Faculty of Engineering
Cairo University

IEEE CUSB

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Ultra-Sound - Sonography

Submitted to:
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Submitted by:
Mohamed Ahmed Abdelaziz
(+20)01552516133
Cairo University
mohamed.ahmed997@eng-st.cu.edu.eg

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1 Introduction

ultrasound diagnostics is an important imaging method in virtually all medical fields. The fact that it is quick, simple and in particular cost-efficient plays a major role in this. Further advantages are provided by the mobility and the broad spectrum of use of modern ultrasound diagnostic systems. Not least, these properties and also the absence of ionizing radiation make its use indispensable these days.

Figure 1: Ultrasound

2 Transducers

In ultrasound diagnostics, the transmitter and receiver are combined in the ultrasound probe. The probe is connected to the ultrasound unit via a cable, thereby enabling very free positioning of the ultrasound probe on the body and thus also virtually any desired examination plane and slice orientation.

In contrast to the x-ray method, which is a transmission method, ultrasound is a so-called reflection method. The ultrasound probe transmits a short ultrasound pulse which penetrates the body and is partially reflected at interfaces, e.g. between liver and kidney. Once the pulse has been emitted, the unit switches the ultrasound probe to receive mode. The ratio of transmission to reception time is approximately 1 : 1000. The reflected components of the sound wave transmitted are then recorded by the ultrasound probe and fed to the unit for further processing.

Figure 2: Transeducers

2.1 Linear

- High Frequency .
- Low Penetration .
- High Resolution
- APP : MSK, Vascular, andsmall Parts .

2.2 Convex

- Large Field Of View .
- Low Frequency .
- High Penetration .
- APP : OB/GYN, Abdominal Bowel , and Bladder .

2.3 Phased array

Used to visualize structures with small insertion probe. usually used in cardiology applications and placed between the ribs.

- APP : Cardiology, Brain Examination .
- TCD : Trans Cranial Doppler.
- TCI : Trans Cranial Image .

2.4 Endo-Cavity

2.4.1 Endo-Vaginal

- Identification of multiple Pregnancy (Twins or Triples) .
- Examining Vagina , Placenta and Cervix .
- Fallopian Tubes , Uterus and Ovaries .
- Early Pregnancy .
- Detect an Ectopic Pregnancy .

2.4.2 Intra-Rectal

Usually used with men to examine the prostate, and diagnosis of rectal cancer.

2.5 T-Shape

It is usually used in surgeries due to its design which allow better accessibility by the surgeon.

3 Echo Ranging

In ultrasound, determination of the position or depth of a body structure on the basis of the time interval between the moment an ultrasonic pulse is transmitted and the moment its echo is received.

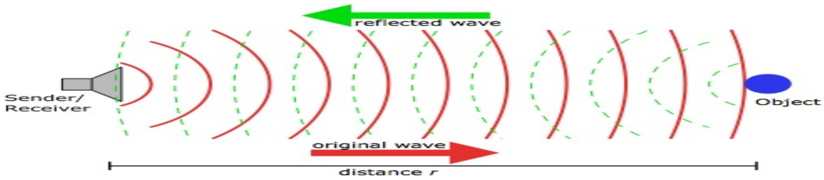


Figure 3: Echo Ranging

4 Ultrasound Modes

4.1 B-Mode

B-mode or 2D mode: In B-mode (brightness mode) ultrasound, a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen. More commonly known as 2D mode now.

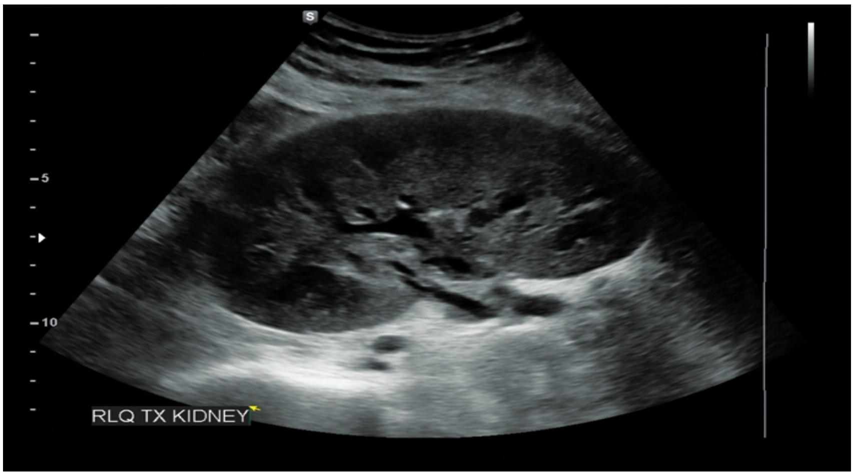


Figure 4: B-Mode

4.2 M-Mode

M-mode or motion mode is a form of ultrasound imaging that is of high clinical utility in the emergency department. It can be used in a variety of situations to evaluate motion and timing, and can document tissue movement in a still image when the recording of a video clip is not feasible.

