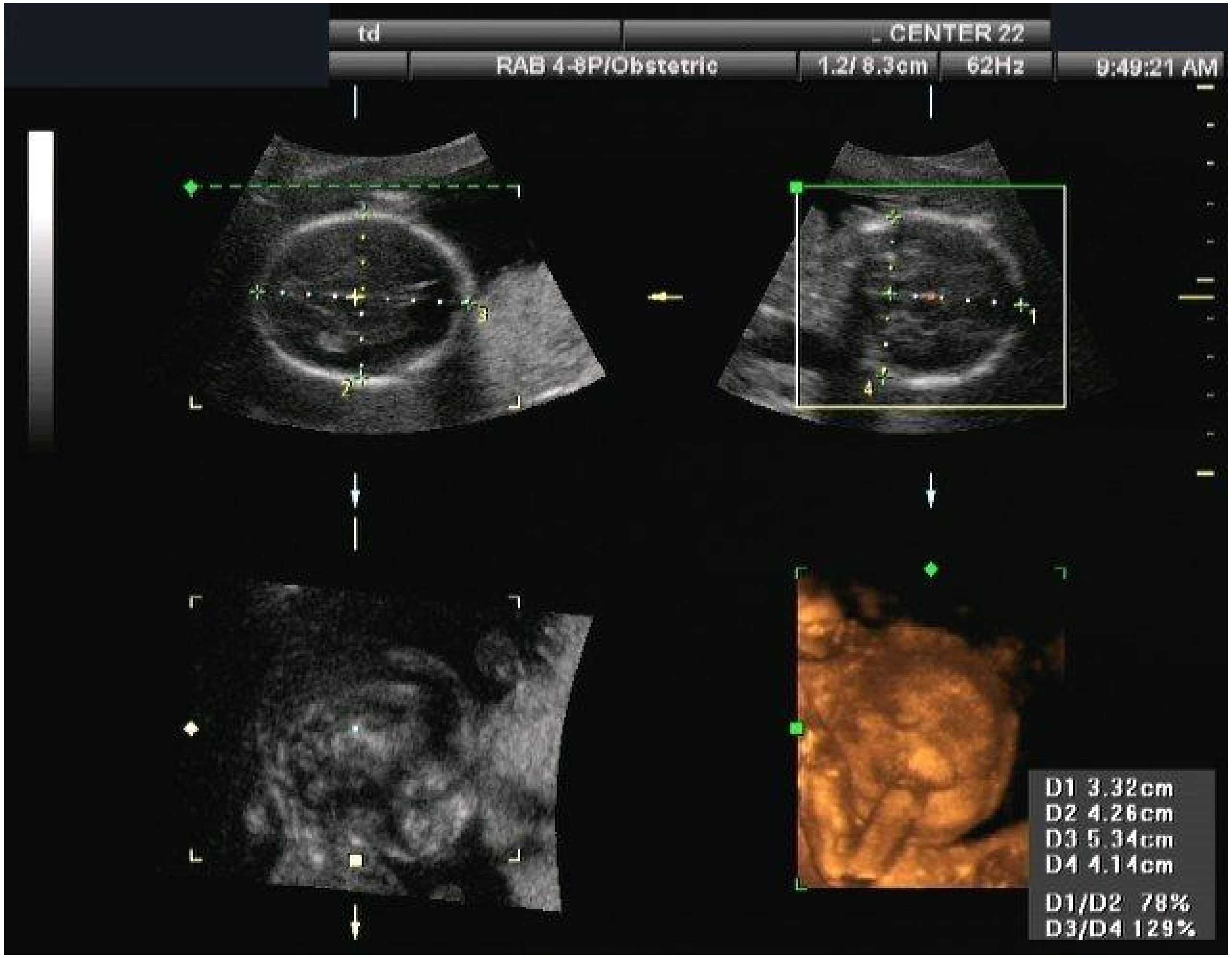

Sector
Linear array
Curved array
A


LONG
RT LOBE
RIGHT
LEFT
Vector
Linear array
Curved array
B

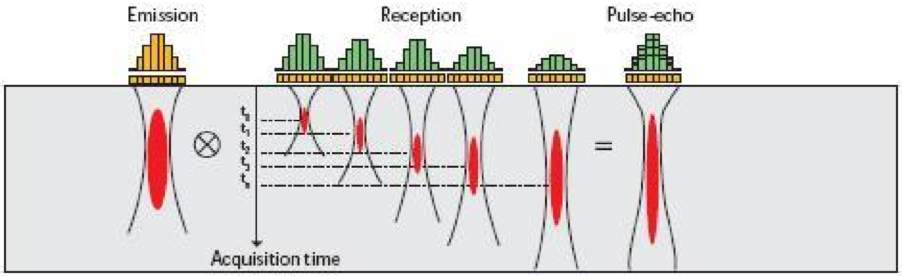
Prikazi

- (*Amplitude*) *A-mode* = A prikaz = 1D prikaz
- (*Brightness*) *B-mode* = B prikaz = 2D prikaz
  postoji i *B-Time* prikaz
- (*Sectorial*) *S-mode* = S prikaz = 2D prikaz
