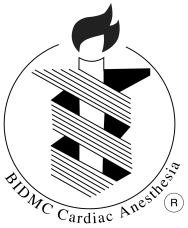
Practical Ultrasound Physics

Resident/Fellow Handout

Feroze Mahmood, MD.
Robina Matyal, MD.





BIDMC
Practical Ultrasound Physics

Resident - Fellow Handout

Feroze Mahmood, MD.
Robina Matyal, MD.

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1

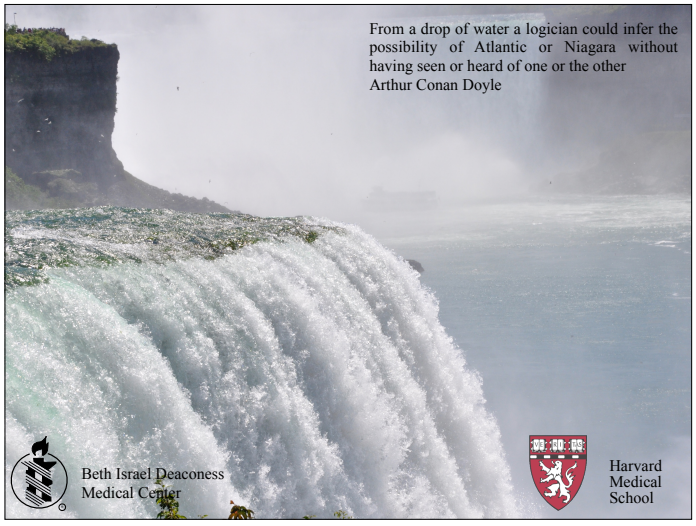
Disclosures

None

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2



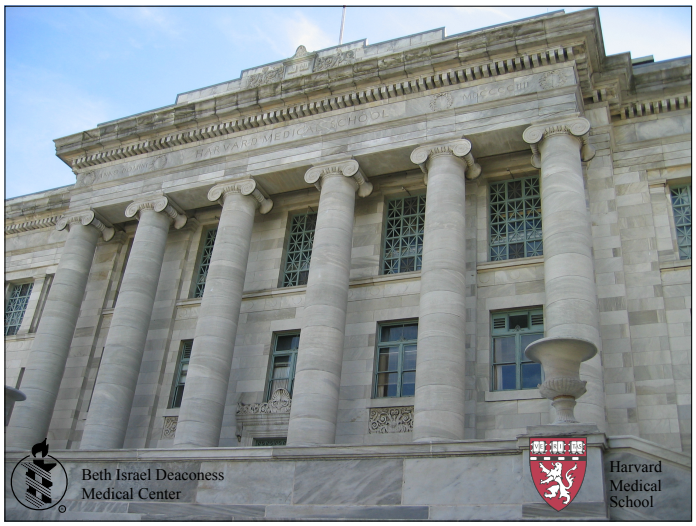
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3



4



5

Conduct of the Workshop

Properties of a sound beam

Acoustic parameters

Transducer design

Impulse transmission

Reflection and reception

Image formation

Artifacts

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6

7

Sound Beam

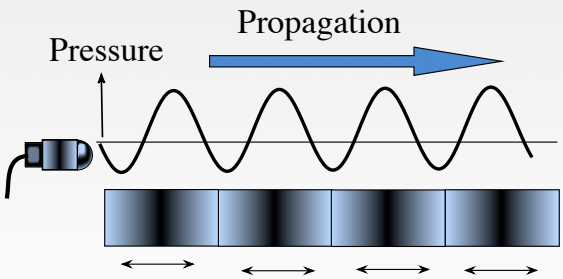
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Longitudinal Waves - Sound Waves

Particles move in the same direction as the wave



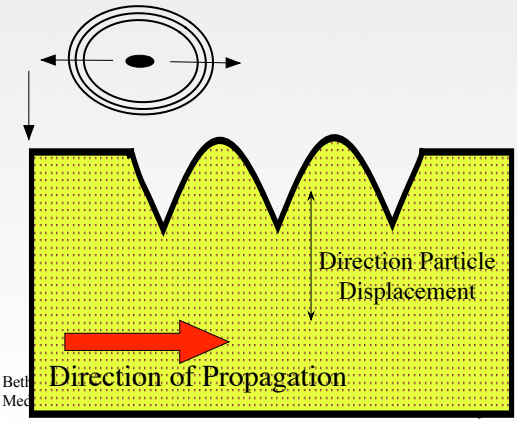
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Transverse Waves

Particles move in a direction perpendicular to the propagation



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Acoustic Parameters

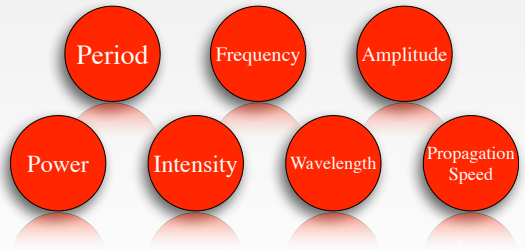
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Acoustic Parameters

Accurately describe the characteristics of a sound wave



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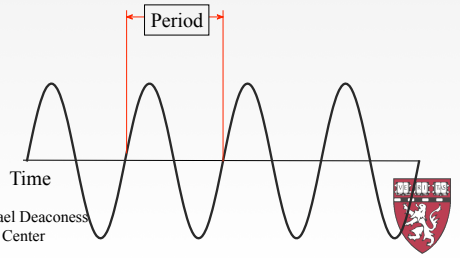
Period

The time it takes a wave to vibrate a single cycle *OR*
Time from the start of one cycle to the start of the next cycle

Units = "Time"

Determined by source

Cannot be changed



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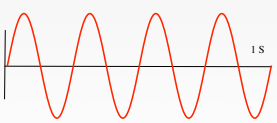
Frequency

13

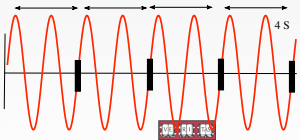
Number of particular events that take place in a specific duration of time

Units = units/sec 1 cycle/sec = 1 Hz. 1000 cycles/sec = 1 KHz. 1,000,000 cycles/sec = 1Mz.	Clinical Ultrasonography 2 MHz - 10 MHz 2-10 million cycles/sec	Determined by source Fixed for a transducer

Frequency determines DEPTH of penetration and RESOLUTION



4 Cycles in 1 second
Frequency: 4 cycles/sec = 4 Hz.



8 Cycles in 4 seconds
Frequency: 8/4 = 2 Hz.

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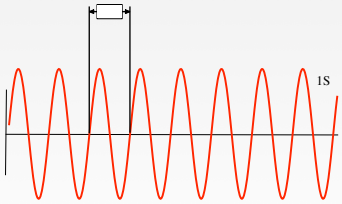
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Period and Frequency

14

Frequency and Period are INVERSELY related

As frequency increases - period decreases
As frequency decreases - period increases



Wave takes 1/8th of a second to vibrate (up and down)
Period = 1/8 second
Frequency = 8/second
Period * Frequency
1/8 * 8 = 1

Reciprocal Relation

Multiple of two reciprocal parameters is 1

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Review of Concepts

15

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Question 1

Which of the following waves has the longest period:

a: 2 MHz.

b: 4,000 Hz.

c: 6 Hz.

d: 1 KHz.

e: 7 Hz.

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16-1

Question 1

Which of the following waves has the longest period:

a: 2 MHz.

b: 4,000 Hz.

c: 6 Hz.

d: 1 KHz.

e: 7 Hz.

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16-2

Question 1

Which of the following waves has the longest period:

a: 2 MHz.

b: 4,000 Hz.

Wave with the lowest frequency will have the LONGEST period

c: 6 Hz.

d: 1 KHz.

e: 7 Hz.

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16-3

Question 2

Of the following wave PERIODS, which wave has the HIGHEST frequency:

a: 8 seconds.

b: 80 micro seconds.

c: 8 milliseconds.

d: 10 milliseconds.

e: 7.5 seconds.

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17-1

Question 2

Of the following wave PERIODS, which wave has the HIGHEST frequency:

a: 8 seconds.

b: 80 micro seconds.

c: 8 milliseconds.

d: 10 milliseconds.

e: 7.5 seconds.

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17-2

Question 2

Of the following wave PERIODS, which wave has the HIGHEST frequency:

a: 8 seconds.

b: 80 micro seconds.

c: 8 milliseconds.

d: 10 milliseconds.

e: 7.5 seconds.

Frequency and Period have an INVERSE relationship
Wave with the SHORTEST period will have the HIGHEST frequency

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17-3

Question 3

Of the following waves with these frequencies, which has the SHORTEST period:

a: 12 KHz.

b: 6,000 Hz.

c: 205 Hz.

d: 1 KHz.

e: 7 Hz.

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18-1

Question 3

Of the following waves with these frequencies, which has the SHORTEST period:

a: 12 KHz.

b: 6,000 Hz.

c: 205 Hz.

d: 1 KHz.

e: 7 Hz.

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18-2

Question 3

Of the following waves with these frequencies, which has the SHORTEST period:

a: 12 KHz.

b: 6,000 Hz.

Wave with the highest frequency will have the SHORTEST period

c: 205 Hz.

d: 1 KHz.

e: 7 Hz.

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18-3

Amplitude

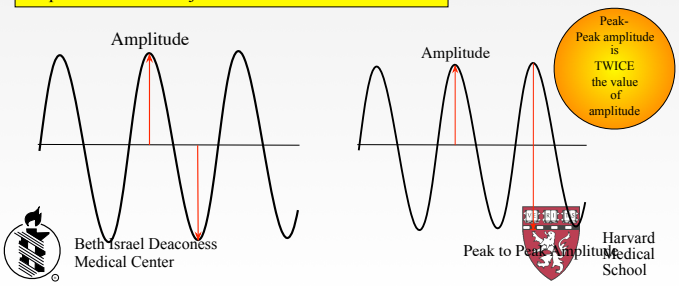
19

It is the "bigness" of the wave
Difference between the MAXIMUM value & AVERAGE or UNDISTURBED value

Units = any of the acoustic variables	Determined initially by the SOURCE As sound wave propagates - Amplitude Decreases

Rate of amplitude decrease depends upon the characteristics of the wave & medium

Amplitude CAN be adjusted on the ultrasound machine



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Amplitude

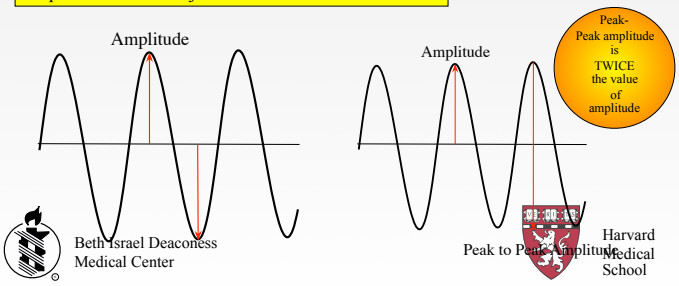
20

It is the "bigness" of the wave
Difference between the MAXIMUM value & AVERAGE or UNDISTURBED value

Units = any of the acoustic variables	Determined initially by the SOURCE As sound wave propagates - Amplitude Decreases

Rate of amplitude decrease depends upon the characteristics of the wave & medium

Amplitude CAN be adjusted on the ultrasound machine



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Power

21

It is also the "bigness" of the wave
Rate of energy transfer or the rate at which work is performed

Units = Watts	Typical value 0.004-0.090 (4-90 milli watts)

Initially determined only by the source - decreases as wave propagates

Rate of power decrease depends upon the characteristics of the wave & medium

Power CAN be adjusted on the ultrasound machine

Power and Amplitude describe the SIZE
When power increases - so does amplitude

$$\text{Power} \propto \text{Amplitude}^2$$

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Intensity

22

It is also the "bigness" of the wave
Concentration of energy in a sound wave - Beam's power/Cross sectional area

Units = Watts/cm^2 | Typical value = 0.01-300 W/cm^2 | Can be changed

Initially determined by the SOURCE - Changes with propagation

Rate of intensity decrease depends upon the shape of the wave & medium

Intensity $\propto$ Amplitude^2

Power $\propto$ Amplitude^2

Intensity $\propto$ Power

} Energy

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Wavelength

23

Distance or the length of a complete cycle

Units = mm, meters | Typical value = 0.15-0.8mm

Determined by the SOURCE *and* the MEDIUM

CANNOT be changed for a particular transducer

Only parameter determined by the SOURCE & the MEDIUM



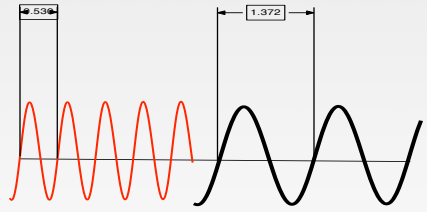
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Wavelength & Frequency

24

As long as sound remains in one medium - **Wavelength** and **Frequency** are INVERSELY related



As frequency INCREASES - wavelength DECREASES

If a wave's frequency is twice that of other, wavelength will be half as much

In soft tissue - sound wave with a 1 MHz frequency has a wavelength of 1.54 mm.

Wavelength = 1.54 mm/μs/frequency (MHz)

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Propagation Speed

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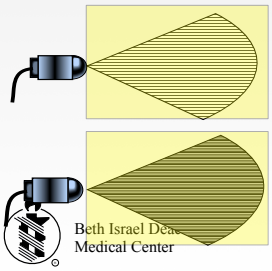
Distance that the sound wave travels through a medium in one second

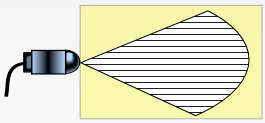
Units = meters/second | Typical value: 300-4000 m/second

Determined ONLY by the medium

Different frequency sounds travel at the same speed through a medium

CANNOT be changed by the sonographer -Determined only by the medium





Different frequency transducers

Same medium

Same propagation speed

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Speed of Sound and Body Tissues

26

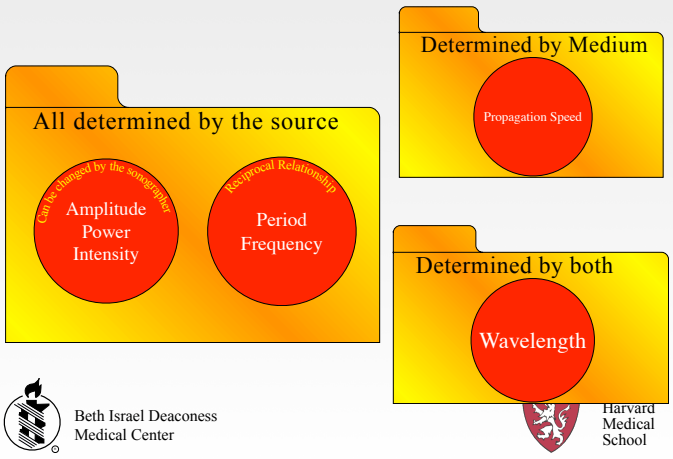
Tissue Type	Speed (m/sec)
Lung	500
Fat	1,450
Soft Tissue	**1,540**
Liver	1,560
Blood	1,560
Muscle	1,560
Tendon	1,600
Bone	3,500

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Review

27



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28

Review of Sound Wave Principles

Parameter	Adjustable	Units	Determined by	Typical Value
Period	No	Seconds,μs,time	Source	0.1-0.5 μs
Frequency	No	Per second, Hz	Source	2-10 MHz
Amplitude	Yes	Pascals, gm/cm^3, dB	Source	1 MPa-3 MPa
Power	Yes	Watts	Source	4-90 mw
Intensity	Yes	Watts/cm^2	Source	0.01-300 w/cm^2
Wavelength	No	mm,distance	Both	0.15-0.8 mm
Speed	No	m/sec	Medium	1500-1600 m/sec

Understanding Ultrasound Physics by Sidney Edelman. Third Edition 1994. ESP Inc. Page 38

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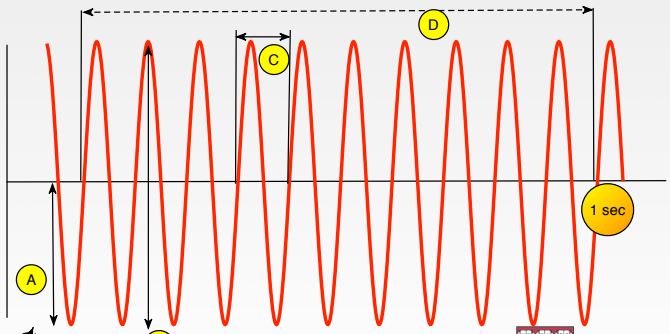
Review Questions

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30

Question 1



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Question 2

What is the wavelength of a 3 Mhz sound in soft tissue?

a: 0.51

b: 0.51 km

c: 0.51mm

d: 0.51 nm

0.51μm

$$\text{Wavelength} = \frac{1.54\ \text{mm}/\mu\text{s}}{\text{Frequency (MHz)}}$$

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31-1

Question 2

What is the wavelength of a 3 Mhz sound in soft tissue?

a: 0.51

b: 0.51 km

c: 0.51mm

d: 0.51 nm

0.51μm

$$\text{Wavelength} = \frac{1.54\ \text{mm}/\mu\text{s}}{\text{Frequency (MHz)}}$$

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31-2

Question 3

If the power of the beam is 1 watt and the area is 5 cm^2, what is the beam intensity:

a: 5 W/cm^2

b: 1 W/cm^2

c: 0.2 W/cm^2

d: 1.5 W/cm^2

1 W

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32-1

Question 3

If the power of the beam is 1 watt and the area is 5 cm^2, what is the beam intensity:

a: 5 W/cm^2

b: 1 W/cm^2

c: 0.2 W/cm^2

d: 1.5 W/cm^2

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32-2

Question 3

If the power of the beam is 1 watt and the area is 5 cm^2, what is the beam intensity:

a: 5 W/cm^2

b: 1 W/cm^2

c: 0.2 W/cm^2

d: 1.5 W/cm^2

Intensity = Power/Beam Area

Intensity = 1/5 = 0.2 cm^2

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32-3

The speed of sound wave with a frequency of 5 MHz in soft tissue will be:

a) 1540 m/sec

b) 2000 m/sec

c) 2500 m/sec

d) 1000 m/sec

e) 500 m/sec

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33-1

33-2

The speed of sound wave with a frequency of 5 MHz in soft tissue will be:

a) 1540 m/sec

b) 2000 m/sec

c) 2500 m/sec

d) 1000 m/sec

500 m/sec

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33-3

The speed of sound wave with a frequency of 5 MHz in soft tissue will be:

a) 1540 m/sec

b) 2000 m/sec

c) 2500 m/sec

d) 1000 m/sec

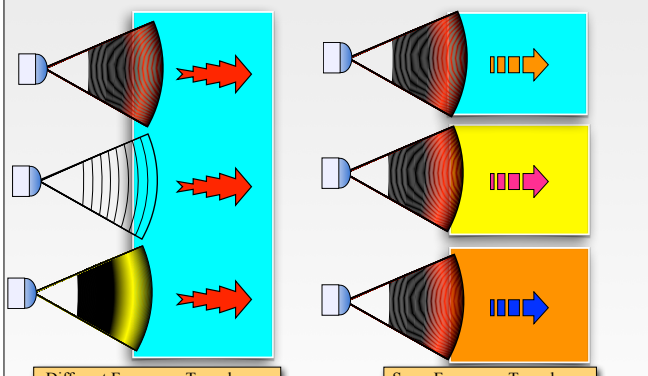
500 m/sec

Speed of Sound and Frequency are UNRELATED

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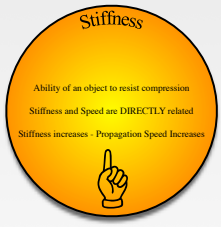
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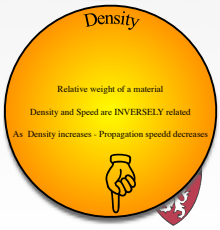
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Speed of Sound

Tissue Type	Speed (m/sec)
Lung	500
Fat	1,450
Soft Tissue	**1,540**
Liver	1,560
Liver	1,560
Blood	1,560
Muscle	1,600
Tendon	1,700
Bone	3,600





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36-1

Match the Units

Wave Length	Watts
Frequency	Second
Intensity	Watts/cm^2
Propagation Speed	Hertz
Period	Meters/second
Power	Millimeters

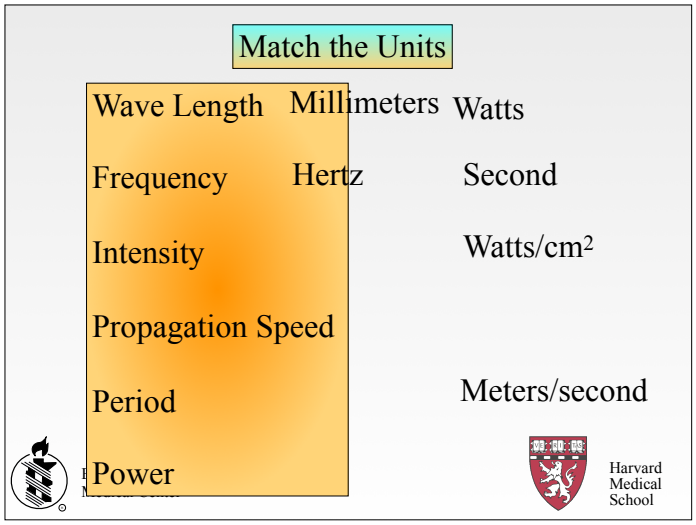
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36-2

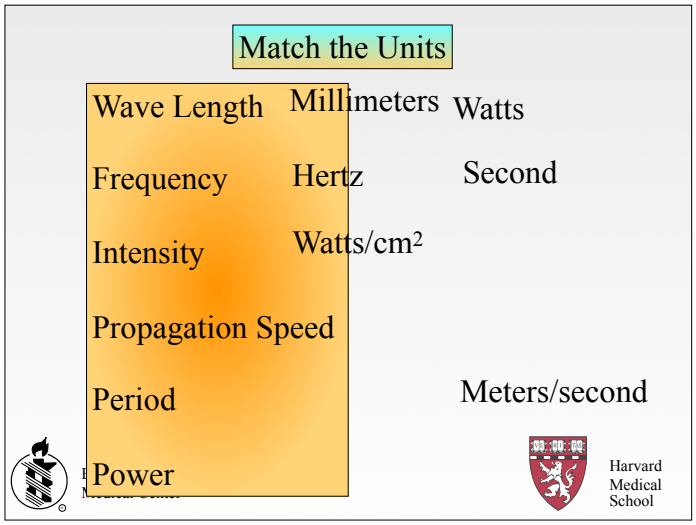
Match the Units

Wave Length	Millimeters
Frequency	Second
Intensity	Watts/cm^2
Propagation Speed	Hertz
Period	Meters/second
Power	Watts

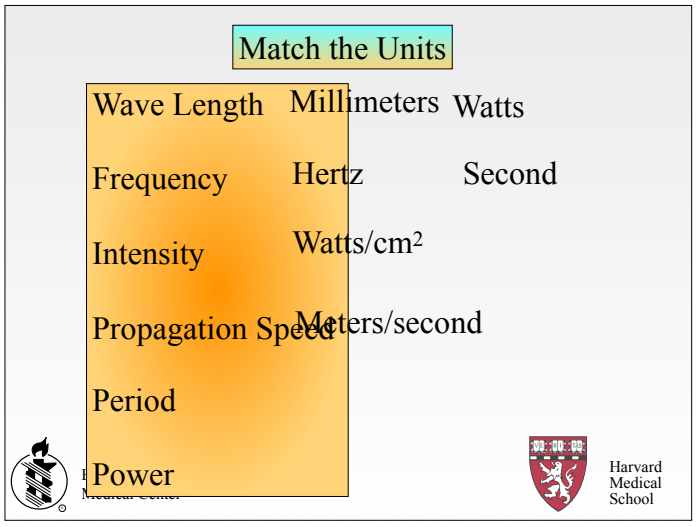
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Match the Units
Wave Length
Frequency
Intensity
Propagation Speed
Period
Power
Millimeters
Hertz
Watts
Second
Watts/cm2
Meters/second
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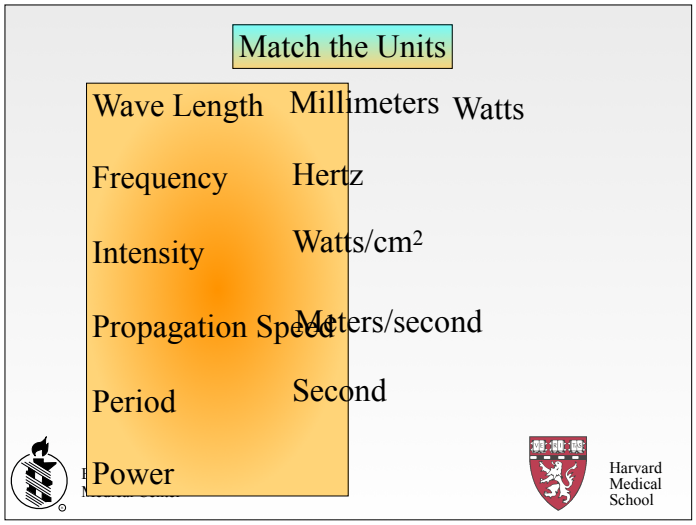
36-3


Match the Units
Wave Length
Frequency
Intensity
Propagation Speed
Period
Power
Millimeters
Hertz
Watts/cm2
Watts
Second
Meters/second
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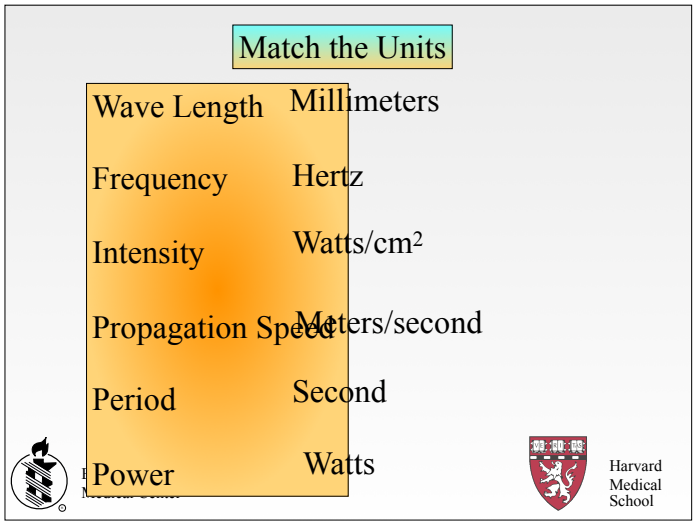
36-4


Match the Units
Wave Length
Frequency
Intensity
Propagation Speed
Period
Power
Millimeters
Hertz
Watts/cm2
Meters/second
Watts
Second
Harvard Medical School

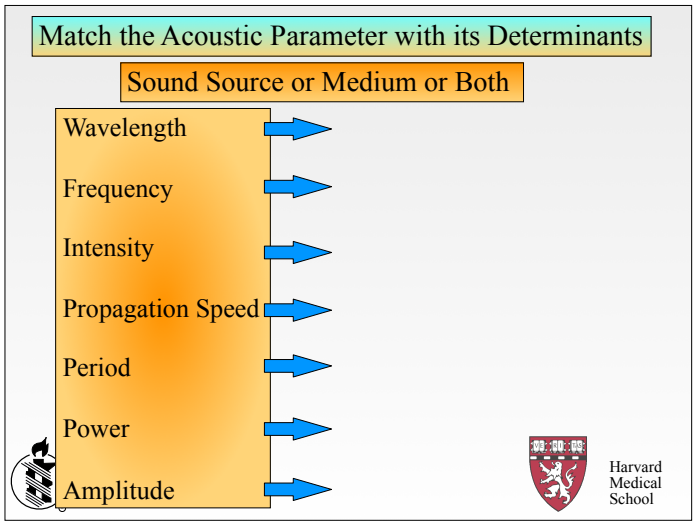
36-5


Match the Units
Wave Length
Frequency
Intensity
Propagation Speed
Period
Power
Millimeters
Hertz
Watts/cm2
Meters/second
Second
Watts
Harvard Medical School

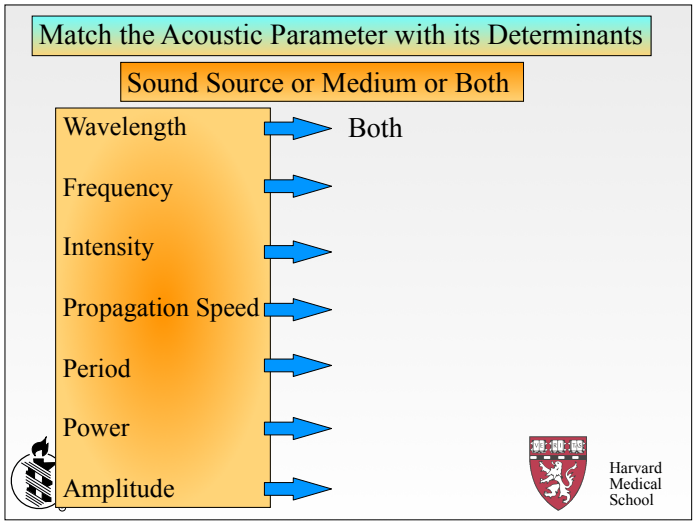
36-6


Match the Units
Wave Length
Frequency
Intensity
Propagation Speed
Period
Power
Millimeters
Hertz
Watts/cm2
Meters/second
Second
Watts
Harvard Medical School

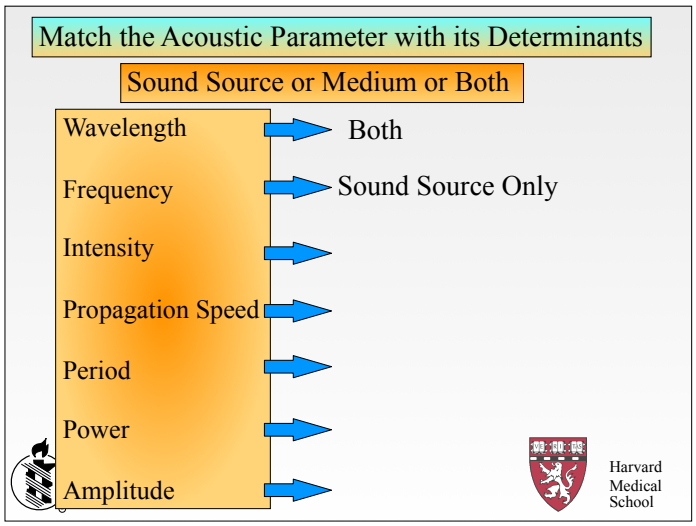
36-7


Match the Acoustic Parameter with its Determinants
Sound Source or Medium or Both
Wavelength
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Harvard Medical School