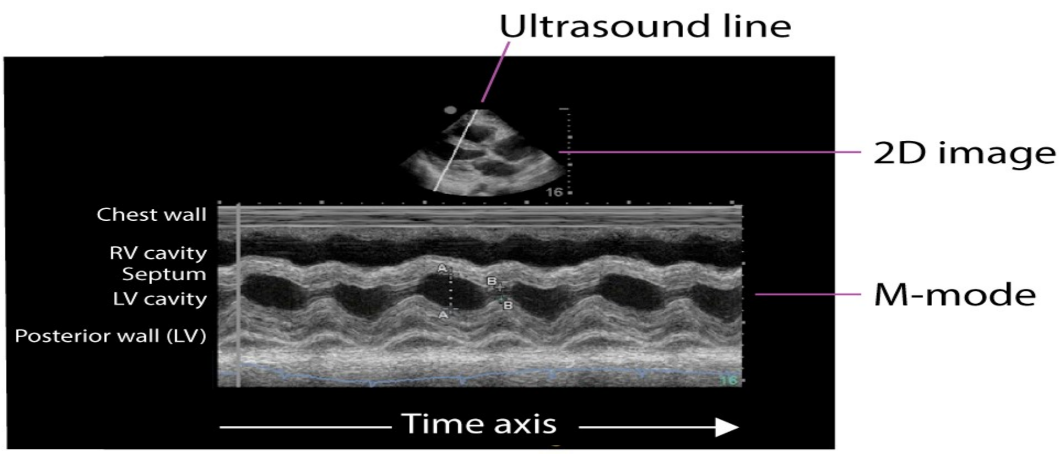


Figure 5: M-Mode

4.3 Doppler-Mode

In addition to calculating the depth of a reflecting interface, the pulse reflection method generally used in ultrasound also provides the possibility of detecting a moving structure and measuring its speed. This is possible due to technical processing of the reflected signals, which differs from the method described before of determining the transit time and which, in addition to displaying the tissue morphology, also enables functional diagnosis of moving tissue volumes and liquids (blood, muscle, urine).
The measurable change in frequency between the emitted and the reflected signal, which in ultrasound is called the Doppler shift or the Doppler frequency shift f_D, is proportional to the speed of the moving structure.

$$\Delta f = f_1 - f_2 = f_1 \frac{2v\cos\theta}{c}$$

A fundamental problem in the practical Doppler measurement is its reliance on angles.$\theta = 90$, which gives $\cos\theta = 0$ does not give a measurable speed.

4.3.1 Spectral Doppler

Utilizing automated Fourier analysis to convert returning sound waves into a series of individual frequencies, spectral Doppler refers to ultrasound modalities which yield graphical representations of flow velocity over time.

Figure 6: Spectral Doppler

4.3.2 Color Doppler

Color Doppler or color flow Doppler is the presentation of the velocity by color scale. Color Doppler images are generally combined with grayscale (B-mode) images to display duplex ultrasonography images, allowing for simultaneous visualization of the anatomy of the area.

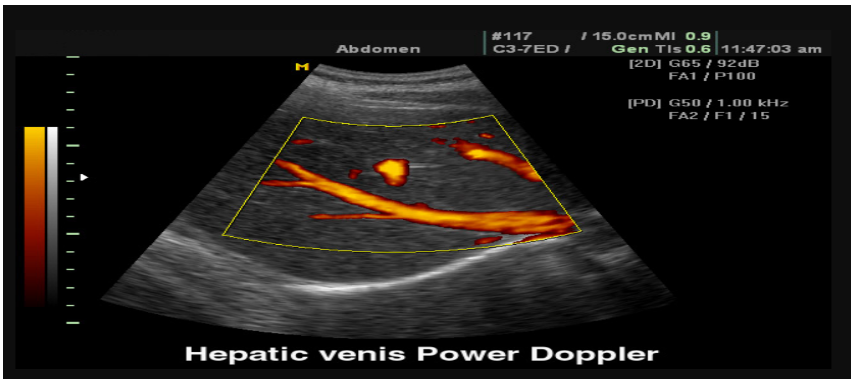


Figure 7: Color Doppler

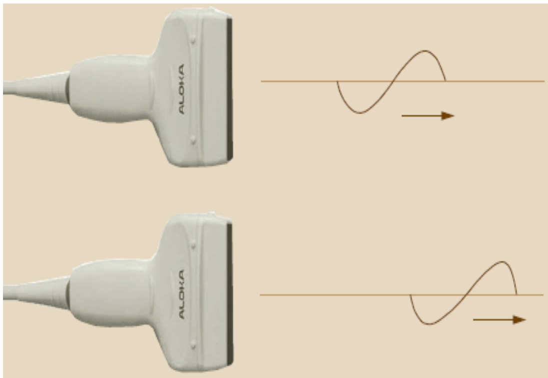
4.4 Tissue Harmonic Imaging

During the course of time of a sinusoidal wavelength, the periodic pressure fluctuation triggered by the ultrasound pulse leads to a regularly changing sound propagation speed. The positive half-wave (pressure) moves with greater speed than the negative half-wave, with the result that the negative-going edge of the positive sound wave becomes increasingly steep as the distance from the sound source increases.
The pulses from an ultrasound unit emitted into the body also experience this deformation on their path through the tissue. The higher the intensity of the sound emitted, the earlier and more pronounced this deformation. Every nonsinusoidal oscillation can be broken down into multiple sinusoidal oscillations of different frequencies by means of Fourier analysis.

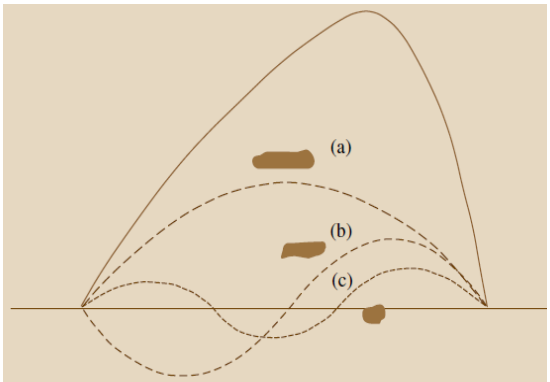
Conventional signal processing suppresses the higher-frequency signal components, so that the dominant fundamental of each reflected signal is primarily used for imaging. In the method known as second harmonic imaging, however, the first overtone (second harmonic) is isolated and used to obtain an image. The fundamental (first harmonic) and all other overtones are filtered out and are not used further. Using the second harmonic frequency has a number of advantages.

