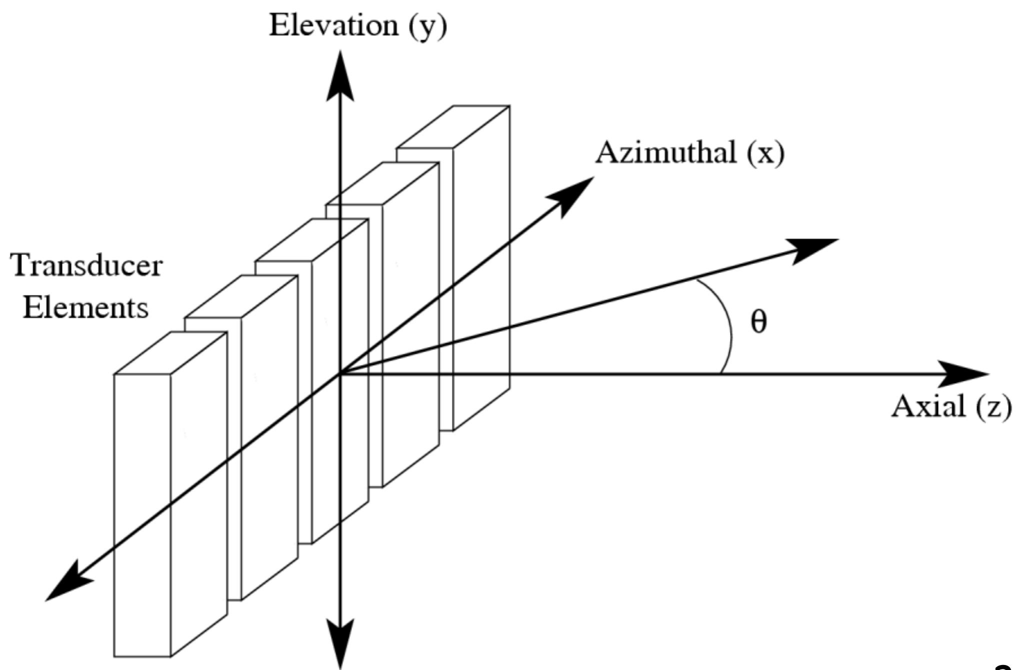
Class 7: Arrays

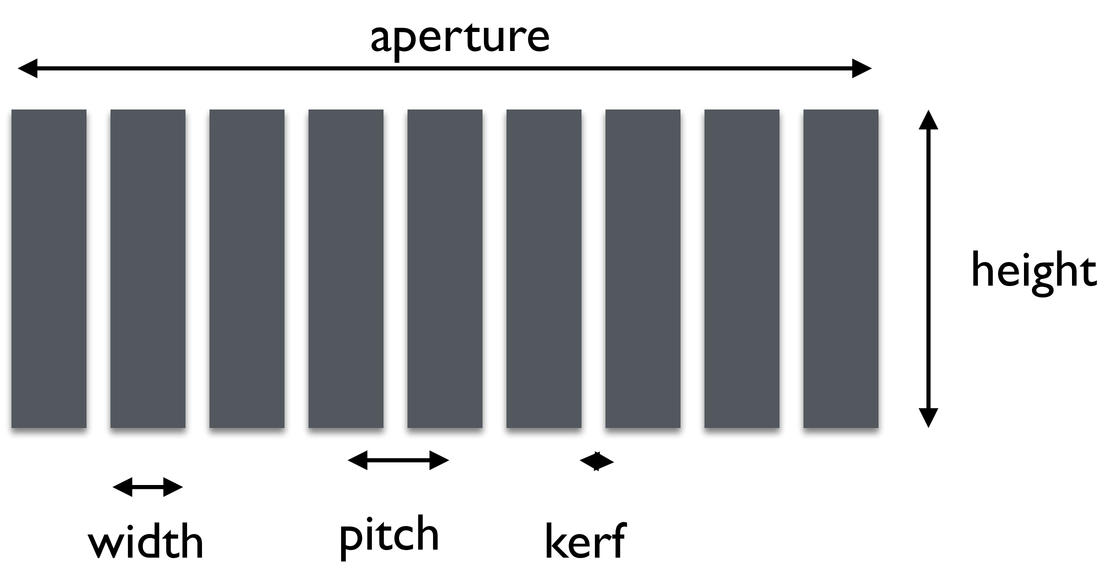
- Arrays
- Grating Lobes with Linear Arrays
- Phased Arrays and More Grating Lobes
- Pulse-Echo or Transmit-Receive and Dynamic Receive Focusing

Class 7

- Arrays
- Grating Lobes with Linear Arrays
- Phased Arrays and More Grating Lobes
- Pulse-Echo or Transmit-Receive and Dynamic Receive Focusing

Definitions



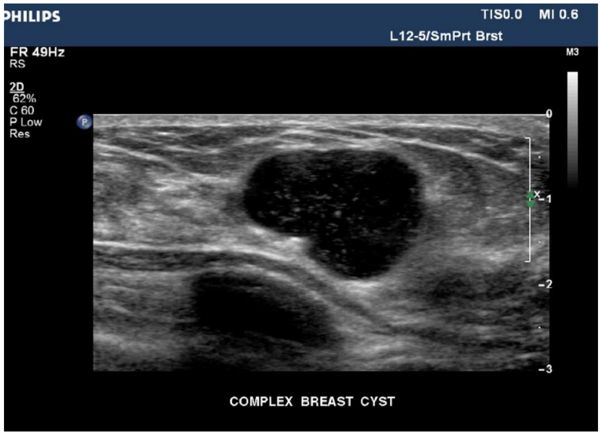


Most Common Transducers

Linear

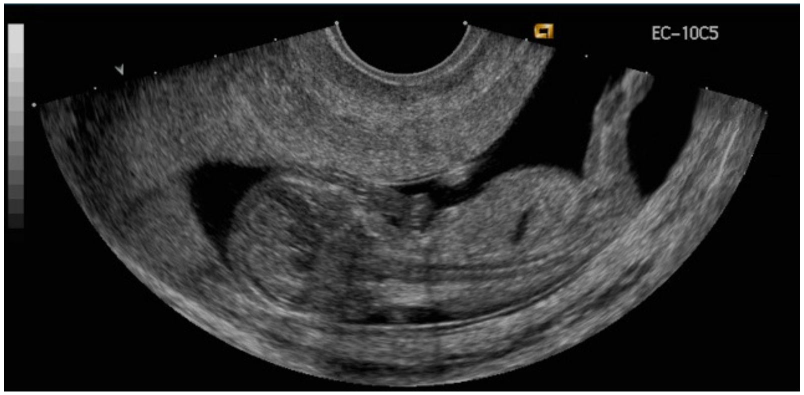
http://sinaiem.us/tutorials/pneumothorax

