Ministry of Higher Education and Scientific Research
Al-Mustaqbal University College
Radiology Techniques Department

Radiological Physics

Al-Mustaqbal University College

3rd

Radiology Techniques Department

By

Assistant lecturer

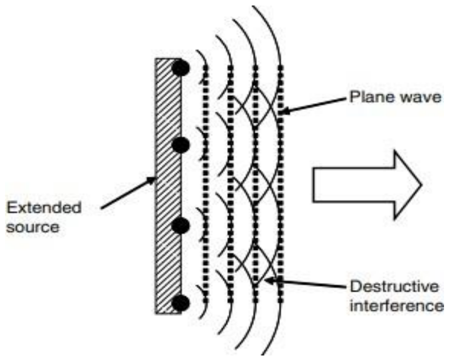
DR. Mohammed Al-bairmany
MS.C. Reem Taumu Yousif
First Semester

Lecture4 : Ultrasound Beams

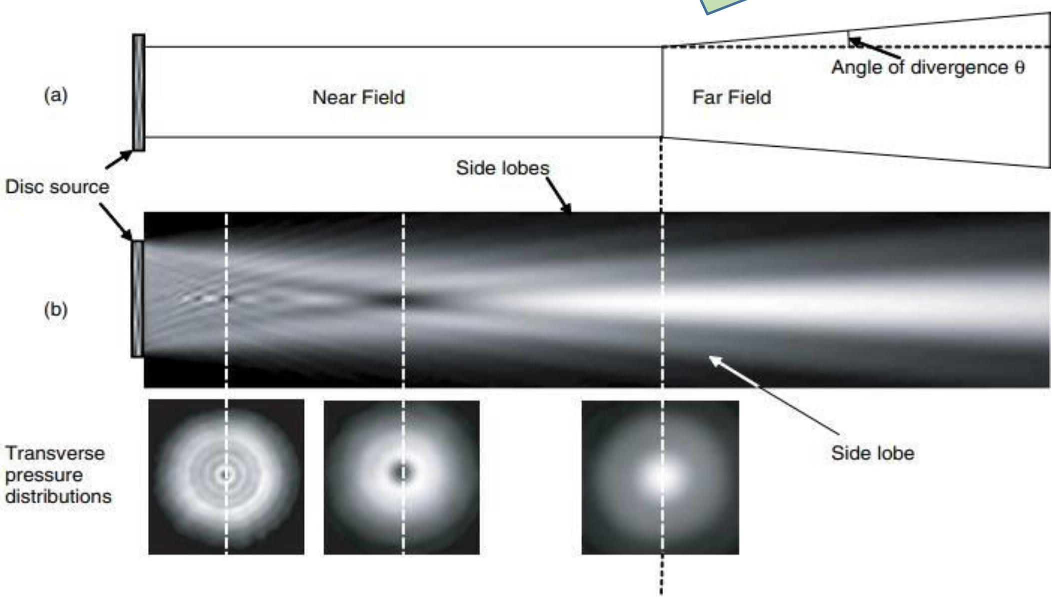
2022/2023

Diffraction

The way in which the wave spreads out as it moves away from the source is determined by the relationship between the width of the source (the aperture) and the wavelength of the wave. If the aperture is smaller than the wavelength, the wave spreads out as it travels (diverges), an effect known as diffraction.



Practical ultrasound sources must compromise between these two extremes to give the optimum combination of narrow beam width and minimal divergence.



The basic shape of the ultrasound beam produced by a plane disc transducer is illustrated in Figure above, it can be divided into two parts. These are :

1. the near field (Fresnel zone), which is roughly cylindrical in shape and has approximately the same diameter as the source and
2. the far field (Fraunhofer zone), which diverges gradually.

The near field length, is given by the expression,

$$D_{fresnel} = a^2/\lambda$$

Where a is the radius of the source

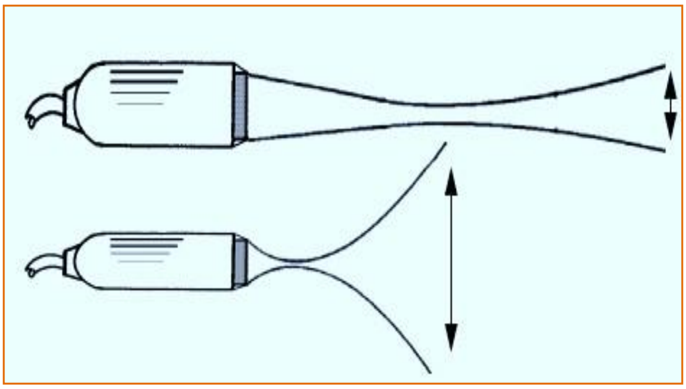
The beam diverges in the far field at an angle given by

$$\sin\theta = 0.61\,\lambda/a$$

Where θ is the angle between the beam axis and the edges of the central lobe of the beam.