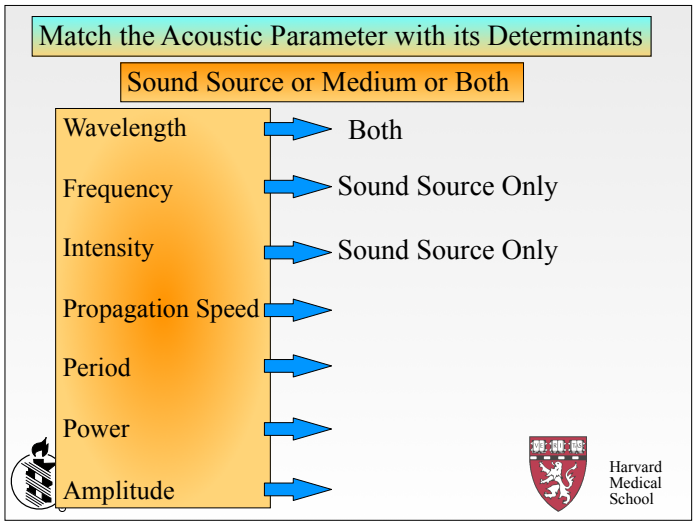
37-1


Match the Acoustic Parameter with its Determinants
Sound Source or Medium or Both
Wavelength
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Both
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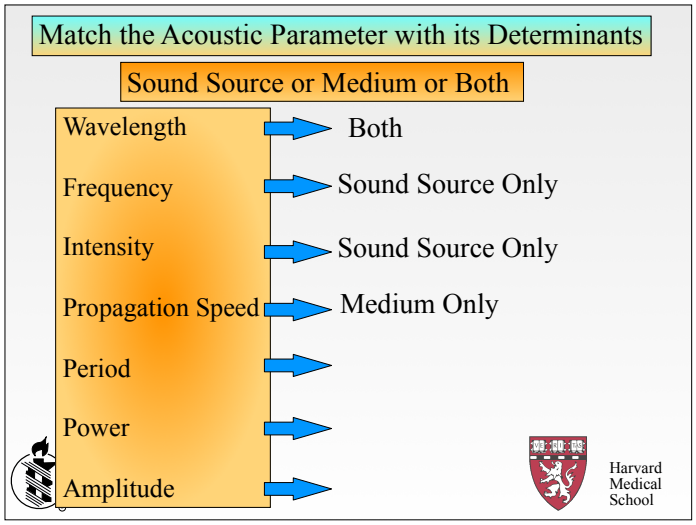
37-2


Match the Acoustic Parameter with its Determinants
Sound Source or Medium or Both
Wavelength
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Both
Sound Source Only
Harvard Medical School

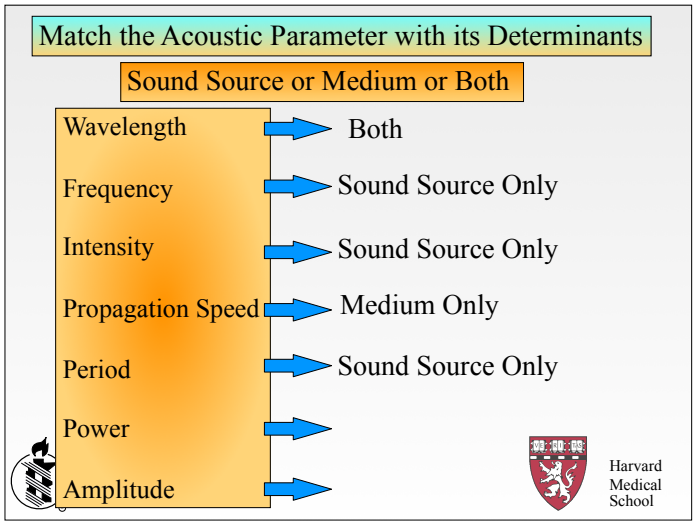
37-3


Match the Acoustic Parameter with its Determinants
Sound Source or Medium or Both
Wavelength
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Both
Sound Source Only
Sound Source Only
Harvard Medical School

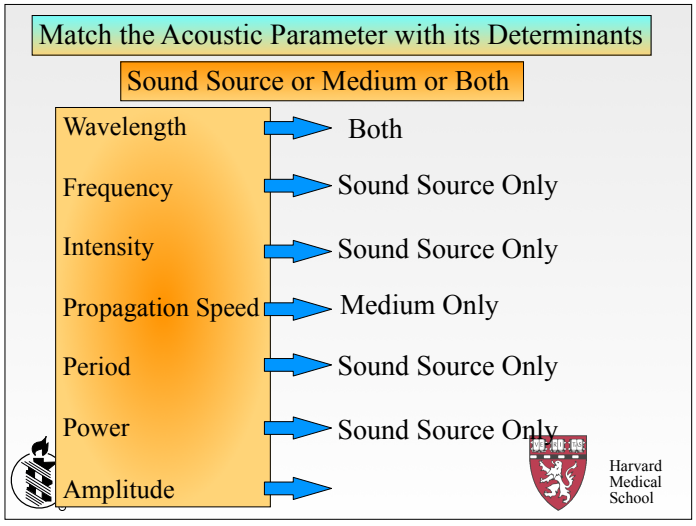
37-4


Match the Acoustic Parameter with its Determinants
Sound Source or Medium or Both
Wavelength
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Both
Sound Source Only
Sound Source Only
Medium Only
Harvard Medical School

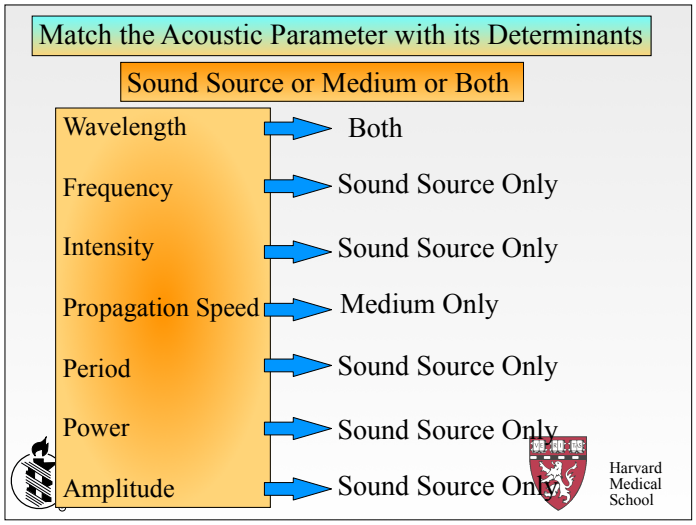
37-5


Match the Acoustic Parameter with its Determinants
Sound Source or Medium or Both
Wavelength
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Both
Sound Source Only
Sound Source Only
Medium Only
Sound Source Only
Harvard Medical School

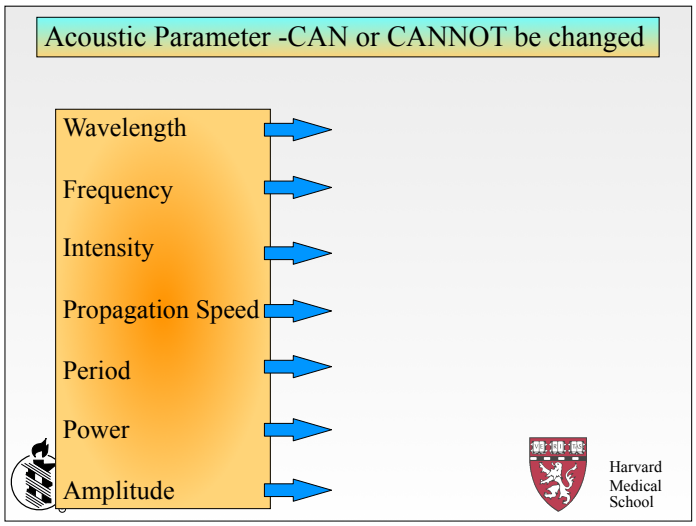
37-6


Match the Acoustic Parameter with its Determinants
Sound Source or Medium or Both
Wavelength
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Both
Sound Source Only
Sound Source Only
Medium Only
Sound Source Only
Sound Source Only
Harvard Medical School

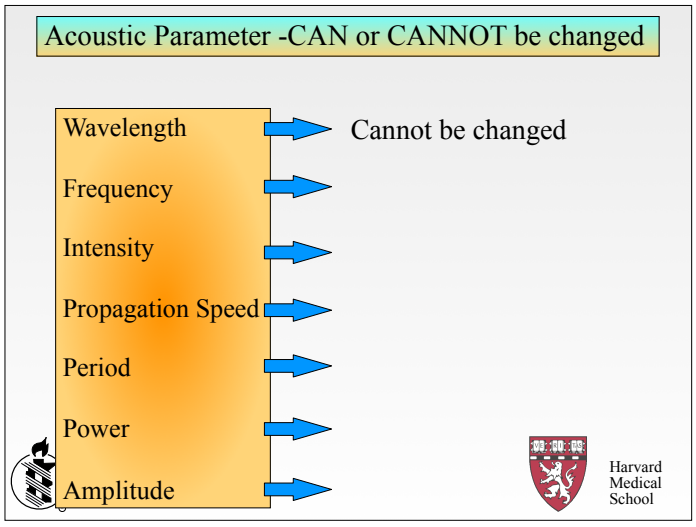
37-7


Match the Acoustic Parameter with its Determinants
Sound Source or Medium or Both
Wavelength
Both
Frequency
Sound Source Only
Intensity
Sound Source Only
Propagation Speed
Medium Only
Period
Sound Source Only
Power
Sound Source Only
Amplitude
Sound Source Only
Harvard Medical School

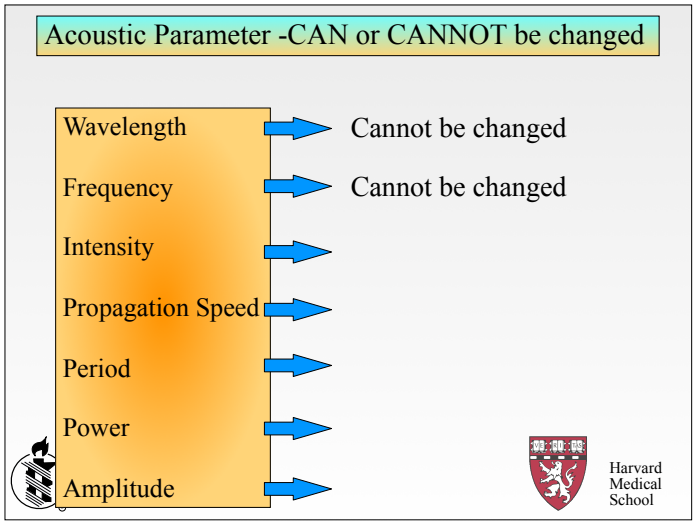
37-8


Acoustic Parameter -CAN or CANNOT be changed
Wavelength
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Harvard Medical School

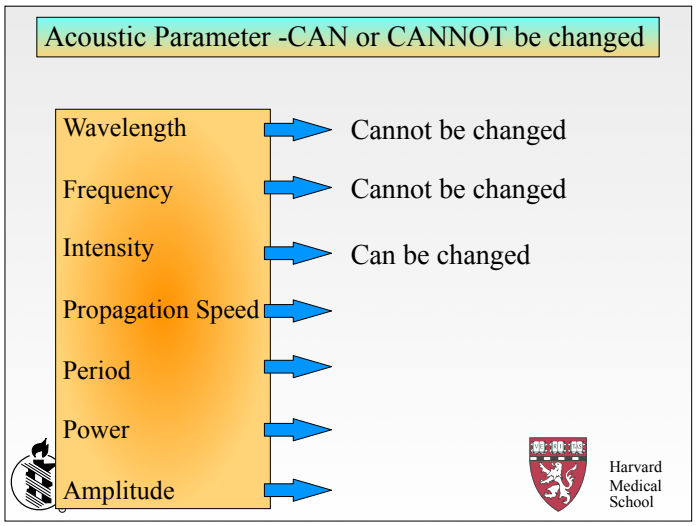
38-1


Acoustic Parameter -CAN or CANNOT be changed
Wavelength
Cannot be changed
Frequency
Intensity
Propagation Speed
Period
Power
Amplitude
Harvard Medical School

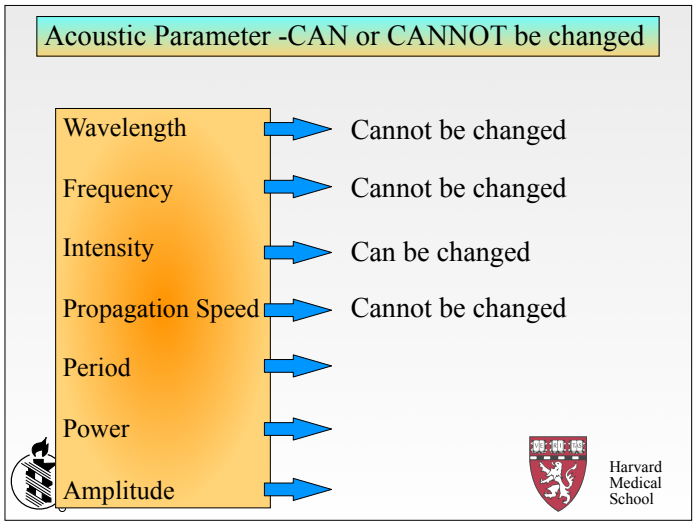
38-2


Acoustic Parameter -CAN or CANNOT be changed
Wavelength
Cannot be changed
Frequency
Cannot be changed
Intensity
Propagation Speed
Period
Power
Amplitude
Harvard Medical School

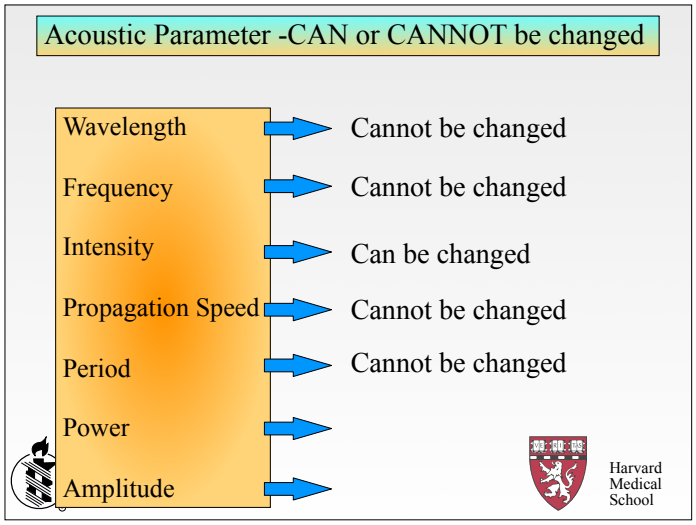
38-3


Acoustic Parameter -CAN or CANNOT be changed
Wavelength
Cannot be changed
Frequency
Cannot be changed
Intensity
Can be changed
Propagation Speed
Period
Power
Amplitude
Harvard Medical School

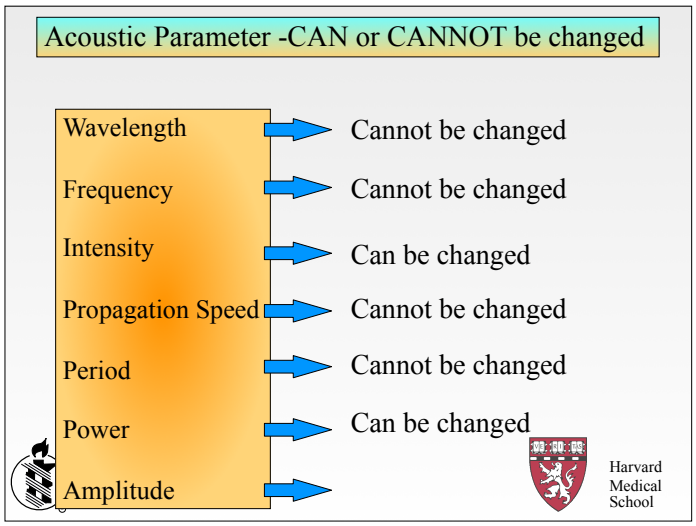
38-4


Acoustic Parameter -CAN or CANNOT be changed
Wavelength
Cannot be changed
Frequency
Cannot be changed
Intensity
Can be changed
Propagation Speed
Cannot be changed
Period
Power
Amplitude
Harvard Medical School

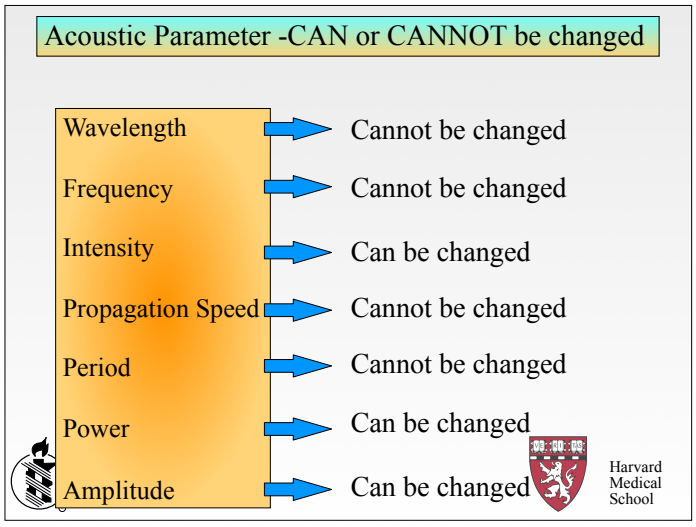
38-5


Acoustic Parameter -CAN or CANNOT be changed
Wavelength
Cannot be changed
Frequency
Cannot be changed
Intensity
Can be changed
Propagation Speed
Cannot be changed
Period
Cannot be changed
Power
Amplitude
Harvard Medical School

38-6


Acoustic Parameter -CAN or CANNOT be changed
Wavelength
Cannot be changed
Frequency
Cannot be changed
Intensity
Can be changed
Propagation Speed
Cannot be changed
Period
Cannot be changed
Power
Can be changed
Amplitude
Harvard Medical School

38-7


Acoustic Parameter -CAN or CANNOT be changed
Wavelength
Cannot be changed
Frequency
Cannot be changed
Intensity
Can be changed
Propagation Speed
Cannot be changed
Period
Cannot be changed
Power
Can be changed
Amplitude
Can be changed
Harvard Medical School

38-8

Which of the following tissue characteristics will have the highest propagation speed of sound:

a) High Density and High Stiffness

b) High Density and Low Stiffness

c) Low Density and High Stiffness

d) Low Density and Low Stiffness

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Harvard Medical School

39-1

Which of the following tissue characteristics will have the highest propagation speed of sound:

a) High Density and High Stiffness

b) High Density and Low Stiffness

c) Low Density and High Stiffness

d) Low Density and Low Stiffness

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39-2

Which of the following tissue characteristics will have the highest propagation speed of sound:

a) High Density and High Stiffness

b) High Density and Low Stiffness

c) Low Density and High Stiffness

d) Low Density and Low Stiffness

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40-1

Which of the following tissue characteristics will have the highest propagation speed of sound:

a) High Density and High Stiffness

b) High Density and Low Stiffness

c) Low Density and High Stiffness

d) Low Density and Low Stiffness

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40-2

Acoustic Parameter their Relationship

- Frequency and Period
- Amplitude and Power
- Amplitude and Intensity
- Power and Intensity
- Wavelength and Intensity
- Wavelength and Frequency
- Density and Propagation Speed
- Stiffness and Propagation Speed
- Frequency and Propagation Speed
- Frequency and Intensity
- Power and Frequency

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41-1

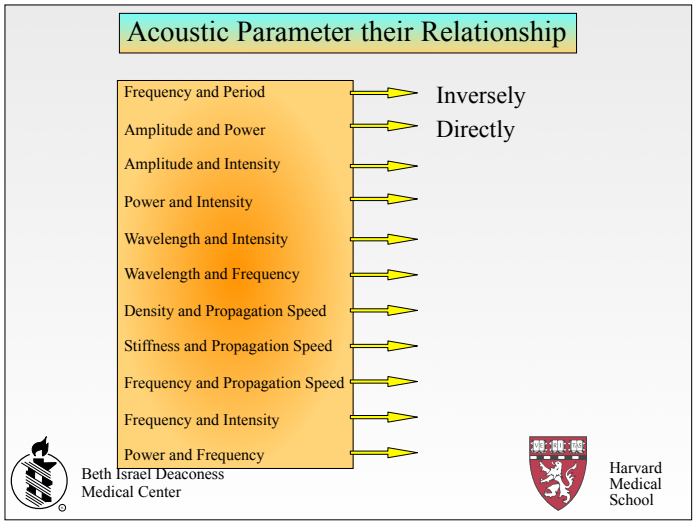
Acoustic Parameter their Relationship

- Frequency and Period → Inversely
- Amplitude and Power
- Amplitude and Intensity
- Power and Intensity
- Wavelength and Intensity
- Wavelength and Frequency
- Density and Propagation Speed
- Stiffness and Propagation Speed
- Frequency and Propagation Speed
- Frequency and Intensity
- Power and Frequency

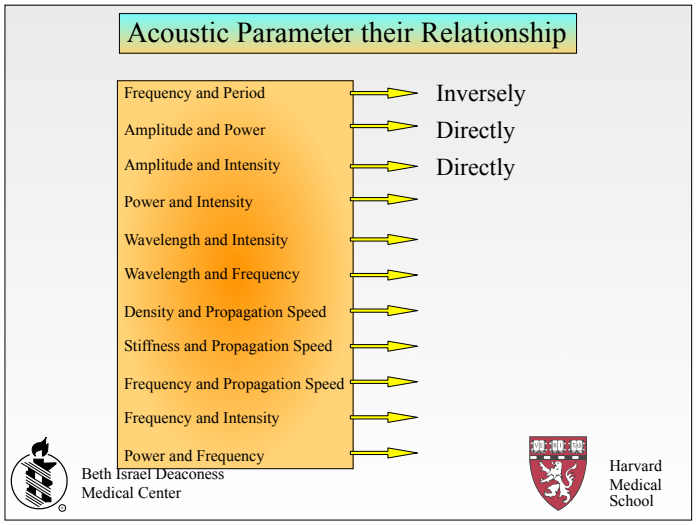
Beth Israel Deaconess Medical Center

Harvard Medical School

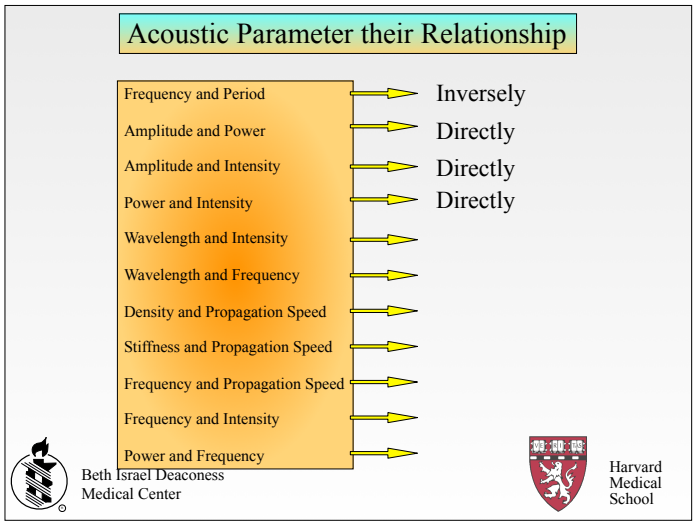
41-2


Acoustic Parameter their Relationship
Frequency and Period
Amplitude and Power
Amplitude and Intensity
Power and Intensity
Wavelength and Intensity
Wavelength and Frequency
Density and Propagation Speed
Stiffness and Propagation Speed
Frequency and Propagation Speed
Frequency and Intensity
Power and Frequency
Inversely
Directly
Beth Israel Deaconess Medical Center
Harvard Medical School

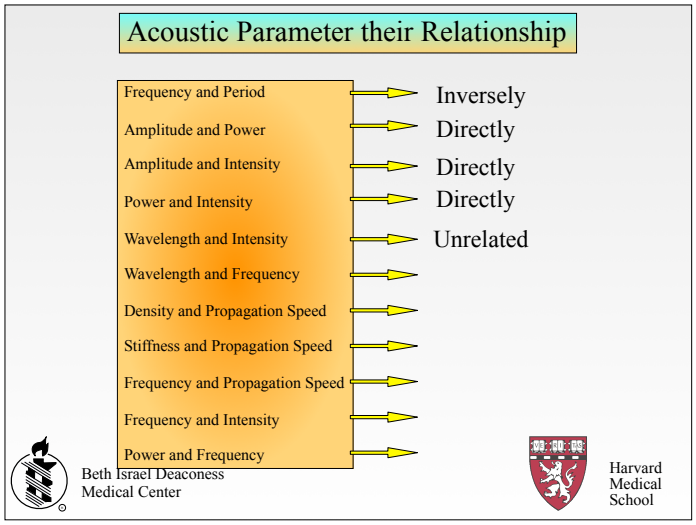
41-3


Acoustic Parameter their Relationship
Frequency and Period
Amplitude and Power
Amplitude and Intensity
Power and Intensity
Wavelength and Intensity
Wavelength and Frequency
Density and Propagation Speed
Stiffness and Propagation Speed
Frequency and Propagation Speed
Frequency and Intensity
Power and Frequency
Inversely
Directly
Directly
Beth Israel Deaconess Medical Center
Harvard Medical School

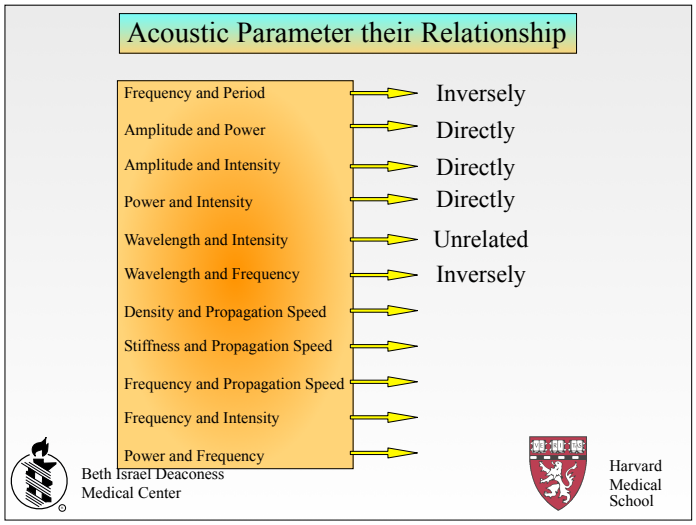
41-4


Acoustic Parameter their Relationship
Frequency and Period
Amplitude and Power
Amplitude and Intensity
Power and Intensity
Wavelength and Intensity
Wavelength and Frequency
Density and Propagation Speed
Stiffness and Propagation Speed
Frequency and Propagation Speed
Frequency and Intensity
Power and Frequency
Inversely
Directly
Directly
Directly
Beth Israel Deaconess Medical Center
Harvard Medical School

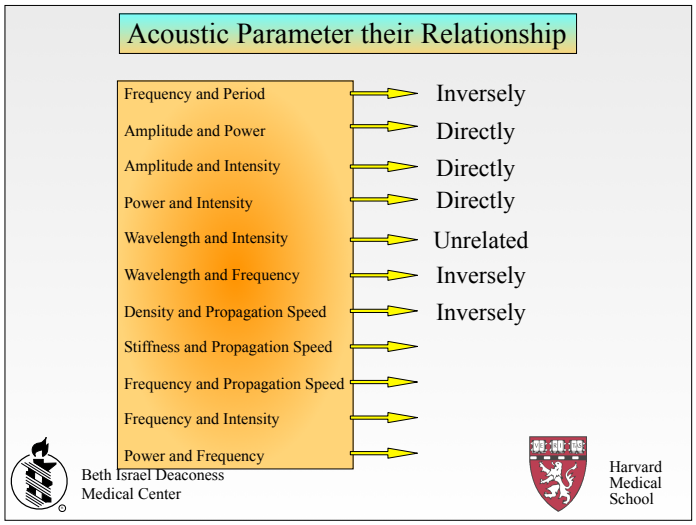
41-5


Acoustic Parameter their Relationship
Frequency and Period
Amplitude and Power
Amplitude and Intensity
Power and Intensity
Wavelength and Intensity
Wavelength and Frequency
Density and Propagation Speed
Stiffness and Propagation Speed
Frequency and Propagation Speed
Frequency and Intensity
Power and Frequency
Inversely
Directly
Directly
Directly
Unrelated
Beth Israel Deaconess Medical Center
Harvard Medical School

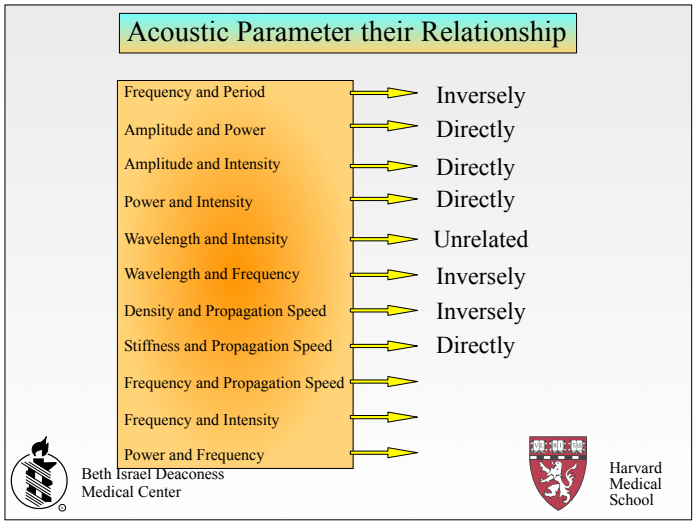
41-6


Acoustic Parameter their Relationship
Frequency and Period
Amplitude and Power
Amplitude and Intensity
Power and Intensity
Wavelength and Intensity
Wavelength and Frequency
Density and Propagation Speed
Stiffness and Propagation Speed
Frequency and Propagation Speed
Frequency and Intensity
Power and Frequency
Inversely
Directly
Directly
Directly
Unrelated
Inversely
Beth Israel Deaconess Medical Center
Harvard Medical School

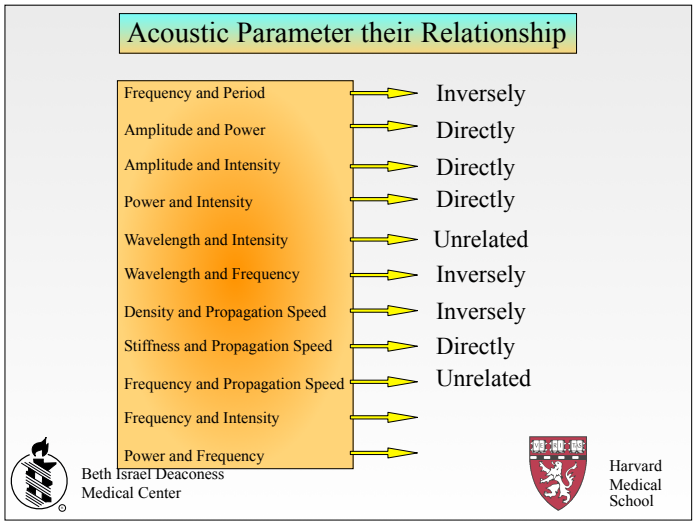
41-7


Acoustic Parameter their Relationship
Frequency and Period
Amplitude and Power
Amplitude and Intensity
Power and Intensity
Wavelength and Intensity
Wavelength and Frequency
Density and Propagation Speed
Stiffness and Propagation Speed
Frequency and Propagation Speed
Frequency and Intensity
Power and Frequency
Inversely
Directly
Directly
Directly
Unrelated
Inversely
Inversely
Beth Israel Deaconess Medical Center
Harvard Medical School

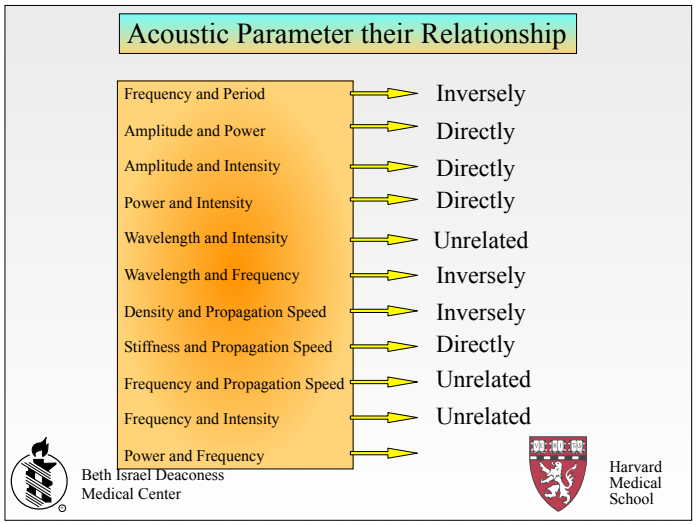
41-8



41-9



41-10



41-11

41-12

Acoustic Parameter their Relationship

Frequency and Period	Inversely
Amplitude and Power	Directly
Amplitude and Intensity	Directly
Power and Intensity	Directly
Wavelength and Intensity	Unrelated
Wavelength and Frequency	Inversely
Density and Propagation Speed	Inversely
Stiffness and Propagation Speed	Directly
Frequency and Propagation Speed	Unrelated
Frequency and Intensity	Unrelated
Power and Frequency	Unrelated