High Frequency
~4cm field of view



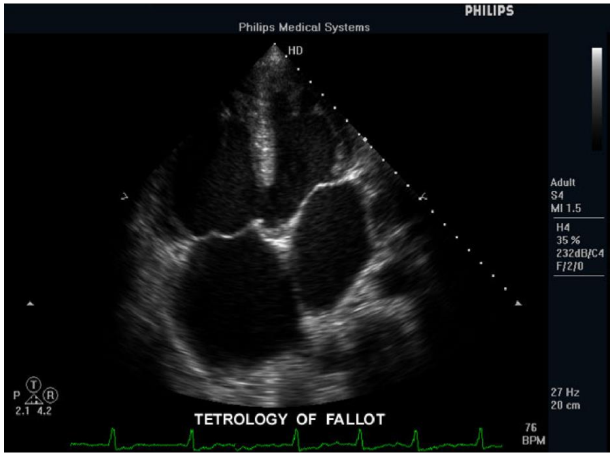
Curvilinear

Low Frequency
-wide field of view

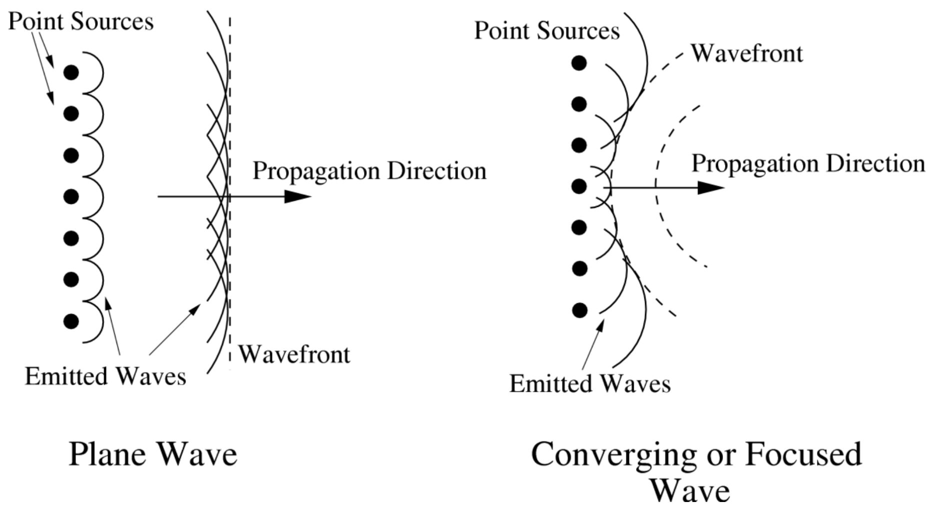


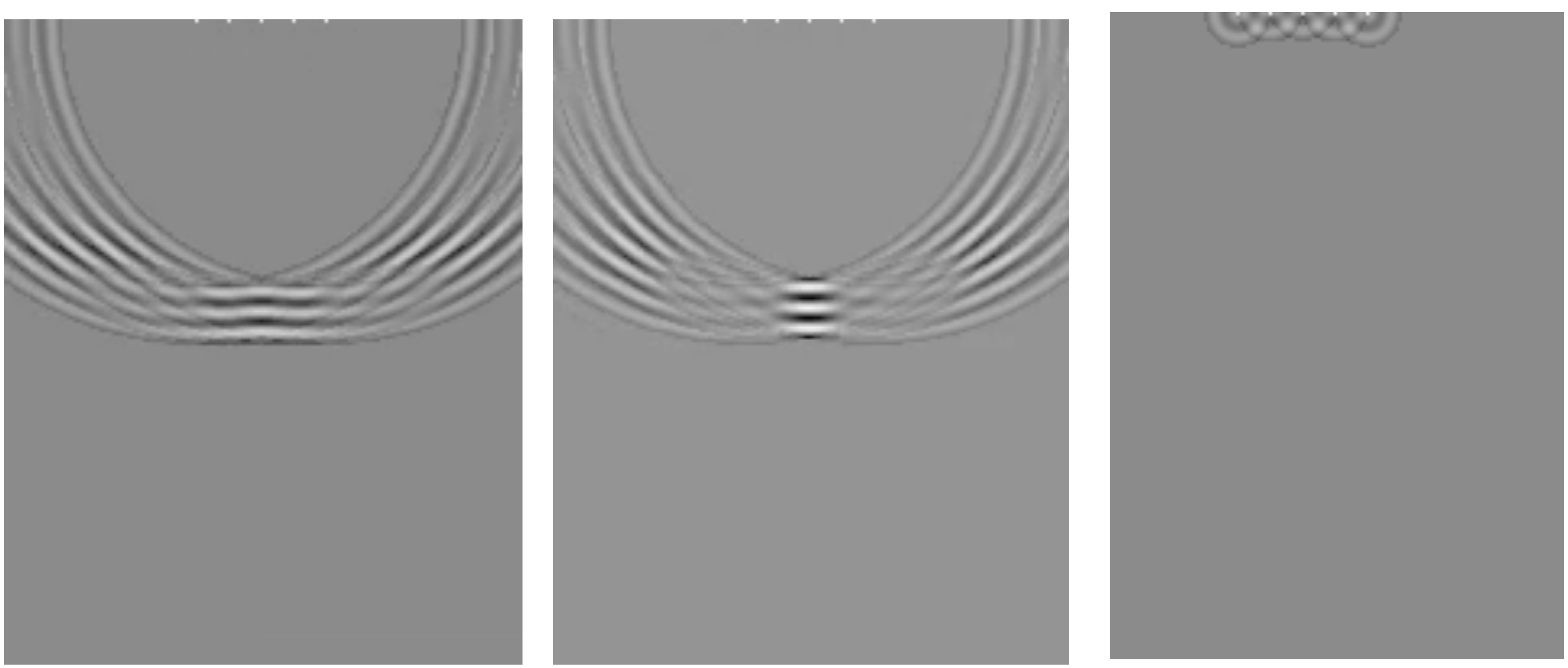
Phased

Low Frequency
-small acoustic window
-wide field of view at depth



Array Beamforming

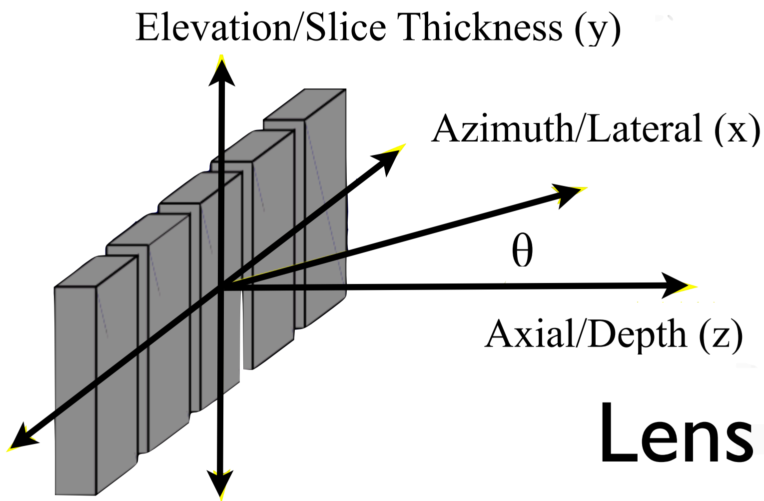


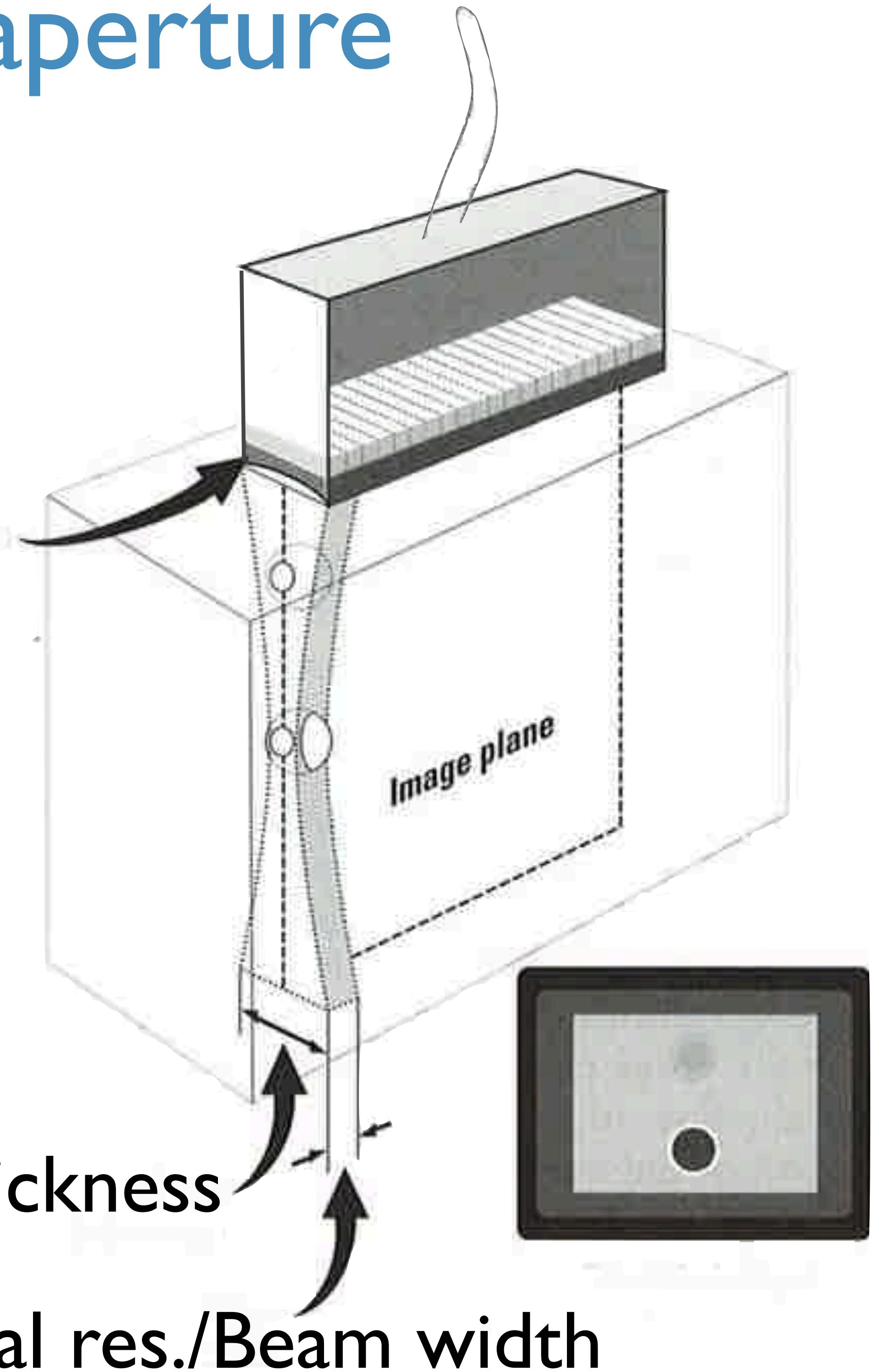


Translate which elements are used

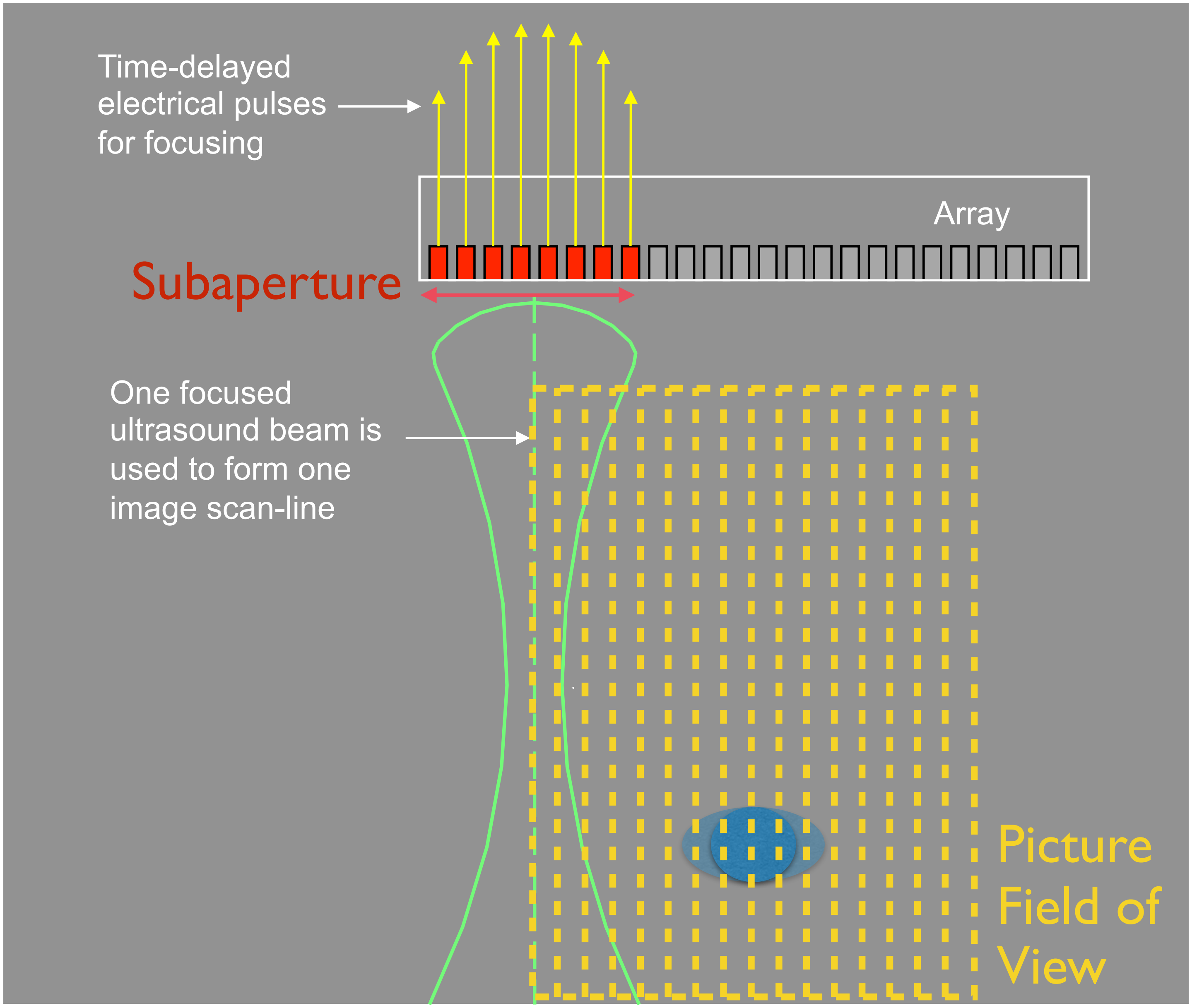
Image one line at a time

Beam From Subaperture





Linear Array Imaging



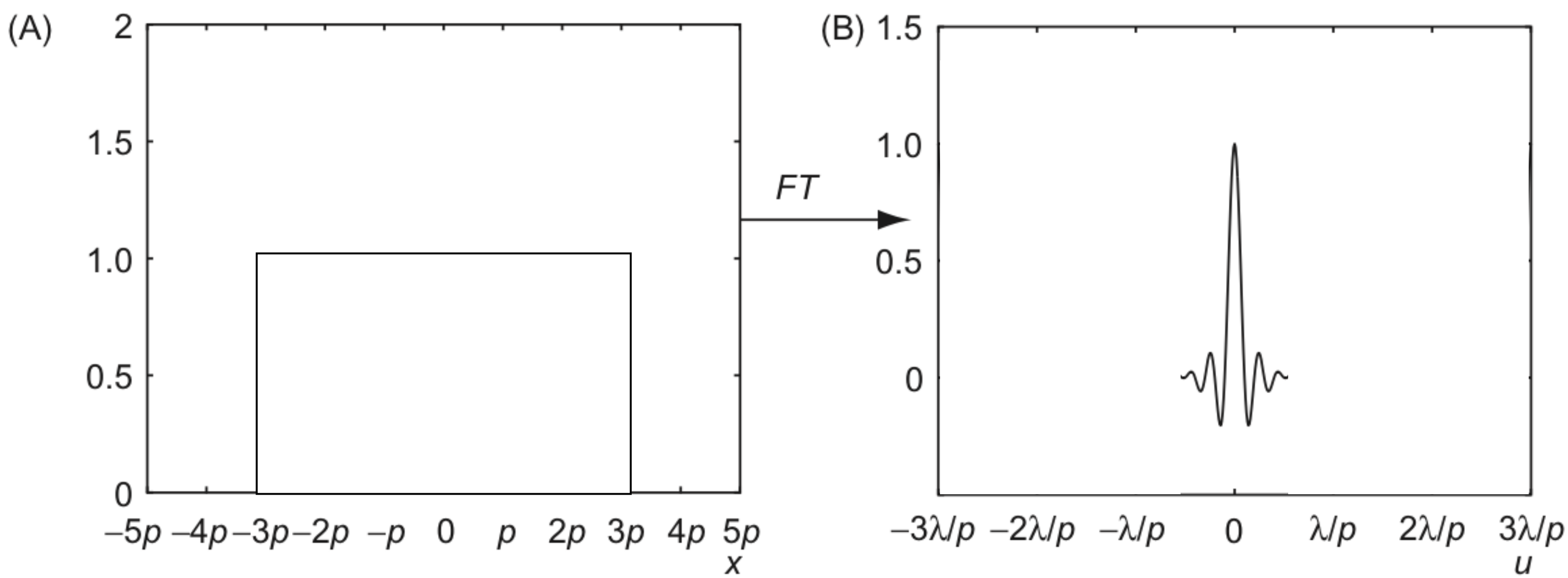
- FOV smaller than array
- Wider beam, any one object goes into multiple lines, lower resolution
- Choice of subaperture size presents a tradeoff between resolution and FOV

$$W = \frac{1.22\lambda F}{D}$$

Class 7

- Arrays
- Grating Lobes with Linear Arrays
- Phased Arrays and More Grating Lobes
- Pulse-Echo or Transmit-Receive and Dynamic Receive Focusing