(H.W) Calculate the divergent angle for a transducer operating at 3 MHz, with a crystal diameter of 1 cm.

- The intensity along the beam axis in the far field falls approximately as the inverse square law



Rules for Transducer Design

For a given transducer diameter,

- the near-field length increases with increasing frequency;
- beam divergence in the far field decreases with increasing frequency

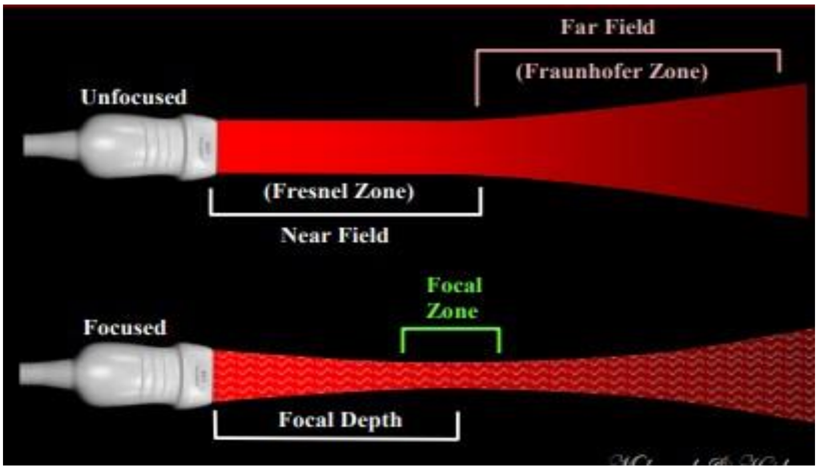
For a given transducer frequency

- the near-field length increases with increasing transducer diameter;
- beam divergence in the far field decreases with increasing transducer diameter.

Frequency (MHz)	*Wavelength (cm)*	*Fresnel Zone Depth (cm)*	*Fraunhofer Divergence Angle (degrees)*
Transducer radius constant at 0.5 cm			
0.5	0.30	0.82	21.5
1.0	0.15	1.63	10.5
2.0	0.075	3.25	5.2
4.0	0.0325	6.50	2.3
8.0	0.0163	13.0	1.1

Radius (cm)	*Fresnel Zone Depth (cm)*	*Fraunhofer Divergence Angle in Water (degrees)*
Frequency constant at 2 MHz		
0.25	0.83	10.6
0.5	3.33	5.3
1.0	13.33	2.6
2.0	53.33	1.3

Focusing



The focusing effect on a beam is strongest when the focal length F is short in relation to the near-field length of a similar unfocused transducer Here, the waves converge rapidly to a very narrow beam width at the focus then diverge rapidly again beyond that point.

The beam width W at the focus is given approximately by the equation

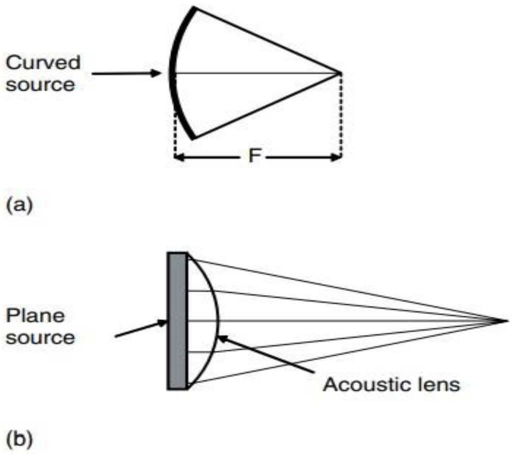
$$W = F \lambda / a$$

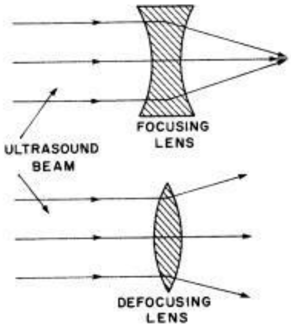
Where: F is the focal length.

Focusing is usually achieved in one of two ways. These are by use of:

(1) a curved source

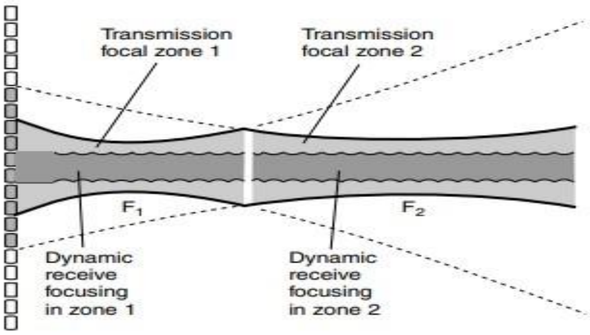
(2) an acoustic lens.