- clearer differentiation between liquid and solid tissues. The reason for this is the more pronounced saw-toothshaped signal deformation in solid structures (tissue) and the lesser degree of deformation in liquid tissues
- the amplitude of the interfering side lobes which occur automatically at the fundamental frequency is too low to generate overtones. which reduces the image artifacts
- more cleanly and clearly delimit liquid-filled cavities in particular, such as the amniotic cavity, the bladder, the cardiac cavities or cysts

Its disadvantage is using the second harmonic is that the reflected second harmonic has less penetrative power as a result of the doubling in the frequency. Because these waves must cover the distance to the ultrasound probe, however, the depth of field of the ultrasound image which can be displayed is overall reduced. Use of this technology should therefore be left to the user, who differentiates depending on the organ being investigated by switching the unit on and off.



(a) Signal Deformation



(b) Fourier Sinusoidals

Figure 8: Harmonic Imaging

4.5 Secondary Modes

4.5.1 Duplex

Presentation of two modes simultaneously: usually 2D and pulsed (wave) Doppler

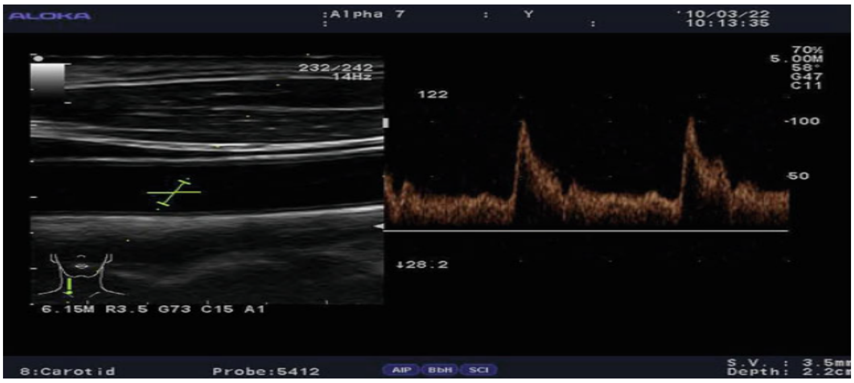


Figure 9: Duplex Mode

4.5.2 Triplex

Presentation of three modes simultaneously: usually 2D, color flow, and pulsed Doppler

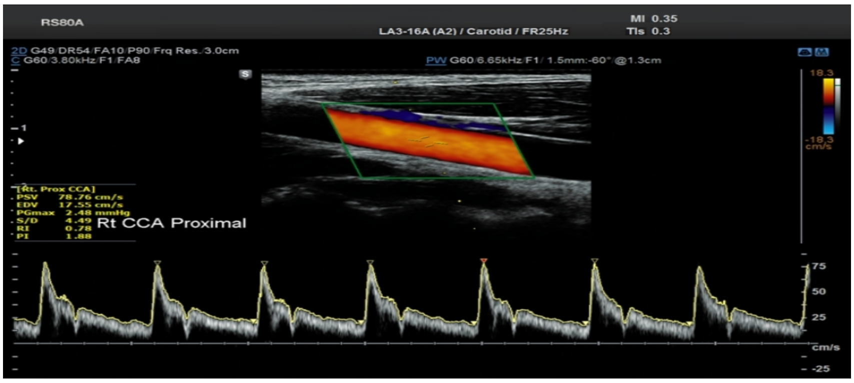


Figure 10: Triplex Mode

4.5.3 3-D & 4-D

Display or Surface/volume rendering used to visualize volume composed of multiple 2D slices. whereas 4D is a 3D image moving in time

Figure 11: 3D Ultrasound

4.5.4 Tissue Doppler Imaging(task1)

4.5.5 Elastography(task1)

4.5.6 Fusion(task1)

4.5.7 Panoramic(task1)

4.5.8 Auto-tracking(task2)

4.5.9 Guided Surgery(task2)

4.5.10 3-D hands free technology(task2)

4.5.11 Magic Cut (task2)

5 Ultrasound Physics

5.1 Reflection & Acoustic Impedance

On the way through the tissue, components of the transmitted sound wave are reflected at interfaces between different organs and sections of organs. The energy of the waves which are reflected is determined in each case by the differences in the so-called wave impedance (Z) of the individual organ parts and sections scanned. There is more or less reflection at these multiple interfaces depending on the relationship between the individual wave impedances, on the angle of impact with respect to the interface and on the surface texture (scattering).

The ideal reflected component is approximately 1%, which corresponds to a reflection coefficient of R = 0.01. Higher reflection coefficients result in a greater loss of energy of the propagated wave overall, thus resulting in insufficient penetration of the ultrasonic beam into deeper tissue.

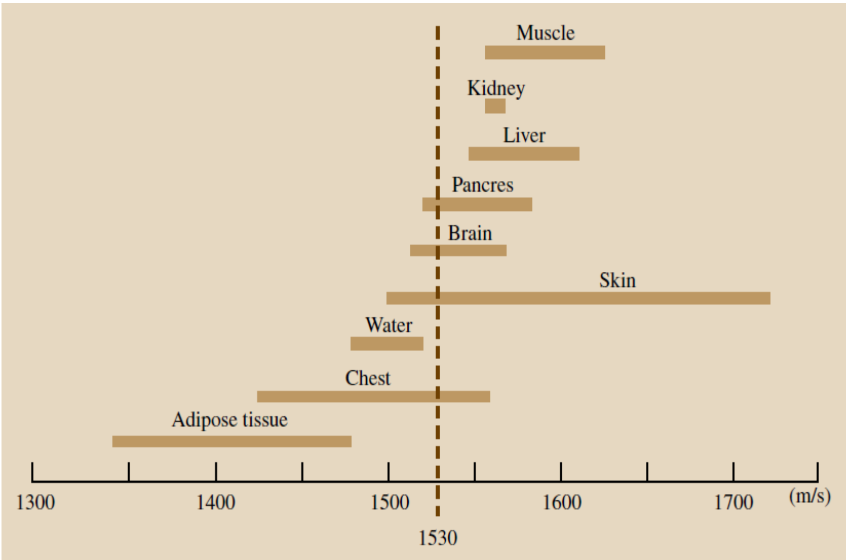


Figure 12: Sound Speed In Tissue

Body Tissue	Acoustic Impedance (10^6 Rayls)
Air	0.0004
Lung	0.18
Fat	1.34
Liver	1.65
Blood	1.65
Kidney	1.63
Muscle	1.71
Bone	7.8