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42-1

By using an ultrasound transducer with “HIGHER FREQUENCY”, the corresponding wavelength will:

a) Increase

b) Decrease

c) Will not be affected

d) Will increase or decrease depending upon the propagation speed

e) Will increase or decrease depending upon the density of the medium

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42-2

By using an ultrasound transducer with “HIGHER FREQUENCY”, the corresponding wavelength will:

a) Increase

b) Decrease

c) Will not be affected

d) Will increase or decrease depending upon the propagation speed

e) Will increase or decrease depending upon the density of the medium

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43

Sound - Tissue Interactions

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44-1

Attenuation and Amplification



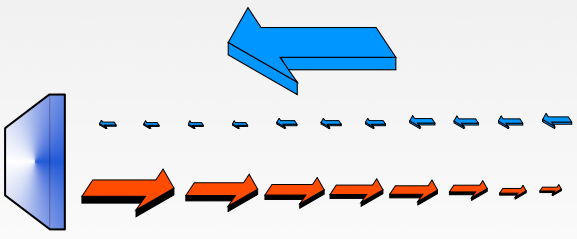
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Harvard Medical School

44-2

Attenuation and Amplification

Amplification after reception

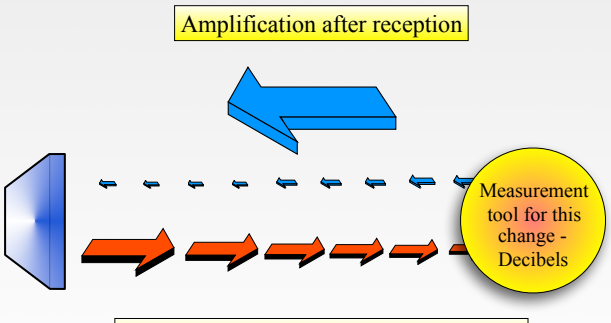


Attenuation of sound during transmission

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Harvard Medical School

Attenuation and Amplification



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Harvard Medical School

44-3

Decibels - dB

Units to quantify the STRENGTH of the ultrasound beam

Decibels - A LOGARITHMIC scale is used for such measurements

Does not represent absolute number - but RELATIVE CHANGE

i.e. Signal strength has tripled or one tenth the original value

Therefore TWO intensities are required

Initial and the actual at the time of measurement

Decibels are ratios
Actual : Initial

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Decibels - dB

Positive decibels - Signals which are getting larger or increasing in strength

When the signal strength DOUBLES - Change is + 3 dB

When the signal strength is ten fold - +10 dB

Negative decibels - Signals which are getting smaller or decreasing in strength

When the signal strength halves - Change is - 3 dB

When the signal strength is ten fold - -10 dB

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46-1

46-2

Decibels - dB

Positive decibels - Signals which are getting larger or increasing in strength

Decibels	Strength
3 dB	Double
10 dB	Ten Times
- 3 dB	Half
-10 dB	Ten Times

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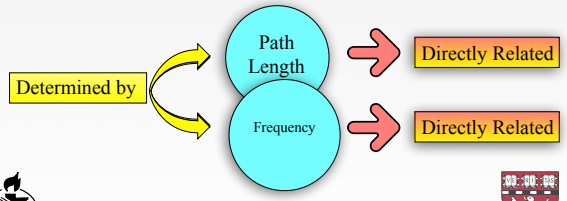
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47

Attenuation

Decrease in INTENSITY, POWER AND AMPLITUDE





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48

Pulse Ultrasound Parameters

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Pulse Ultrasound

Imaging systems produce short burst of ultrasound - **PULSES**

A “Pulse” is a collection of cycles that travel together

A “Pulse” must have a beginning and an end

In a “Pulse” multiple cycles move together

Pulse Ultrasound & Train - Similarities

Train - Individual box cars, but travel as a single entity

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49-1

Pulse Ultrasound

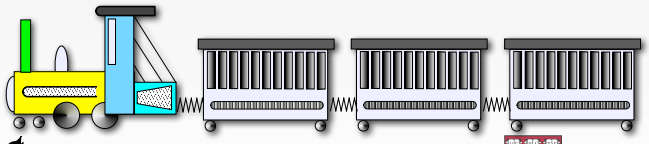
Imaging systems produce short burst of ultrasound - **PULSES**

A “Pulse” is a collection of cycles that travel together

A “Pulse” must have a beginning and an end

In a “Pulse” multiple cycles move together

Pulse Ultrasound & Train - Similarities



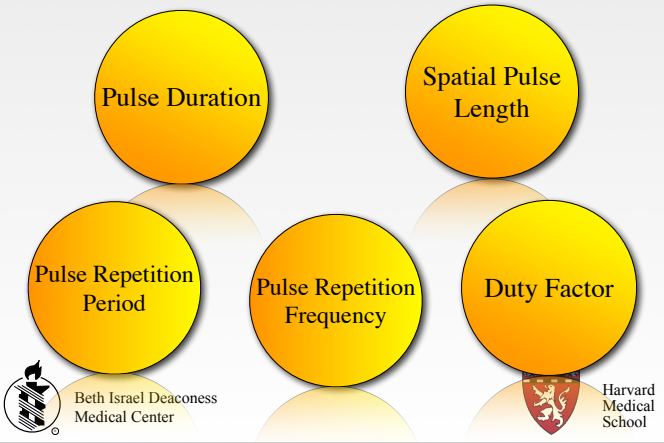
Train - Individual box cars, but travel as a single entity

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49-2

More Acoustic Parameters



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50

51

Anatomy of an Ultrasound Beam

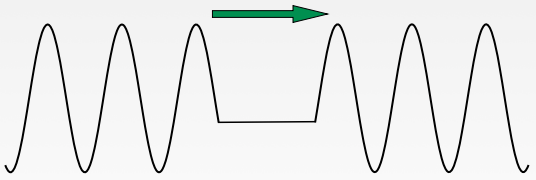
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52

Pulse Ultrasound - Components

Receive Time
Listening Time
Off Time



Transmit Time
Talking Time
ON Time

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53

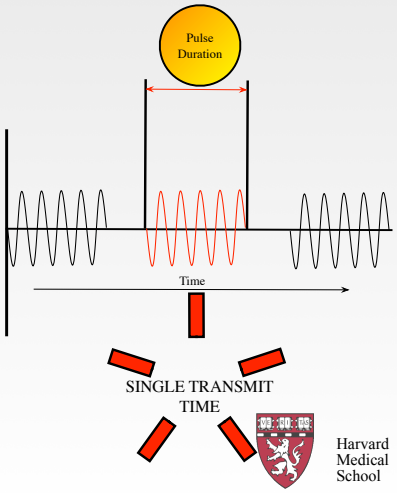
PULSE DURATION
Actual time from the START of the pulse to the END of the pulse
Pulse Duration: "SINGLE TRANSMIT

UNITS
Reported in units of time
miliseconds, microseconds or seconds

TYPICAL VALUE
(Diagnostic Ultrasound)
0.3 - 2.0μ seconds

DETERMINED BY
Sound Source ONLY

ADJUSTMENT
CANNOT be adjusted for a particular transducer



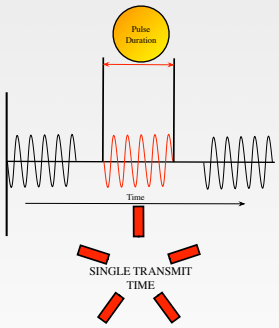
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Pulse Duration

54

Pulse Duration (μs) = # cycles× period (μs)

Pulse Duration (μs) = # Cycles/Frequency (MHz)



Directly proportional to the NUMBER of cycles in the pulse

Directly proportional to the PERIOD

Inversely proportional to FREQUENCY

Shorter duration pulses - Better Image quality

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Spatial Pulse Length

55

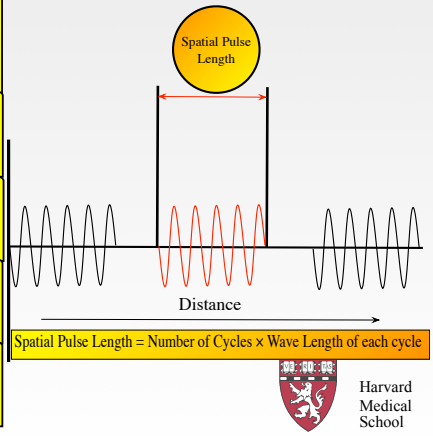
SPATIAL PULSE LENGTH
DISTANCE that a pulse occupies in space from the start to the end of the pulse

UNITS
Reported in units of distance
mm

TYPICAL VALUE
(Diagnostic Ultrasound)
0.1-1.0 mm

DETERMINED BY
Sound Source and Medium

Adjustment
Cannot be altered by the sonographer



Spatial Pulse Length = Number of Cycles x Wave Length of each cycle

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Spatial Pulse Length

56

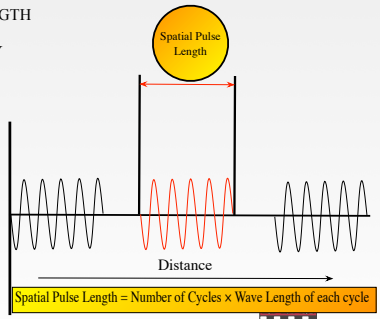
Directly proportional to the NUMBER of cycles in the pulse

Directly proportional to the WAVELENGTH

Inversely proportional to FREQUENCY

Spatial Pulse Length
DISTANCE

Pulse Duration
TIME



Spatial Pulse Length = Number of Cycles x Wave Length of each cycle

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Pulse Repetition Period

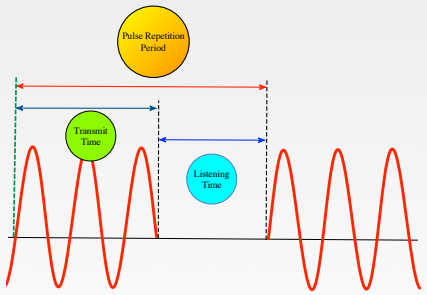
PULSE REPETITION PERIOD
TIME from the start of one pulse to the start of the next pulse

UNITS
Reported in units of time
ms

TYPICAL VALUE
(Diagnostic Ultrasound)
Pulse duration = 100 μs to 1 ms
Pulse repetiton period is 100-1000 times longer than pulse duration

DETERMINED BY
Sound source only
Determined by the IMAGING DEPTH - Selected by sonographer

Adjustment
CAN be adjusted by changing the imaging depth



Pulse Repetition Period = 1 Transmit time + 1 Listening Time

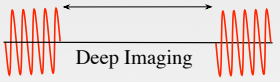
Harvard Medical School

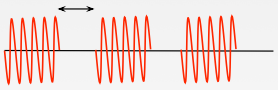
58

Pulse Repetition Period

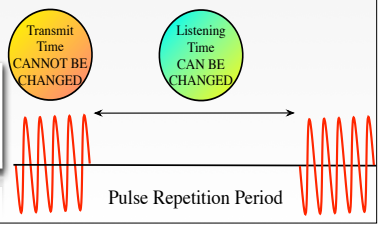
As depth of view increases
Pulse Repetition Period Increases

As depth of view decreases
Pulse Repetition Period Decreases





Components of Pulse Repetition Period
- Transmit Time - Cannot be changed
- Listening Tine - CAN be changed



59

Pulse Repetition Frequency

PULSE REPETITION FREQUENCY (PRF)
NUMBER of pulses an ultrasound transmits each second
Number of *cyles* in each pulse not important
Number of *PULSES* are important

UNITS
Reported Hertz (Hz) or per second

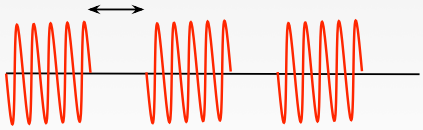
TYPICAL VALUE
(Diagnostic Ultrasound)
1,000-10,000 Hz
(1-10,000 PULSES/Second)

DETERMINED BY
Sound source only
Determined by the IMAGING DEPTH - Selected by sonographer

Adjustment
CAN be adjusted by changing the imaging depth



Lower PRF



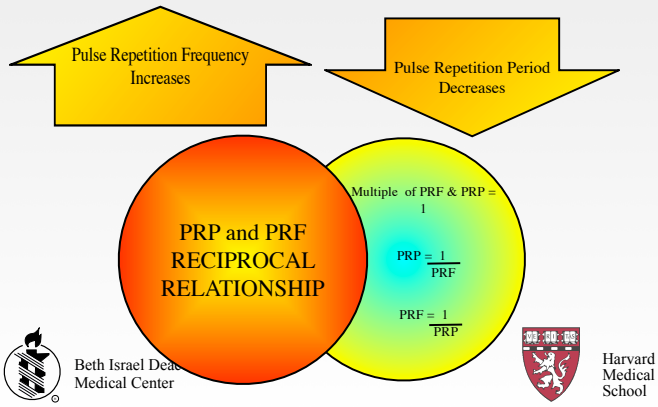
Higher PRF

Harvard Medical School

Pulse Repetition Period vs. Pulse Repetition Frequency

60

Pulse repetition period and Pulse repetition frequency are INVERSELY related



Beth Israel Deaconess Medical Center

Harvard Medical School

Review Questions

61

Beth Israel Deaconess Medical Center

Harvard Medical School

Question 1

62-1

Which of the following values of pulse repetition frequency would have the longest pulse repetition period:

a: 2 kHz

b: 4,000 Hz

c: 6 Hz

d: 1 k Hz

e: 4.5 k Hz

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Harvard Medical School

Question 1

Which of the following values of pulse repetition frequency would have the longest pulse repetition period:

a: 2 kHz

b: 4,000 Hz

c: 6 Hz

d: 1 k Hz

e: 4.5 k Hz

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Harvard Medical School

62-2

Question 1

Which of the following values of pulse repetition frequency would have the longest pulse repetition period:

a: 2 kHz

b: 4,000 Hz

c: 6 Hz

d: 1 k Hz

e: 4.5 k Hz

PRF is reciprocal to PRP

Lowest PRF would have the longest PRP

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Harvard Medical School

62-3

Question 2

Which of the following waves with these pulse repetition period have the highest pulse repetition frequency:

a: 8 seconds

b: 80 milliseconds

c: 7.5 milliseconds

d: 5 milliseconds

e: 400 k seconds

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Harvard Medical School

63-1

Question 2

Which of the following waves with these pulse repetition period have the highest pulse repetition frequency:

a: 8 seconds

b: 80 milliseconds

c: 7.5 milliseconds

d: 5 milliseconds

e: 400 k seconds

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Harvard Medical School

63-2

Question 2

Which of the following waves with these pulse repetition period have the highest pulse repetition frequency:

a: 8 seconds

b: 80 milliseconds

c: 7.5 milliseconds

d: 5 milliseconds

e: 400 k seconds

Due to the reciprocal relationship, the pulse with the shortest pulse repetition period will have the highest pulse repetition frequency

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63-3

Question 3

Which of the following pulse repetition frequencies listed have the shortest pulse repetition period:

a: 12 kHz

b: 6,000 Hz

c: 20 kHz

d: 1 kHz

e: 1.5 MHz

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Harvard Medical School

64-1

Question 3

Which of the following pulse repetition frequencies listed have the shortest pulse repetition period:

a: 12 kHz

b: 6,000 Hz

c: 20 kHz

d: 1 kHz

e: 1.5 MHz

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Harvard Medical School

64-2

Question 3

Which of the following pulse repetition frequencies listed have the shortest pulse repetition period:

a: 12 kHz

b: 6,000 Hz

c: 20 kHz

d: 1 kHz

e: 1.5 MHz

Choice “E” has the highest PRF - Hence the shortest pulse repetition period

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Harvard Medical School

64-3

Question 4

Which of the following listed pulse repetition periods listed have the lowest pulse repetition frequency:

a: 8 seconds

b: 80 µseconds

c: 8,000 nano seconds

d: 8 milliseconds

e: 12 seconds

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65-1

Question 4

Which of the following listed pulse repetition periods listed have the lowest pulse repetition frequency:

a: 8 seconds

b: 80 µseconds

c: 8,000 nano seconds

d: 8 milliseconds

e: 12 seconds



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Harvard Medical School

65-2

Question 4

Which of the following listed pulse repetition periods listed have the lowest pulse repetition frequency:

a: 8 seconds

b: 80 µseconds

c: 8,000 nano seconds

Choice "E" has the longest PRp - Hence the lowest pulse repetition frequency

d: 8 milliseconds

e: 12 seconds



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65-3

Question 5

True or False

Two waves can have identical pulse repetition frequencies with different pulse repetition periods

True False

Question 6

Two waves can have identical pulse repetition frequencies with different pulse periods

True False



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Harvard Medical School

66-1

Question 5

True or False

Two waves can have identical pulse repetition frequencies with different pulse repetition periods

True

False

Question 6

Two waves can have identical pulse repetition frequencies with different pulse periods

True

False

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Harvard Medical School

66-2

Question 5

True or False

Two waves can have identical pulse repetition frequencies with different pulse repetition periods

True

False

It is not possible to have identical PRF's with different PRP's

Question 6

Two waves can have identical pulse repetition frequencies with different pulse periods

True

False

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Harvard Medical School

66-3

Question 5

True or False

Two waves can have identical pulse repetition frequencies with different pulse repetition periods

True

False

It is not possible to have identical PRF's with different PRP's

Question 6

Two waves can have identical pulse repetition frequencies with different pulse periods

True

False

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Harvard Medical School

66-4

66-5

Question 5

True or False

Two waves can have identical pulse repetition frequencies with different pulse repetition periods

True

False

It is not possible to have identical PRF's with different PRP's

Question 6

Two waves can have identical pulse repetition frequencies with different pulse periods

True

False

Pulse repetition frequency and Period are unrelated

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Harvard Medical School

67-1

Question 7

True or False

Two waves can have the same pulse repetition frequencies with different frequencies

True

False

Question 7

Pulse repetition period and pulse repetition frequency are determined by the imaging depth

True

False

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Harvard Medical School

67-2

Question 7

True or False

Two waves can have the same pulse repetition frequencies with different frequencies

True

False

Question 7

Pulse repetition period and pulse repetition frequency are determined by the imaging depth

True

False

Beth Israel Deaconess Medical Center

Harvard Medical School

Question 7

True or False

Two waves can have the same pulse repetition frequencies with different frequencies

True

False

Frequency and pulse repetition frequency are unrelated

Question 7

Pulse repetition period and pulse repetition frequency are determined by the imaging depth

True

False

Beth Israel Deaconess Medical Center

Harvard Medical School

67-3

Question 7

True or False

Two waves can have the same pulse repetition frequencies with different frequencies

True

False

Frequency and pulse repetition frequency are unrelated

Question 7

Pulse repetition period and pulse repetition frequency are determined by the imaging depth

True

False

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Harvard Medical School

67-4

Question 7

True or False

Two waves can have the same pulse repetition frequencies with different frequencies

True

False

Frequency and pulse repetition frequency are unrelated

Question 7

Pulse repetition period and pulse repetition frequency are determined by the imaging depth

Both can be adjusted by changing the imaging depth

True

False

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Harvard Medical School

67-5

68

Duty Factor

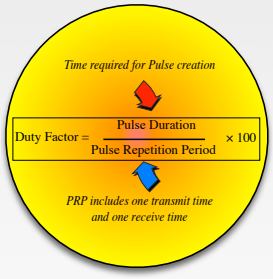
DUTY FACTOR (DF)
Percentage of fraction of time that the system is TRANSMITTING a pulse

UNITS
None
Dimensionless

TYPICAL VALUE
(Diagnostic Ultrasound)
0.002-0.005 or 0.2-0.5%
0.2% - Transmitting for 0.2% & Listening for 99.8% of the time
1% - Only transmitting

DETERMINED BY
Sound source only
Determined by the IMAGING DEPTH - Selected by sonographer

Adjustment
CAN be adjusted by changing the imaging depth
Inversely related to imaging depth



Maximum value = 1 or 100% - Continuous wave sound

Minimum value = 0

Typical value = 0.2%

Harvard Medical School

69-1

Which of the following parameters will be affected by changing the imaging depth: *(More than ONE may be correct):*

a) Pulse Repetition Frequency

b) Duty Factor

c) Propagation Speed

d) Pulse Repetition Period

e) Amplitude

f) Spatial Pulse Length

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Harvard Medical School

69-2

Which of the following parameters will be affected by changing the imaging depth: *(More than ONE may be correct):*

a) Pulse Repetition Frequency

b) Duty Factor

c) Propagation Speed

d) Pulse Repetition Period

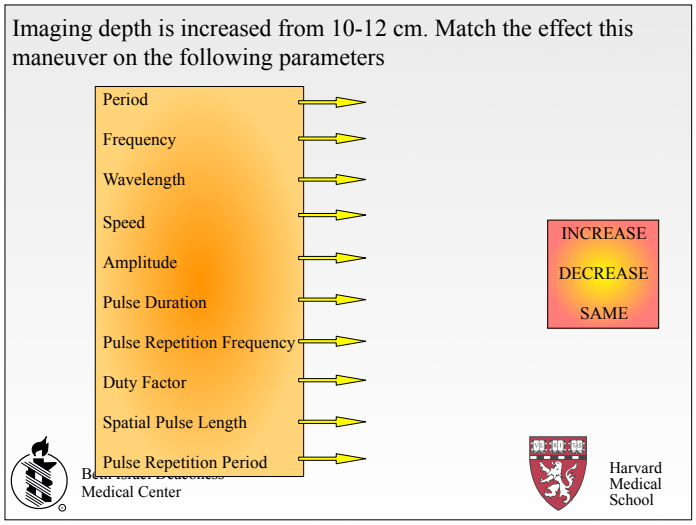
e) Amplitude

f) Spatial Pulse Length

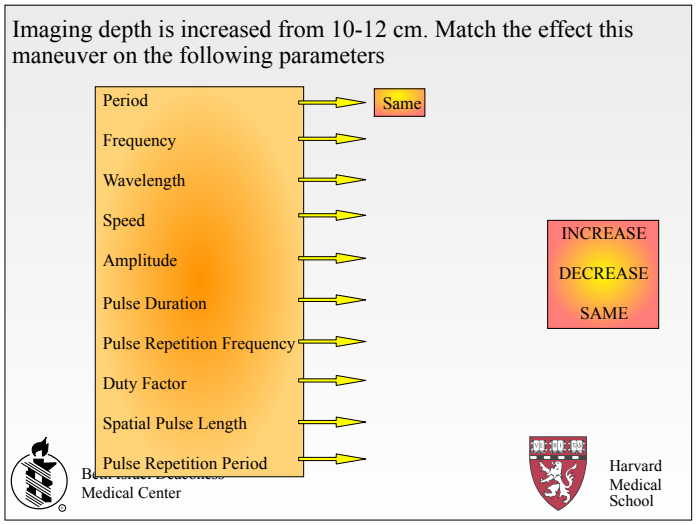
Beth Israel Deaconess Medical Center

Harvard Medical School

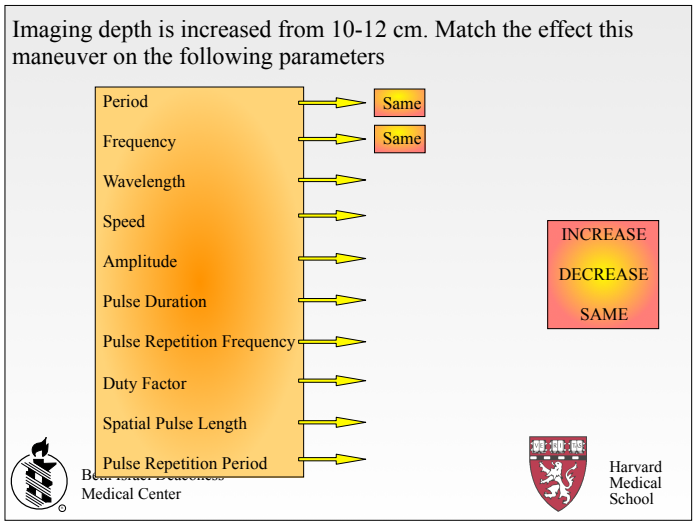
70-1


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Frequency
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
INCREASE
DECREASE
SAME
Medical Center
Harvard Medical School

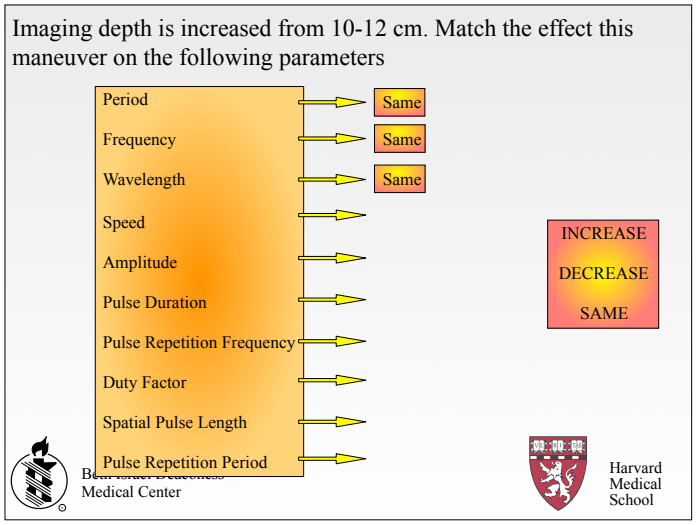
70-2


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Same
Frequency
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
INCREASE
DECREASE
SAME
Medical Center
Harvard Medical School

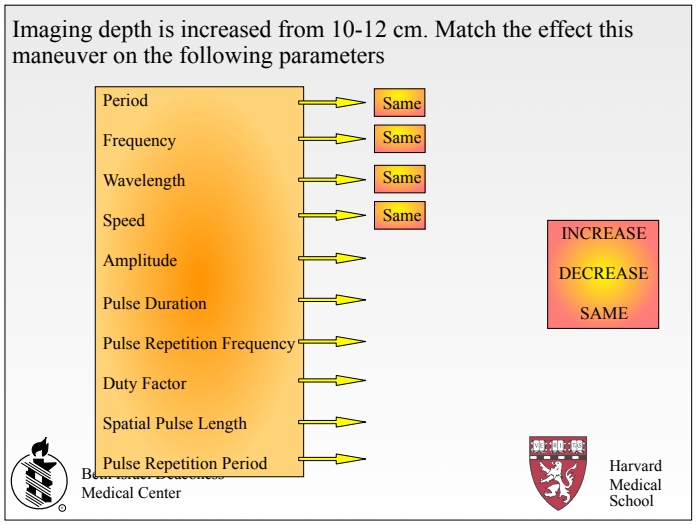
70-3


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Same
Frequency
Same
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
INCREASE
DECREASE
SAME
Medical Center
Harvard Medical School

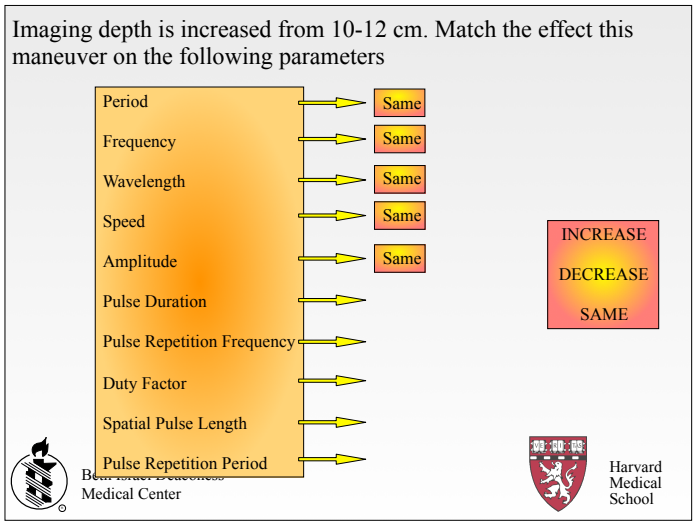
70-4


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Frequency
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
Same
Same
Same
INCREASE
DECREASE
SAME
Medical Center
Harvard Medical School

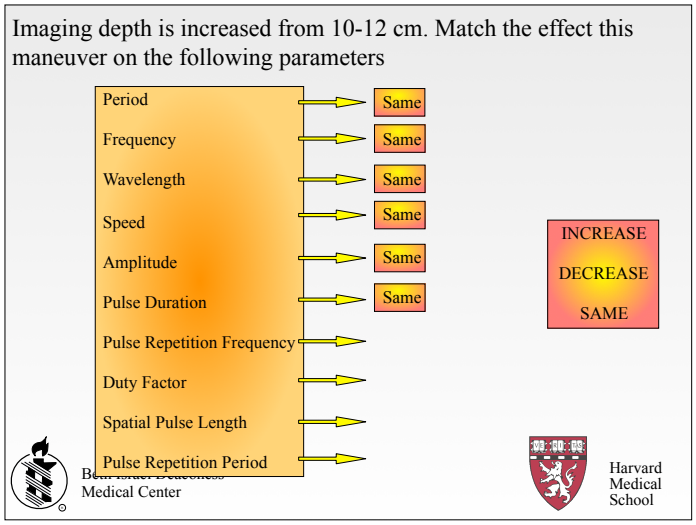
70-5


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Frequency
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
Same
Same
Same
Same
INCREASE
DECREASE
SAME
Medical Center
Harvard Medical School

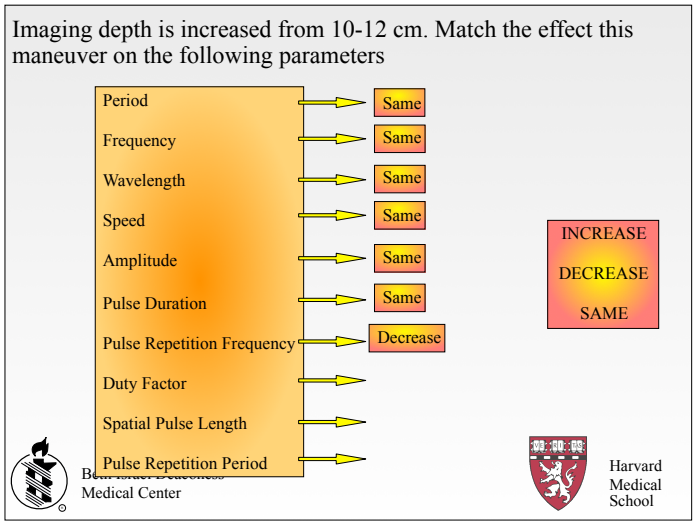
70-6


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Frequency
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
Same
Same
Same
Same
Same
INCREASE
DECREASE
SAME
Medical Center
Harvard Medical School