  u usporedbi s B prikazom (koji je pravokutni presjek/prikaz) S prikaz daje 2D prikaz za raspon kutova (sektor)
- (*Contrast*) *C-mode* = C prikaz = 3D prikaz
- (*Motion*) *M-mode* = M prikaz = prikaz (najćešće 2D slika) u realnom vremenu

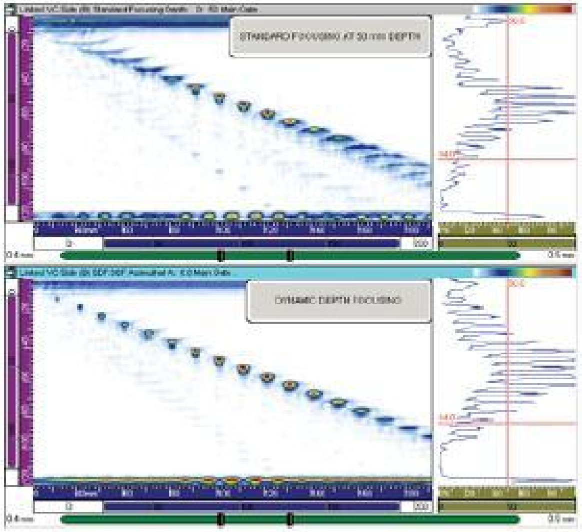
Prikazi


td
CENTER 22
RAB 4-8P/Obstetric
1.2/ 8.3cm
62Hz
9:49:21 AM
D1 3.32cm
D2 4.26cm
D3 5.34cm
D4 4.14cm
D1/D2 78%
D3/D4 129%