Single Element Rectangular Aperture



FT

$$rect\left(\frac{x}{L_x}\right) \Leftrightarrow \sin c\left(\frac{L_x u}{\lambda}\right)$$

$$rect(\frac{x}{L_x}) \Leftrightarrow \sin c(L_x f)$$

$$u = f\lambda$$

Ideal Array of point sources

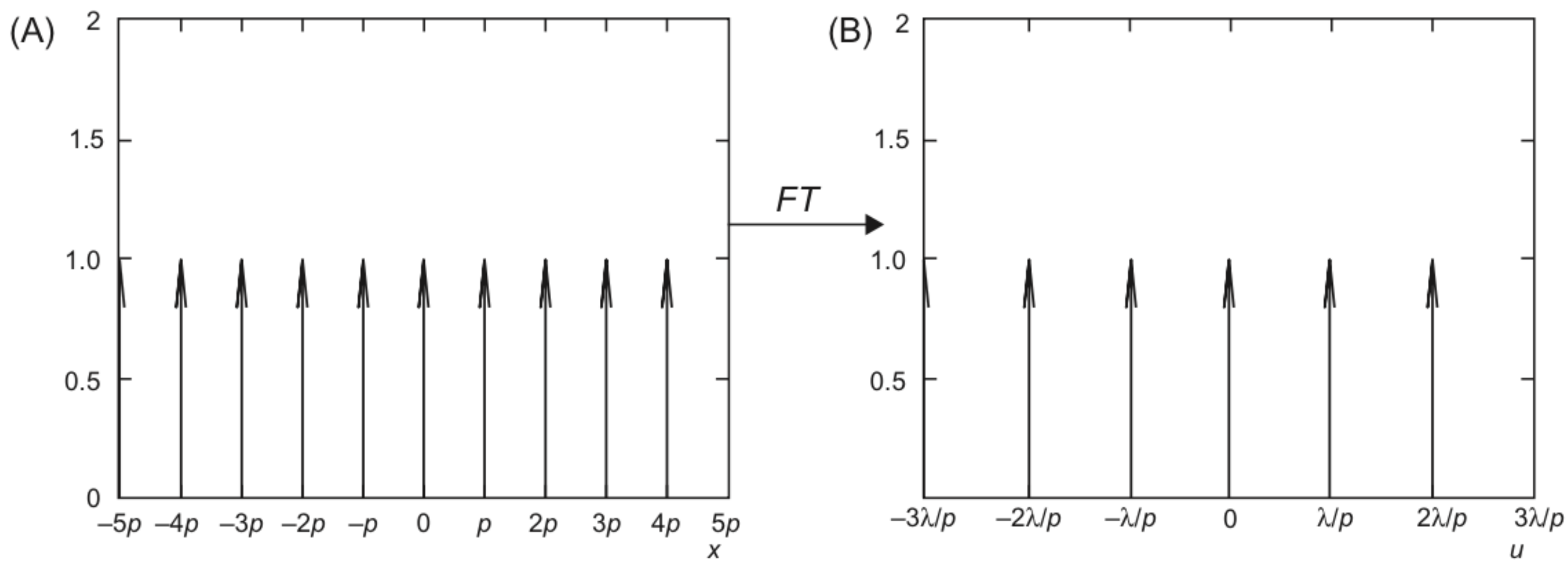


Figure 7.11

$$comb\left(\frac{x}{p}\right) \overset{\text{FT}}{\Leftrightarrow} comb\left(\frac{u}{\lambda / p}\right)$$

grating lobes

Subaperture Array of Point Sources

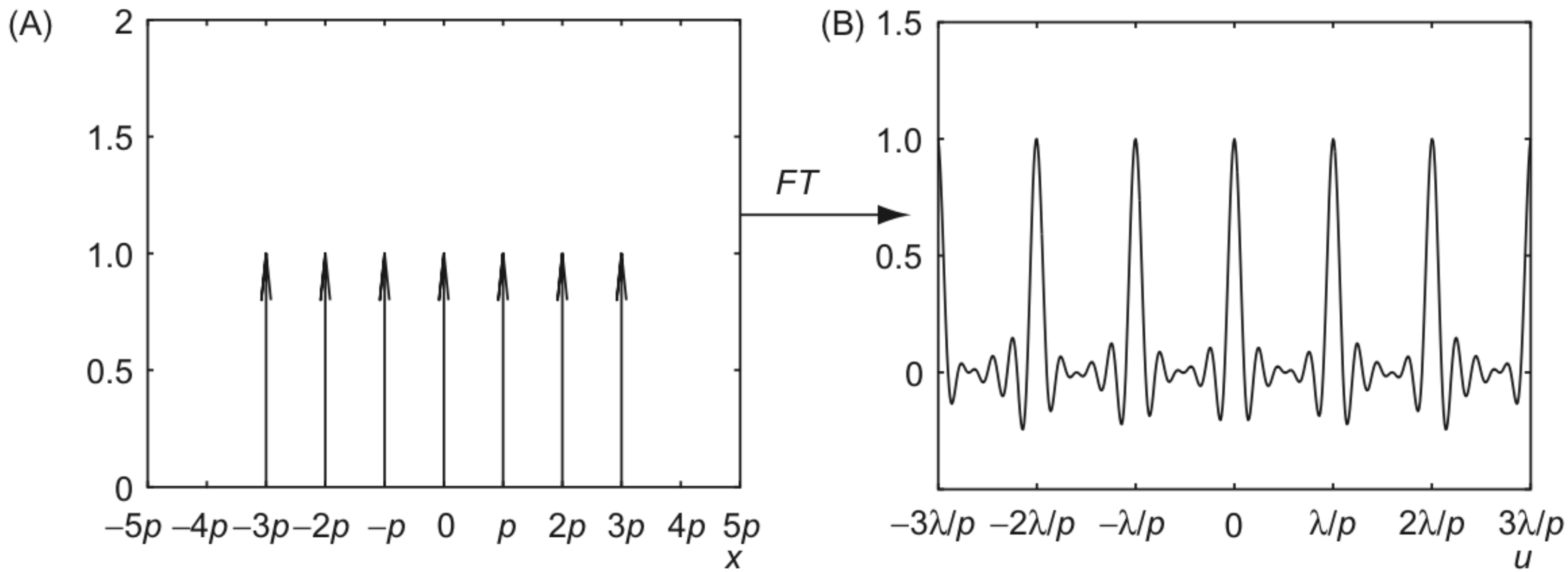


Figure 7.12

FT

$$comb\left(\frac{x}{p}\right)rect\left(\frac{x}{L_x}\right)\Leftrightarrow comb\left(\frac{u}{\lambda / p}\right) * \sin c\left(\frac{L_x u}{\lambda}\right)$$

grating lobes

Subaperture Array of Finite Width Sources

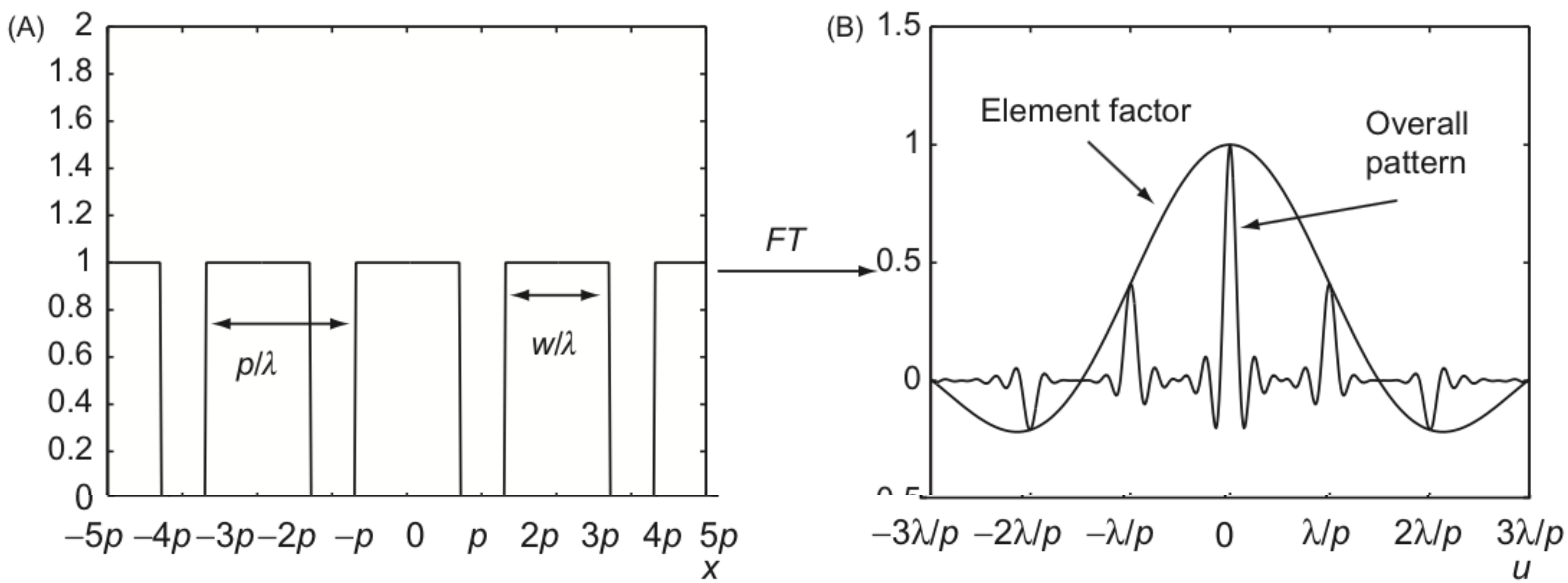


Figure 7.15

FT

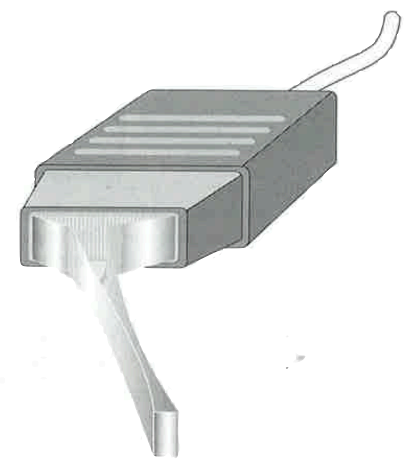
$$\left(comb\left(\frac{x}{p}\right) * rect\left(\frac{x}{w}\right)\right) rect\left(\frac{x}{L_x}\right) \Leftrightarrow \left(comb\left(\frac{u}{\lambda / p}\right) \operatorname{sin} c\left(\frac{u}{\lambda / w}\right)\right) * \operatorname{sin} c\left(\frac{L_x u}{\lambda}\right)$$

envelope on the grating lobes

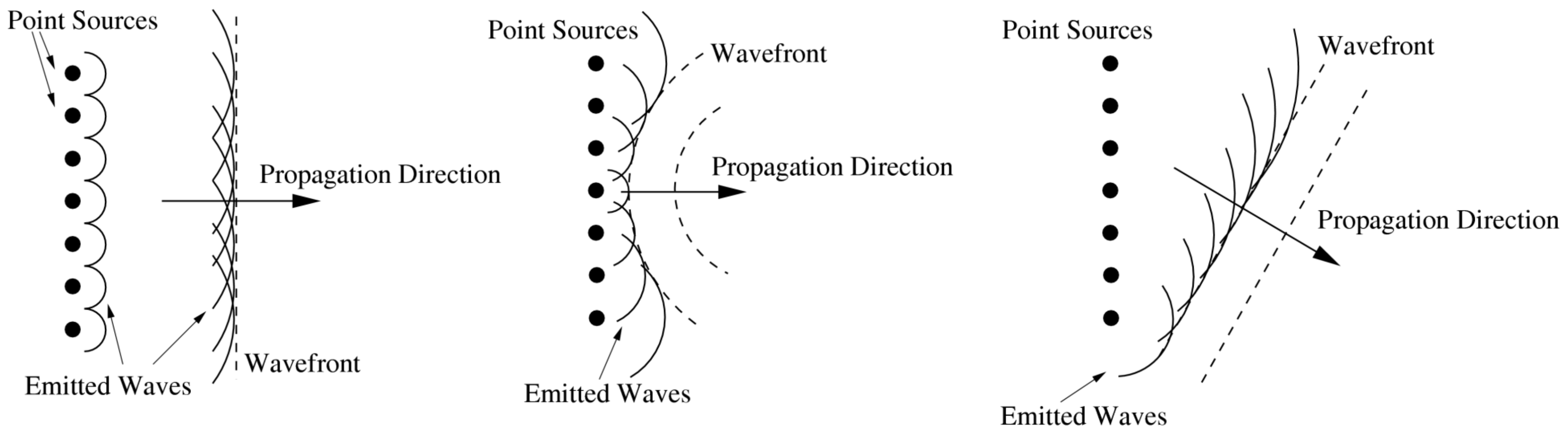
Szabo

Class 7

- Arrays
- Grating Lobes with Linear Arrays
- Phased Arrays and More Grating Lobes
- Pulse-Echo or Transmit-Receive and Dynamic Receive Focusing