Figure 13: Acoustic Impedence

5.2 Axial Resolution

Higher transmission frequencies lose more energy over the same travelling distance than lower transmission frequencies and thus achieve a shorter penetration depth than lower frequencies.
However, high frequencies have an advantage in terms of the axial resolution on account of their shorter wavelength (λ). In a theoretical best-case scenario, the minimum wavelength for separate imaging of two interfaces is a single wavelength. A frequency of 5 MHz, for example, gives a wavelength of 0.3 mm, whereas a frequency of 10MHz corresponds to a wavelength of 0.15 mm. More individual interfaces can therefore theoretically be resolved at 10 than at 5MHz. In the figure we can notice with the frequency increases we can detect more surfaces and have more differentiation axially along the beam.

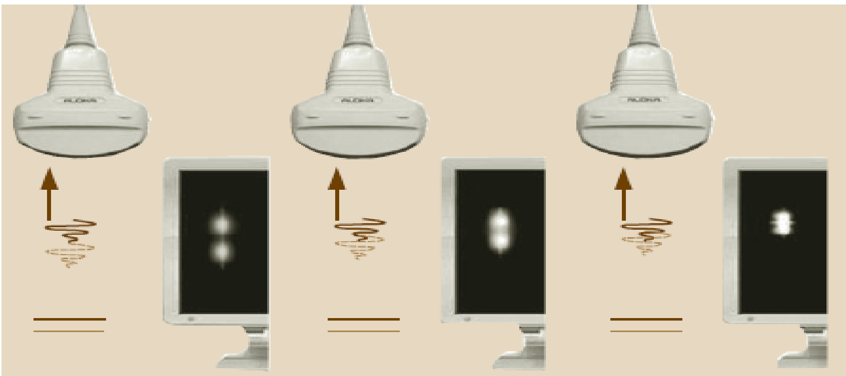


Figure 14: Axial Resolution

5.3 Scattering

Scattering is a term used in physics to describe a wide range of physical processes where moving particles or radiation of some form, such as light or sound, is forced to deviate from a straight trajectory by localized non-uniformities (including particles and radiation) in the medium through which they pass. Two important aspects of scattering: ultrasonic power scattered back is small compared to reflections and Beam angle-independent appearance in the image unlike reflections
Rough surfaces also cause diffusive reflection.

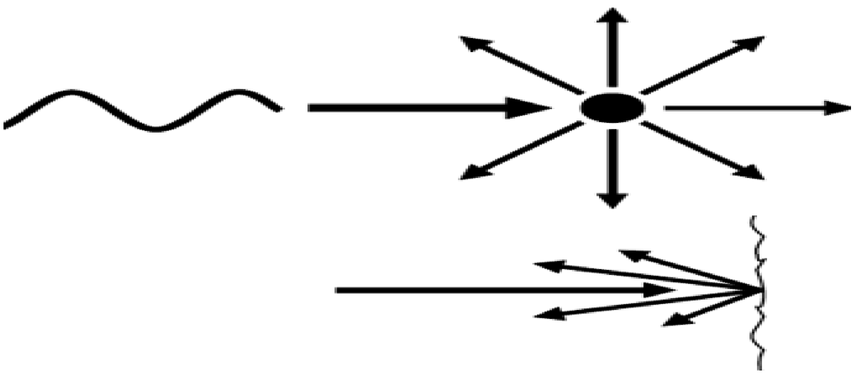


Figure 15: scattering

5.4 Refraction

Ultrasound waves are only refracted at a different medium interface of different acoustic impedance. Refraction allows enhanced image quality by using acoustic lenses. Refraction can result in ultrasound double-image artifacts. During attenuation the ultrasound wave stays on the same path and is not deflected. It may cause shift in the real position of the organs.

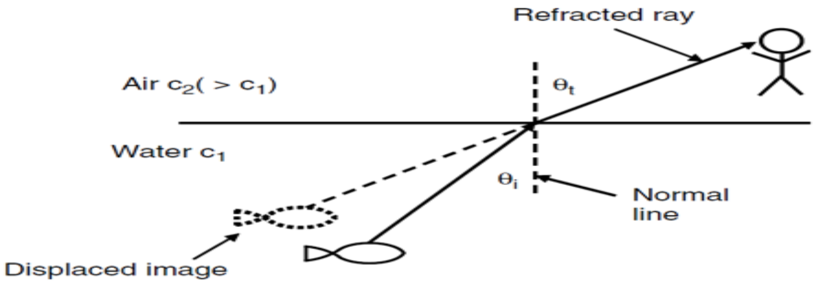


Figure 16: Refraction

5.5 Attenuation

The amplitude and intensity of ultrasound waves decrease as they travel through tissue, a phenomenon known as attenuation. Given a fixed propagation distance, attenuation affects high frequency ultrasound waves to a greater degree than lower frequency waves. This dictates the use of lower frequency transducers for deeper areas of interest, albeit at the expense of resolution. It is also a tissue property for example bone cause much higher attenuation than fat or fluid which cause shadowing.

Body Tissue	Attenuation Coefficient (dB/cm at 1MHz)
Water	0.002
Blood	0.18
Fat	0.63
Liver	0.5-0.94
Kidney	1.0
Muscle	1.3-3.3
Bone	5

Figure 17: Attenuation

5.6 Interference & Diffraction

Interference refers to the phenomenon where two waves of the same kind overlap to produce a resultant wave of greater, lower, or the same amplitude. Diffraction is defined as the bending of a wave around the corners of an obstacle or aperture. this cause the generation of near field and far field which have different pressure distributions according to Fourier transform. the far field is important as it is used to construct the image due to its uniform pressure distribution pattern.