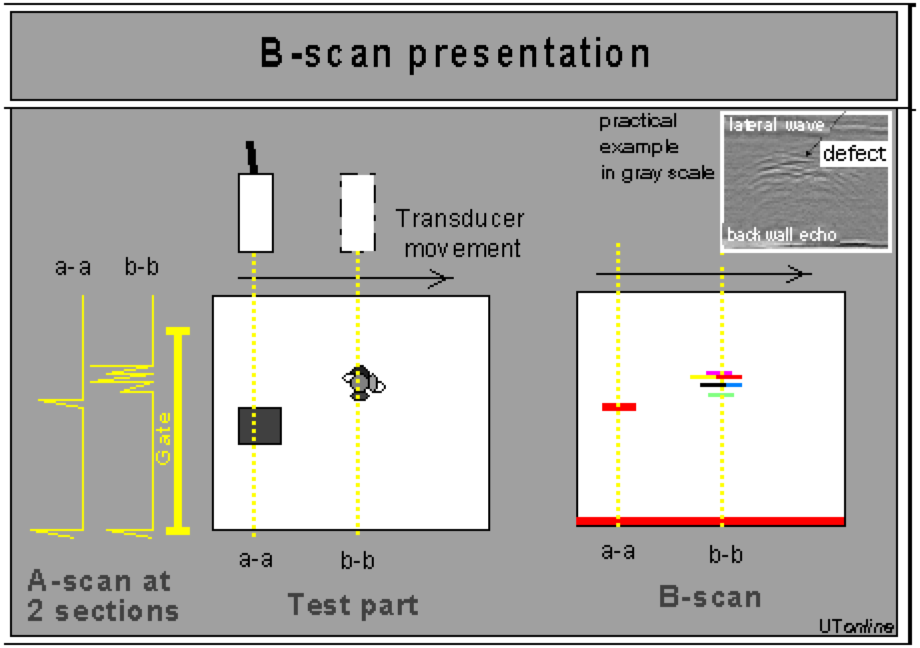
Prikazi



Emission
Reception
Pulse-echo
Acquisition time

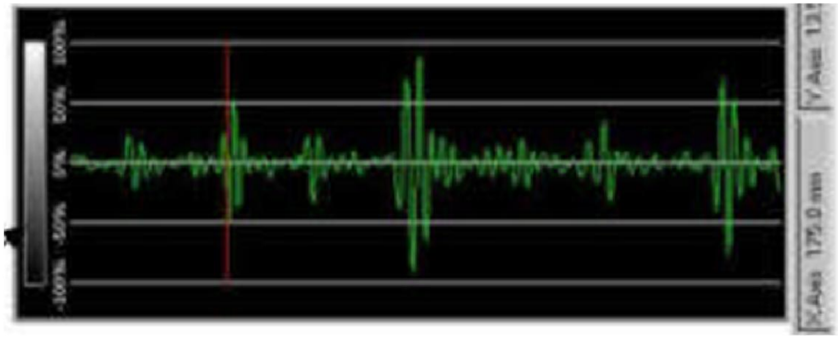


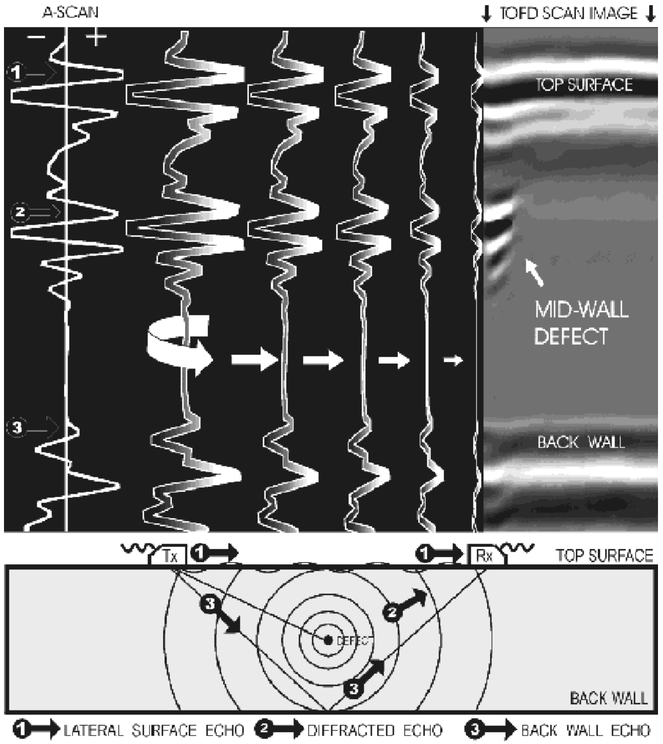
STANDARD FOCUSING AT 50 mm DEPTH
DYNAMIC DEPTH FOCUSING