Steering

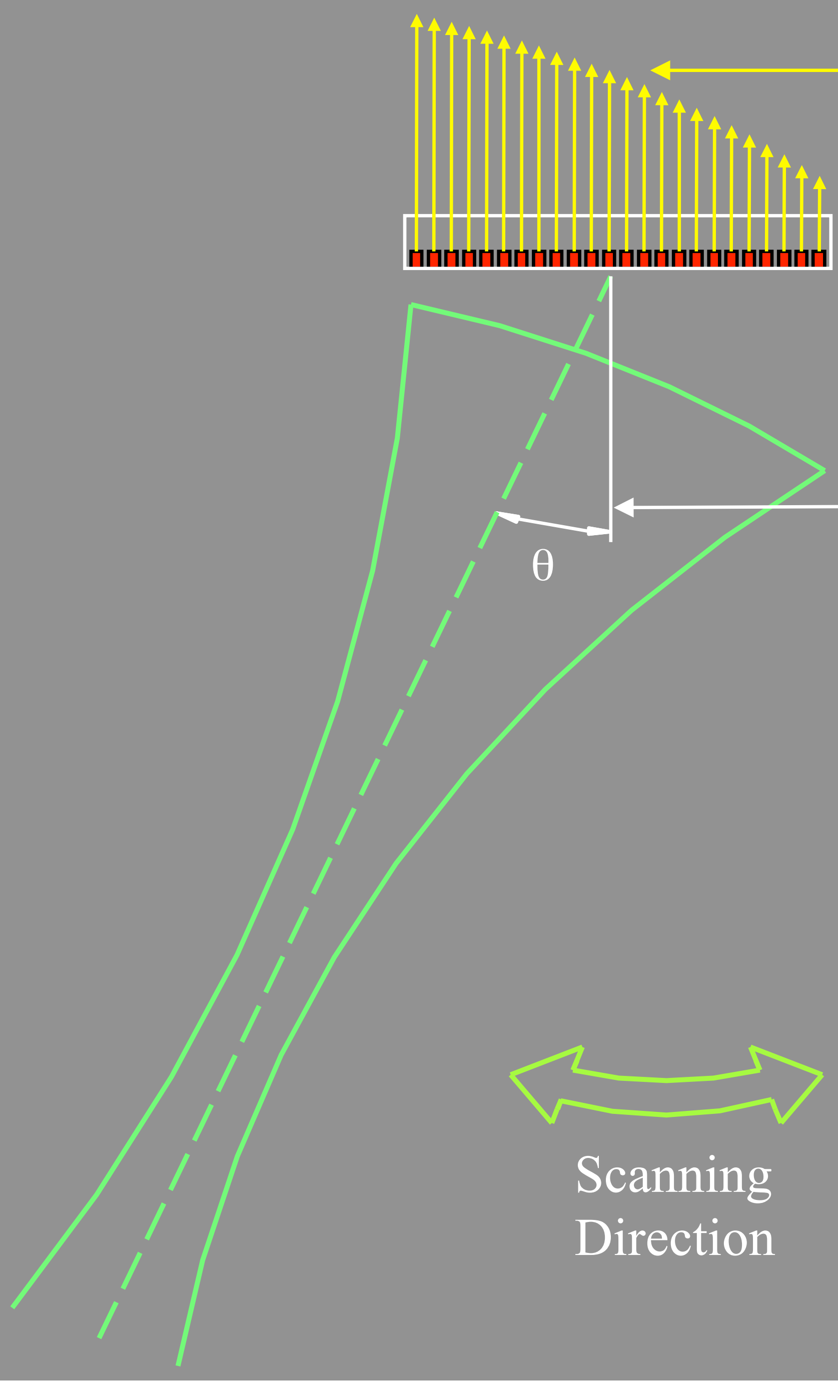


Plane Wave

Converging or Focused Wave

Steered Wave

Beam Steering



Utilizes the entire aperture for each scan line

Electronic sector scanning is achieved through varying the steering angle θ

Steered Subaperture Array of Finite Width Sources

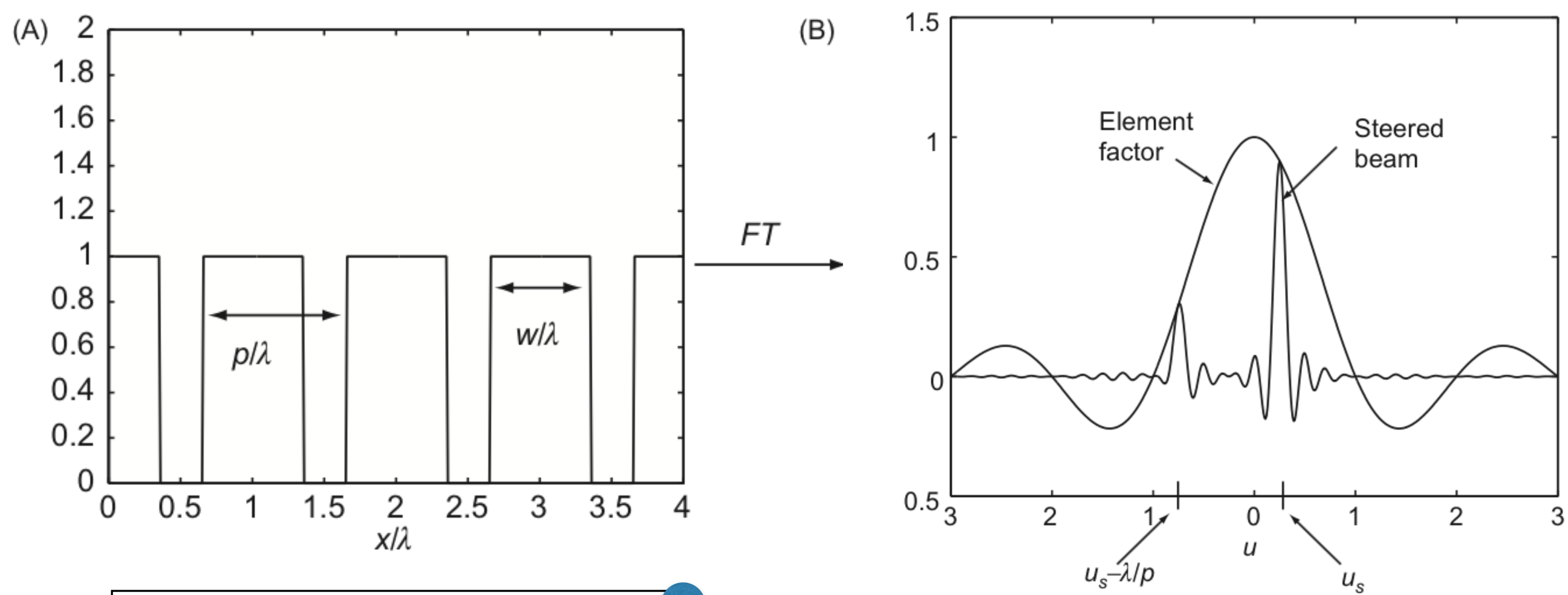
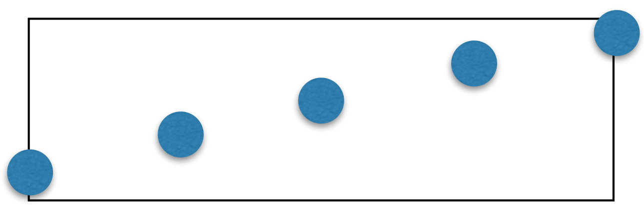


Figure 7.17
Array angular response when steered at θ_s.

Phase



$$\left(comb\left(\frac{x}{p}\right) * rect\left(\frac{x}{w}\right)\right) rect\left(\frac{x}{L_x}\right) \Leftrightarrow \left(comb\left(\frac{u}{\lambda / p}\right) \operatorname{sinc}\left(\frac{u}{\lambda / w}\right)\right) * \operatorname{sinc}\left(\frac{L_x u}{\lambda}\right)$$

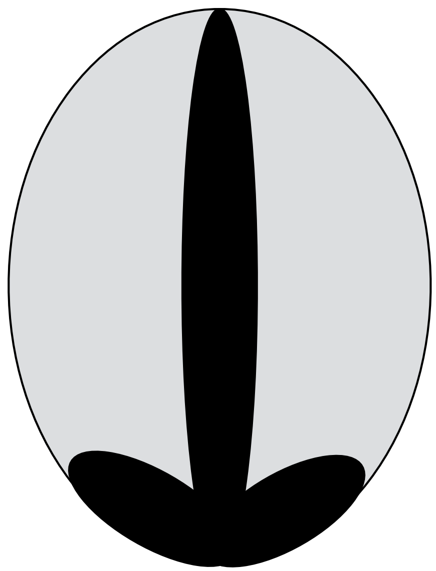
linear phase → translation

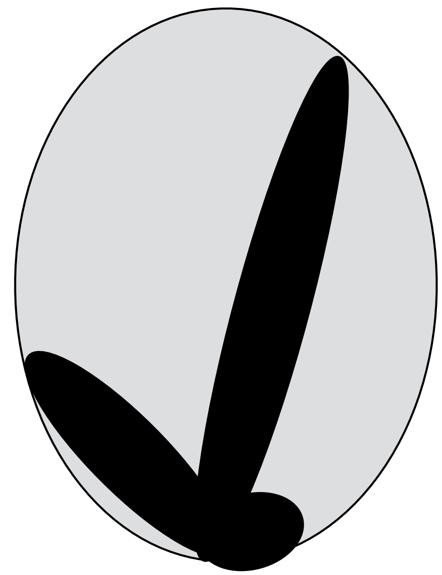
grating lobes modulated by the envelope

Szabo

Beam pattern follows the envelope

Grating lobes at 60°

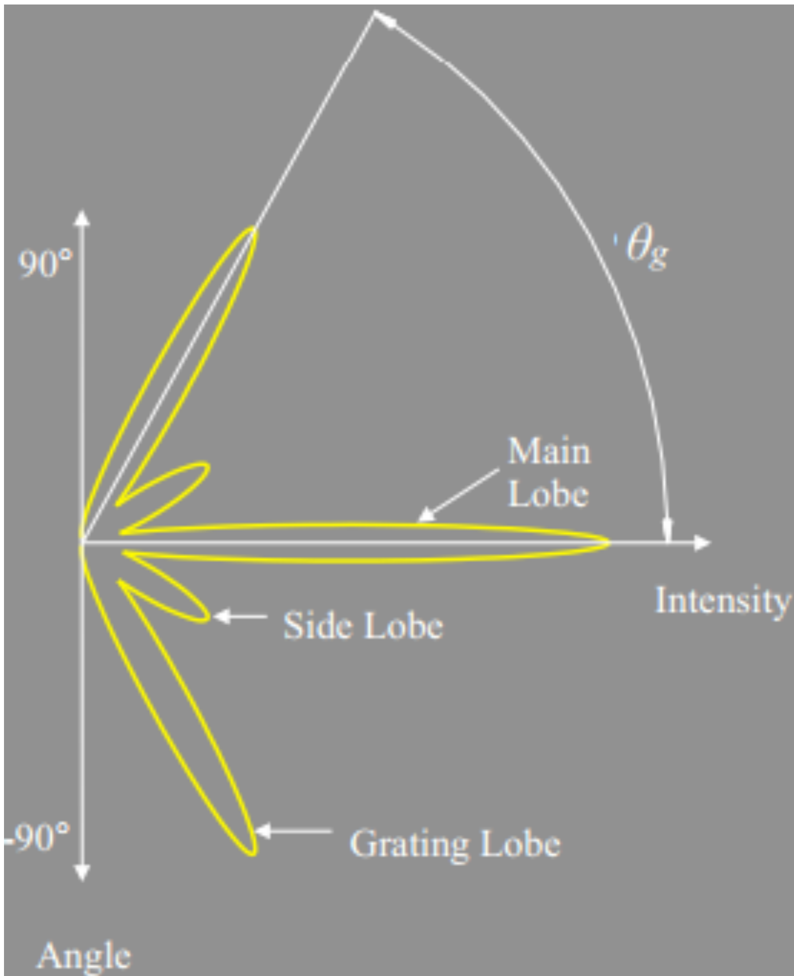




Steered 15° to right
Main lobe intensity decreases
Grating lobe intensity increases