The curved source (Figure above) is manufactured with a radius of curvature of F and hence produces curved wave fronts which converge at a focus F cm from the source.

Scan plane multiple-zone focusing



Further improvement in lateral resolution, For example, the operator might select transmission foci at two different depths – F 1 and F 2

- the greater the number of focal zones, the longer is spent time on each scan line

The length of the focal zone of a particular ultrasound beam is the distance over which a reasonable focus and pulse-echo response are obtained.

The equation of focal zone length is

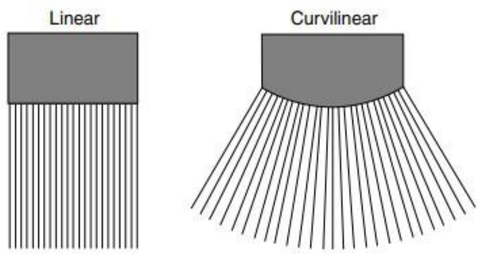
$$\text{Focal zone length} = 10\lambda\left(\frac{f}{d}\right)^2$$

where d = 2a = the diameter of the transducer

The ratio (*f* /d) is often described as the f-number of the transducer or other focusing element.

Linear- and curvilinear-array transducers

<u>Linear arrays</u>



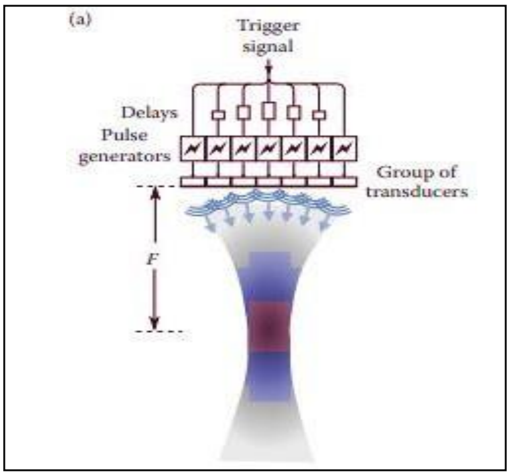
- offer a rectangular field of view
- and are therefore particularly suitable when the region of interest extends right up to the surface (e.g. neck or limbs)

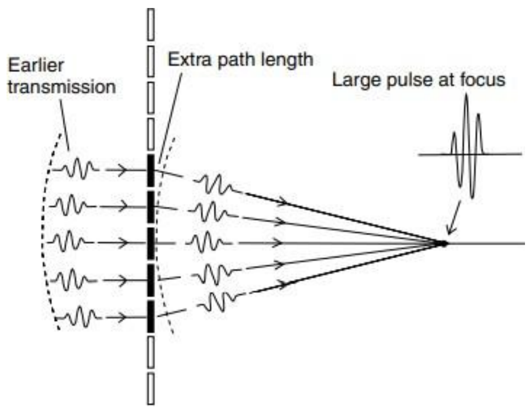
<u>Curvilinear arrays</u>

- work in the same way as linear arrays, but differ in that the array of elements along the front face forms a curve
- but have the additional advantage that the field of view becomes wider with depth.
- They are therefore popular for abdominal applications, including obstetrics

Beam shape control in the scan plane

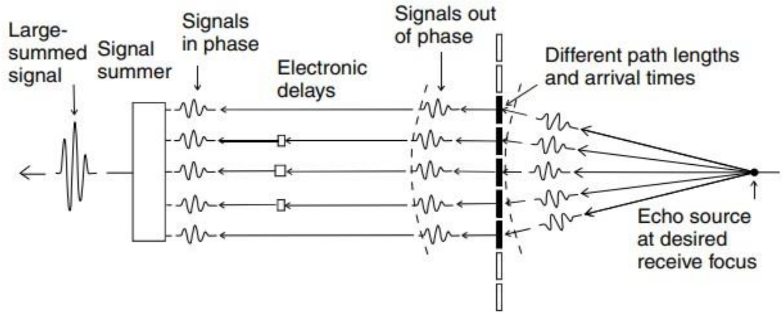
<u>Scan plane focusing in transmission</u>

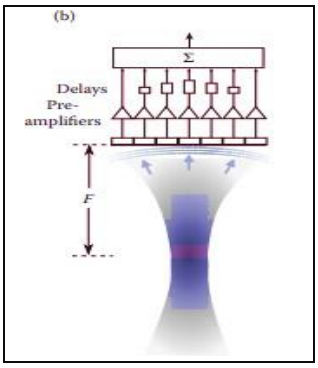




For linear-array transducers, focusing in transmission requires that pulses from all the elements arrive simultaneously at the transmission focus, in order to concentrate the power into a narrow ‘focal zone’.