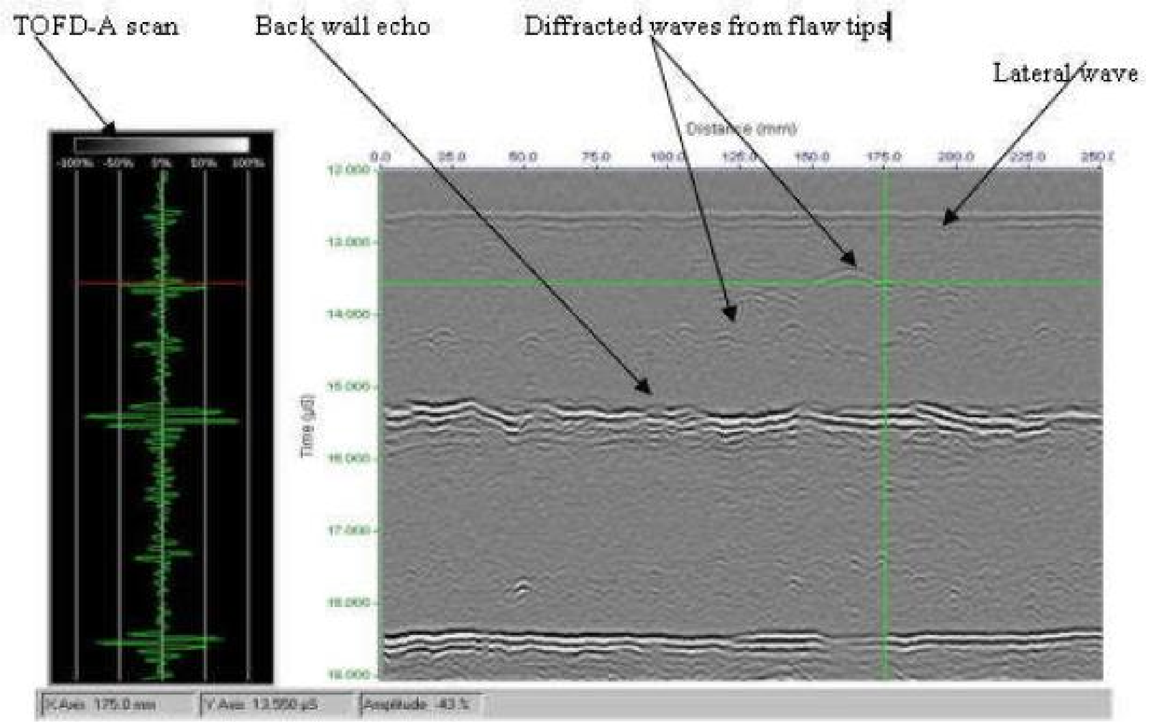


B-scan presentation
practical example in gray scale
lateral wave
defect
back wall echo
Transducer movement
a-a
b-b
Gate
A-scan at 2 sections
Test part
B-scan
UTonline