Grating Lobes

Energy goes into the near field from grating lobes



$$\theta_g = \sin^{-1}\left(\frac{n\lambda}{p}\right)$$

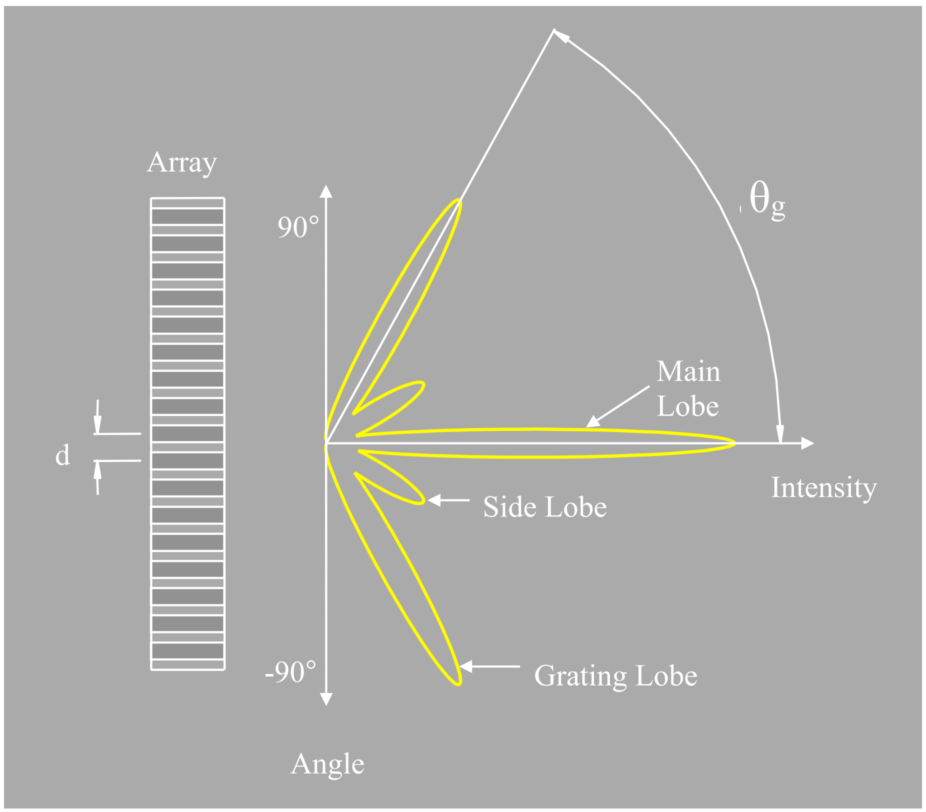
θ_g = Grating lobe angle

λ = Wavelength in medium

p = Element spacing “pitch”

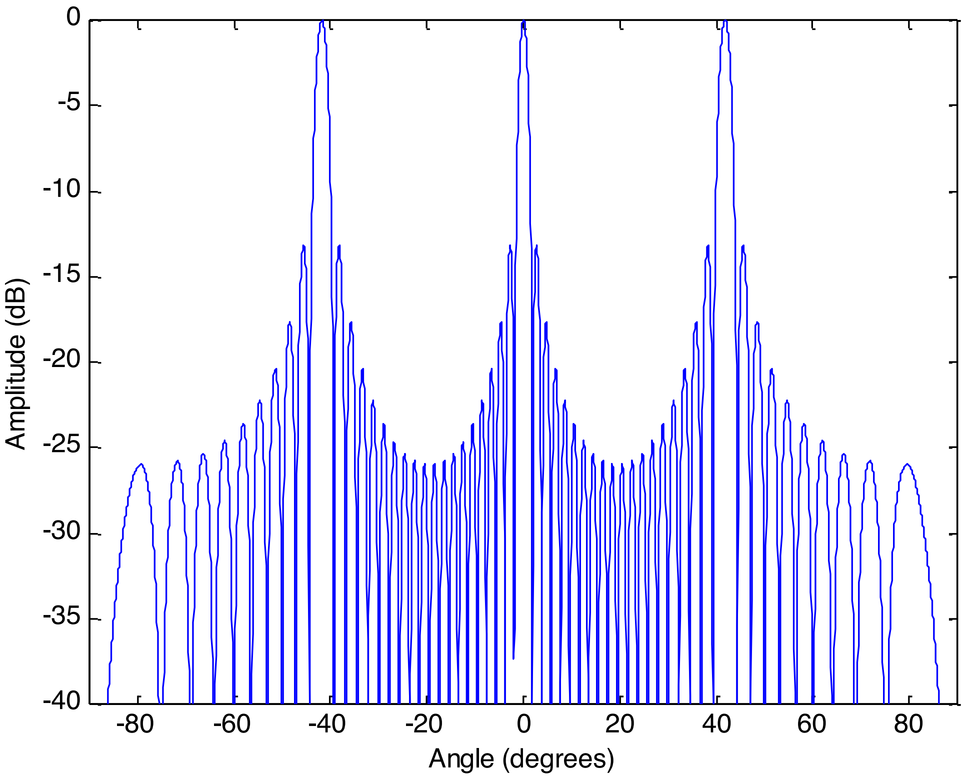
Correcting for Grating Lobes

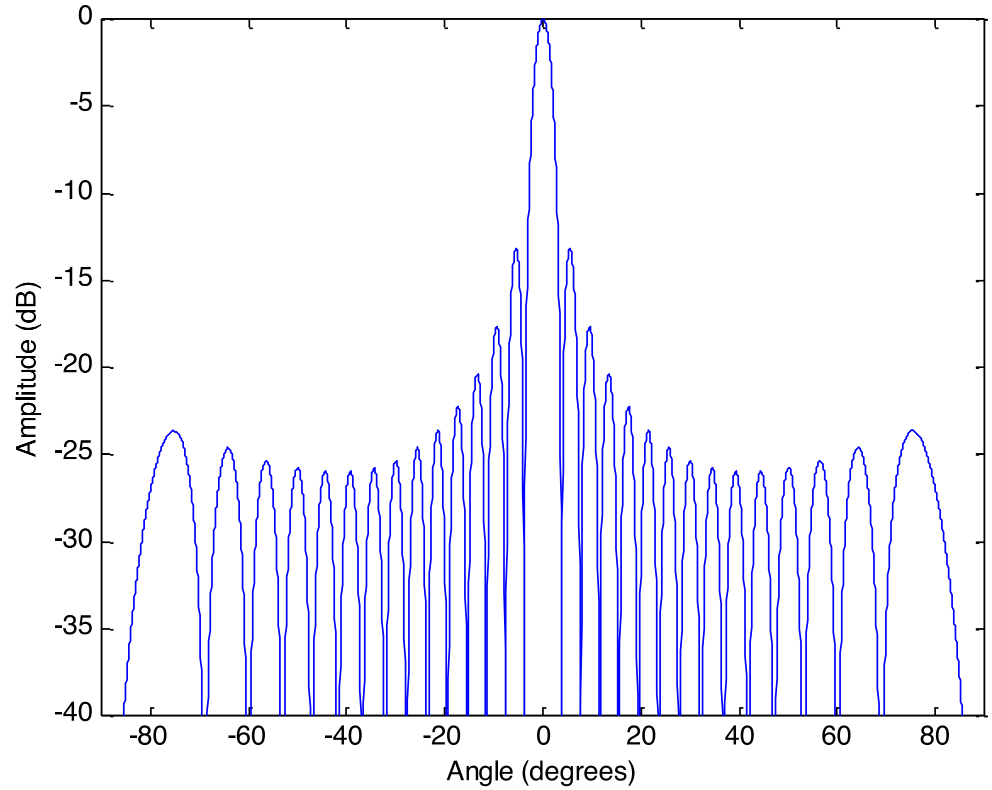
- If the element spacing is less than λ, the grating lobe is greater than 90 degrees



$$\sin(\theta_g) = \left(\frac{\lambda}{p}\right)$$

What is the pitch?





$$\sin(\theta_g) = \left(\frac{\lambda}{p}\right)$$

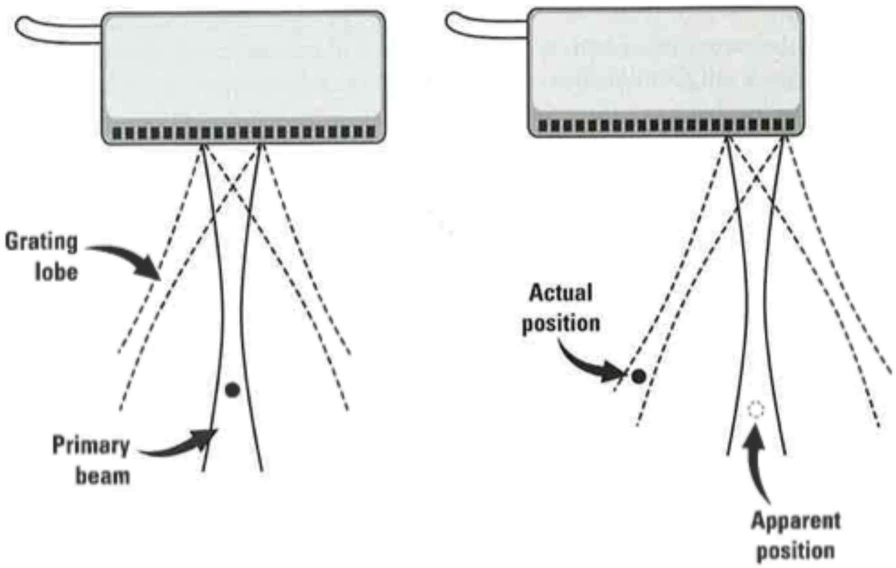
$$\sin(40°) = \left(\frac{\lambda}{p}\right)$$