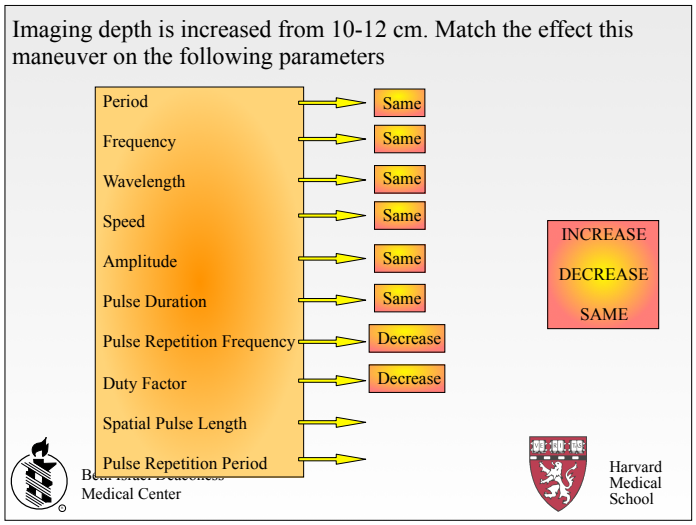
70-7


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Frequency
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
Same
Same
Same
Same
Same
Same
INCREASE
DECREASE
SAME
Medical Center
Harvard
Medical
School

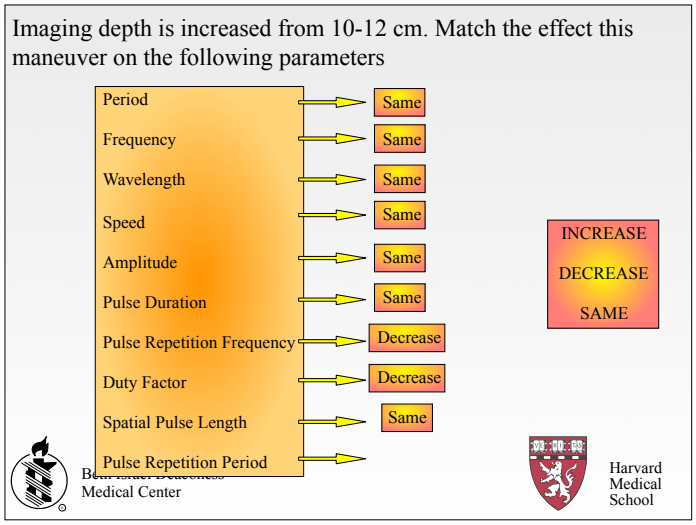
70-8


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Frequency
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
Same
Same
Same
Same
Same
Same
Decrease
INCREASE
DECREASE
SAME
Medical Center
Harvard
Medical
School

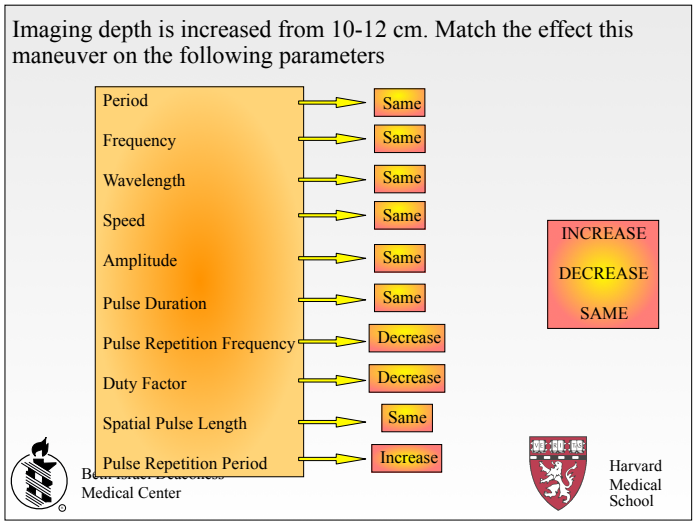
70-9


Imaging depth is increased from 10-12 cm. Match the effect this maneuver on the following parameters
Period
Frequency
Wavelength
Speed
Amplitude
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition Period
Same
Same
Same
Same
Same
Same
Decrease
Decrease
INCREASE
DECREASE
SAME
Medical Center
Harvard
Medical
School

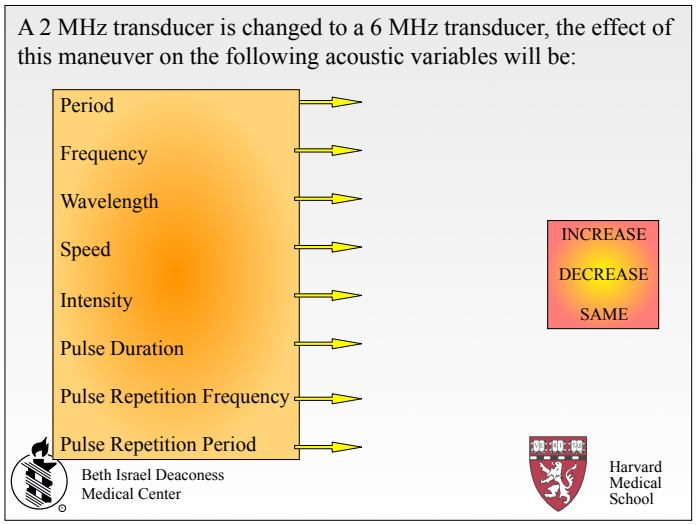
70-10



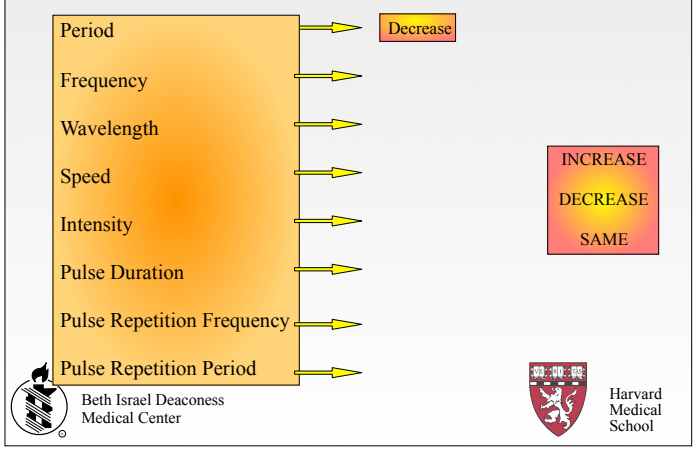
70-11



71-1

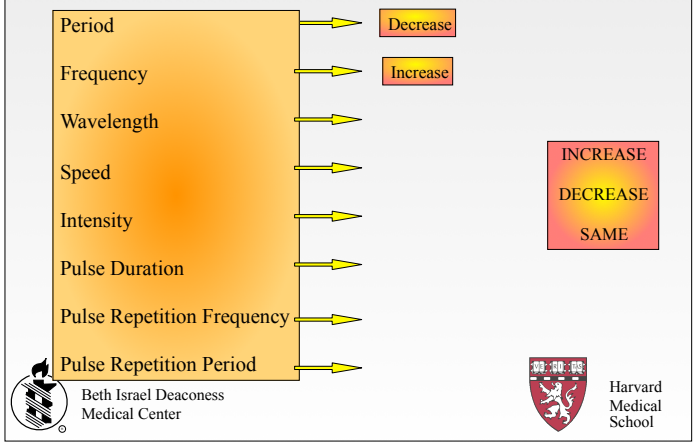


A 2 MHz transducer is changed to a 6 MHz transducer, the effect of this maneuver on the following acoustic variables will be:



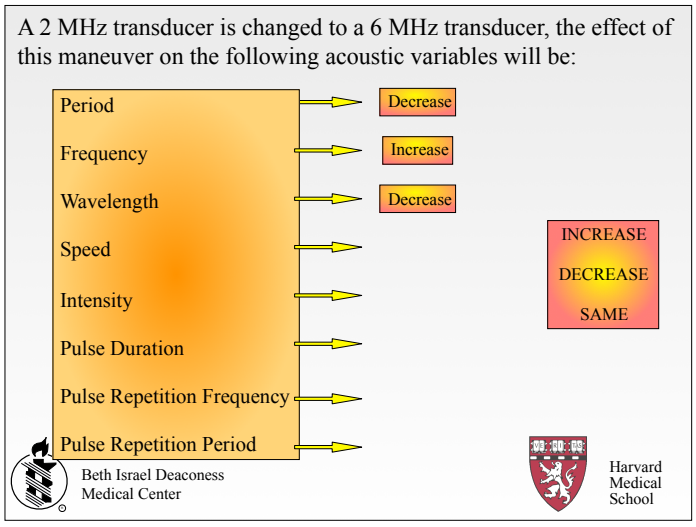
71-2

A 2 MHz transducer is changed to a 6 MHz transducer, the effect of this maneuver on the following acoustic variables will be:



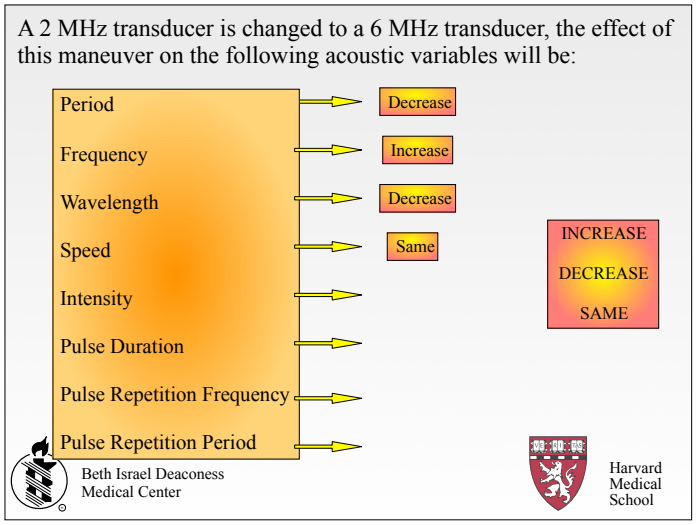
71-3

A 2 MHz transducer is changed to a 6 MHz transducer, the effect of this maneuver on the following acoustic variables will be:

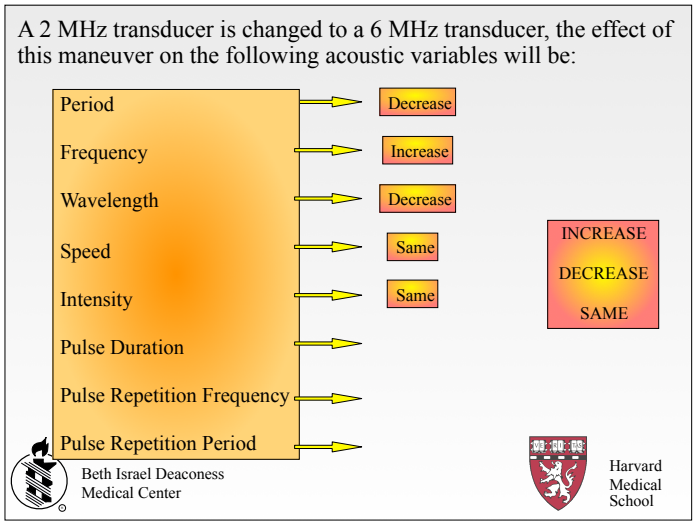


71-4

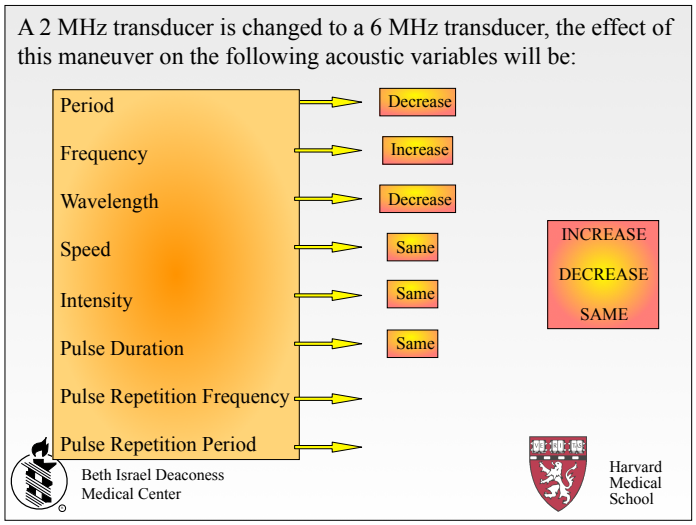
71-5


A 2 MHz transducer is changed to a 6 MHz transducer, the effect of this maneuver on the following acoustic variables will be:
Period
Frequency
Wavelength
Speed
Intensity
Pulse Duration
Pulse Repetition Frequency
Pulse Repetition Period
Decrease
Increase
Decrease
Same
INCREASE
DECREASE
SAME
Beth Israel Deaconess Medical Center
Harvard Medical School

71-6

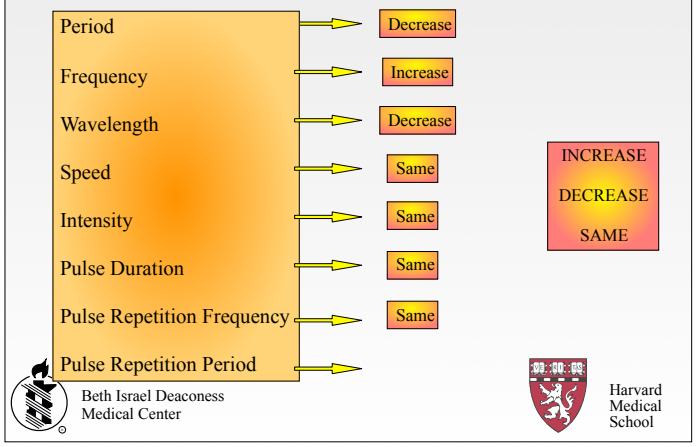

A 2 MHz transducer is changed to a 6 MHz transducer, the effect of this maneuver on the following acoustic variables will be:
Period
Frequency
Wavelength
Speed
Intensity
Pulse Duration
Pulse Repetition Frequency
Pulse Repetition Period
Decrease
Increase
Decrease
Same
Same
INCREASE
DECREASE
SAME
Beth Israel Deaconess Medical Center
Harvard Medical School

71-7


A 2 MHz transducer is changed to a 6 MHz transducer, the effect of this maneuver on the following acoustic variables will be:
Period
Frequency
Wavelength
Speed
Intensity
Pulse Duration
Pulse Repetition Frequency
Pulse Repetition Period
Decrease
Increase
Decrease
Same
Same
Same
INCREASE
DECREASE
SAME
Beth Israel Deaconess Medical Center
Harvard Medical School

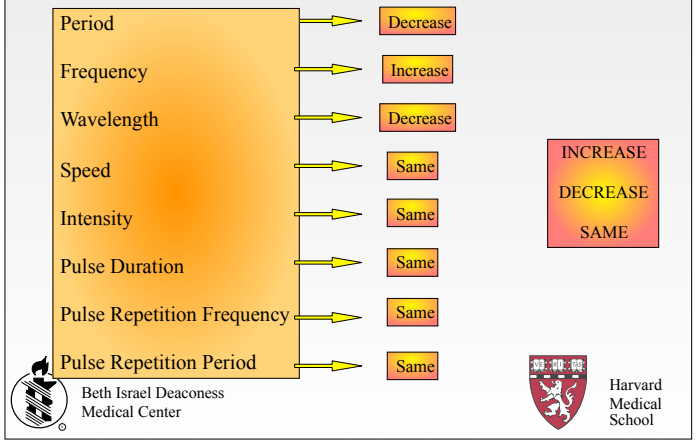
71-8

A 2 MHz transducer is changed to a 6 MHz transducer, the effect of this maneuver on the following acoustic variables will be:



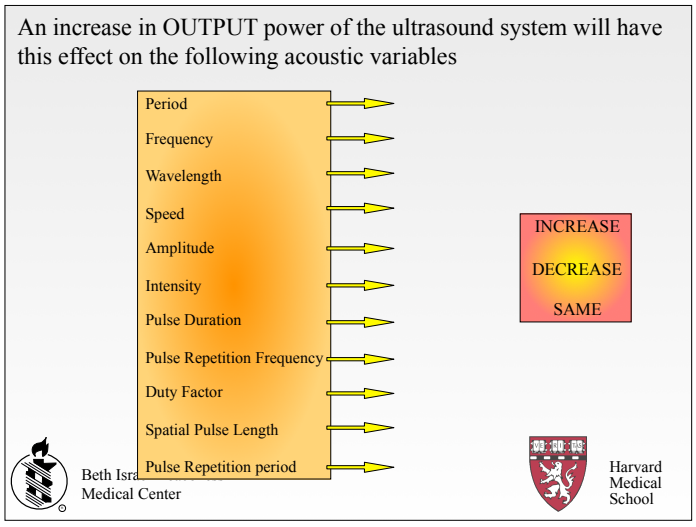
71-9

A 2 MHz transducer is changed to a 6 MHz transducer, the effect of this maneuver on the following acoustic variables will be:

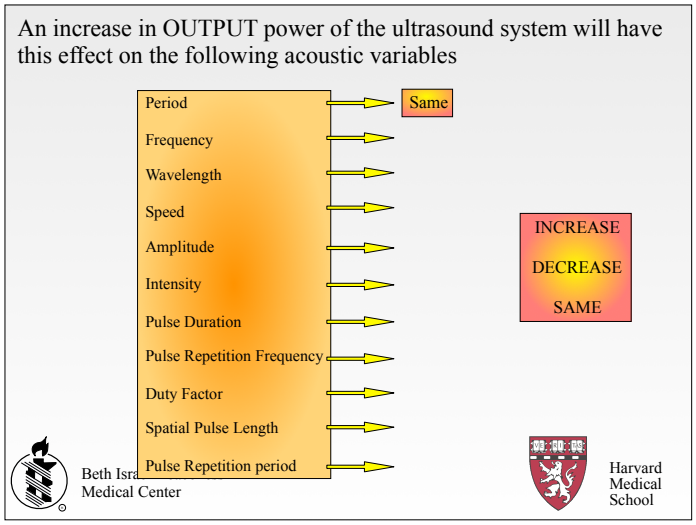


72-1

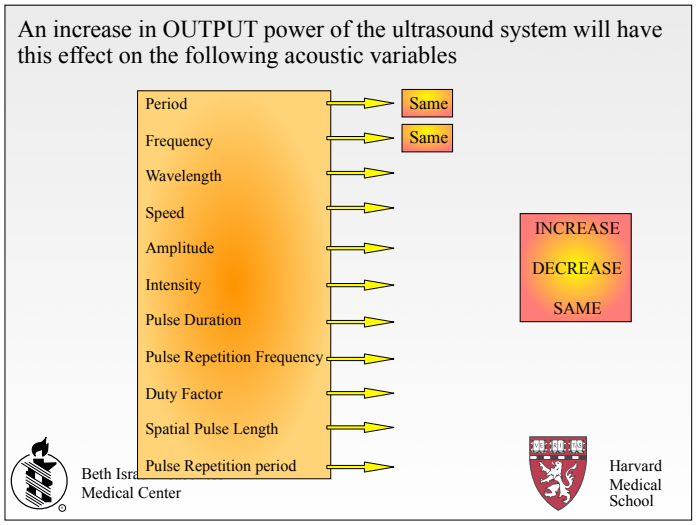
An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables



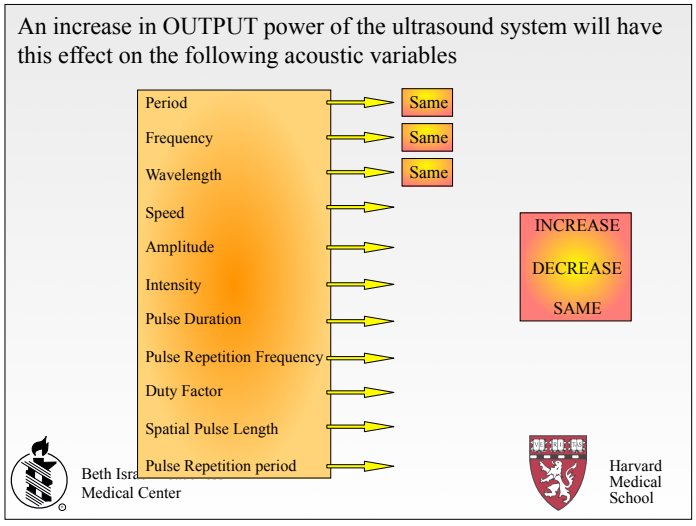
72-2


An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
INCREASE
DECREASE
SAME
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School

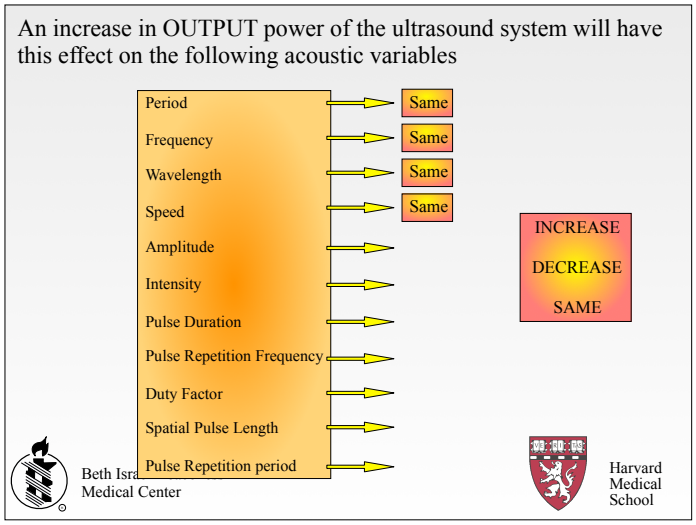
72-3


An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
Same
INCREASE
DECREASE
SAME
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School

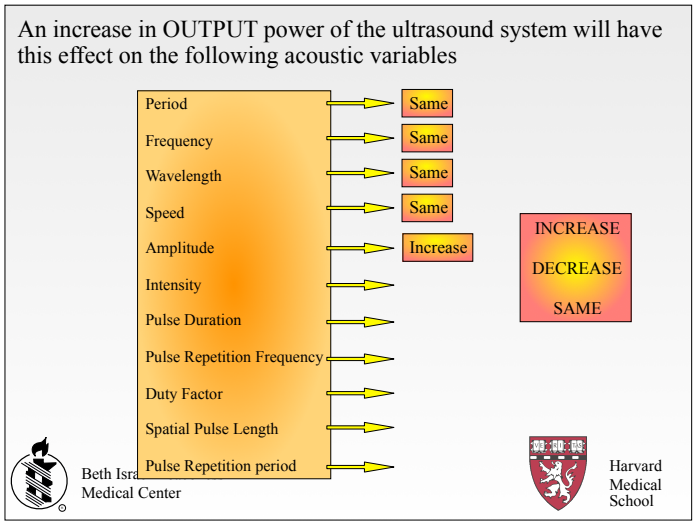
72-4


An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
Same
Same
INCREASE
DECREASE
SAME
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School

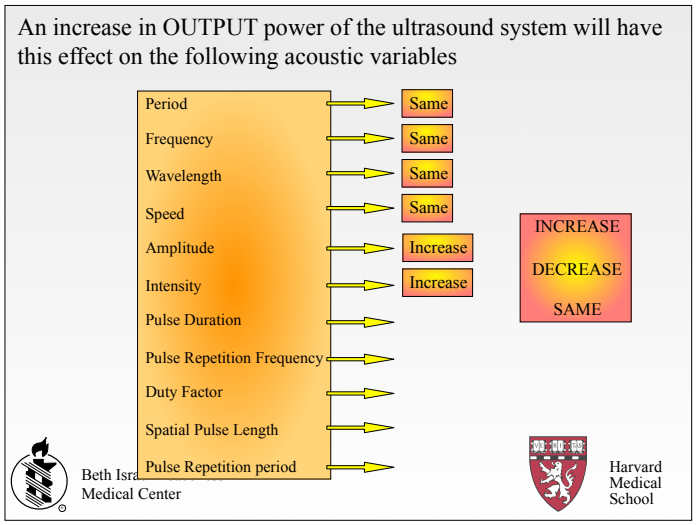
72-5


An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
Same
Same
Same
INCREASE
DECREASE
SAME
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School

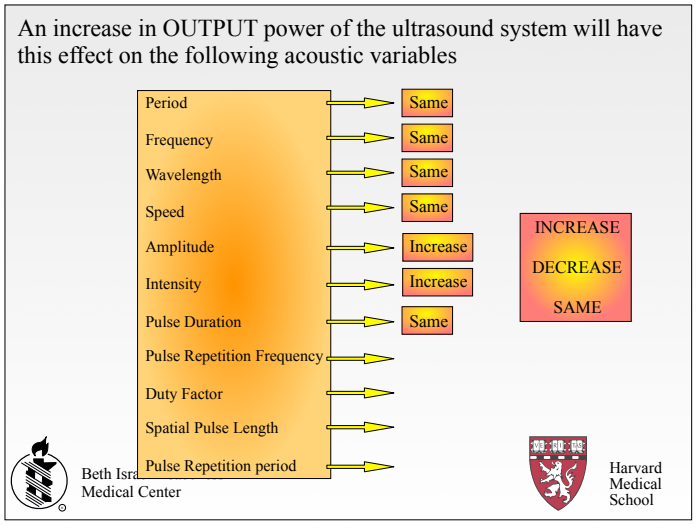
72-6


An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
Same
Same
Same
Increase
INCREASE
DECREASE
SAME
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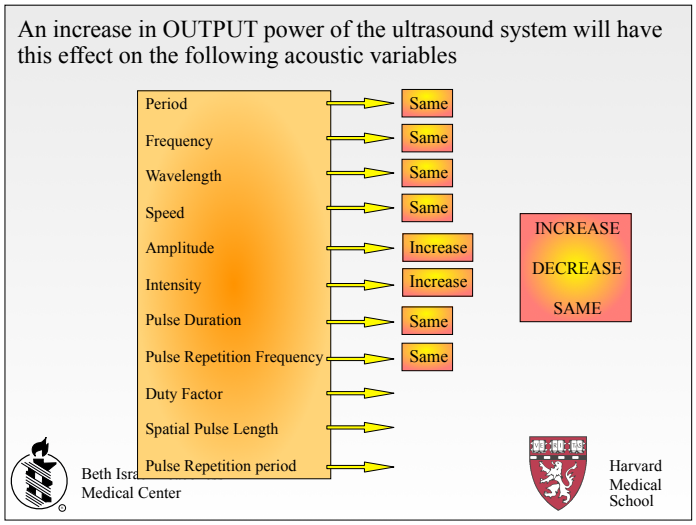
72-7


An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
Same
Same
Same
Increase
Increase
INCREASE
DECREASE
SAME
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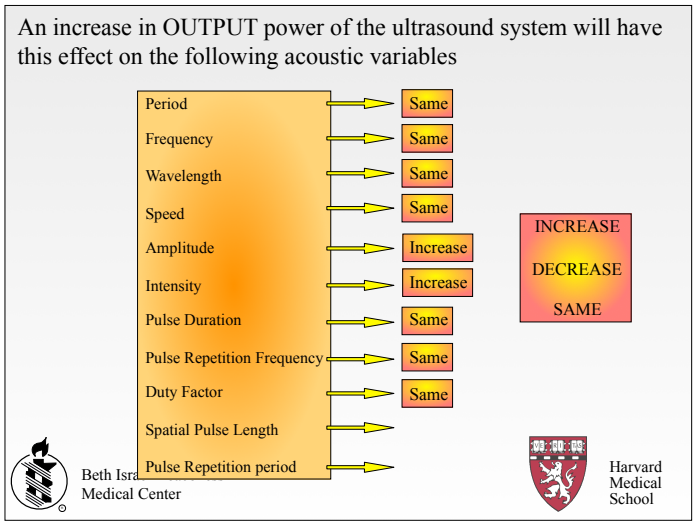
72-8


An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
Same
Same
Same
Increase
Increase
Same
INCREASE
DECREASE
SAME
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School

72-9

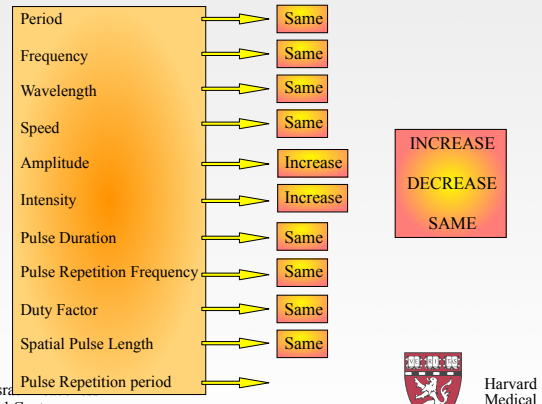

An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
Same
Same
Same
Increase
Increase
Same
Same
INCREASE
DECREASE
SAME
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School

72-10


An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables
Period
Frequency
Wavelength
Speed
Amplitude
Intensity
Pulse Duration
Pulse Repetition Frequency
Duty Factor
Spatial Pulse Length
Pulse Repetition period
Same
Same
Same
Same
Increase
Increase
Same
Same
Same
INCREASE
DECREASE
SAME
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72-11

An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables

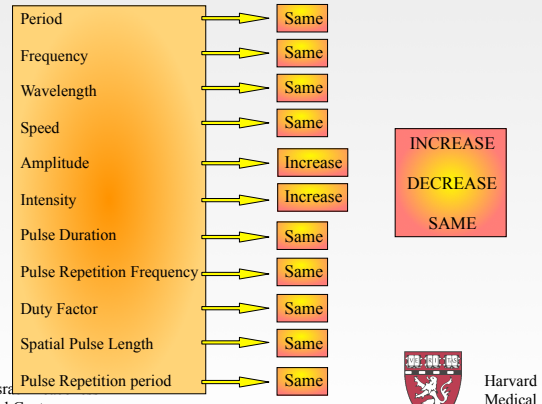


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72-12

An increase in OUTPUT power of the ultrasound system will have this effect on the following acoustic variables



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73

Putting it all Together

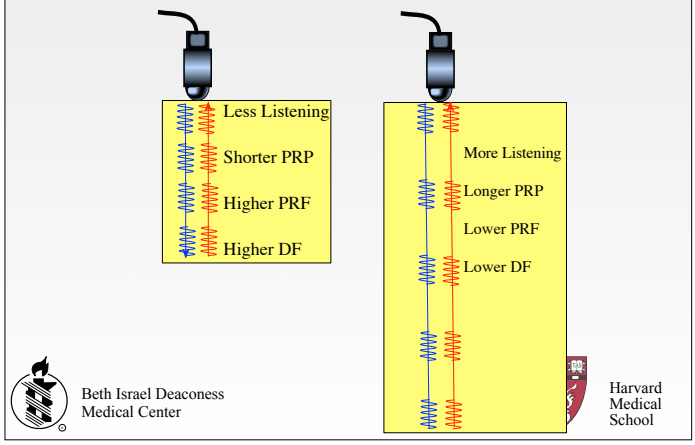
Shallow vs. Deep Imaging

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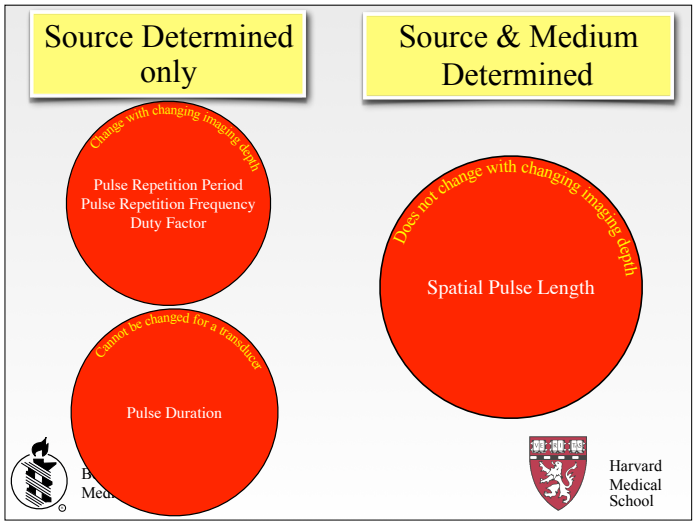
Review of Imaging Depth