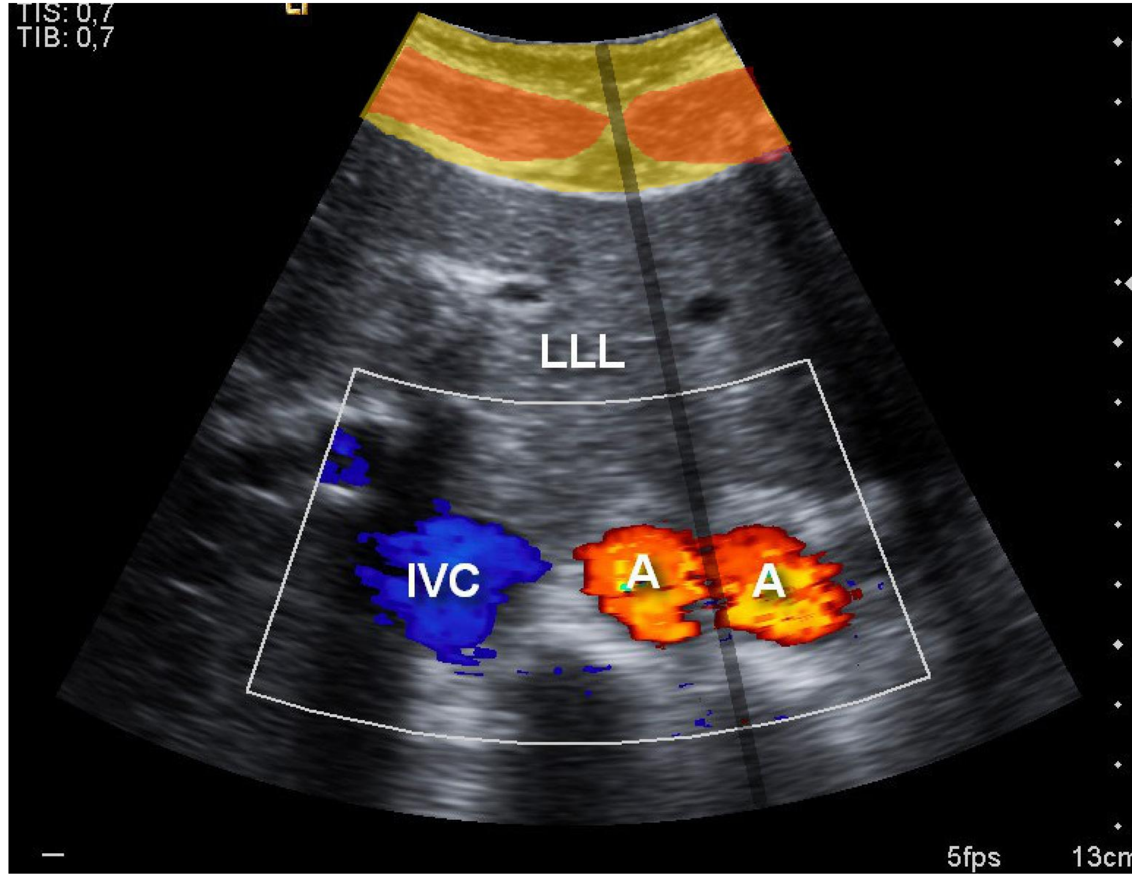
Generiranje 2D prikaza temeljem 1D prikaza