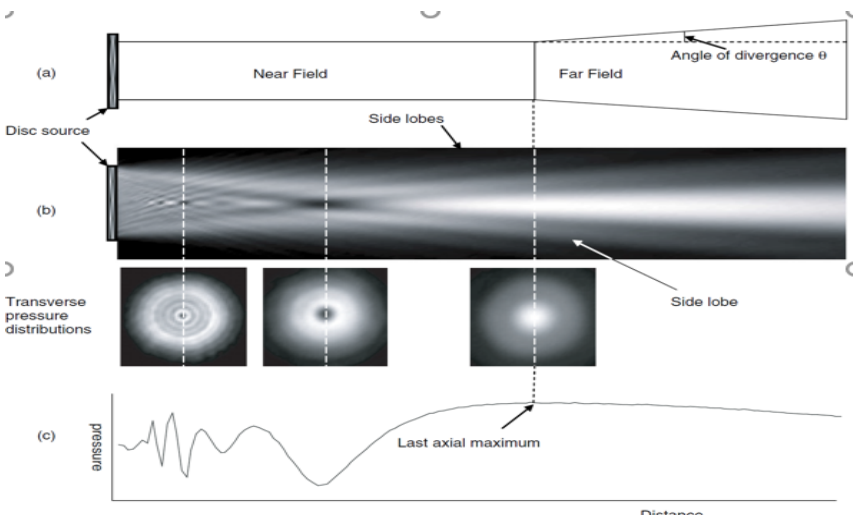


Figure 18: Interference and Diffraction

6 Transducer

6.1 Backing Layer

Is used to damp the sound wave in order not to affect the crystals and the image quality.

6.2 Focusing Lens

Used to focus the beam in the elevation direction Focusing may also be presented electronically.

6.3 Matching Layer

cause the reflected sound waves to cancel out each other it its thickness is $\frac{\lambda}{4}$

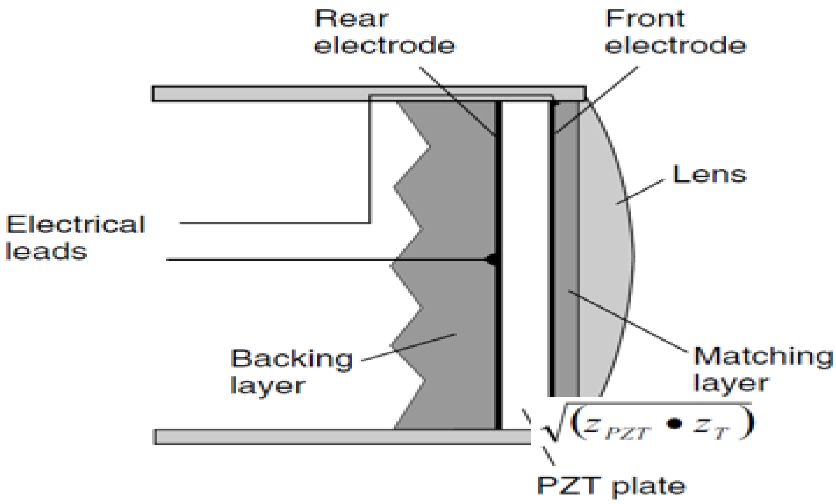


Figure 19: Transducer Structure

6.4 Beam Forming & Transmission Zones & Lateral Resolution

Beam shape is the Fourier transformation of the transducer gate . For a uniform excitation the profile Is represented by Sinc beam shape (contain Side lobes) which cause image artifacts.

Solution is by (apodization), but it also affect the Lateral resolution(bluring).

Transmission zones: mean to acquire the same line with Different focal zones and combine them together. This Affect the time of the scan and the FPS Note : Active elements which acquire a line the shifted To acquire the next to form the image takes nearly $\frac{1}{20}s \rightarrow 20$ FPS (real time).

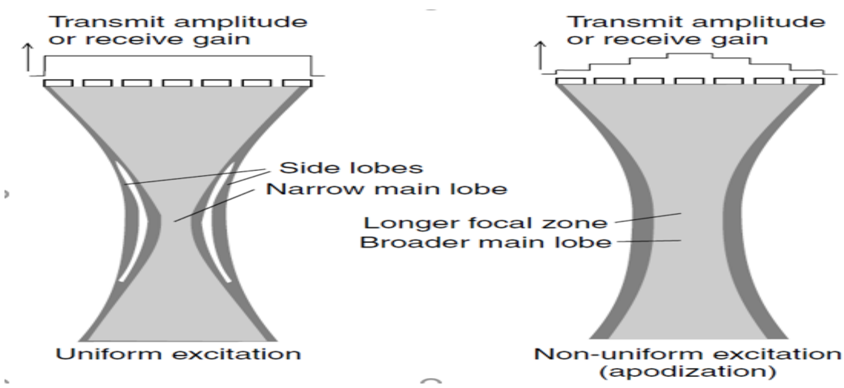


Figure 20: Apodization

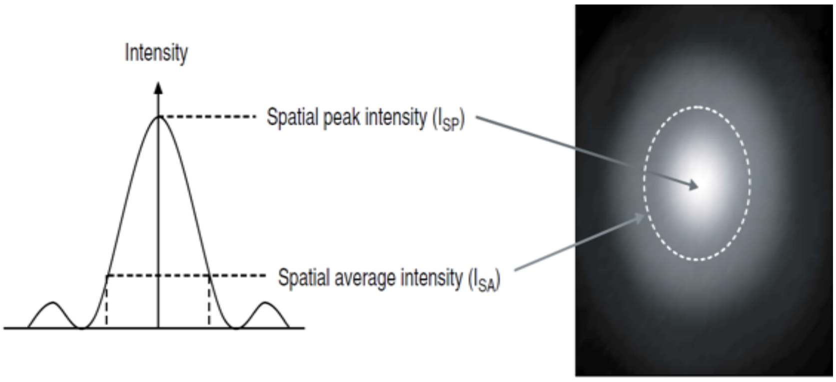


Figure 21: Fourier Sinc

6.4.1 Side Lobes

Produced due to the sinc function pattern and cause image artifacts. it should be removed. (Apodization, Harmonic imaging) remove the side lobes, but result in broader focal zone which affect lateral resolution.