74



Source Determined only / Source & Medium Determined

75



Review of Pulse Sound Wave Principles

76

Parameter	Adjustable	Units	Determined by	Typical Value
Pulse Duration	No	μs,time	Source	0.5-3.0 μs
Pulse Repetition Period	Yes	msec,time	Source	0.1-1.0 ms
Pulse Repetition Frequency	Yes	Hz,per sec	Source	1-10 kHz
Spatial Pulse Length	No	mm, length	Both	0.1-1.0 mm
Duty Factor	Yes	None	Source	0.2-0.5%

Understanding Ultrasound Physics by Sidney Edelman. Third Edition 1994. ESP Inc. Page 62

Review Questions

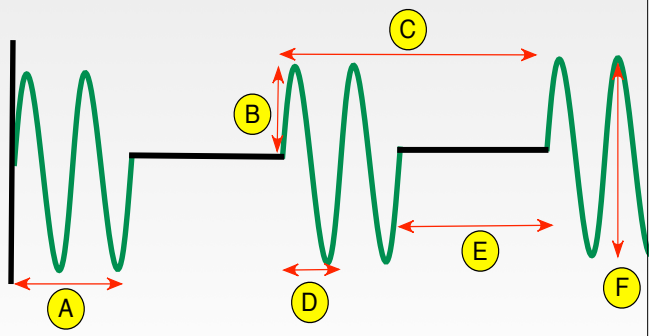
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77

Question 8

Name the letters



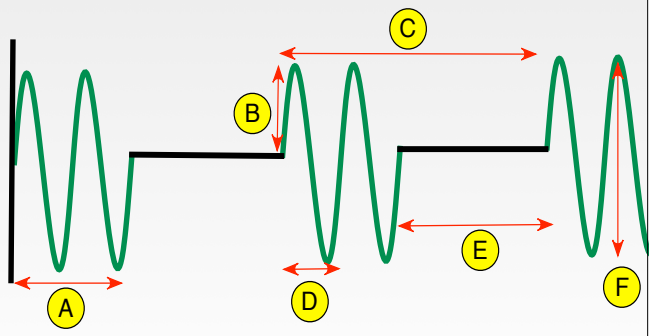
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78-1

Question 8

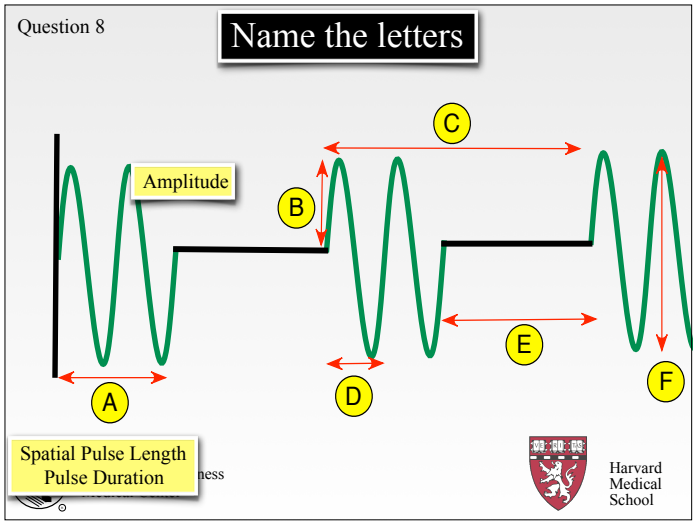
Name the letters



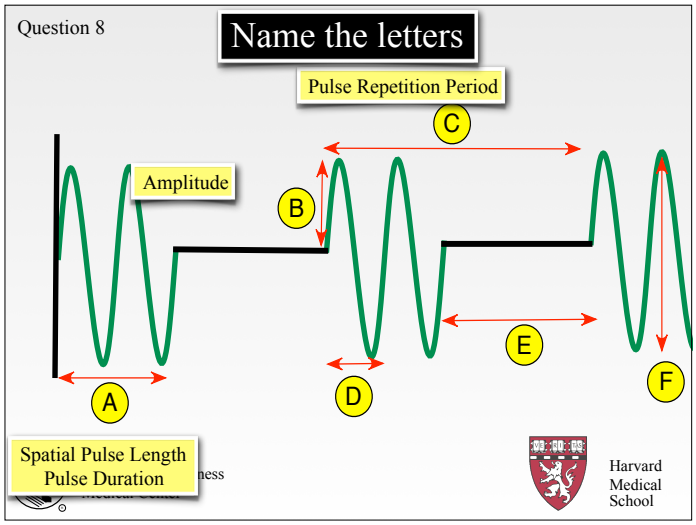
Spatial Pulse Length
Pulse Duration

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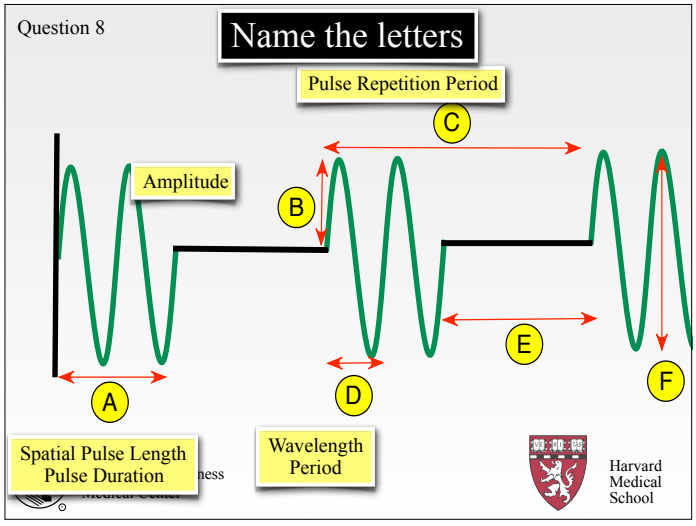
78-2


Question 8
Name the letters
Amplitude
A
B
C
D
E
F
Spatial Pulse Length
Pulse Duration
Harvard
Medical
School

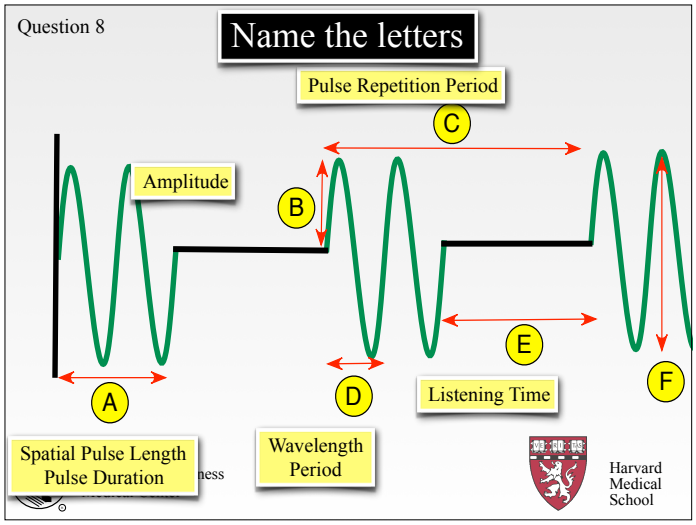
78-3


Question 8
Name the letters
Pulse Repetition Period
Amplitude
A
B
C
D
E
F
Spatial Pulse Length
Pulse Duration
Harvard
Medical
School

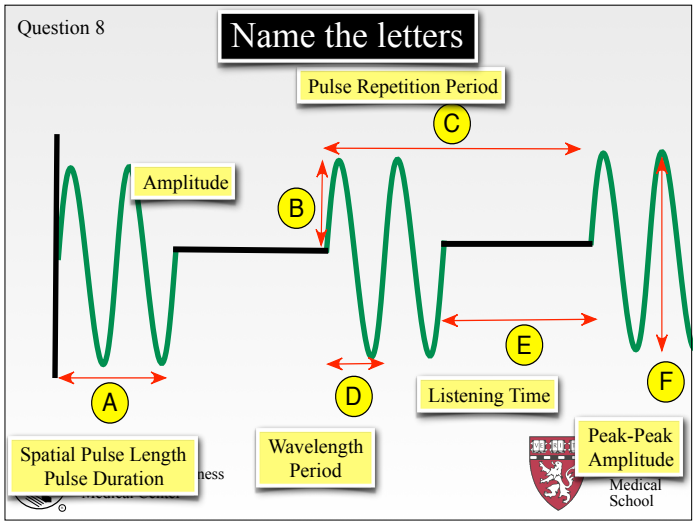
78-4


Question 8
Name the letters
Pulse Repetition Period
Amplitude
A
B
C
D
E
F
Spatial Pulse Length
Pulse Duration
Wavelength
Period
Harvard
Medical
School

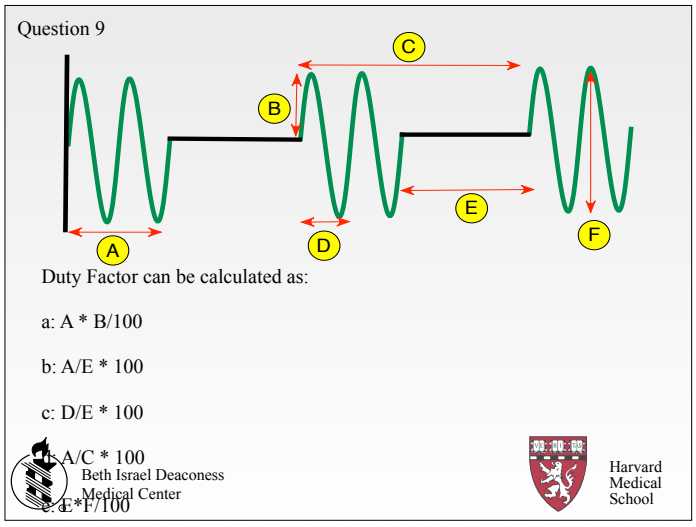
78-5


Question 8
Name the letters
Pulse Repetition Period
C
Amplitude
B
E
F
A
D
Listening Time
Spatial Pulse Length
Pulse Duration
Wavelength
Period
Harvard
Medical
School

78-6

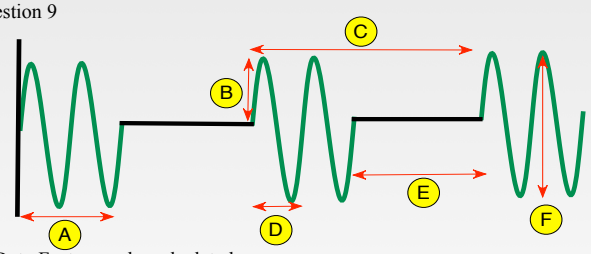

Question 8
Name the letters
Pulse Repetition Period
C
Amplitude
B
E
F
A
D
Listening Time
Peak-Peak
Amplitude
Spatial Pulse Length
Pulse Duration
Wavelength
Period
Medical
School

78-7


Question 9
C
B
E
F
A
D
Duty Factor can be calculated as:
a: A * B/100
b: A/E * 100
c: D/E * 100
d: A/C * 100
e: E*F/100
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Harvard
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School

79-1

Question 9



Duty Factor can be calculated as:

a: A * B/100

b: A/E * 100

c: D/E * 100

d: A/C * 100

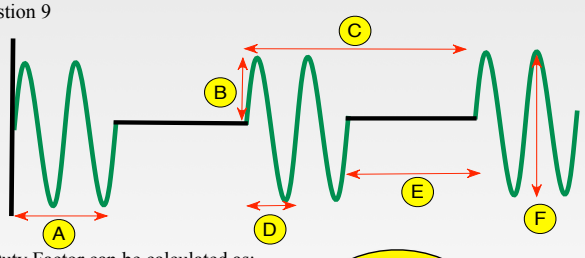
e: E*F/100

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79-2

Question 9



Duty Factor can be calculated as:

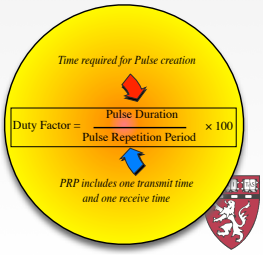
a: A * B/100

b: A/E * 100

c: D/E * 100

d: A/C * 100

e: E*F/100



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79-3

Question 10

Which of the following parameters can be changed by changing the imaging depth: (Multiple Correct Answers)

a: Pulse Repetition Frequency

b: Duty Factor

c: Propagation Speed

d: Pulse Repetition Period

e: Amplitude

Spatial Pulse Length

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80-1

Question 10

Which of the following parameters can be changed by changing the imaging depth: (Multiple Correct Answers)

a: Pulse Repetition Frequency

b: Duty Factor

c: Propagation Speed

d: Pulse Repetition Period

e: Amplitude

Spatial Pulse Length
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80-2

Question 10

Which of the following parameters can be changed by changing the imaging depth: (Multiple Correct Answers)

a: Pulse Repetition Frequency

b: Duty Factor

c: Propagation Speed

d: Pulse Repetition Period

e: Amplitude

Spatial Pulse Length
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80-3

Question 10

Which of the following parameters can be changed by changing the imaging depth: (Multiple Correct Answers)

a: Pulse Repetition Frequency

b: Duty Factor

c: Propagation Speed

d: Pulse Repetition Period

e: Amplitude

Spatial Pulse Length
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80-4

81

Transducer Design

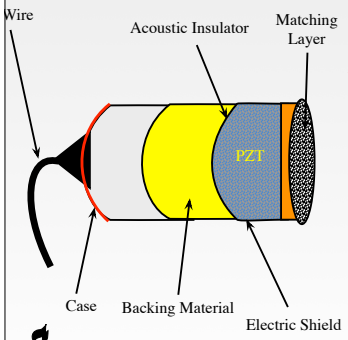
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Transducer Design

Case: Protective covering



Electric Shield: Prevent electrical noise

Acoustic Insulator: Uncouples the internal components from the case

PZT: Piezo Electric Crystal

Wire: Electric Connection

Matching Layer: Electric Connection

Backing Material: Reduces the "ringing" of the pulse

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Matching Layer

Designed to be between the "Active Element and Skin"

Decreases reflections at the PZT/Skin boundary - increasing transmission

Same function as the "Gel" applied on the skin for examination

Backing Material

Reduces the ringing of crystals

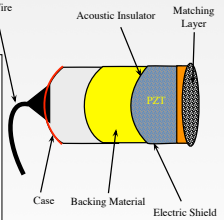
Sound pulse becomes shorter - enhanced axial resolution

High degree of sound absorption - same impedance as PZT

Without the backing material

PZT crystals ring for a long time

Pulse becomes longer in length AND duration



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Backing Material

84

Decreased Sensitivity

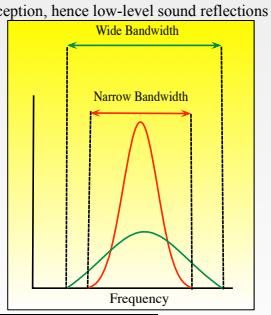
Reduces vibration during transmission as well as during reception, hence low-level sound reflections converted into meaningful signals during reflection

Bandwidth

PZT is unable to vibrate freely due to the presence of the backing material

Short duration pulse - "Click" - Has multiple frequencies rather than a single "Resonant frequency"

Bandwidth - difference in the highest and lowest frequencies in the probe



Quality Factor

$$\text{Quality Factor} = \frac{\text{Main Frequency}}{\text{Bandwidth}}$$

Wide bandwidth probes have a LOW-Q, Narrow bandwidth probes have HIGH-Q

Imaging probes have "Backing Material" and hence have LOW-Q

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Imaging versus Non-Imaging Transducers

85

Imaging Transducers	Non-Imaging Transducers
• Short duration and length pulses	• Continuous wave - Longer duration and length
• Backing material to limit ringing	• No backing material
• Reduced sensitivity	• Increased sensitivity
• Wide bandwidth	• Narrow bandwidth
• Low Q-Factor	• Higher Q-Factor
• Improved axial resolution	• No image formed

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Piezoelectric Material

86

Lead Zirconate Titanate

Can undergo **POLARIZATION-** Exposure to electrical field while being heated

Contraction and Expansion

Production of ultrasound pulses

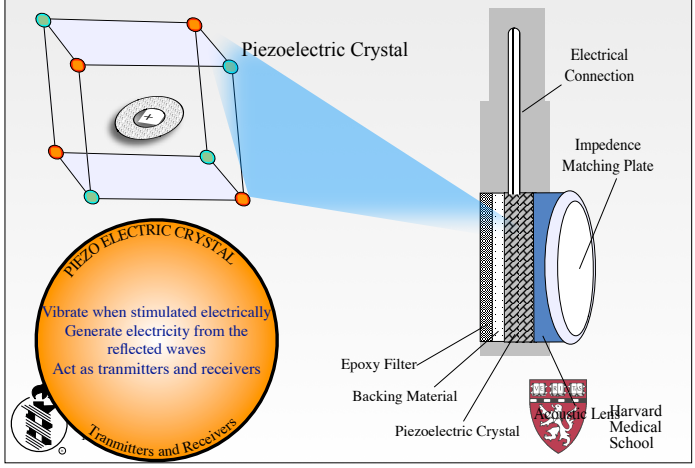
CURIE POINT: The temperature at which the polarization is achieved

Exposure to temperature higher than the CURIE POINT - Loss of polarization or **Depolarization**

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Transesophageal Echo - Transducer Design



87

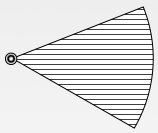
Impulse Formation

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88

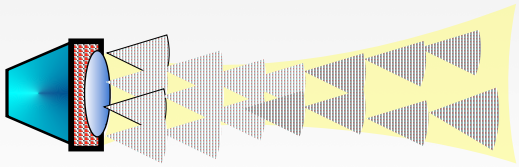
Spherical Waves and Huygen's Principle



Sound waves emitted by small PZT's diverge in V shape

These are called spherical waves, diffraction patterns or Huygen's wavelets

"Hour glass" shaped beam produced by "interference" of many Huygen's wavelets

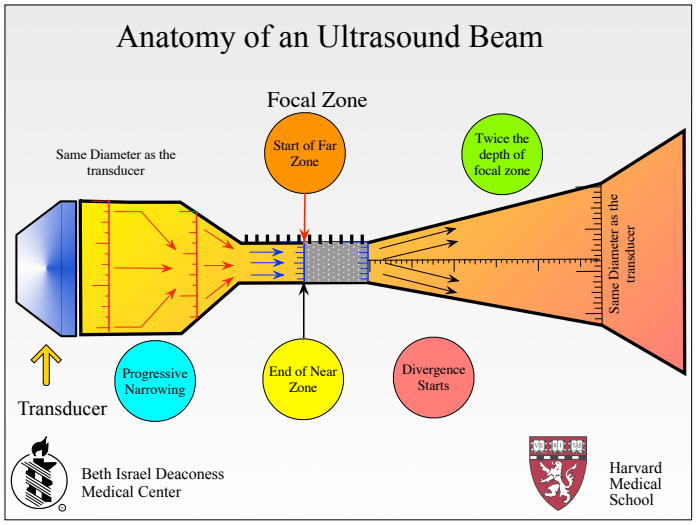


Constructive Interference by Huygen's Wavelets - Hour glass shape beam

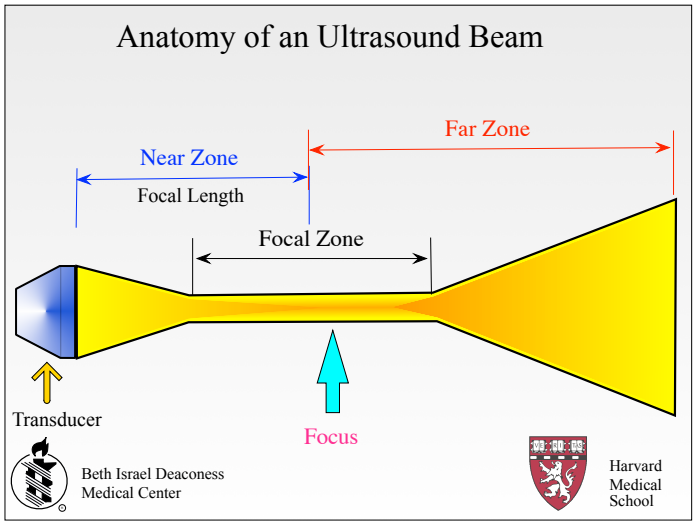
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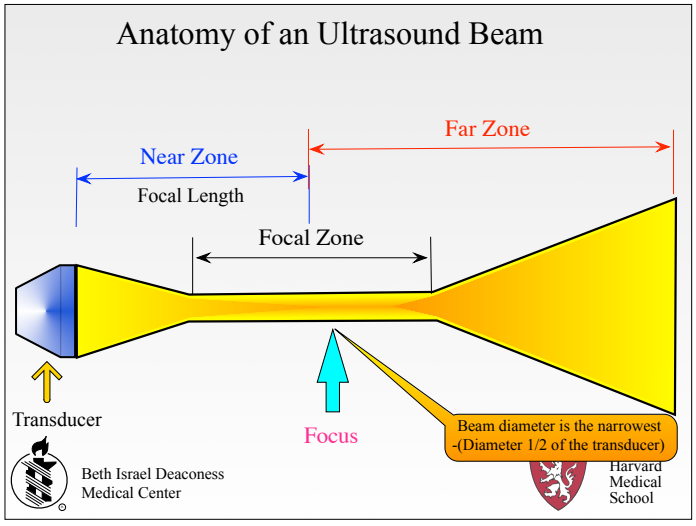
89


Anatomy of an Ultrasound Beam
Focal Zone
Same Diameter as the transducer
Start of Far Zone
Twice the depth of focal zone
Same Diameter as the transducer
Transducer
Progressive Narrowing
End of Near Zone
Divergence Starts
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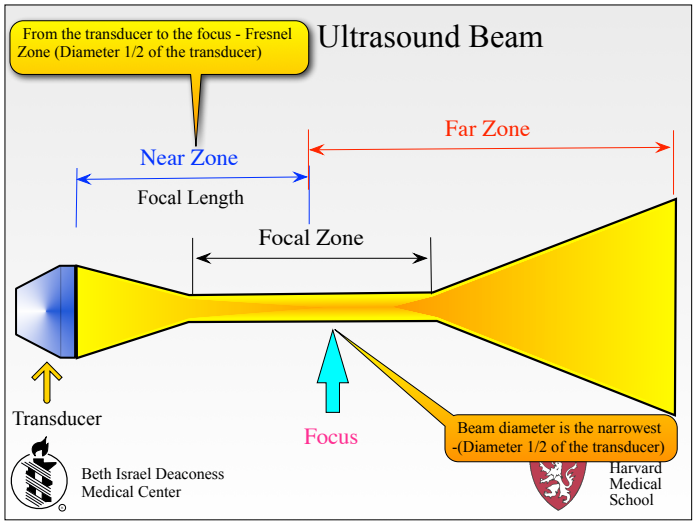
90


Anatomy of an Ultrasound Beam
Far Zone
Near Zone
Focal Length
Focal Zone
Transducer
Focus
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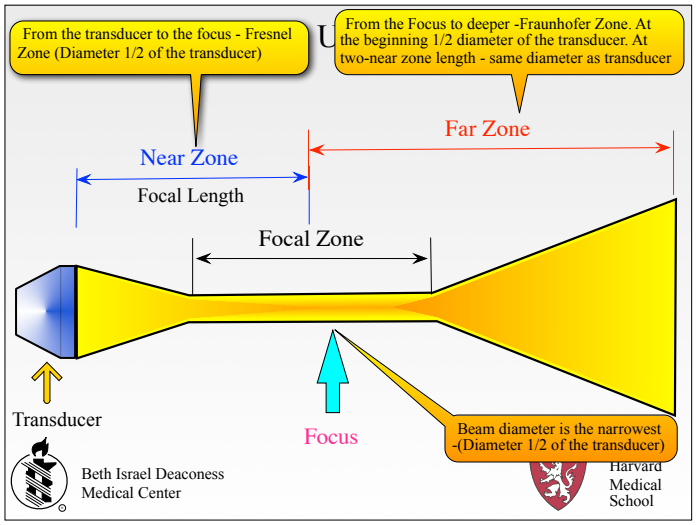
91-1


Anatomy of an Ultrasound Beam
Far Zone
Near Zone
Focal Length
Focal Zone
Transducer
Focus
Beam diameter is the narrowest
-(Diameter 1/2 of the transducer)
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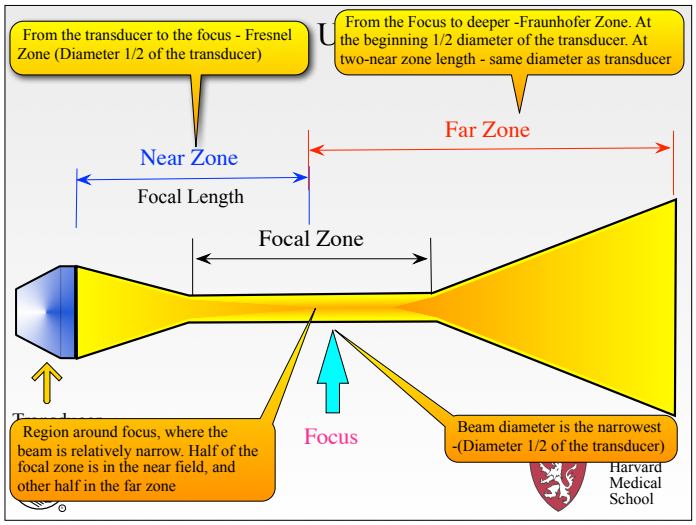
91-2


From the transducer to the focus - Fresnel Zone (Diameter 1/2 of the transducer)
Ultrasound Beam
Far Zone
Near Zone
Focal Length
Focal Zone
Transducer
Focus
Beam diameter is the narrowest -(Diameter 1/2 of the transducer)
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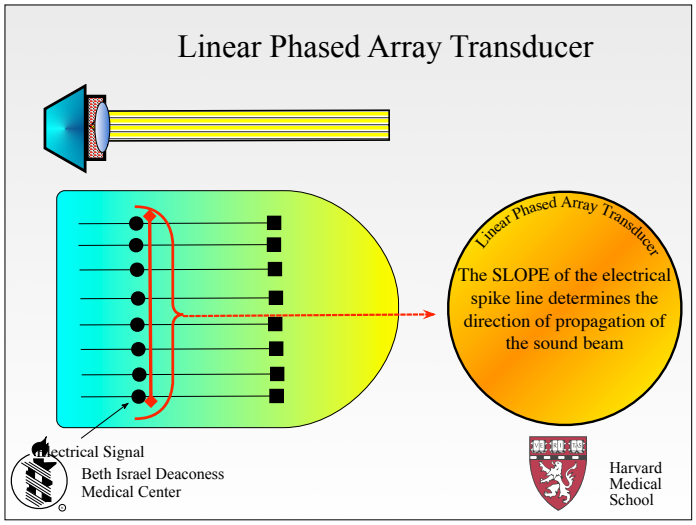
91-3


From the transducer to the focus - Fresnel Zone (Diameter 1/2 of the transducer)
From the Focus to deeper -Fraunhofer Zone. At the beginning 1/2 diameter of the transducer. At two-near zone length - same diameter as transducer
Far Zone
Near Zone
Focal Length
Focal Zone
Transducer
Focus
Beam diameter is the narrowest -(Diameter 1/2 of the transducer)
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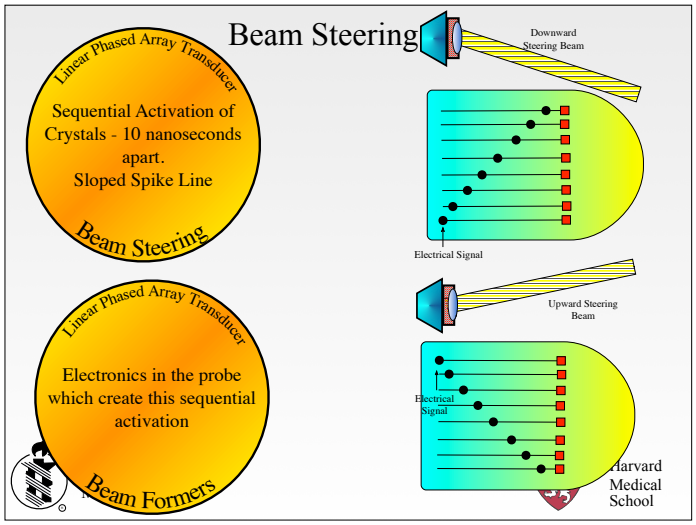
91-4


From the transducer to the focus - Fresnel Zone (Diameter 1/2 of the transducer)
From the Focus to deeper -Fraunhofer Zone. At the beginning 1/2 diameter of the transducer. At two-near zone length - same diameter as transducer
Far Zone
Near Zone
Focal Length
Focal Zone
Region around focus, where the beam is relatively narrow. Half of the focal zone is in the near field, and other half in the far zone
Focus
Beam diameter is the narrowest -(Diameter 1/2 of the transducer)
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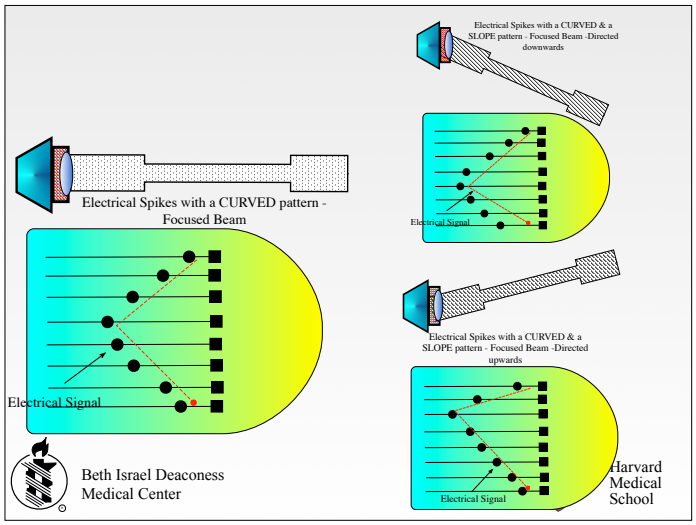
91-5


Linear Phased Array Transducer
Linear Phased Array Transducer
The SLOPE of the electrical spike line determines the direction of propagation of the sound beam
Electrical Signal
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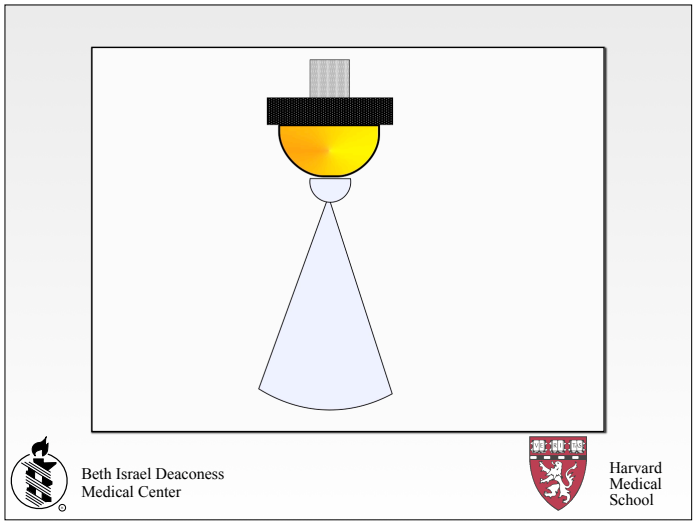
92