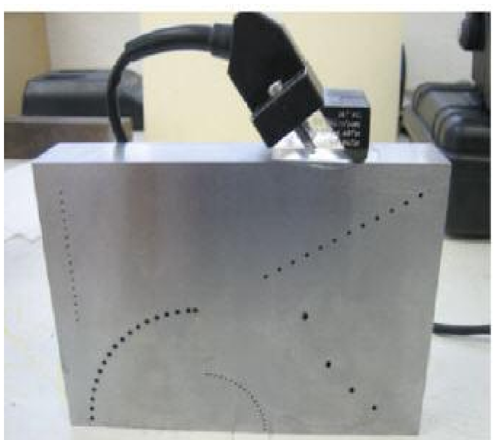


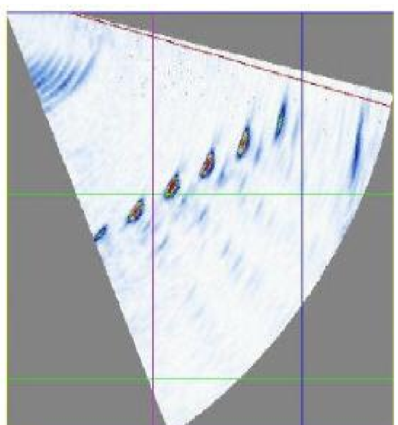


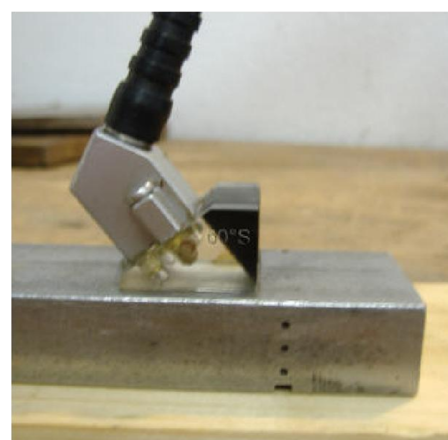


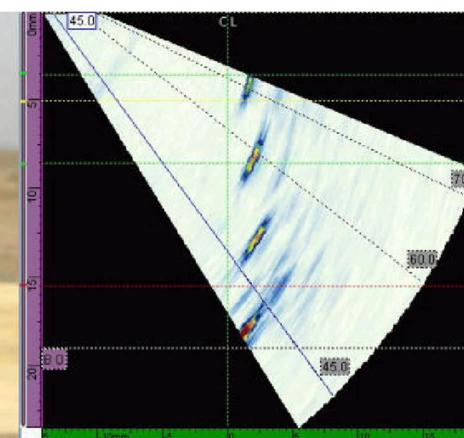
S-prikazi

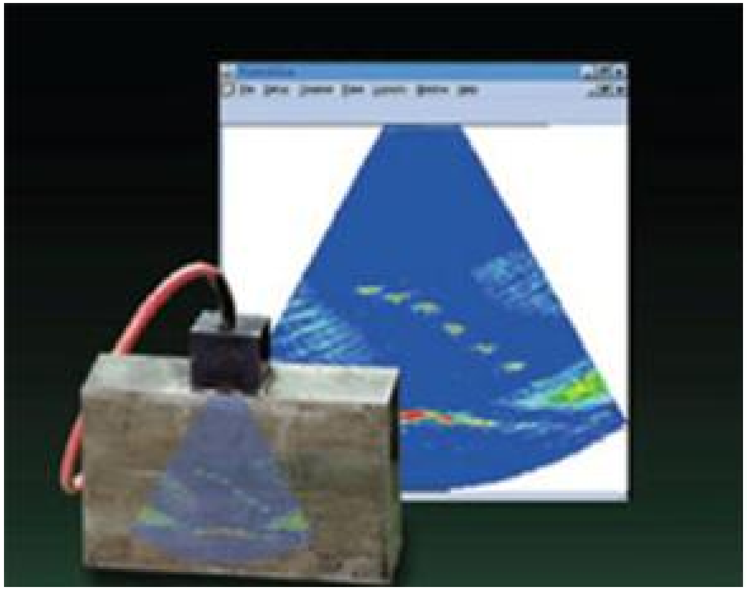


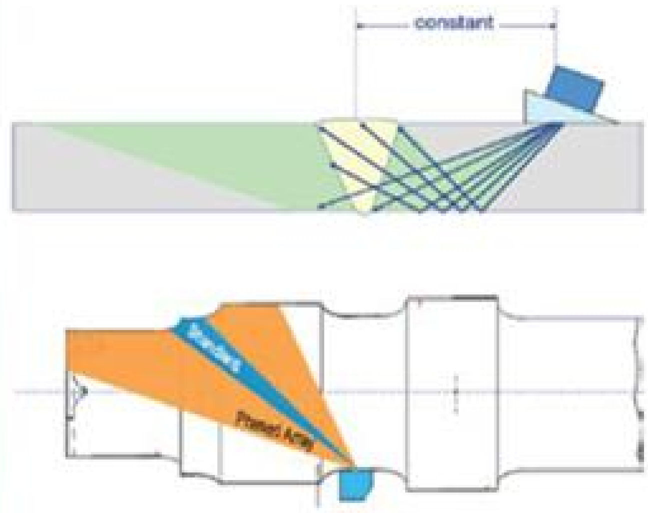












- http://www.imageprocessingbasics.com/spatial-resolution/
- TGC – TCG (pdf@moodle)
- https://www.youtube.com/wa