6.4.2 Grating Lobes

No grating lobes, if the center-to-center distance between elements is half a wavelength or less

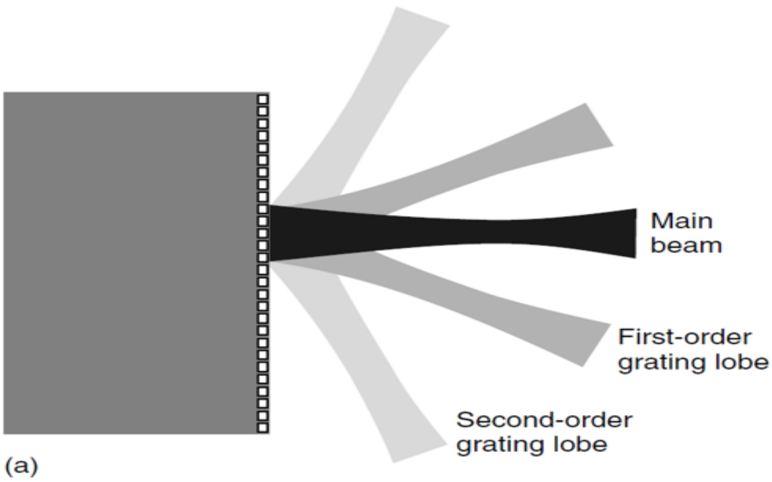


Figure 22: Grating lobes

6.5 1.5-D & 2-D Array & Thickness Resolution

As in transmission zone the number of active elements affect the lateral resolution and the beam divergence, the thickness of the beam increase. by adding an array structured probes; the thickness can be controlled.

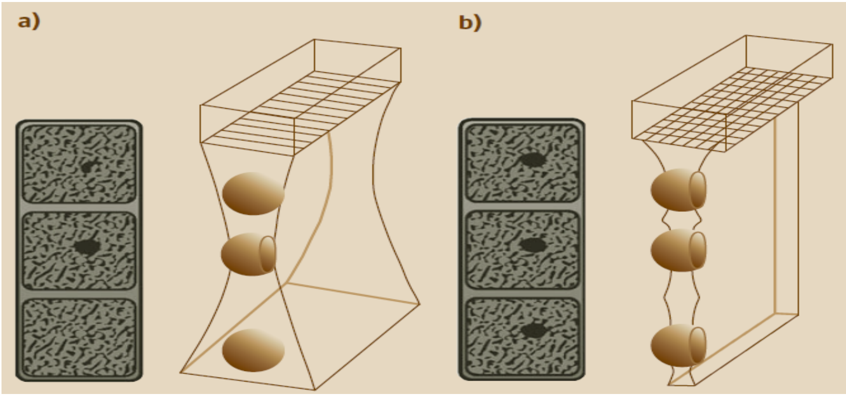


Figure 23: Thickness Resolution

6.6 Frame Rate

Frame rate is the frequency at which consecutive images called frames appear on a display. The term applies equally to film and video cameras, computer graphics, and motion capture systems. Frame rate may also be called the frame frequency, and be expressed in hertz.
In Ultrasound frame rate is the reciprocal of the frame time which can be calculated from the equation $\frac{2dN}{c}$. the frame time typically equal $\frac{1}{20}s$

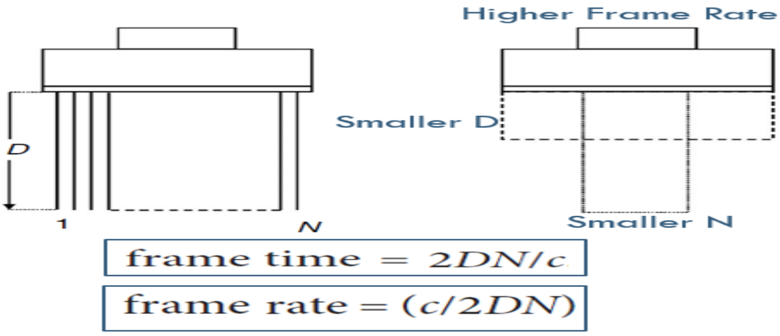


Figure 24: Frame Rate

7 Image Enhancement

7.1 Time Gain Compensation

Time gain compensation (TGC) is an additional feature that reduces impact of wave attenuation by tissues through increased intensity of the received signal in proportion to the depth.

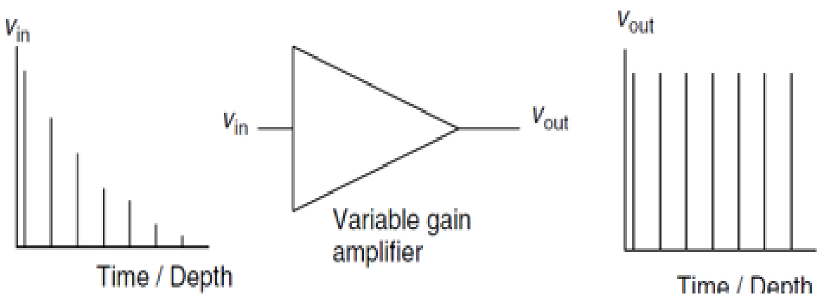


Figure 25: TGC

7.2 Dynamic Range

Dynamic range is the range of amplitudes from largest to the smallest echo signals that an ultrasound system can detect.