Beam Steering
Linear Phased Array Transducer
Sequential Activation of Crystals - 10 nanoseconds apart.
Sloped Spike Line
Beam Steering
Linear Phased Array Transducer
Electronics in the probe which create this sequential activation
Beam Formers
Downward Steering Beam
Electrical Signal
Upward Steering Beam
Electrical Signal
Harvard Medical School

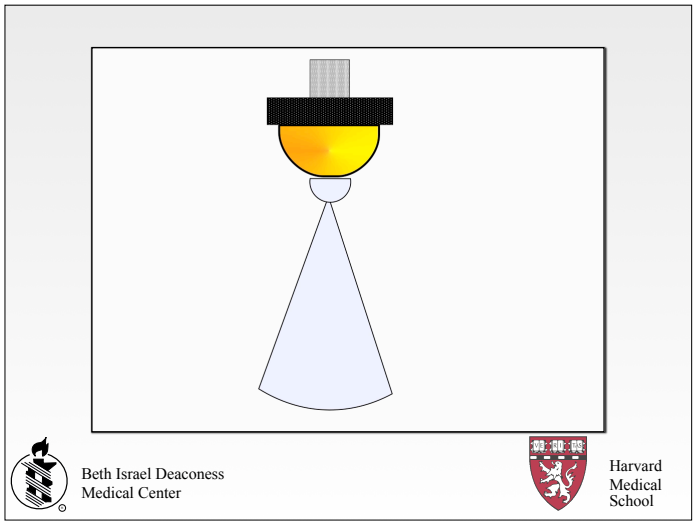
93


Electrical Spikes with a CURVED & a SLOPE pattern - Focused Beam -Directed downwards
Electrical Spikes with a CURVED pattern - Focused Beam
Electrical Signal
Electrical Spikes with a CURVED & a SLOPE pattern - Focused Beam -Directed upwards
Electrical Signal
Electrical Signal
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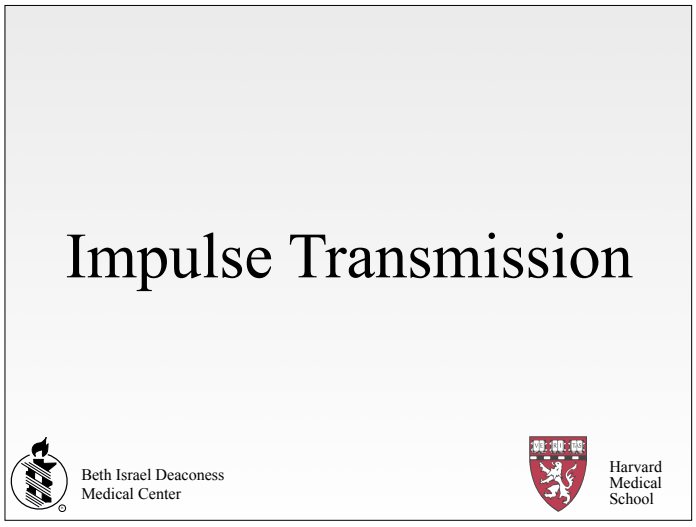
94


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95-1


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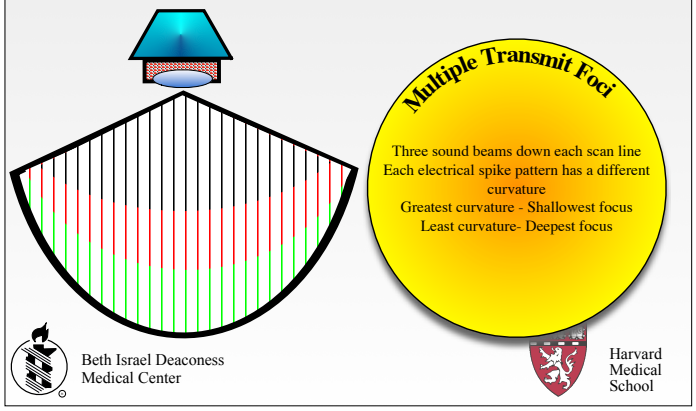
95-2


Impulse Transmission
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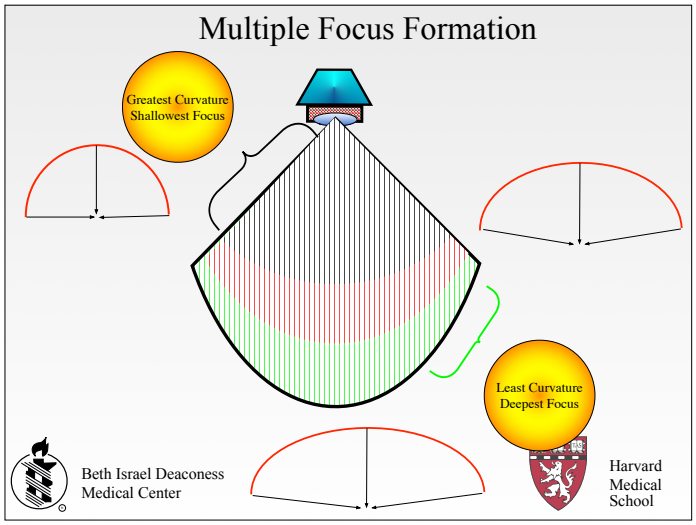
Phased Array Transducers and Multiple Transmit Foci

97



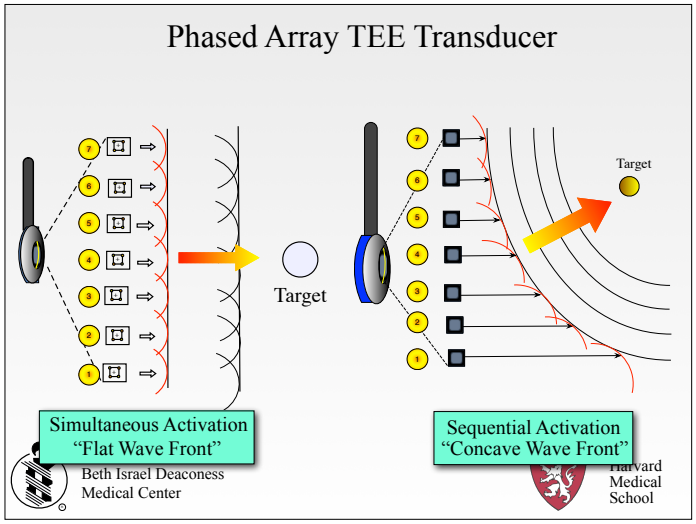
Multiple Focus Formation

98



Phased Array TEE Transducer

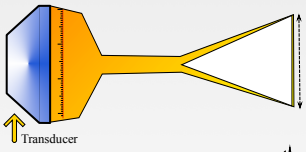
99



100

Beam Divergence

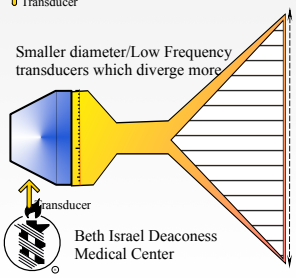
Larger diameter/High Frequency transducers which diverge less



Beam Divergence and Crystal Diameter are inversely related

Larger Diameter Crystals Improve **LATERAL RESOLUTION**

Smaller diameter/Low Frequency transducers which diverge more



Beam Divergence and Frequency are inversely related

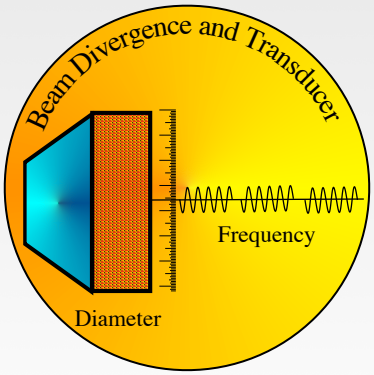
High Frequency Crystals Improve **LATERAL RESOLUTION**

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Beam Divergence and Transducer



$$\text{Sin Divergence Angle} = \frac{1.85}{\text{Diameter (mm)} \times \text{Frequency (MHz)}}$$

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Resolution

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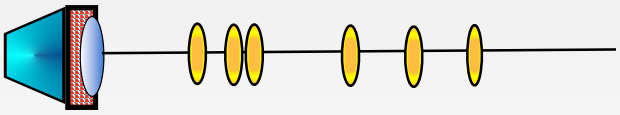
Harvard Medical School

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Resolution

"Ability to image accurately"

Axial Resolution



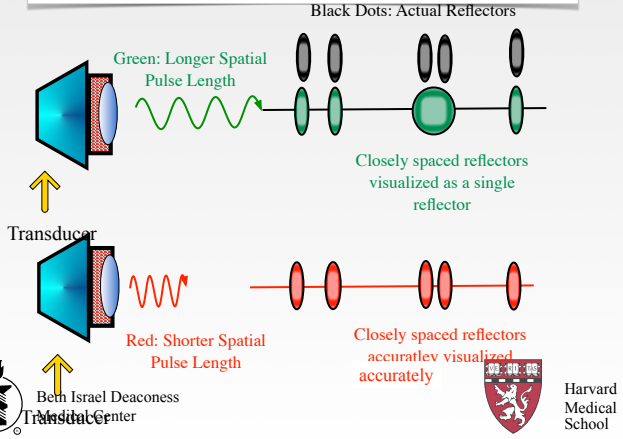
- Ability of the system to display closely placed two structures which are parallel to the ultrasound beam
- Determined by **SPATIAL PULSE LENGTH (Source and Medium)**
- Shorter duration pulses increase axial resolution
- Also called longitudinal, radial or depth resolution
- **CANNOT** be adjusted for a specific transducer
- **Typical Value:** 0.1 - 1.0 mm.

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Axial Resolution & Spatial Pulse Length



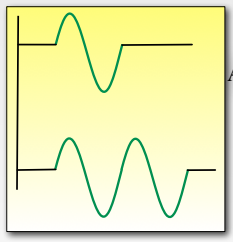
Beth Israel Deaconess Medical Center

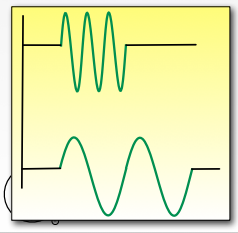
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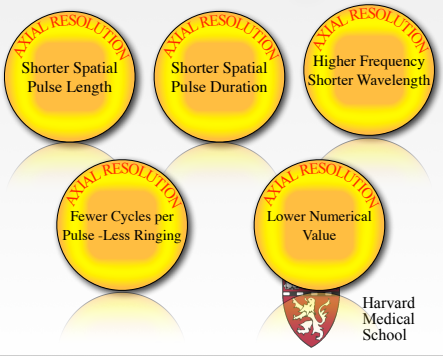
105

Axial Resolution

$$\text{Axial Resolution} = \frac{\text{Spatial Pulse Length (mm)}}{2}$$

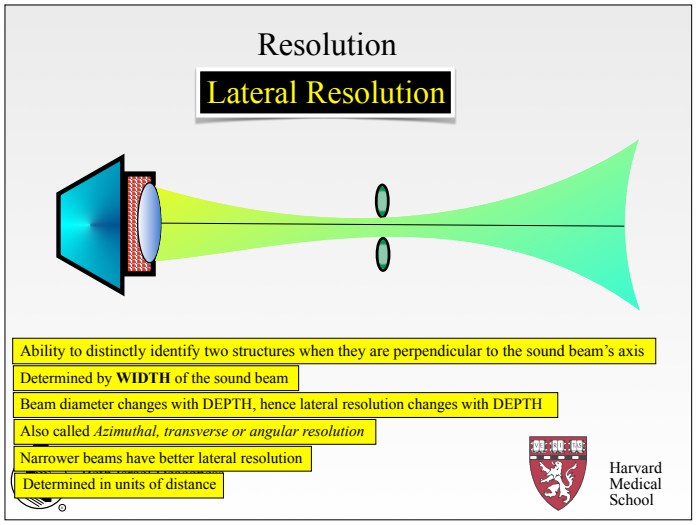




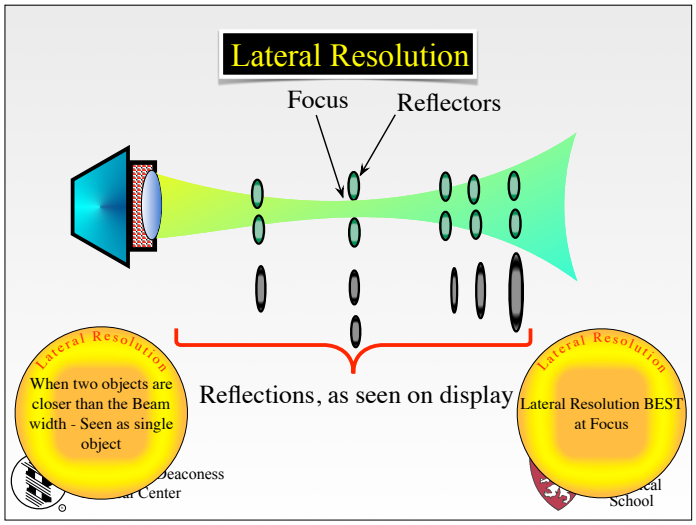


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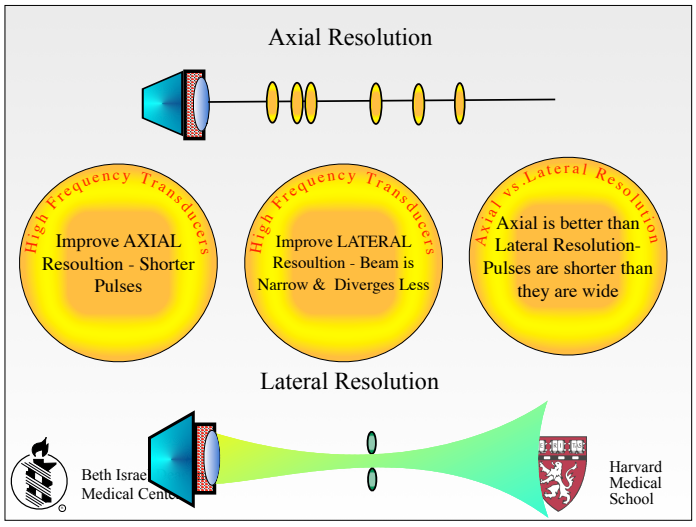
106

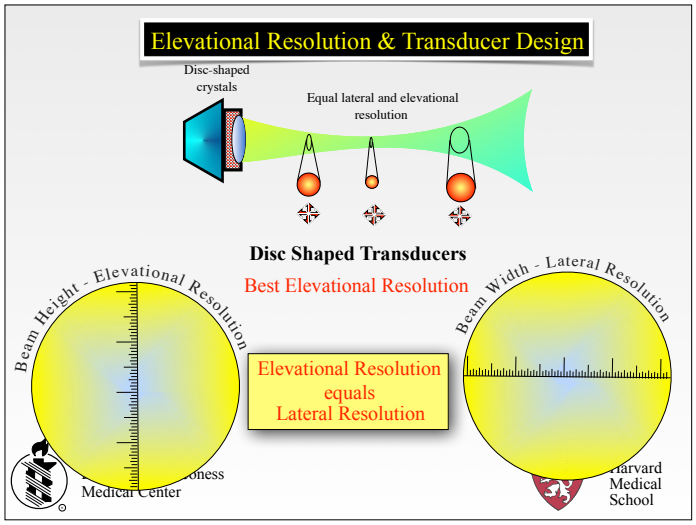

Resolution
Lateral Resolution
Ability to distinctly identify two structures when they are perpendicular to the sound beam's axis
Determined by **WIDTH** of the sound beam
Beam diameter changes with DEPTH, hence lateral resolution changes with DEPTH
Also called *Azimuthal, transverse or angular resolution*
Narrower beams have better lateral resolution
Determined in units of distance
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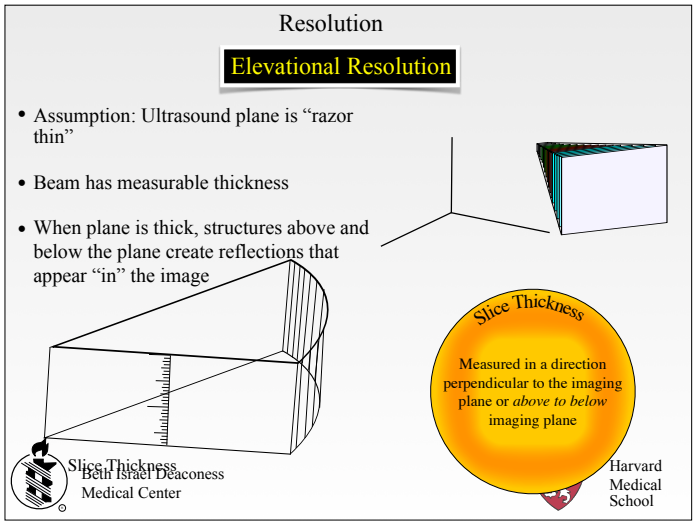

Lateral Resolution
Focus
Reflectors
Lateral Resolution
When two objects are closer than the Beam width - Seen as single object
Reflections, as seen on display
Lateral Resolution
Lateral Resolution BEST at Focus
School

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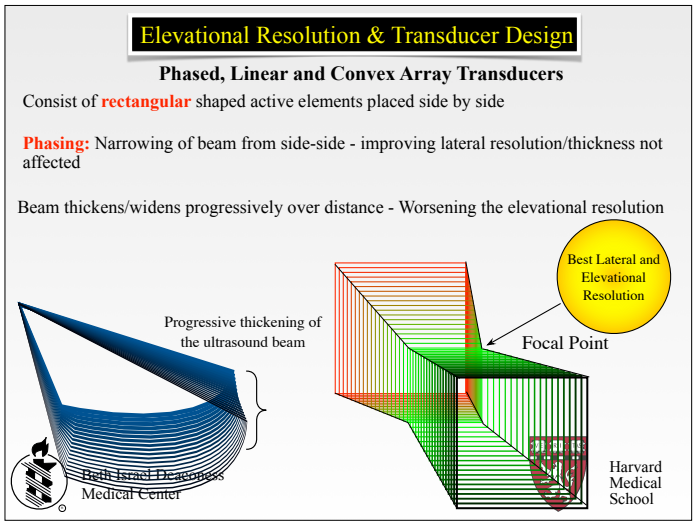

Axial Resolution
High Frequency Transducers
Improve AXIAL Resoultion - Shorter Pulses
High Frequency Transducers
Improve LATERAL Resoultion - Beam is Narrow & Diverges Less
Axial vs Lateral Resolution
Axial is better than Lateral Resolution- Pulses are shorter than they are wide
Lateral Resolution
Harvard Medical School


Elevational Resolution & Transducer Design
Disc-shaped crystals
Equal lateral and elevational resolution
Disc Shaped Transducers
Best Elevational Resolution
Beam Height - Elevational Resolution
Beam Width - Lateral Resolution
Elevational Resolution equals Lateral Resolution
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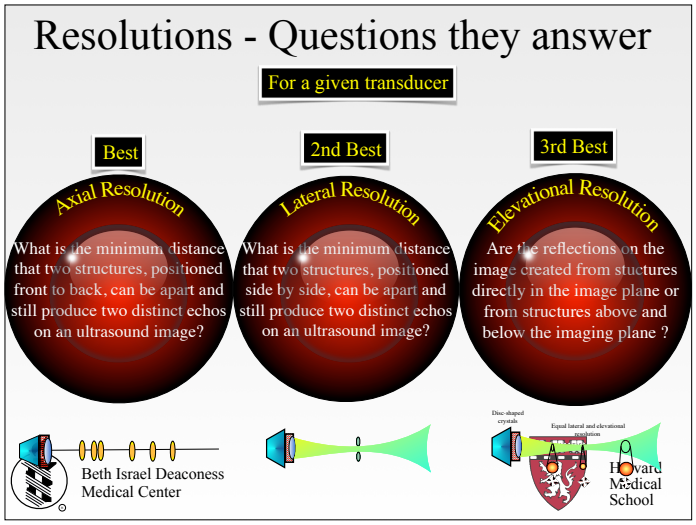
109


Resolution
Elevational Resolution
• Assumption: Ultrasound plane is "razor thin"
• Beam has measurable thickness
• When plane is thick, structures above and below the plane create reflections that appear "in" the image
Slice Thickness
Slice Thickness
Measured in a direction perpendicular to the imaging plane or above to below imaging plane
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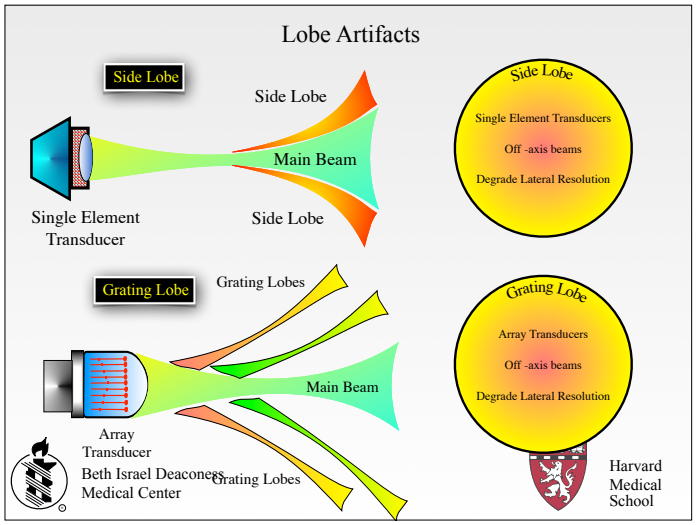
110


Elevational Resolution & Transducer Design
Phased, Linear and Convex Array Transducers
Consist of rectangular shaped active elements placed side by side
Phasing: Narrowing of beam from side-side - improving lateral resolution/thickness not affected
Beam thickens/widens progressively over distance - Worsening the elevational resolution
Best Lateral and Elevational Resolution
Progressive thickening of the ultrasound beam
Focal Point
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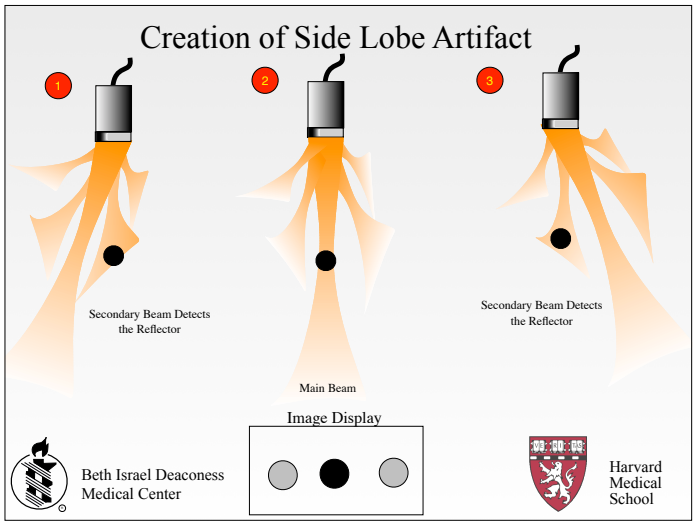
111


Resolutions - Questions they answer
For a given transducer
Best
Axial Resolution
What is the minimum distance that two structures, positioned front to back, can be apart and still produce two distinct echos on an ultrasound image?
2nd Best
Lateral Resolution
What is the minimum distance that two structures, positioned side by side, can be apart and still produce two distinct echos on an ultrasound image?
3rd Best
Elevational Resolution
Are the reflections on the image created from stuctures directly in the image plane or from structures above and below the imaging plane ?
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Lobe Artifacts
Side Lobe
Side Lobe
Main Beam
Side Lobe
Single Element Transducer
Side Lobe
Single Element Transducers
Off -axis beams
Degrade Lateral Resolution
Grating Lobe
Grating Lobes
Main Beam
Grating Lobes
Array Transducer
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Grating Lobe
Array Transducers
Off -axis beams
Degrade Lateral Resolution
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Creation of Side Lobe Artifact
1
2
3
Secondary Beam Detects the Reflector
Main Beam
Secondary Beam Detects the Reflector
Image Display
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Focusing

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Focusing

Improves **LATERAL** resolution by creating a **NARROWER** beam

External Focusing

Performed with a lens (Fixed/Mechanical)

Internal Focusing

Performed with a curved active element (Fixed/Mechanical)

Phased Array Focusing

Performed electronically (Adjustable)

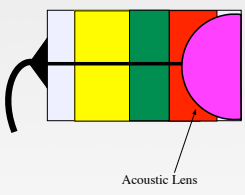
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Fixed Focusing Techniques

External Focusing

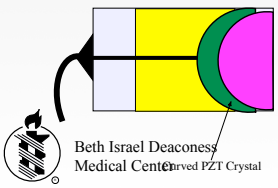


Focal depth and extent of focusing cannot be changed

Acoustic lens introduced in front of the PZT

Arc of the lens determines the extent of focusing

Internal Focusing



Focal depth and extent of focusing cannot be changed

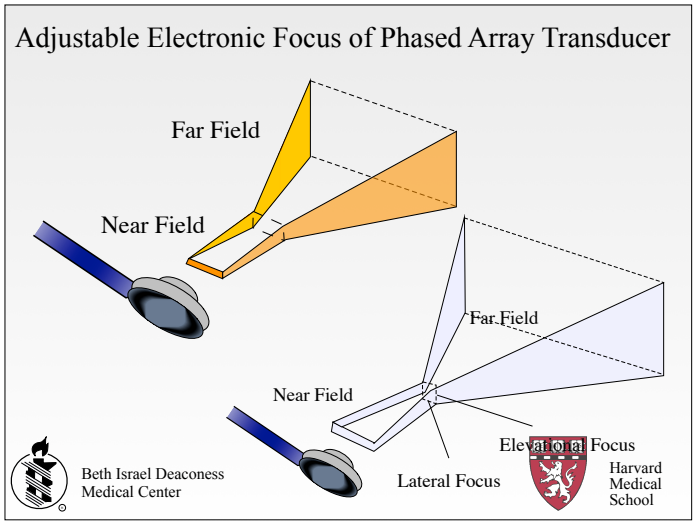
Arc of the curved PZT crystals determines the extent of focusing

More commonly used commercially

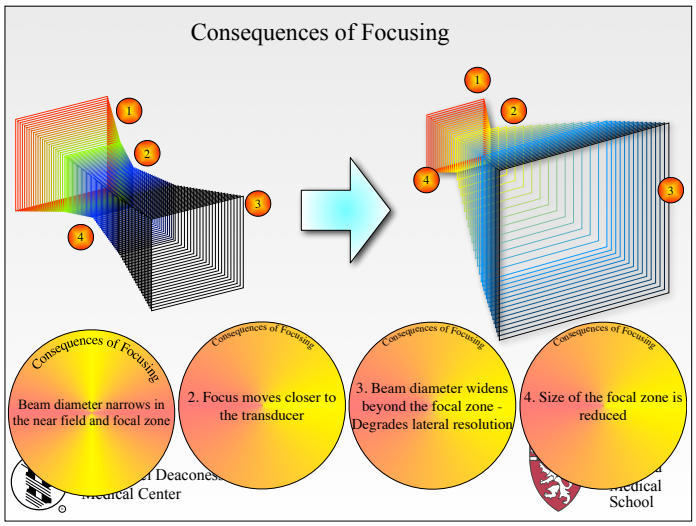
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Real-Time Imaging

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Frame Rate and Temporal Resolution

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FRAME RATE
Ability of the system to create numerous frames each second - operational parameter to make a 'movie"

UNITS
Reported in Hertz or per second

DETERMINED BY
1. Sound speed in the medium
2. Depth of imaging

Speed of sound is constant (1540m/sec)
Clinically -Imaging depth determines frame rate

Temporal Resolution
Ability to precisely position moving structures from instant to instant
Accuracy in Time

Temporal Resolution
Determined by Frame Rate
Higher Frame Rate -Better Temporal Resolution
Accuracy in Time

Temporal Resolution
Related to Frame Rate
Units
Hertz or per second
Accuracy in Time

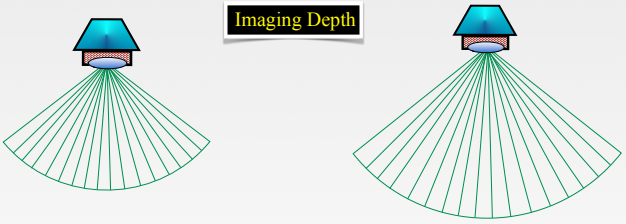
Temporal Resolution
Frame Rate & $Time_{Frame}$ are
INVERSELY related
Image created in 1/10 second
Framr rate = 10 frames/sec
Accuracy in Time

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System Settings and Frame Rate

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Imaging Depth



Shallow Imaging	Deep Imaging
• Short go-return time	• Longer go-return time
Shorter $Time_{Frame}$ (Time to form a single frame)	Longer $Time_{Frame}$ (Time to form a single frame)
• Higher Frame Rate	• Lower Frame Rate
• Superior Temporal Resolution	• Inferior Temporal Resolution

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System Settings and Frame Rate

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Number of Pulses

Pulses per Image and Frame Rate are INVERSELY related

More Pulses per image - Lower Frame Rate

Fewer Pulse per image - Higher Frame Rate

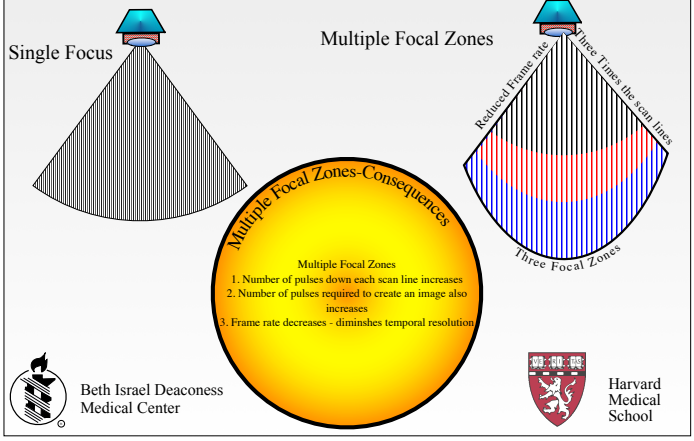
Factors determining Number of Pulses Per Frame
Number of Focal Points
Sector Size
Line Density

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Multi-Focus



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Single Focus	Multiple Focus
One pulse per scan	Multiple pulses per scan
Shorter $Time_{Frame}$	Longer $Time_{Frame}$
Higher frame rate	Lower frame rate
Superior temporal resolution	Inferior temporal resolution
Inferior lateral resolution	Superior lateral resolution

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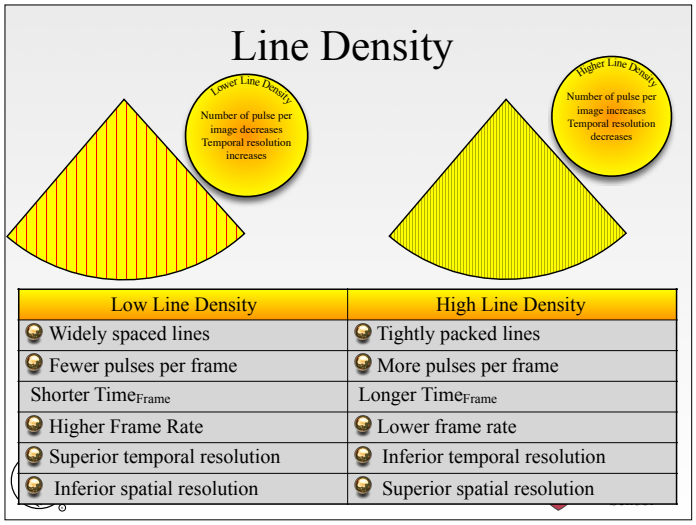
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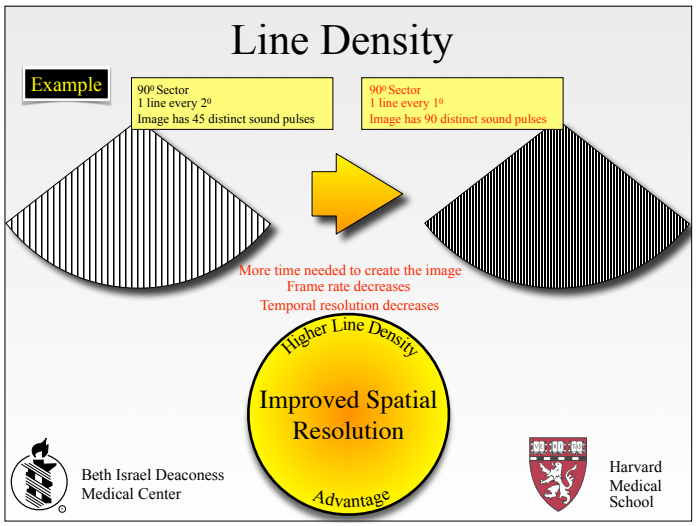
Sector Size