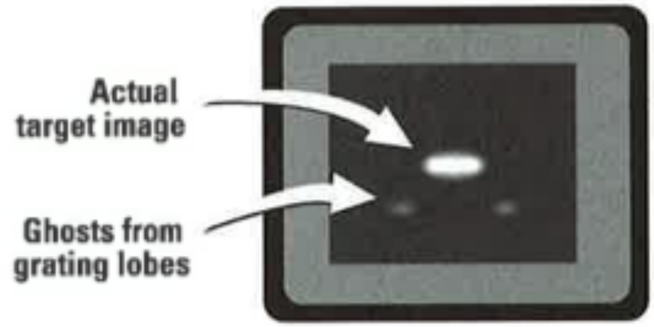
$$d = 1.55\lambda$$

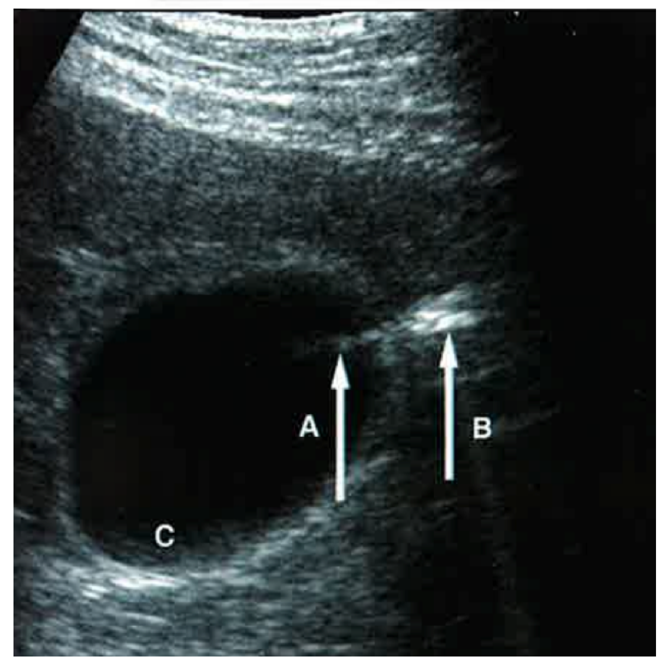
$$\sin(90°) = \left(\frac{\lambda}{d}\right)$$

$$d = \lambda$$

Grating Lobe Artifacts



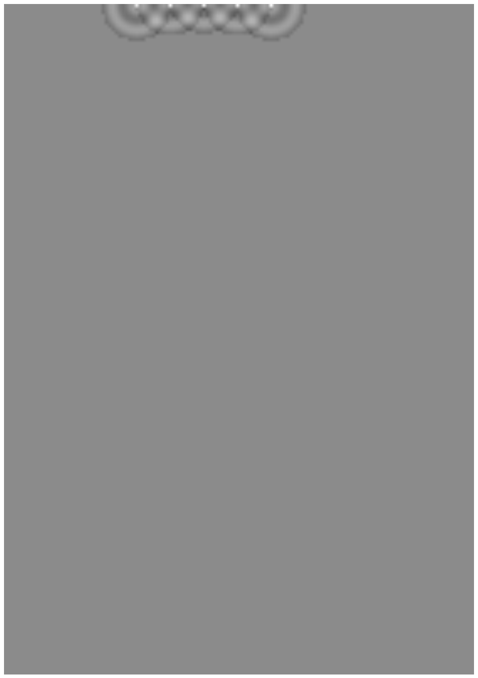




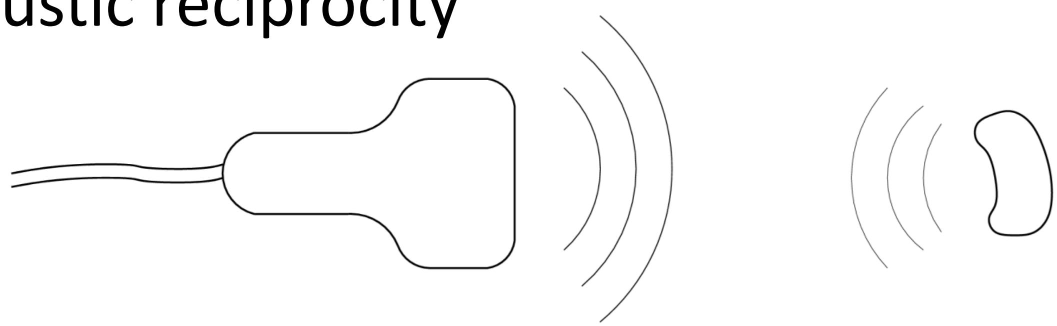
Class 7

- Arrays
- Grating Lobes with Linear Arrays
- Phased Arrays and More Grating Lobes
- Pulse-Echo or Transmit-Receive and Dynamic Receive Focusing

Pulse - Echo



- Because US is pulse-echo, we are concerned with both the transmitted pressure field (Tx) and the receiver sensitivity (Rx)
  - Rx sensitivity is the locations in the field where the receiver is sensitive to incoming waves
- Rx can be determined using the principle of acoustic reciprocity



Acoustic Reciprocity

- The receiver sensitivity is equal to the transmit diffraction pattern of the receiver acting as a source

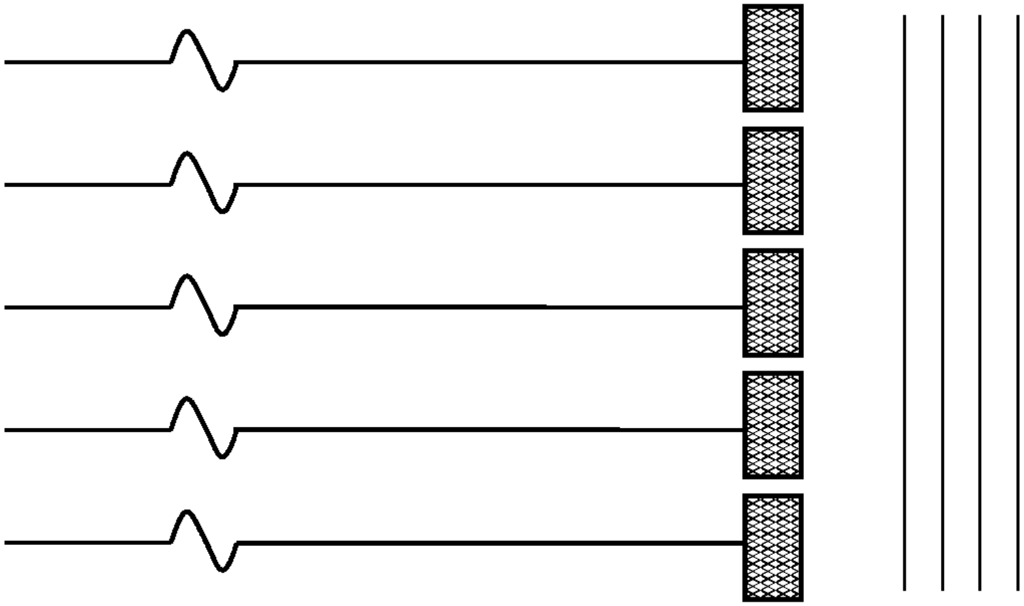
$Rx = \cos(\pi D f_x)$

Pulse Echo Sensitivity

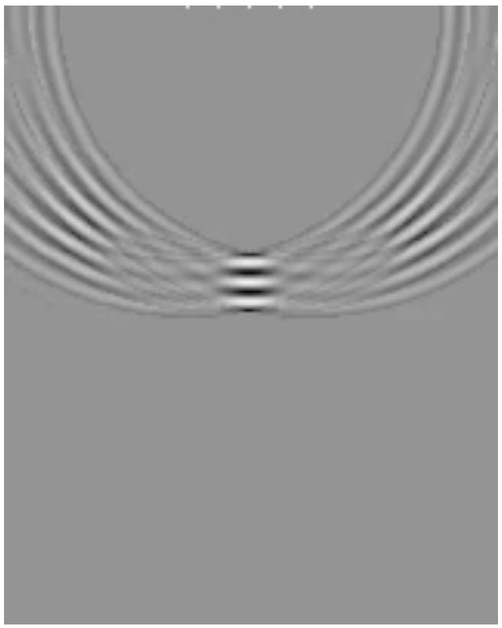
- The pulse-echo beam pattern (i.e. the sensitivity of the ultrasound system) is equal to the product of the transmit diffraction pattern and the receive sensitivity pattern:

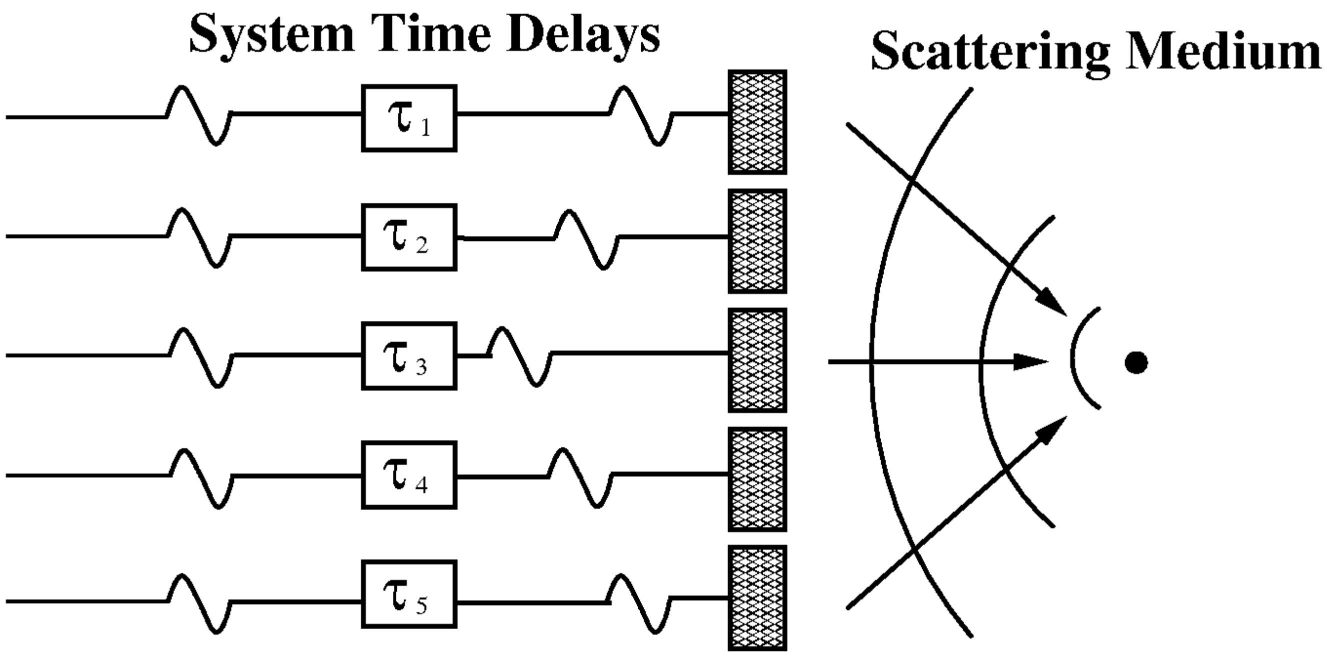
$$B(x,y) = Tx(x,y)Rx^*(x,y)$$

Transmit Beamforming: Plane Wave

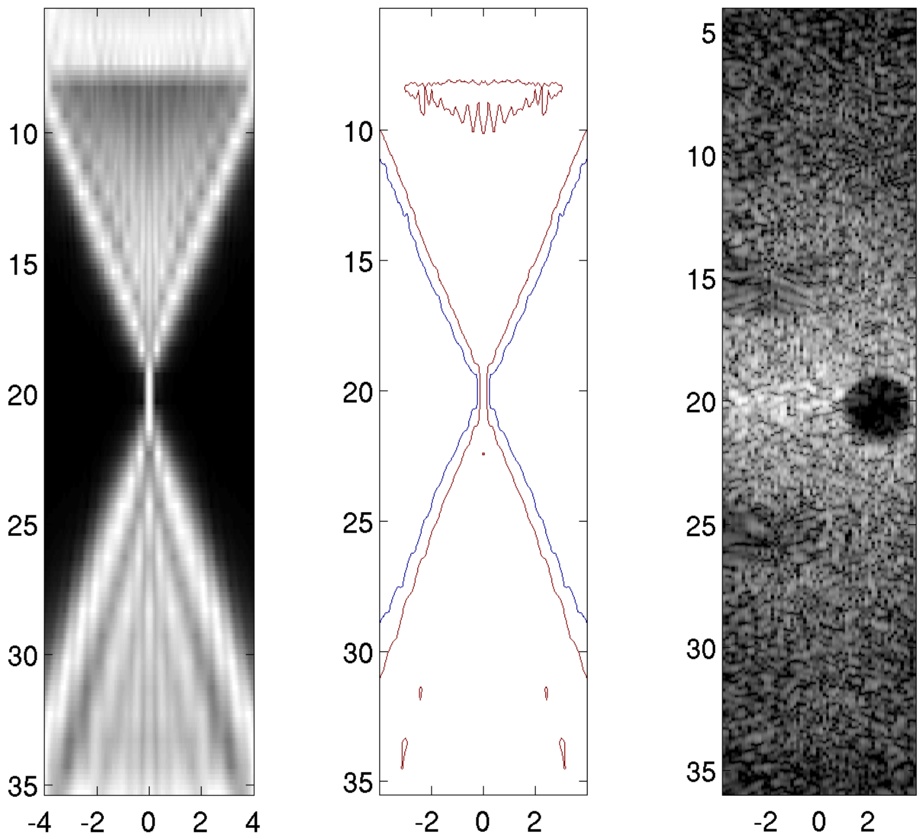


Transmit Beamforming: Focused Wave



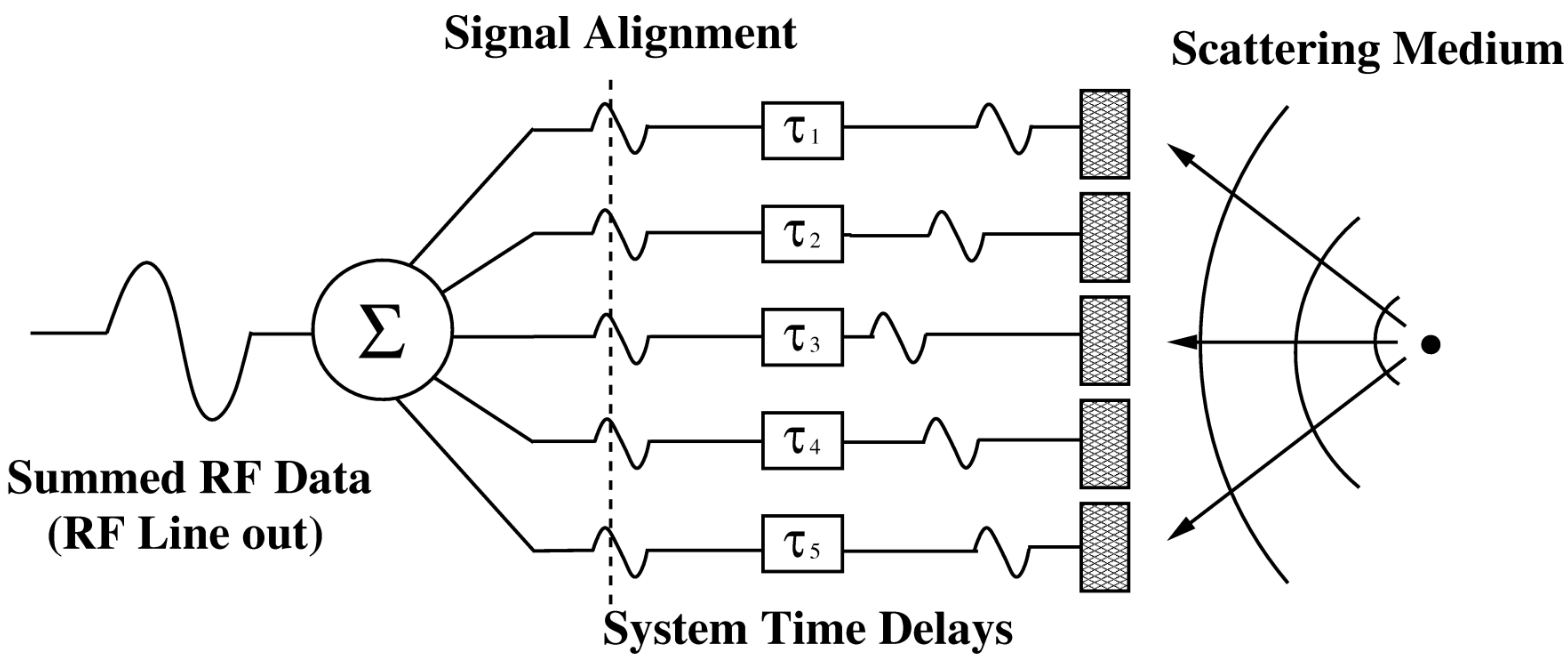


Transmit Beam



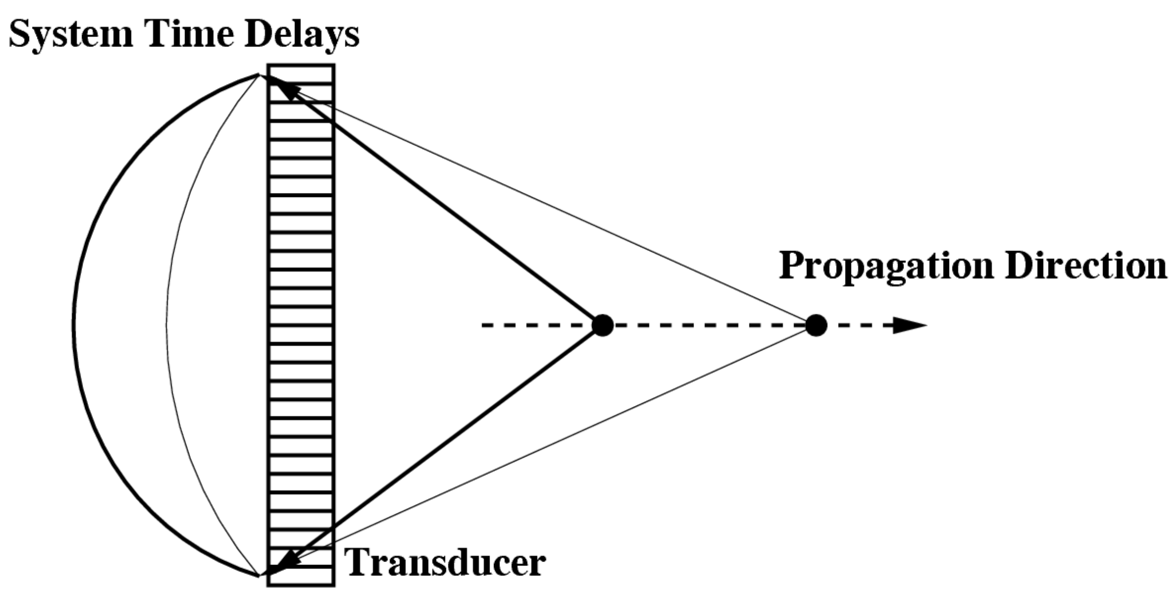
Receive Beamforming

- Transmit beamforming in reverse:



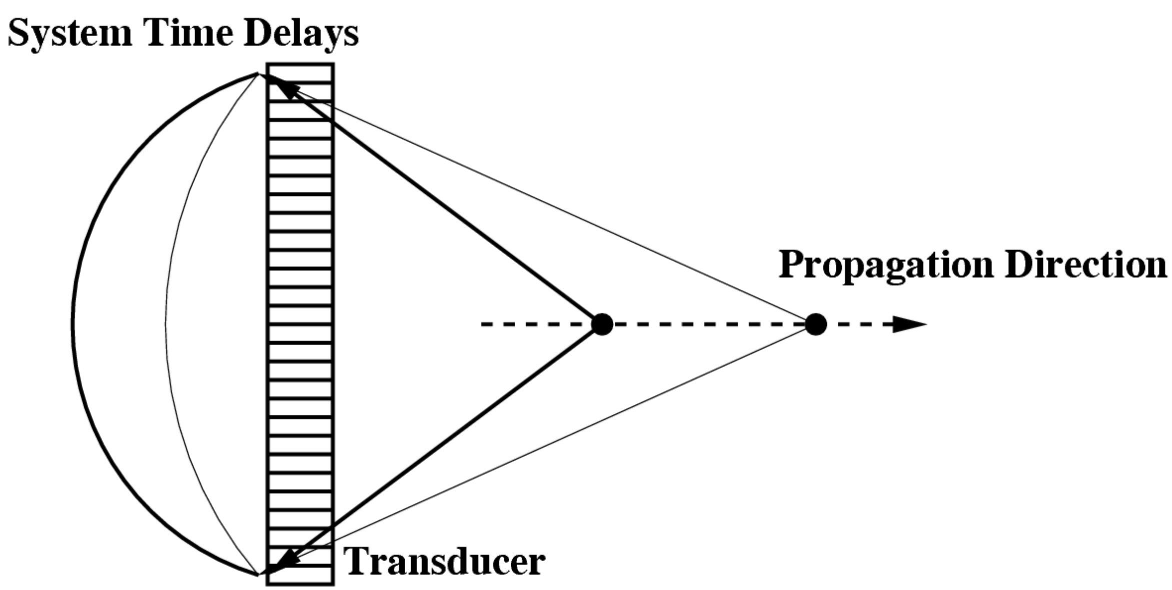
Use same equation as before to compute time delays for receiving!

Transmit Focusing at Different Depths

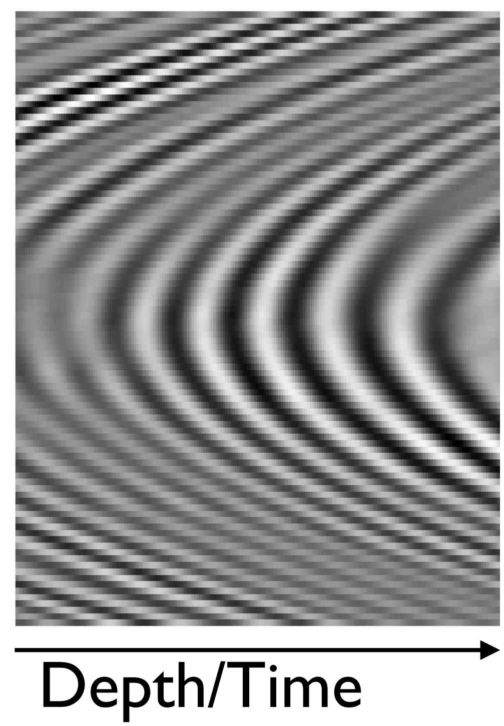


Dynamic Receive Focusing

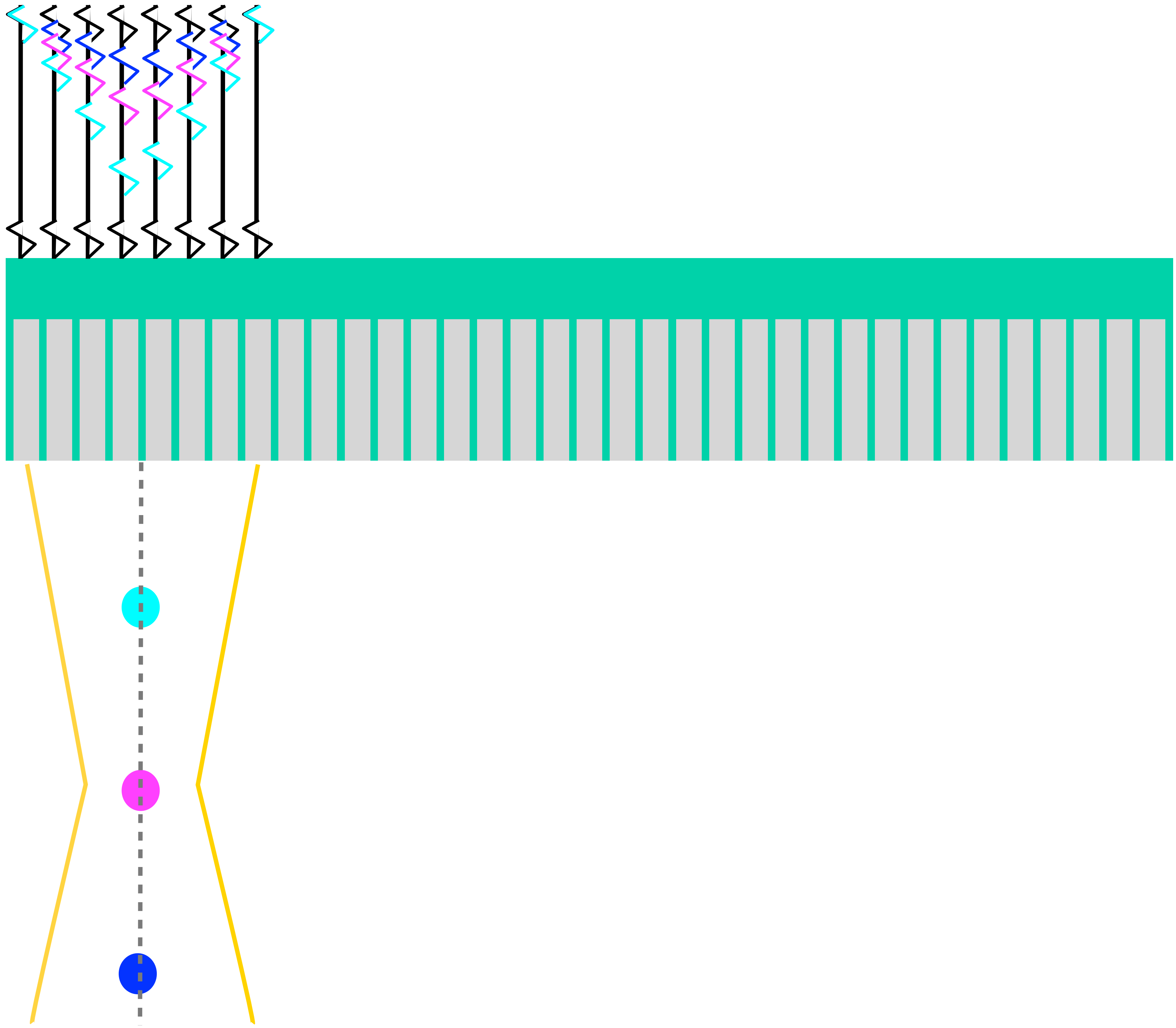
- Continuously adjust the delays



Raw (undelayed)