- The higher the DR the better detectable small intensity echoes with better contrast . To detect the blood we need nearly 100dB.
- Interfaced are constructed with nearly 40 dB
- Solution is done using dynamic range compression (logarithmic amplifier)
- Uniform gain is not suitable, but if small echoes are amplified more than large echoes then small echoes are better detectable

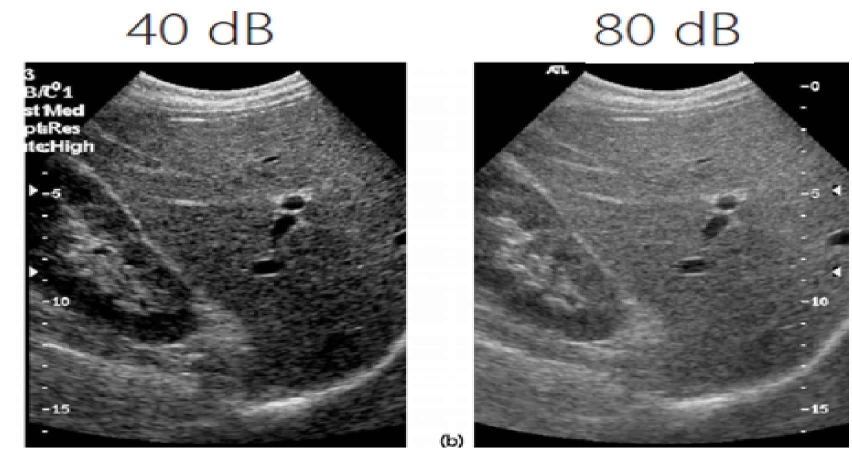


Figure 26: Dynamic Range

8 Doppler Imaging

8.1 Spectral Doppler

8.1.1 Pulsed Wave Doppler

- Range information is available and region is selectable by user
- Limitations on maximum velocity and accuracy

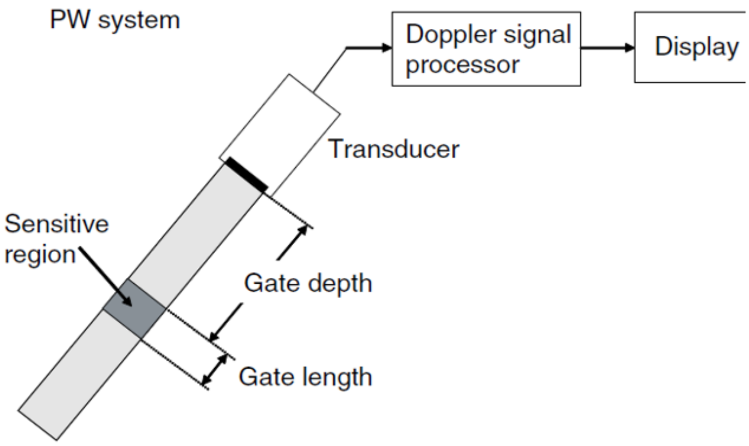


Figure 27: Pulsed Wave

8.1.2 Continues Wave Doppler

- Only a small region for Doppler sensitivity
- No range information
- No limitation on maximum velocity and high velocity accuracy

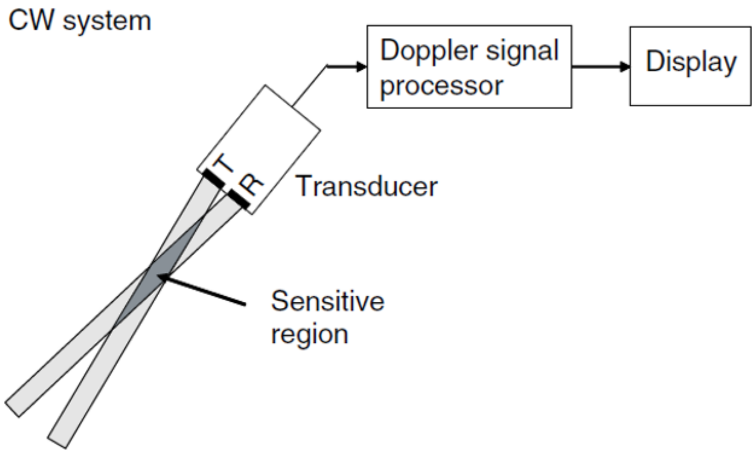


Figure 28: Continues wave

8.2 Color Doppler

8.2.1 Velocity Doppler

Spatial map overlaid on a B-mode gray-scale image to show the blood flow mean velocity. Direction of flow encoded in colors blue away from the transducer and red toward it.