Increase in SECTOR SIZE (Field of View), increases the number of pulses required to make an image and decreases TEMPORAL RESOLUTION

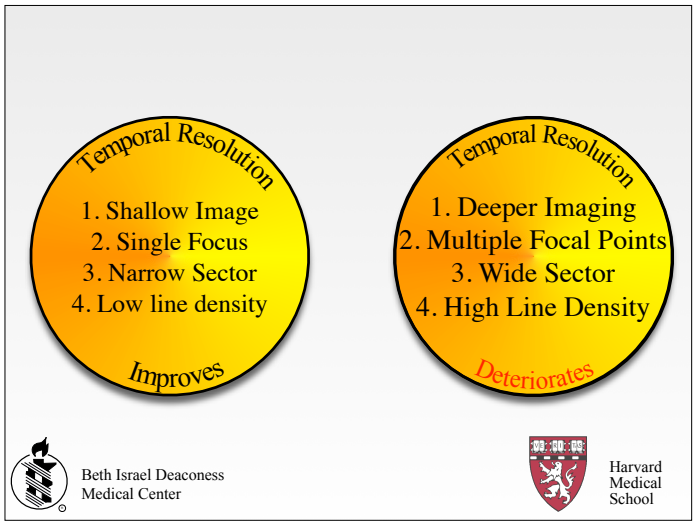
Narrow Sector	Wide Sector
Few pulses per frame	More pulses per frame
Shorter T_{Frame}	Longer T_{Frame}
Higher Frame Rate	Lower Frame Rate
Superior Temporal Resolution	Inferior Temporal Resolution


Line Density
Lower Line Density
Number of pulse per image decreases
Temporal resolution increases
Higher Line Density
Number of pulse per image increases
Temporal resolution decreases
Low Line Density
Widely spaced lines
Fewer pulses per frame
Shorter Time Frame
Higher Frame Rate
Superior temporal resolution
Inferior spatial resolution
High Line Density
Tightly packed lines
More pulses per frame
Longer Time Frame
Lower frame rate
Inferior temporal resolution
Superior spatial resolution

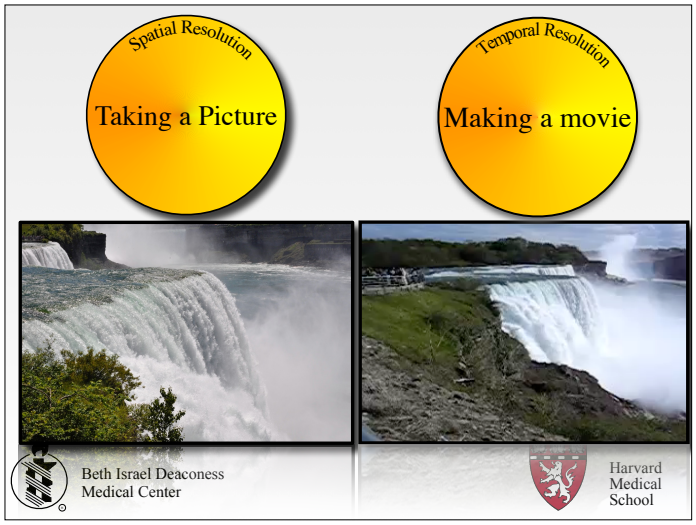
127


Line Density
Example
90⁰ Sector
1 line every 2⁰
Image has 45 distinct sound pulses
90⁰ Sector
1 line every 1⁰
Image has 90 distinct sound pulses
More time needed to create the image
Frame rate decreases
Temporal resolution decreases
Higher Line Density
Improved Spatial Resolution
Advantage
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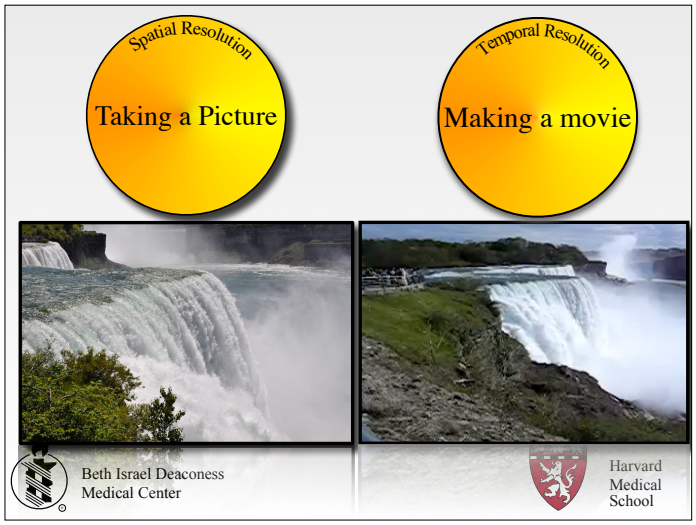
128


Temporal Resolution
1. Shallow Image
2. Single Focus
3. Narrow Sector
4. Low line density
Improves
Temporal Resolution
1. Deeper Imaging
2. Multiple Focal Points
3. Wide Sector
4. High Line Density
Deteriorates
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130-1



130-2

Receiver

Converts received information (Signals) for eventual display

Functions performed

1. Amplification
2. Compensation
3. Compression
4. Demodulation
5. Reject

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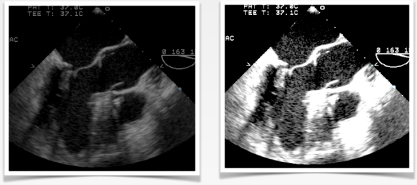
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Amplification

Each returning signal from the field is made larger

Entire image affected - Made brighter or darker - Equally AMPLIFIED



Cannot differentiate SIGNAL from NOISE

Signal to Noise ratio DOES NOT improve

It is ADJUSTABLE

Measured in Decibels (dB)

Also known as receiver gain

PRE-AMPLIFICATION
Amplification in the transducer

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Compensation

Creates an image which is uniformly bright - from top to bottom

In an adequately compensated image identical reflectors at different depth are displayed with the same brightness

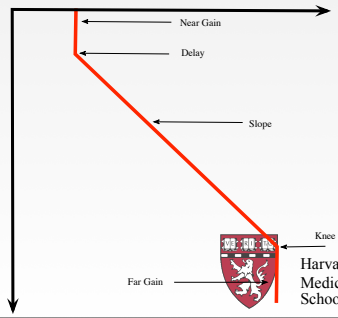
Can be adjusted

A form of variable amplification

Units: dB

Compensation treats echos differently - based on the depth of reflection

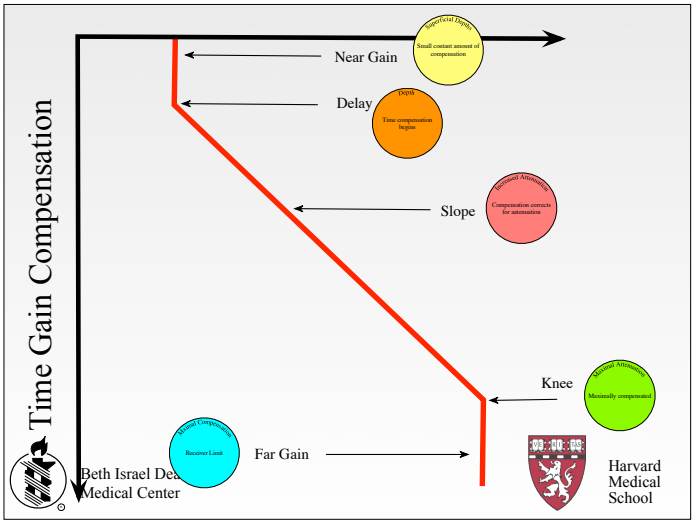
Synonyms: Time gain compensation, depth gain compensation and Swept gain



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135

Compensation

Improperly Compensated



Properly Compensated



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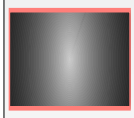
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136

Compression

Keeps the gray scale content of the image within the range of detection of human eye

Human eye can differentiate 20 shades of gray



Performed without changing the ranking between signals - Largest remain largest

Compression

- Integral to System — Cannot be changed
- **Log Compression**: Adjustable/Small differences in weak signals
- UserAdjustable — Can be changed

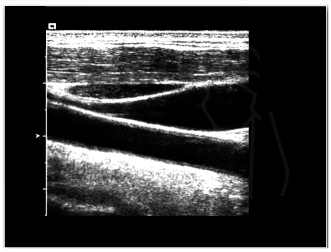
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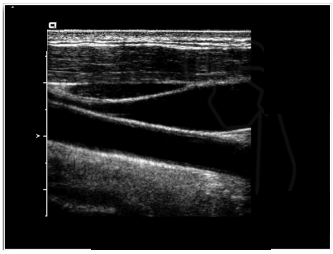
137

Compression

Less Compression



More Compression



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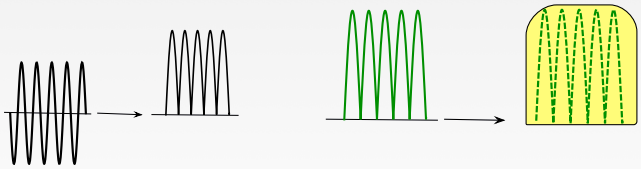
138

Demodulation

Change of electrical signals for display on the screen
Two step process

Rectification

Smoothing



Changes all negative voltages to positive voltages

Not Adjustable

Elimination of roughness and bumps

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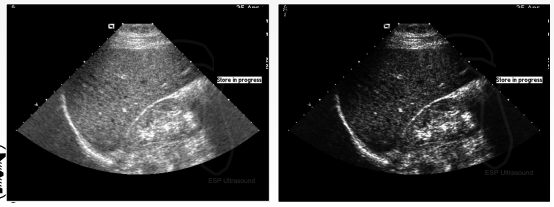
139

Reject

Allows sonographer to control whether low-level gray scale information will appear on the monitor

Very low-level signals may be associated with meaningless information

Adjustable



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140

Receiver Functions

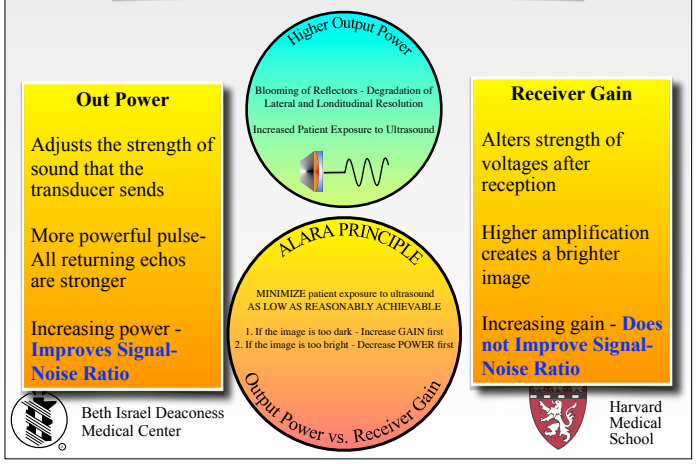
Function	Adjustable	Signal Processed	Effect on Image
Amplification	Yes	All signals treated equally	Entire image gets brighter
Compensation	Yes	Signals treated differently based on depth	Image will be uniformly bright - top to bottom
Compression	Yes	Signals treated differently depending on strength	Changes gray scale mapping
Demodulation	No	Prepares electrical signals for display	None
Reject	Yes	Only weak signals affected - Strong signals remain unchanged	Weak echos are present or eliminated

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Output Power versus Receiver Gain

141



Dynamic Range

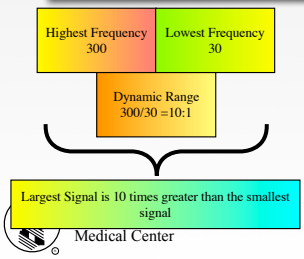
142

Method of reporting the extent to which a signal can vary and still be accurately measured

Reported in units of dB

Relative ratio - Between the largest and smallest signal

The Dynamic Range of information decreases the more it is processed



Component	Dynamic Range
Transducer	120 dB
Receiver	100-120 dB
Scan Converter	40-50 dB
Display	20-30 dB
Archive	[illegible] dB

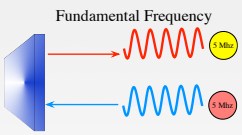
Medical Center

Harvard Medical School

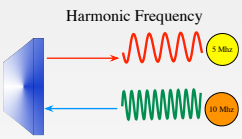
Harmonic Imaging

143

Creation of an image from sound reflections at twice the frequency of the transmitted sound



Created by transducer and transmitted into body



Twice the fundamental frequency created by transducer

Fundamental Image

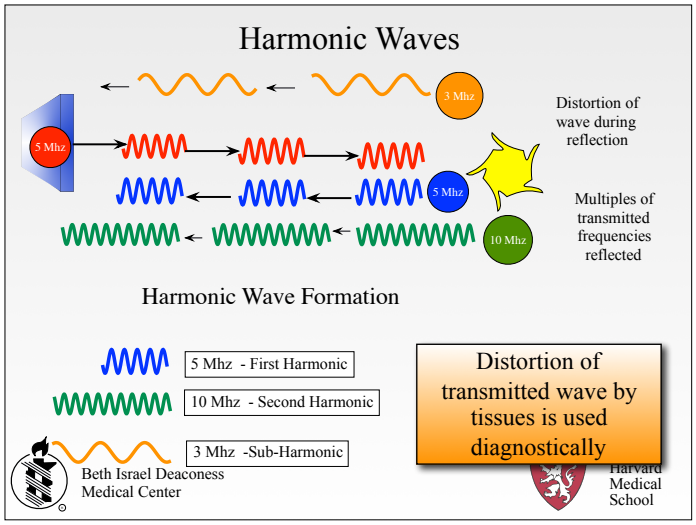
Image created by processing of reflections that have the same frequency as the transmitted sound

Harmonic Image

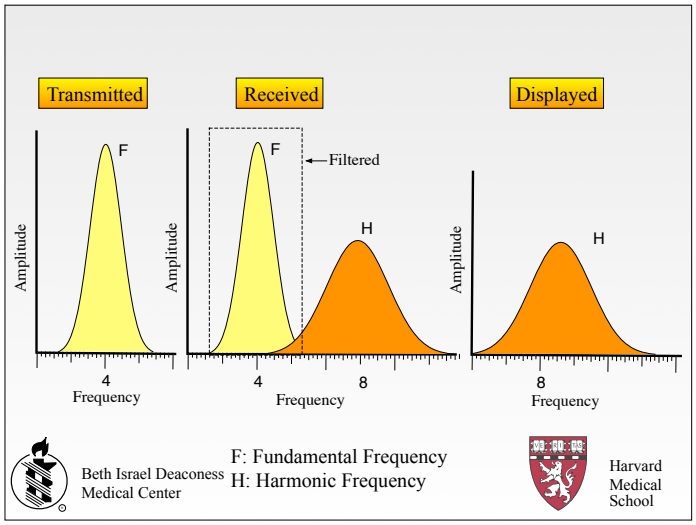
Image created by processing of reflections that are twice frequency of the transmitted sound

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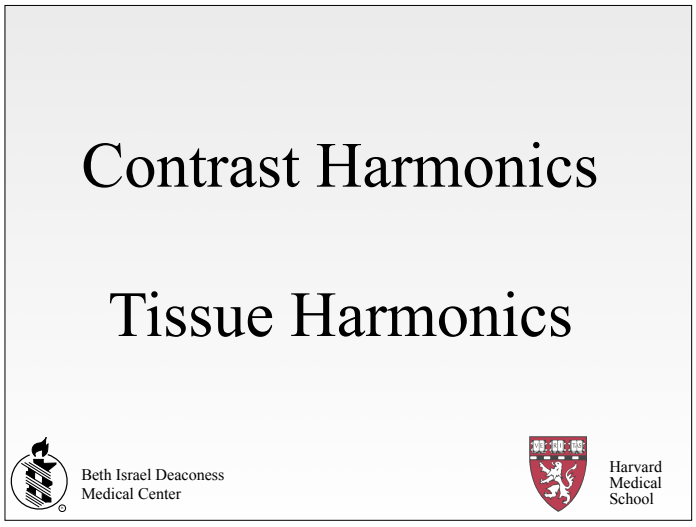
144

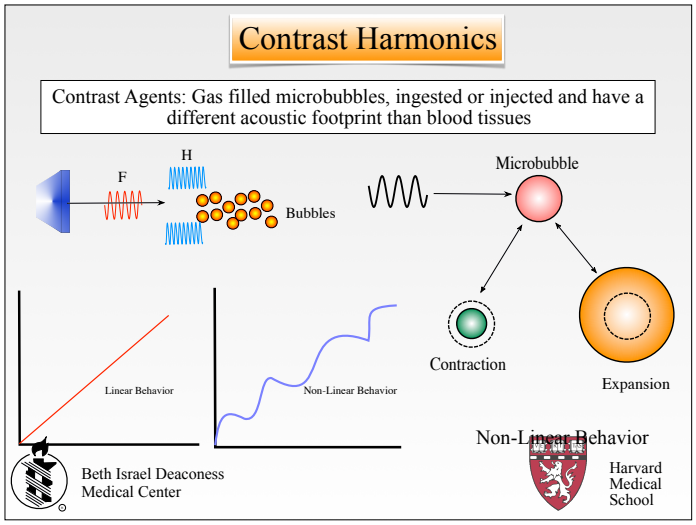

Harmonic Waves
3 Mhz
5 Mhz
5 Mhz
10 Mhz
Distortion of wave during reflection
Multiples of transmitted frequencies reflected
Harmonic Wave Formation
5 Mhz - First Harmonic
10 Mhz - Second Harmonic
3 Mhz -Sub-Harmonic
Distortion of transmitted wave by tissues is used diagnostically
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145

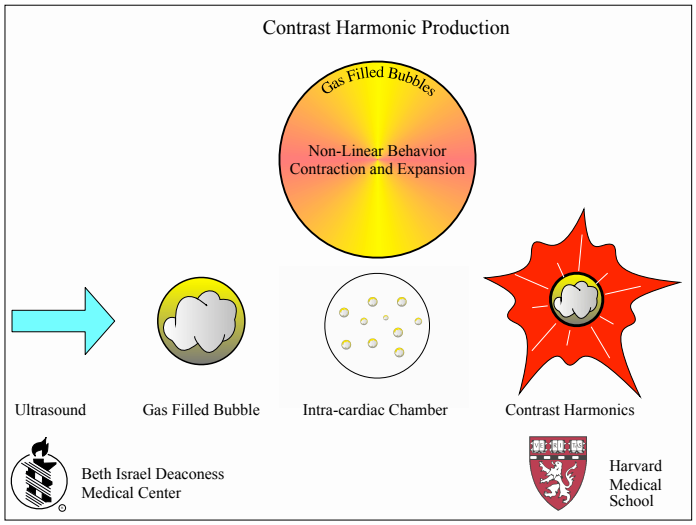

Transmitted
Received
Displayed
F
F
Filtered
H
H
Amplitude
Amplitude
Amplitude
4
Frequency
4
8
Frequency
8
Frequency
F: Fundamental Frequency
H: Harmonic Frequency
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Harvard Medical School

146

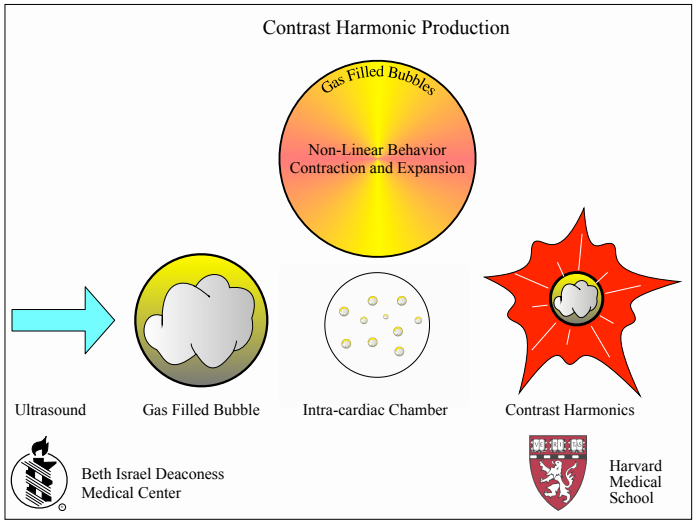

Contrast Harmonics
Tissue Harmonics
Beth Israel Deaconess Medical Center
Harvard Medical School



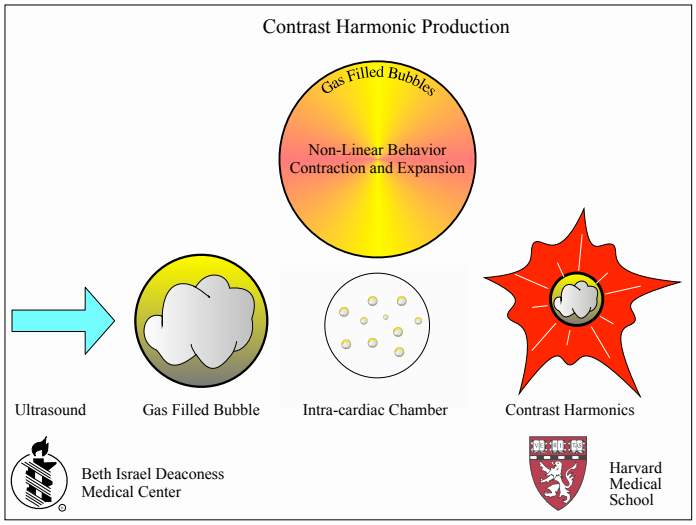
147



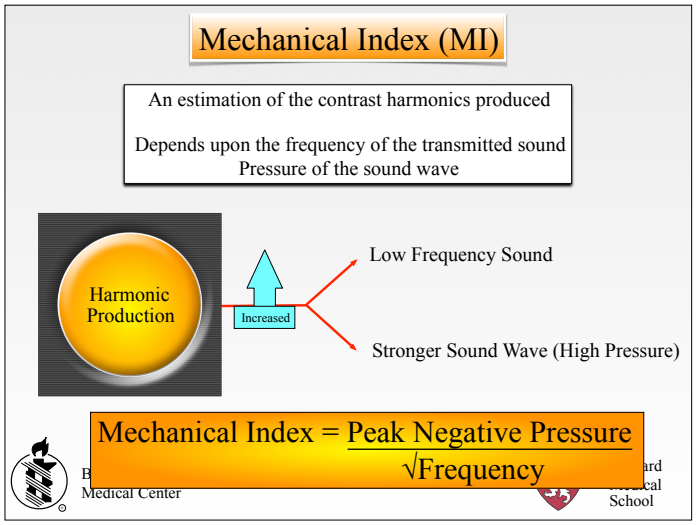
148-1



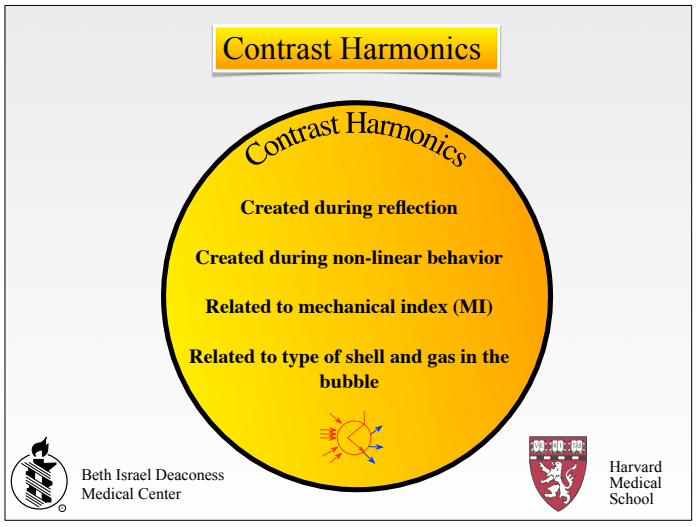
148-2


Contrast Harmonic Production
Gas Filled Bubbles
Non-Linear Behavior
Contraction and Expansion
Ultrasound
Gas Filled Bubble
Intra-cardiac Chamber
Contrast Harmonics
Beth Israel Deaconess
Medical Center
Harvard
Medical
School

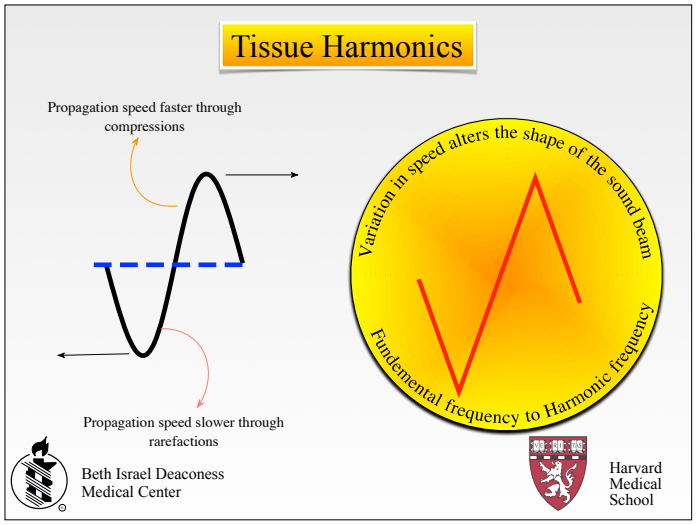
148-3


Mechanical Index (MI)
An estimation of the contrast harmonics produced
Depends upon the frequency of the transmitted sound
Pressure of the sound wave
Harmonic
Production
Increased
Low Frequency Sound
Stronger Sound Wave (High Pressure)
Mechanical Index = Peak Negative Pressure / √Frequency
Medical Center
School

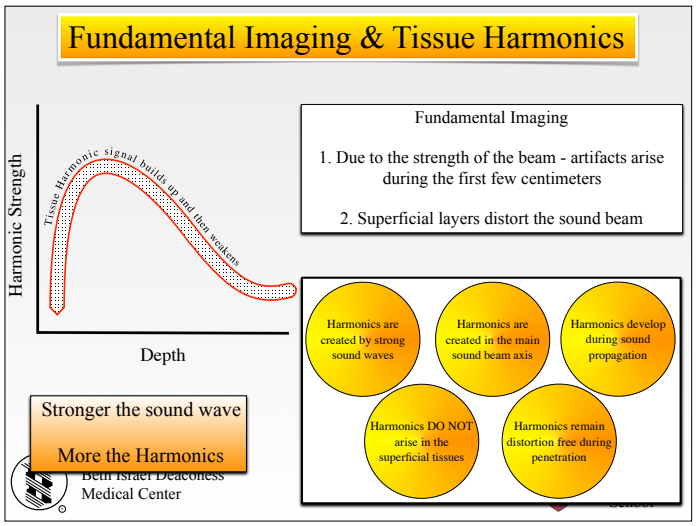
149


Contrast Harmonics
Contrast Harmonics
Created during reflection
Created during non-linear behavior
Related to mechanical index (MI)
Related to type of shell and gas in the bubble
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Harvard
Medical
School

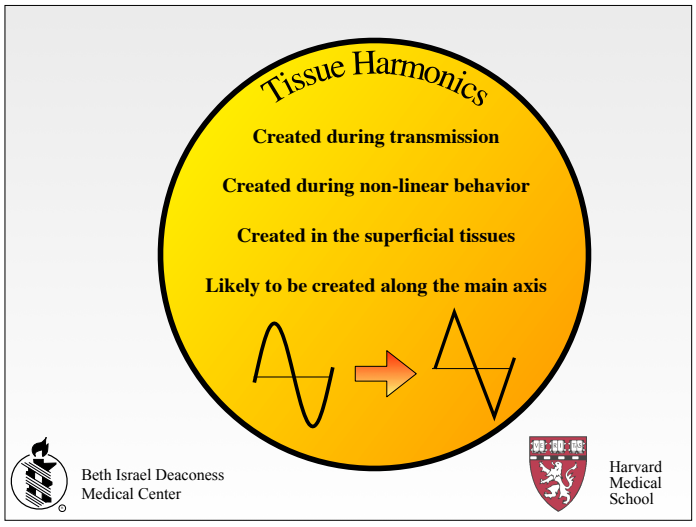
150


Tissue Harmonics
Propagation speed faster through compressions
Propagation speed slower through rarefactions
Variation in speed alters the shape of the sound beam
Fundamental frequency to Harmonic frequency
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Harvard Medical School

151


Fundamental Imaging & Tissue Harmonics
Harmonic Strength
Tissue Harmonic signal builds up and then weakens
Depth
Fundamental Imaging
1. Due to the strength of the beam - artifacts arise during the first few centimeters
2. Superficial layers distort the sound beam
Stronger the sound wave
More the Harmonics
Harmonics are created by strong sound waves
Harmonics are created in the main sound beam axis
Harmonics develop during sound propagation
Harmonics DO NOT arise in the superficial tissues
Harmonics remain distortion free during penetration
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152


Tissue Harmonics
Created during transmission
Created during non-linear behavior
Created in the superficial tissues
Likely to be created along the main axis
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Harmonic Imaging - Putting it all together

154

Contrast Harmonics

- Created during reflection
- Created during non-linear behavior
- Related to mechanical index (MI)
- Related to type of shell and gas in the bubble

Tissue Harmonics

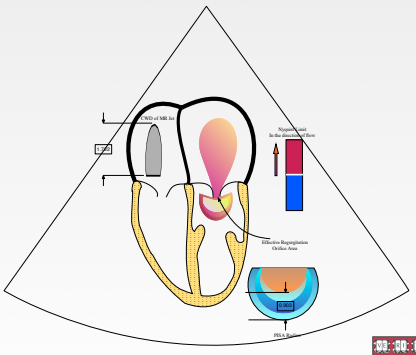
- Created during transmission
- Created during non-linear behavior
- Created in the superficial tissues
- Likely to be created along the main axis

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Image Formation

155



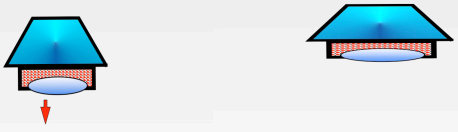
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Harvard Medical School