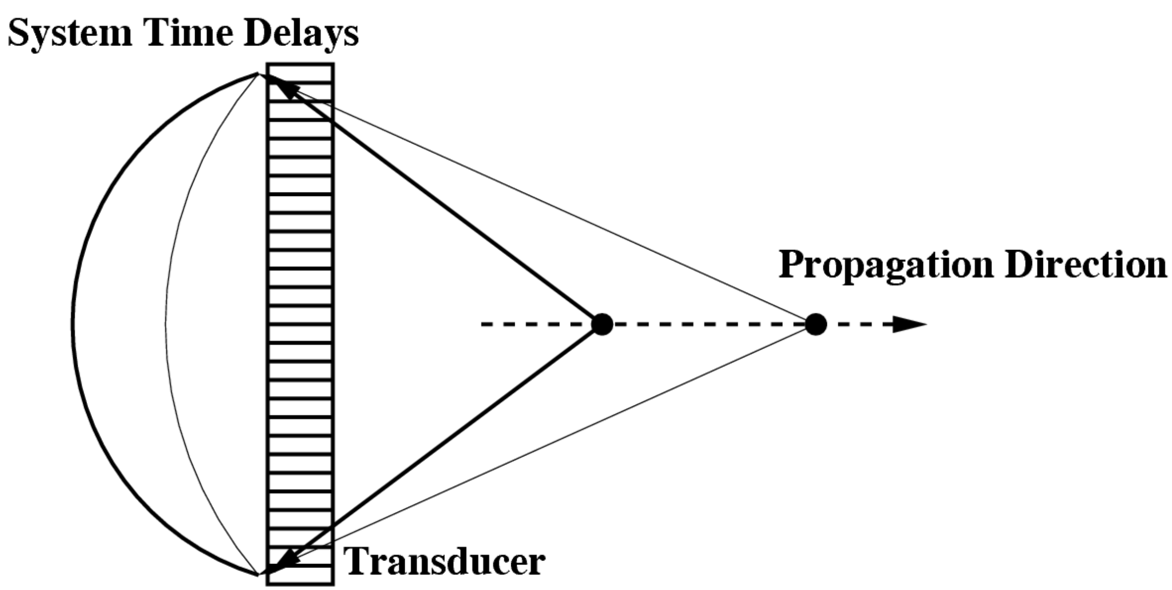


Dynamic Focusing on Receive

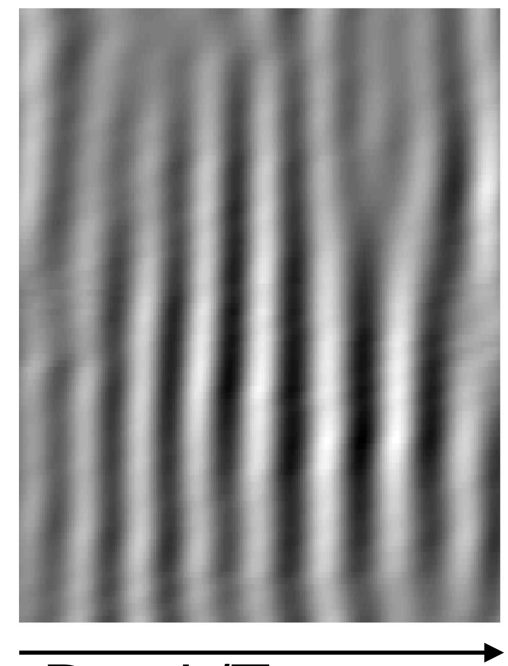


Dynamic Receive Focusing

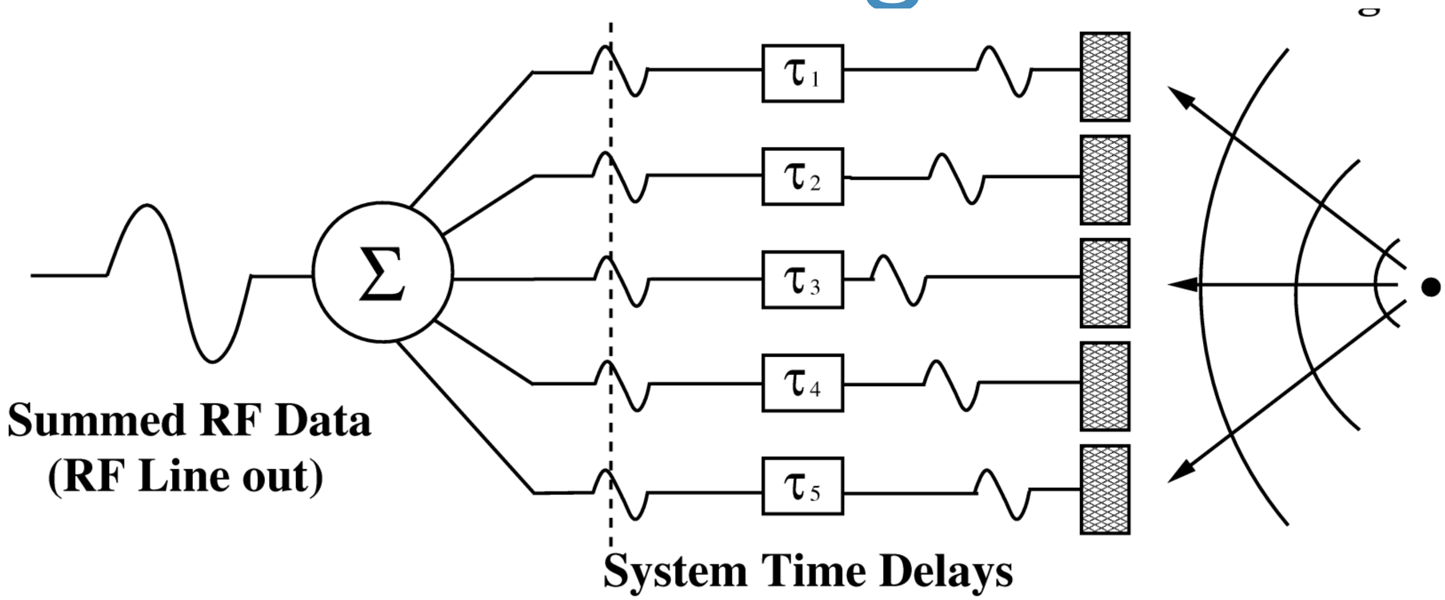
- Continuously adjust the delays

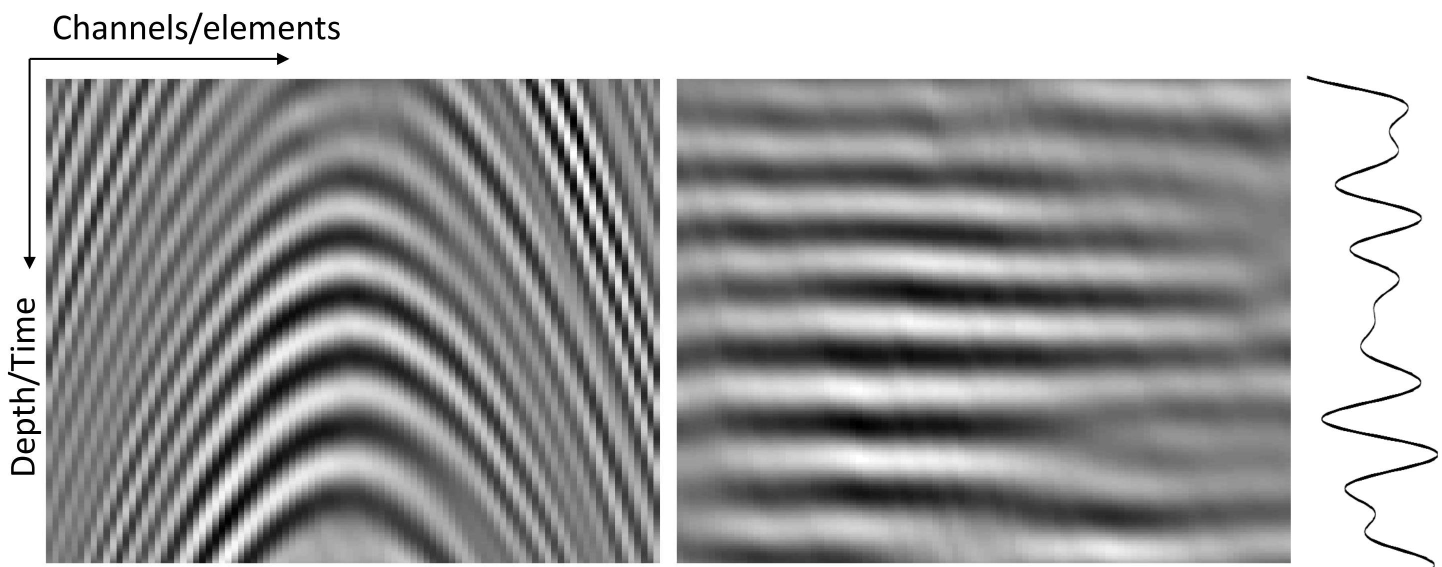


delayed



Receive Beamforming



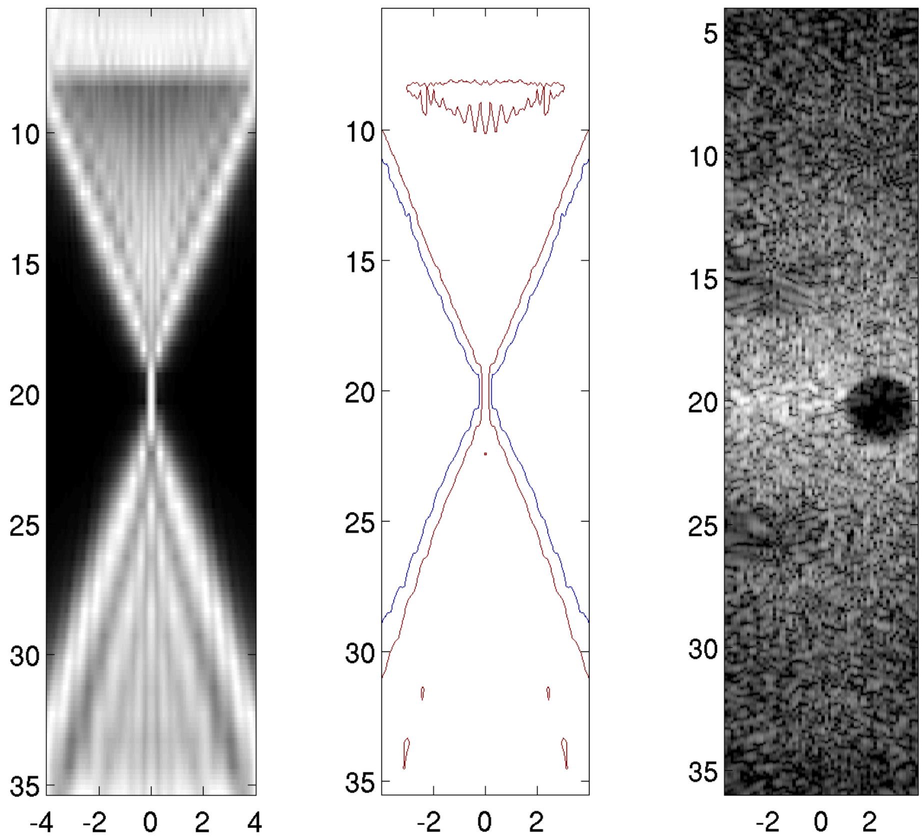


Unfocused signal received from the near field

Focused signal using time-delays: Note how wavefronts appear as "plane waves"

RF Sum

Transmit Beamforming Only



Dynamic Receive Beamforming