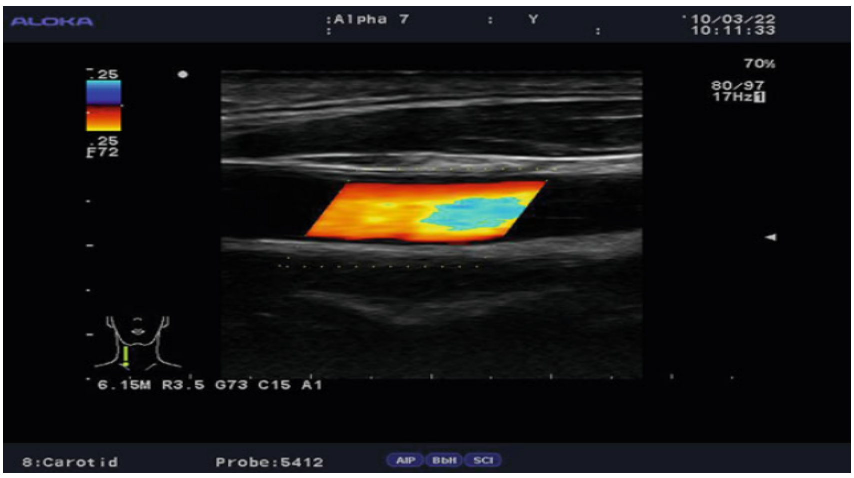


Figure 29: Colour Doppler

8.2.2 Power Doppler

color-coded image is based on intensity rather than on direction of flow

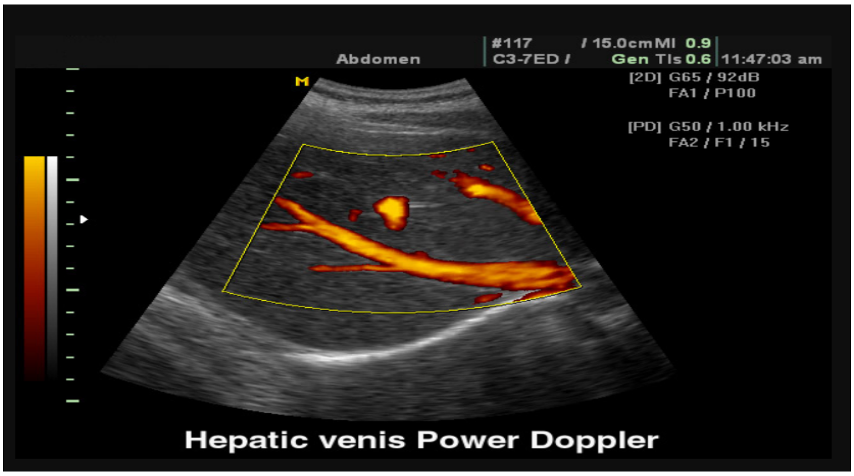


Figure 30: Power Doppler

8.3 Clutter

Signal from Stationery tissue and wall motion. Critical step in Doppler processing in order to remove the very high amplitude stationery tissue signal in order to have better fit to the ADC range.

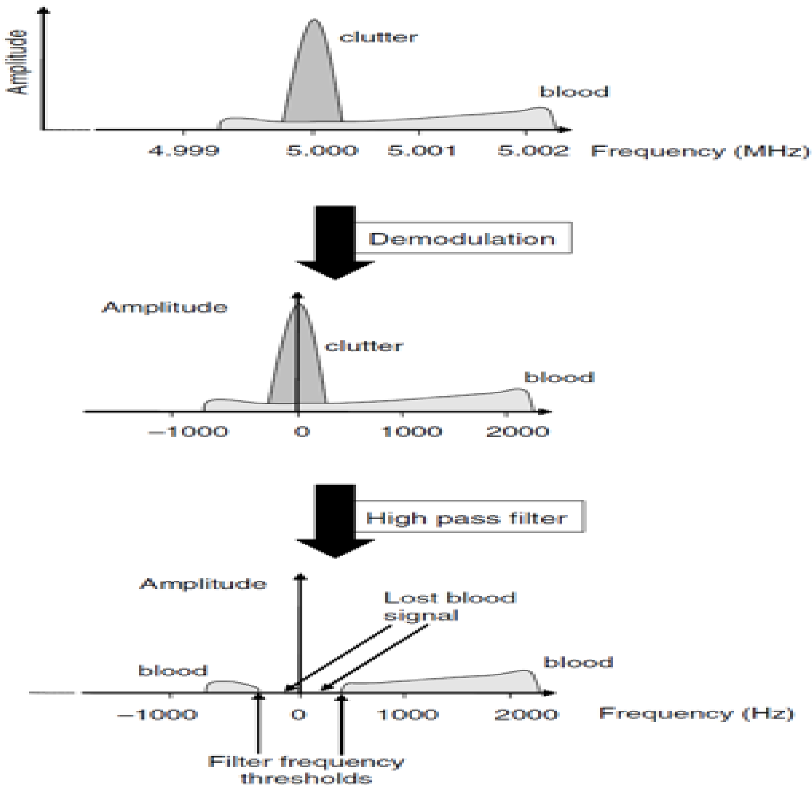


Figure 31: Clutter

9 Market Segmentation

9.1 Cardiology Segmentation

High		4D Echo with Latest and highest cardiac technology.
Med	**High**	Basic Echocardiography Adult + Pediatric Stress Echo + Tissue Doppler Imaging + Tissue Tracking Imaging + Left Ventricle Analysis.
	Med	Basic Echocardiography Adult + Pediatric Stress Echo + Tissue Doppler Imaging.
	Low	Basic Echocardiography Adult + Pediatric
Elementary		**Basic Echocardiography System with adult and CW Basic Cardiac measurement package.**

Figure 32: Cardiology segmentation

9.2 OB & GYN Segmentation

High	**High End**	Superior Image Quality with 30 Volume/Second 4D Realistic View – CT View – HD Live – Multi Slices View – 4D Follicle and 4D Vaginal Probe .
	Med	Superior Image Quality with 30 Volume/Second 4D and Realistic View – CT View – HD Live – Multi Slices View.
	Low	Superior Image Quality with 30 Volume/Second 4D.
Med	**High**	Basic Color Doppler System with Basic 4D Option 20 Volume/Second with basic software and some image enhancement software.
	Med	Basic Color Doppler System with Elementary 4D Option 16 Volume/Second with basic software.
	Low	Basic Color Doppler System
Elementary	**High**	Basic Ultrasound B/W Trolley Based with advanced 2D image enhancement modes SRI – Cross Beam – THI.
	Med	Basic Ultrasound B/W Portable High Image Quality
	Low	Basic Ultrasound B/W Portable System

Figure 33: ob & GYN Segmentation

9.3 Shared Service Segmentation

High	**High End**	High Med + Elastography Brest and Thyroid + Liver Share wave technology + Fusion + Navigation + 4D Linear + Pluiq Quantifications
	Med	Superior Image Quality + Elastography Brest and Thyroid + Liver Share wave technology
	Low	Superior Image Quality + Elastography Brest and Thyroid + Contrast Imaging
Med	**High**	High Image Quality +2D Advanced Applications + High Range 4D 30 volume/Sec + Advanced Cardiology + Special Probes
	Med	High Image Quality +2D Advanced Applications + Med Range 4D 20 volume/Sec
	Low	High Image Quality +2D Advanced Applications + Elementary 4D 16 volume/Sec.
Elementary	**High**	Basic Ultrasound Color Doppler with Cardiology Included Advanced 2D applications (Compound and Noise reduction)
	Med	Basic Ultrssound Color Doppler with Cardiology
	Low	Basic Ultrasound Color Doppler without Cardiology

Figure 34: shared service segmentation