Scan plane dynamic focusing and aperture in reception



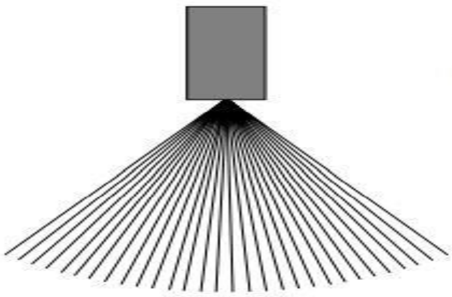


Similarly, in reception, carefully **pre-selected electronic delays (dynamic focusing)** are used to ensure that an echo from a desired receive focus takes the same time to reach the signal summed, irrespective of which element is considered.

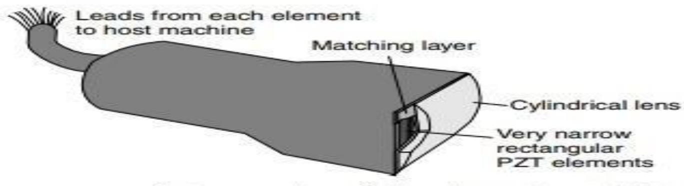
- When the delayed echo signals are summed together they produce a strong response from any reflector at or near the focus

Phased Array

- Phased array type uses shorter transducer with fewer elements.
- If energized simultaneously, acts as a single transducer, and the beam travel forward. If energized separately, in rapid sequence, the pulses reinforce only in one direction, called steering.

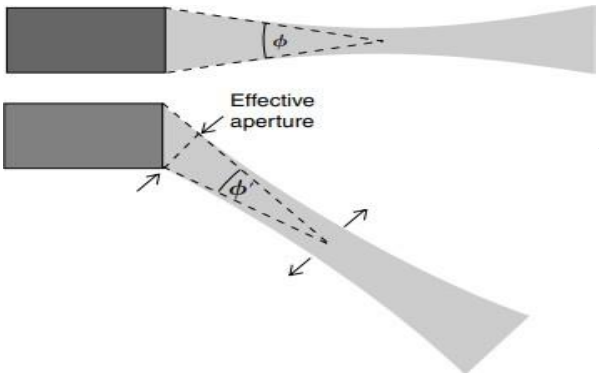


Sector scan format of a phased-array transducer.



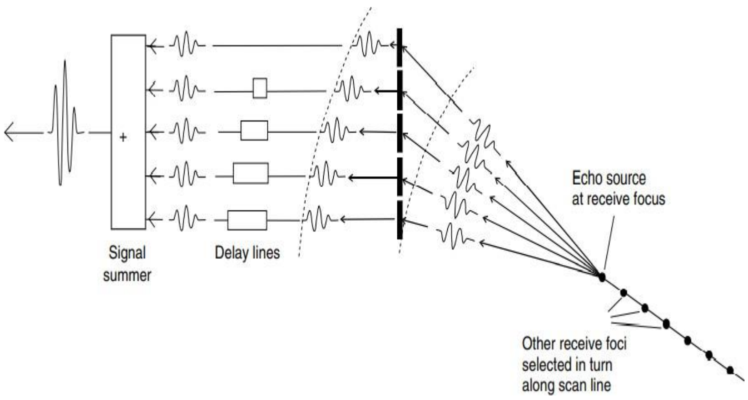
Cut-away view of the elements, matching layer and lens of a phased-array transducer.

When using a phased-array transducer, the operator should always angle the probe so that any region of particular interest is in the centre of the field of view.

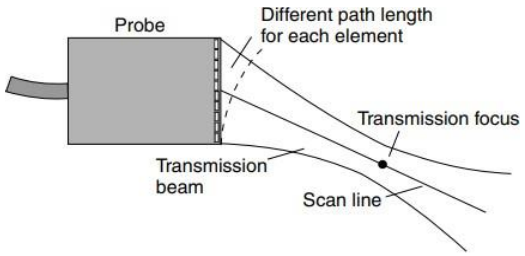


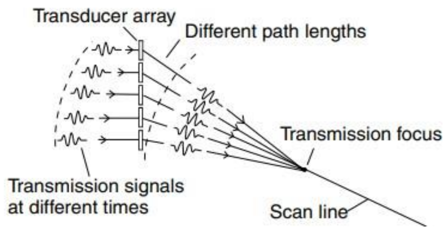
The beam from a phased array transducer becomes wider as the angle of deflection increases.

Reception



Transmission





- The principle is the same as for a linear-array transducer, except that the receive foci lie along a scan line that is generally oblique.