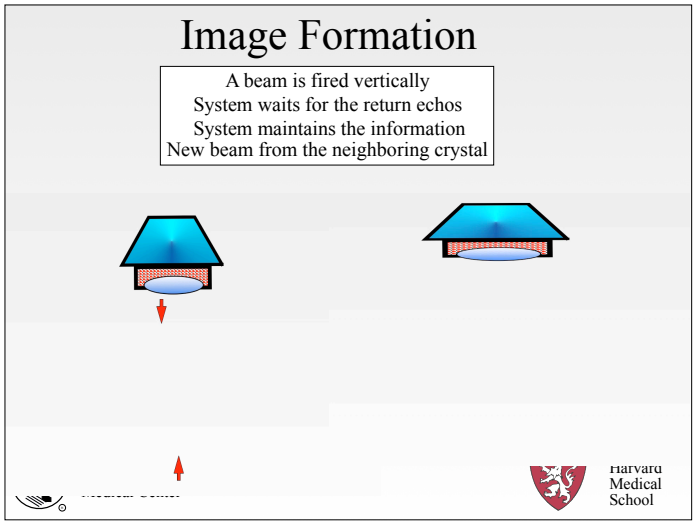
Image Formation

156-1

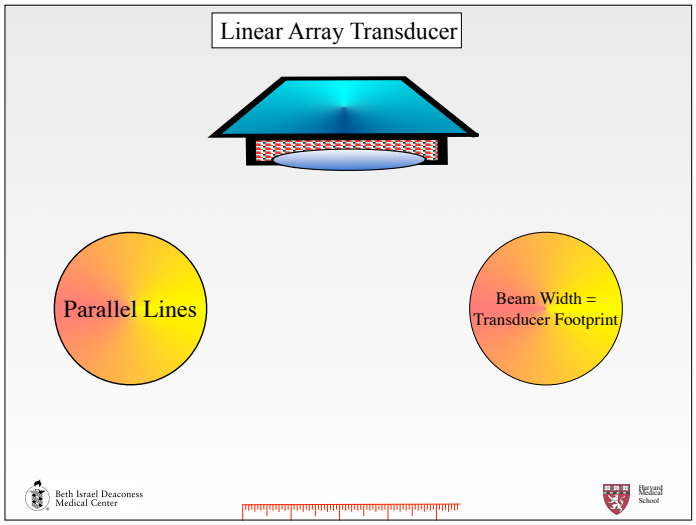
A beam is fired vertically
System waits for the return echos
System maintains the information
New beam from the neighboring crystal



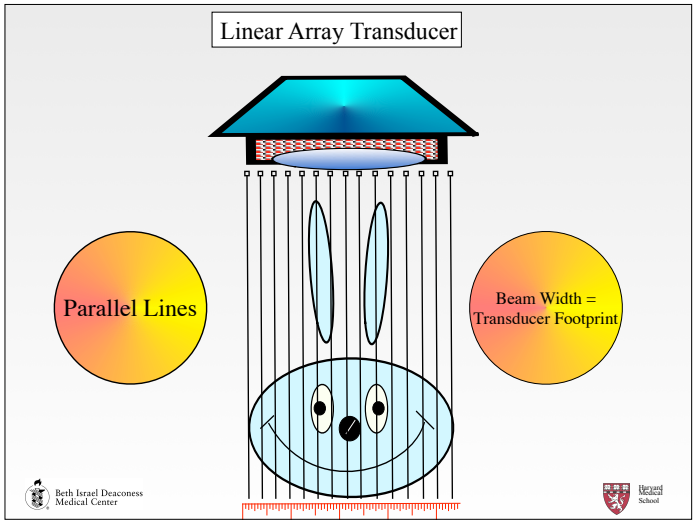
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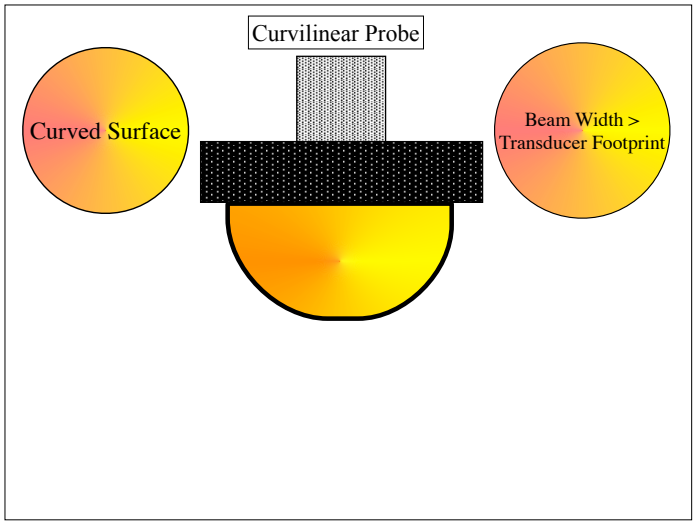
156-2



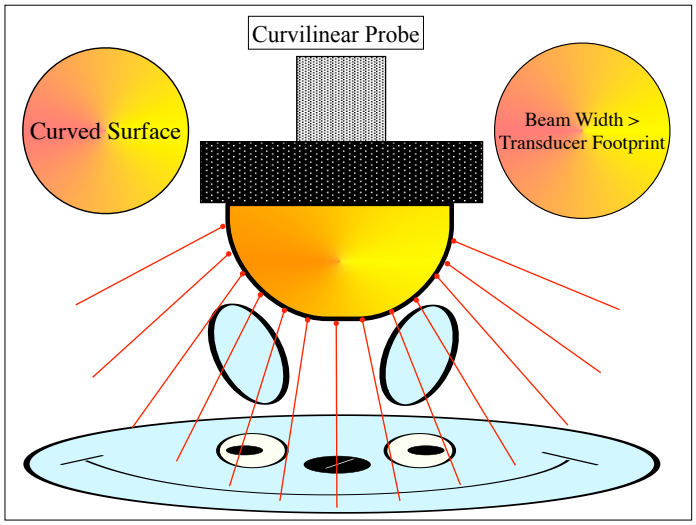
157-1



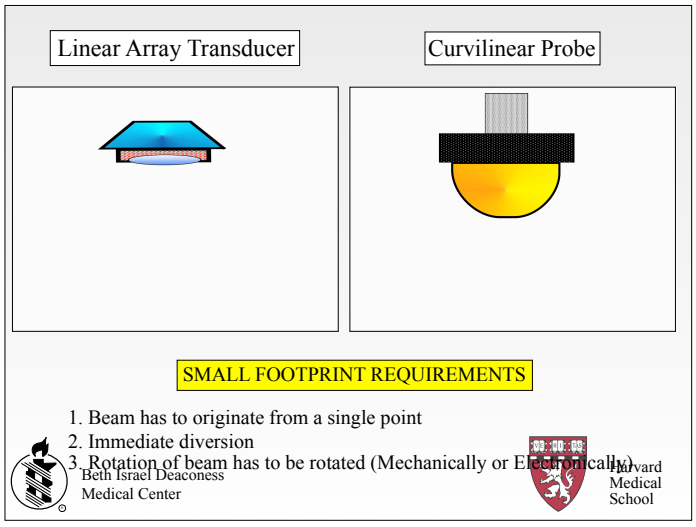
157-2



158-1



158-2

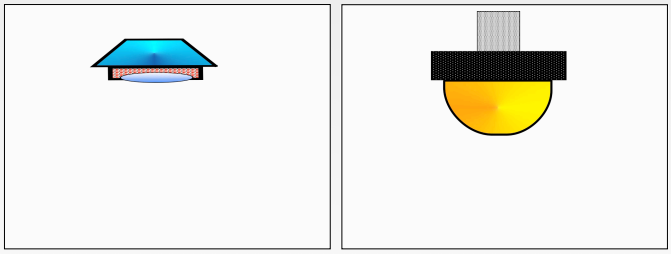


159-1

159-2

Linear Array Transducer

Curvilinear Probe



SMALL FOOTPRINT REQUIREMENTS

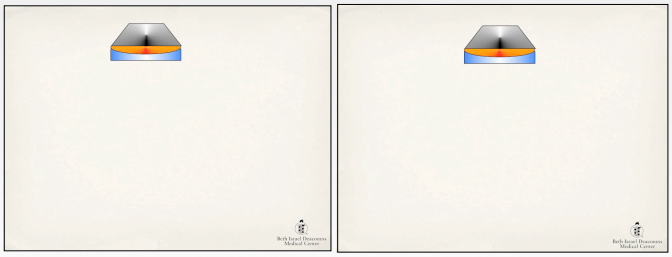
1. Beam has to originate from a single point
2. Immediate diversion
3. Rotation of beam has to be rotated (Mechanically or Electronically)

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160-1

Image Formation

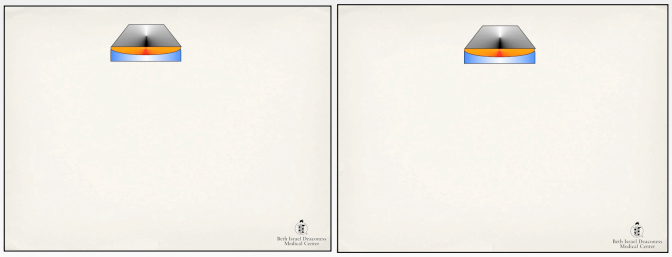


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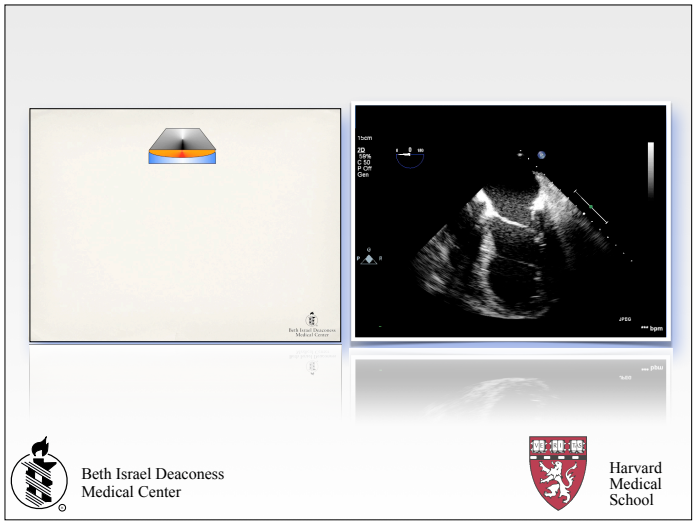
160-2

Image Formation

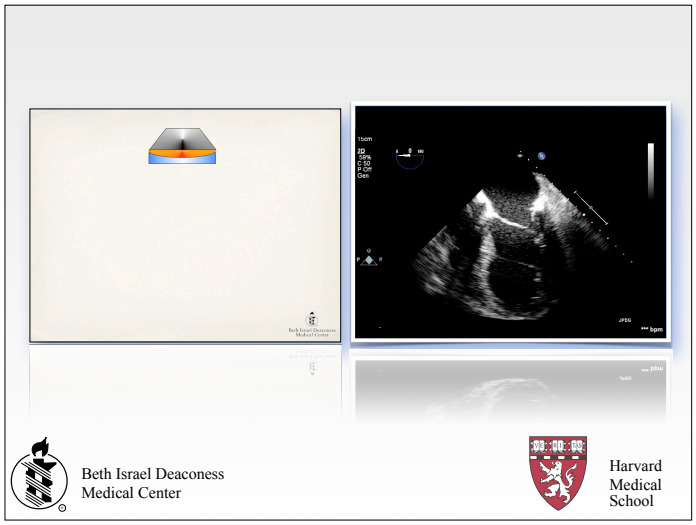


Beth Israel Deaconess Medical Center

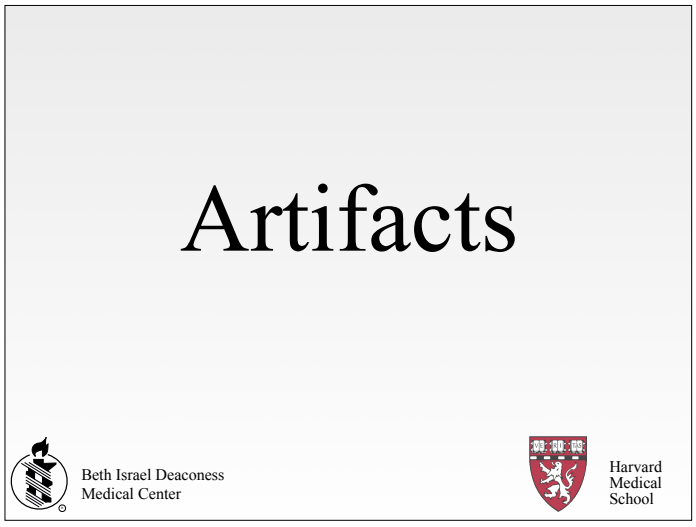
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161-1



161-2



162

Artifacts

Beam Dimension Artifacts

Assumption: All echos have originated from the central axis of a solitary razor thin ultrasound beam

Reality: All echos have originated from the full thickness of a three-dimensional beam as well as from secondary beams (Side Lobes)

Consequence: When a structure is detected from anywhere from within the three-dimensional beam or from secondary beams - An echo will be produced and displayed as though it has generated from the center of the beam

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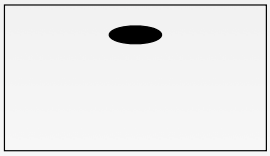
163

Beam Width Artifacts



When two reflectors lying side by side in the beam appear as one

Image Display



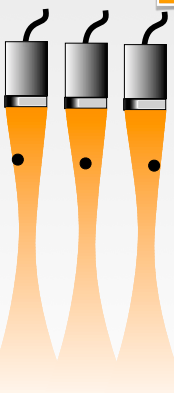
For two reflectors to be displayed as distinct entities, they must be separated by a distance greater than the beam width

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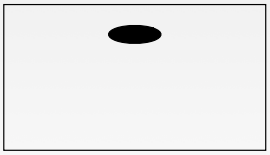
164

Beam Width Artifacts



A narrow reflector within the beam appears wider

Image Display



As the beam sweeps through a dot reflector from left to right, the dot reflector remains within the beam and will generate an echo - appear wider than it is

Width of this reflector equals the beam width

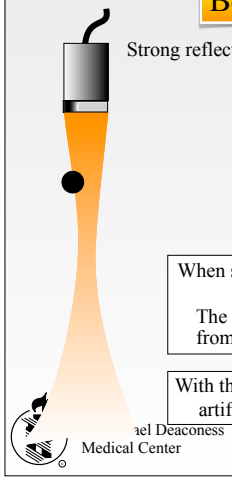
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165

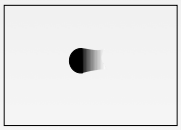
166

Beam Width Artifacts



Strong reflectors to the side of the echo free space appear within the beam

Image Display



When strong reflectors are detected at the edge of the ultrasound beam - an echo is generated
The system assumes that the echo has originated from the center of the beam and places it as such

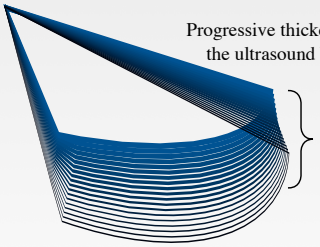
With this kind of artifact - the structure generating the artifact is ALWAYS seen adjacent to the artifact

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Medical Center

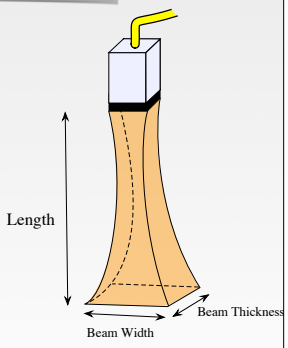
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167

Beam Thickness Artifact



Progressive thickening of the ultrasound beam



Elevational plane is perpendicular to the main imaging plane

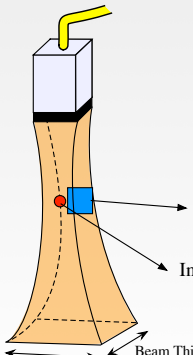
Any structures ABOVE and BELOW the imaging plane will be shown in display

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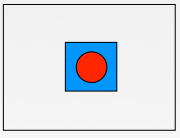
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Creation of Beam Thickness Artifact



2D Image Display



Length

Behind the beam

Infront of the beam

Display has structures within the MAIN beam and above and below it

Beam Thickness

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Beam Width

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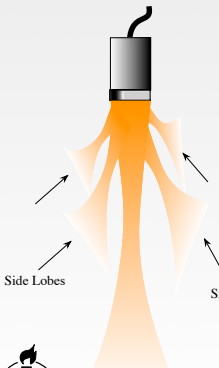
Side Lobe and Grating Lobe Artifacts

169

Due to "secondary beams"

Single Crystal Transducers: Side Lobe

Electronic Array Transducers: Grating Lobe



Structures interrogated by secondary beams -generate echos

Assumed to originate from the center of the beam

Generally have much lower amplitude than main beam echos

Most obvious in echo-free cavities

Commonly seen as linear strucrtures

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Beam Width versus Slice Thickness Artifact

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Beam Width Artifact	Slice Thickness Artifact
Structure causing the artifact is always imaged next to the artifact	Structure causing the artifact is NOT imaged on the display next to artifact

Rotating the beam 90⁰ sometimes helps in differentiation

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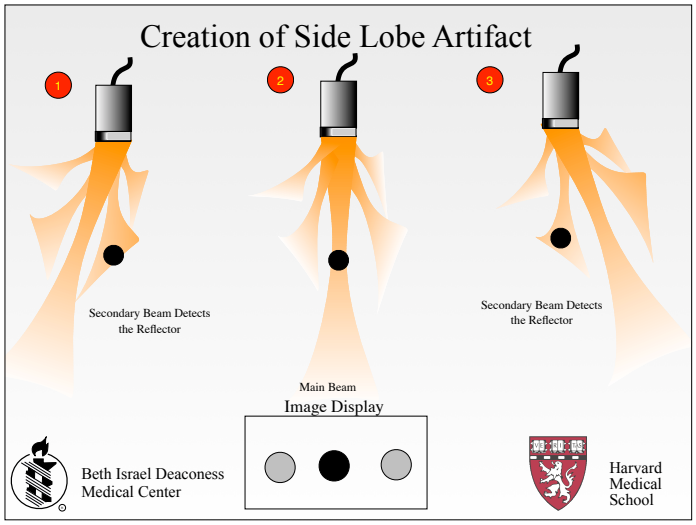
Grating Lobe Artifact versus Beam Width Artifact

171

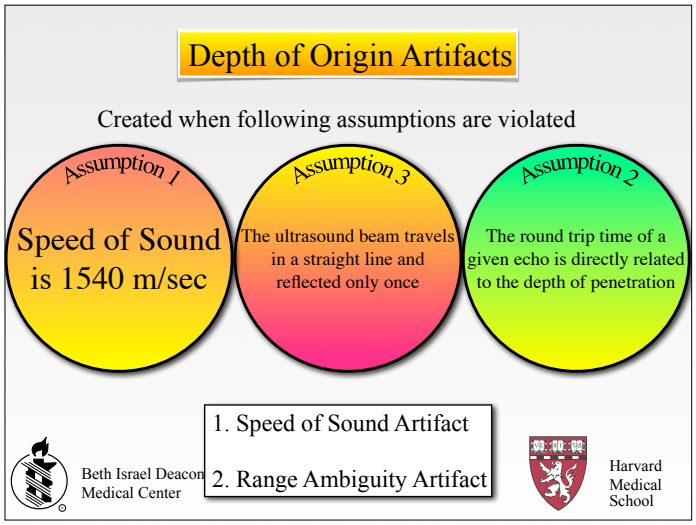
Beam Width Artifact	Grating Lobe Artifact
Width of artifact = Width of beam Artifact is lateral extension of real structures	Width of artifact > Width of beam Artifact is replication of real structure

Both artifacts are similar in appearance

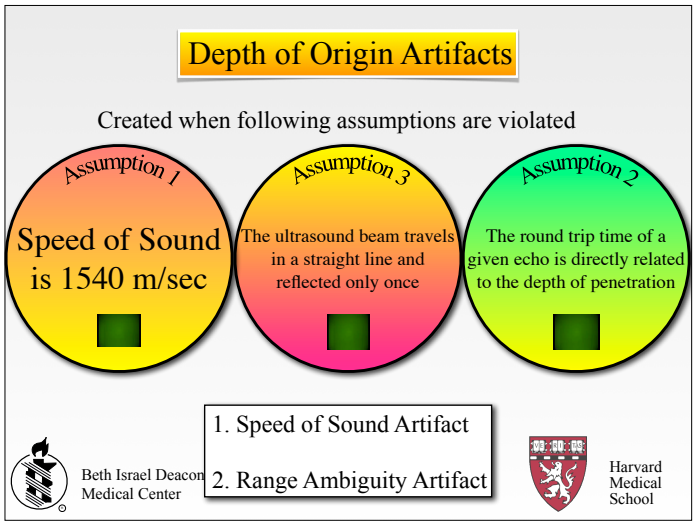
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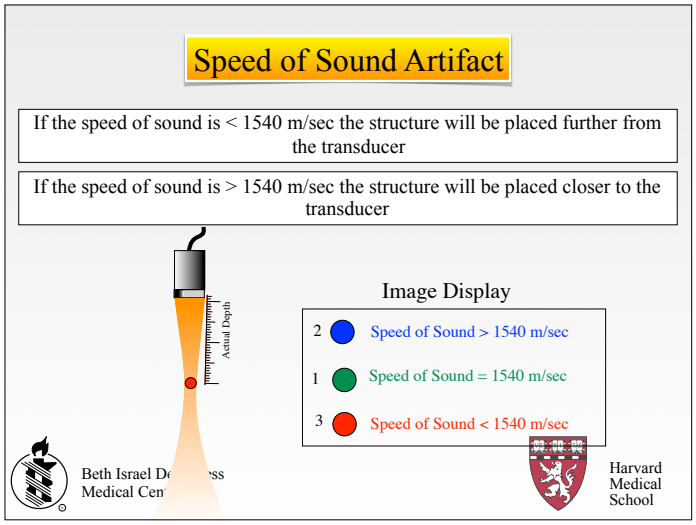


173-1

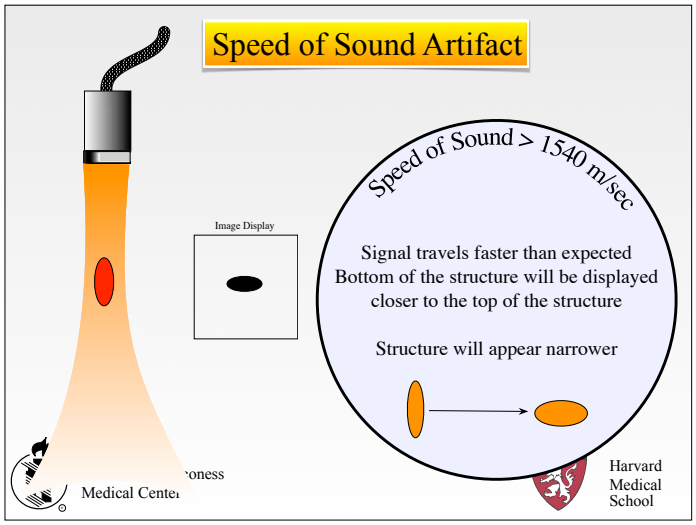


173-2

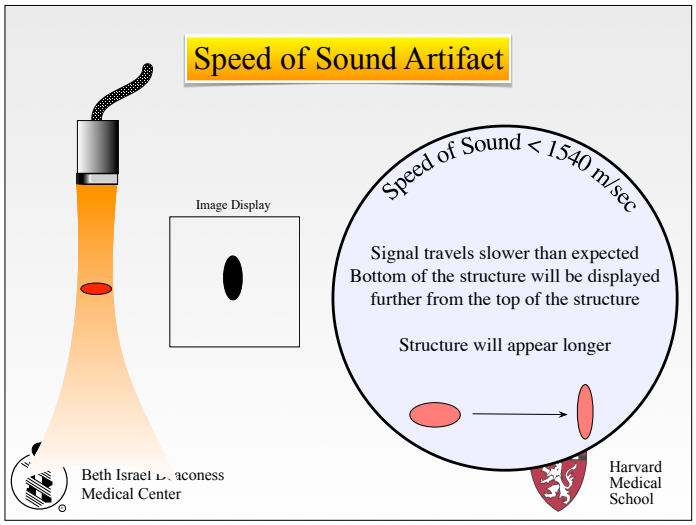
174


Speed of Sound Artifact
If the speed of sound is < 1540 m/sec the structure will be placed further from the transducer
If the speed of sound is > 1540 m/sec the structure will be placed closer to the transducer
Actual Depth
Image Display
2 Speed of Sound > 1540 m/sec
1 Speed of Sound = 1540 m/sec
3 Speed of Sound < 1540 m/sec
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Speed of Sound Artifact
Image Display
Speed of Sound > 1540 m/sec
Signal travels faster than expected
Bottom of the structure will be displayed closer to the top of the structure
Structure will appear narrower
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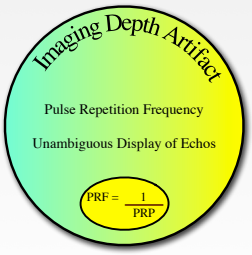

Speed of Sound Artifact
Image Display
Speed of Sound < 1540 m/sec
Signal travels slower than expected
Bottom of the structure will be displayed further from the top of the structure
Structure will appear longer
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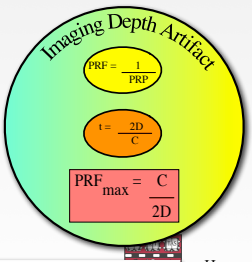
177

Range Ambiguity Artifact

For an unambiguous display of images sufficient time must be allowed for the wave to return before the next wave is emitted

It is assumed for each pulse that all echos are received before the next pulse is transmitted





PRF must decrease for an unambiguous display of images

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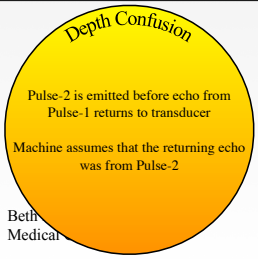
178

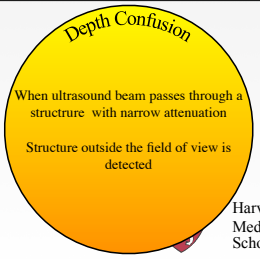
Range Ambiguity Artifact

Occurs when a second pulse is emitted before an echo returns from the first pulse

High Pulse Repetition Frequency Mode

Assumption: Returning echo signal is from the most recently emitted pulse

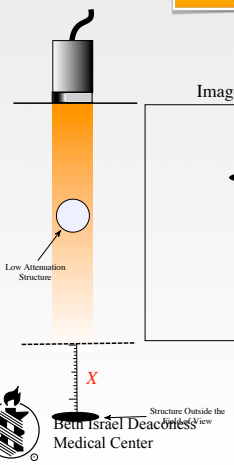




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Range Ambiguity Artifact



Deeper structures will be detected when the beam passes through a low attenuation structure

Structures outside the field of view will be detected

If returning echos form outside structures return after transmission of the first pulse - the structure will be placed in the field of view because it will be assumed to have originated from the most recent pulse

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Beam Path Artifacts

Assumptions violated

1. Ultrasound beam travels in a straight line and is reflected only once

2. Speed of sound in tissues is always 1540 m/sec

Display echos in the wrong place

Duplication of a structure

Reverberation Artifact

Refraction Artifact

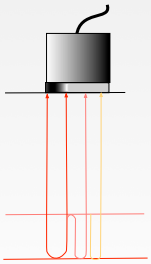
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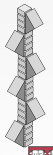
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Reverberation Artifact

Created when there is a large acoustic mismatch between two closely spaced interfaces perpendicular to the ultrasound beam





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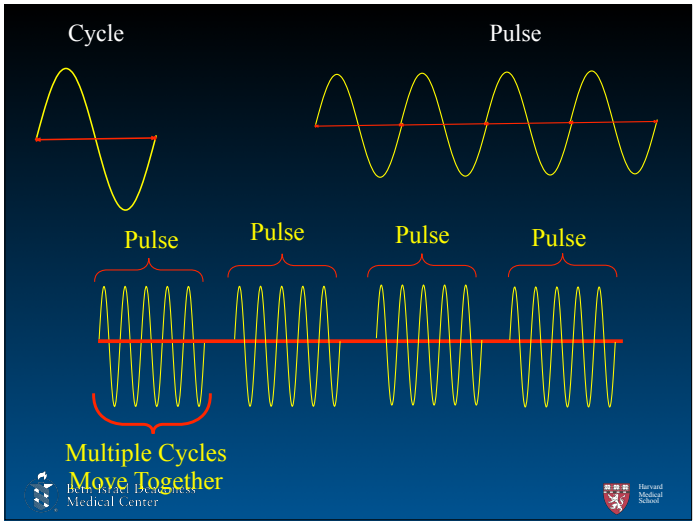
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Final Review

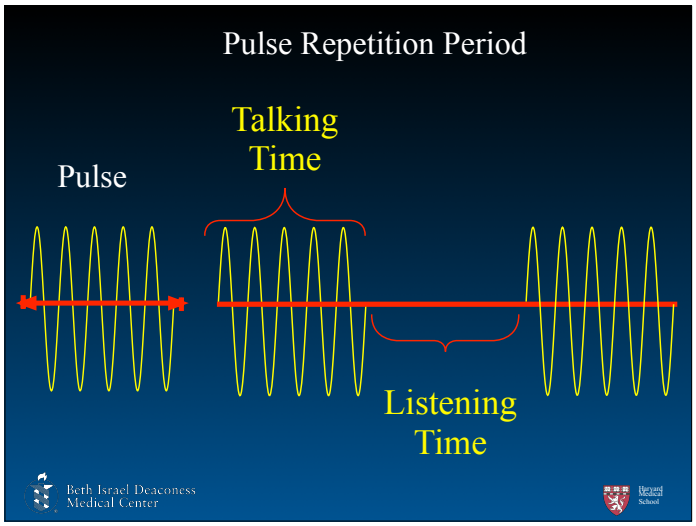
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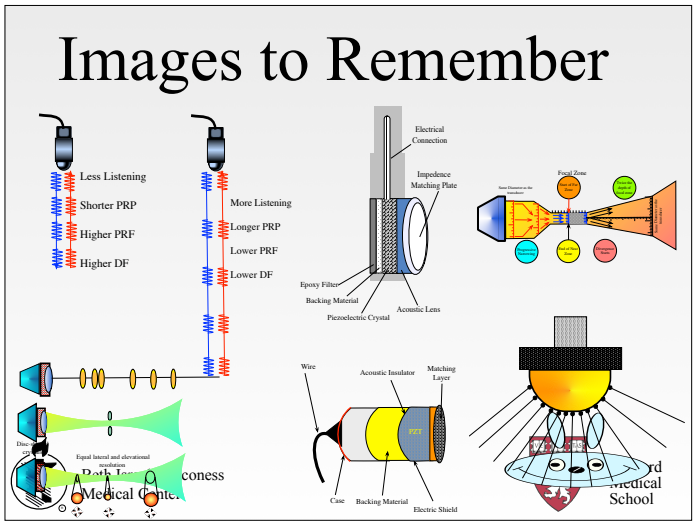
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Cycle
Pulse
Pulse
Pulse
Pulse
Pulse
Multiple Cycles
Move Together
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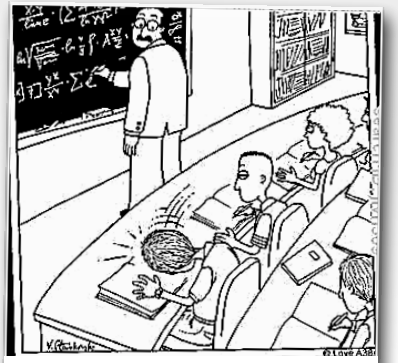

Pulse Repetition Period
Talking
Time
Pulse
Listening
Time
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Images to Remember
Less Listening
Shorter PRP
Higher PRF
Higher DF
More Listening
Longer PRP
Lower PRF
Lower DF
Electrical
Connection
Impedence
Matching Plate
Epoxy Filler
Backing Material
Piezoelectric Crystal
Acoustic Lens
Focal Zone
Wire
Acoustic Insulator
Matching
Layer
PZT
Case
Backing Material
Electric Shield
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Thanks



Professor Herman paused when he heard the unmistakable thud- another brain imploding

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