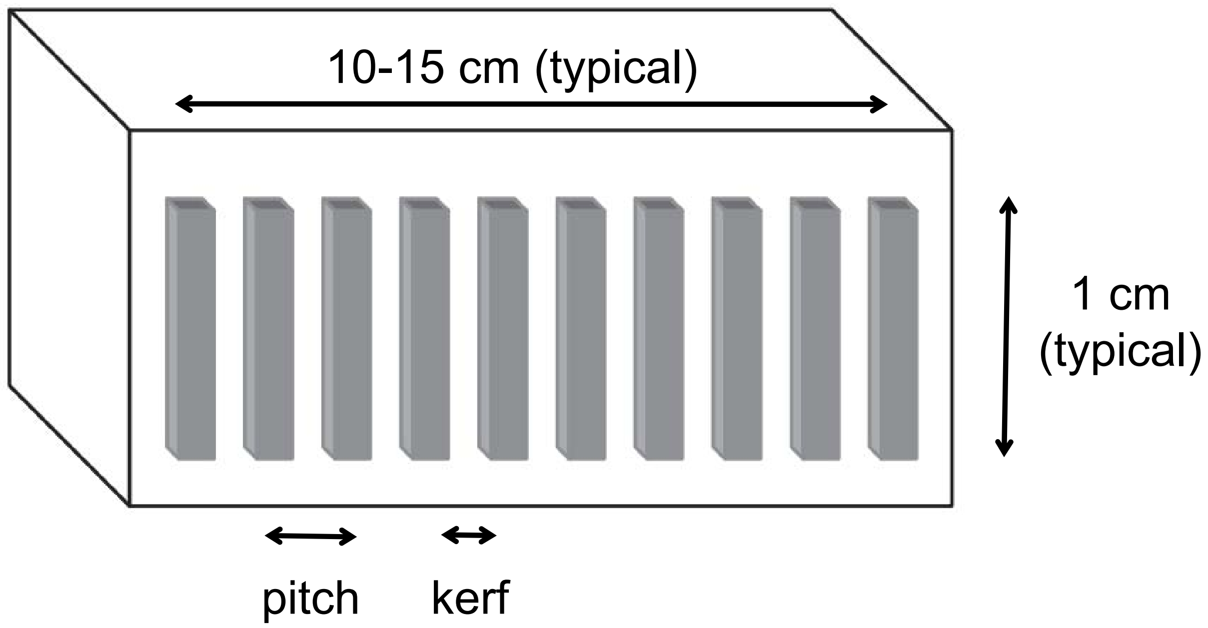
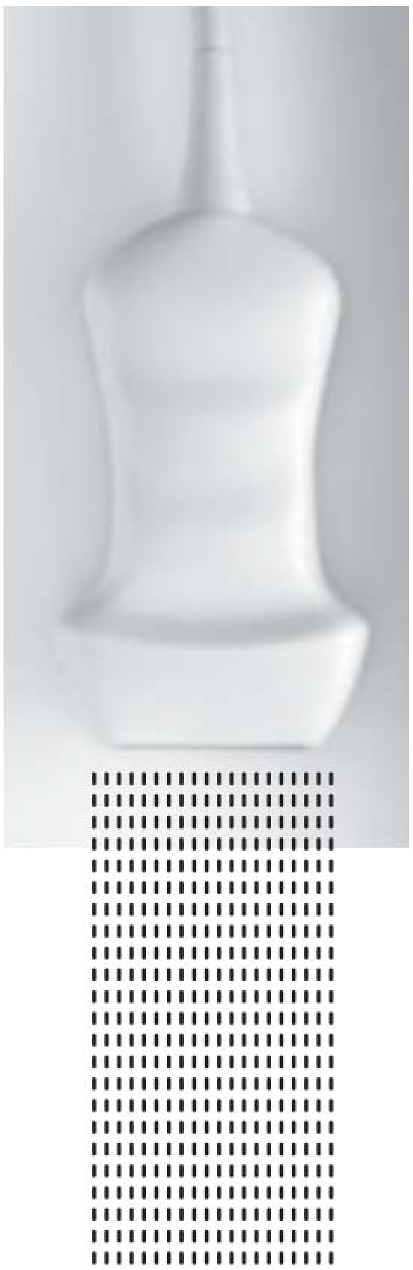
Linear Array





Large number of individual transducers (128-512)

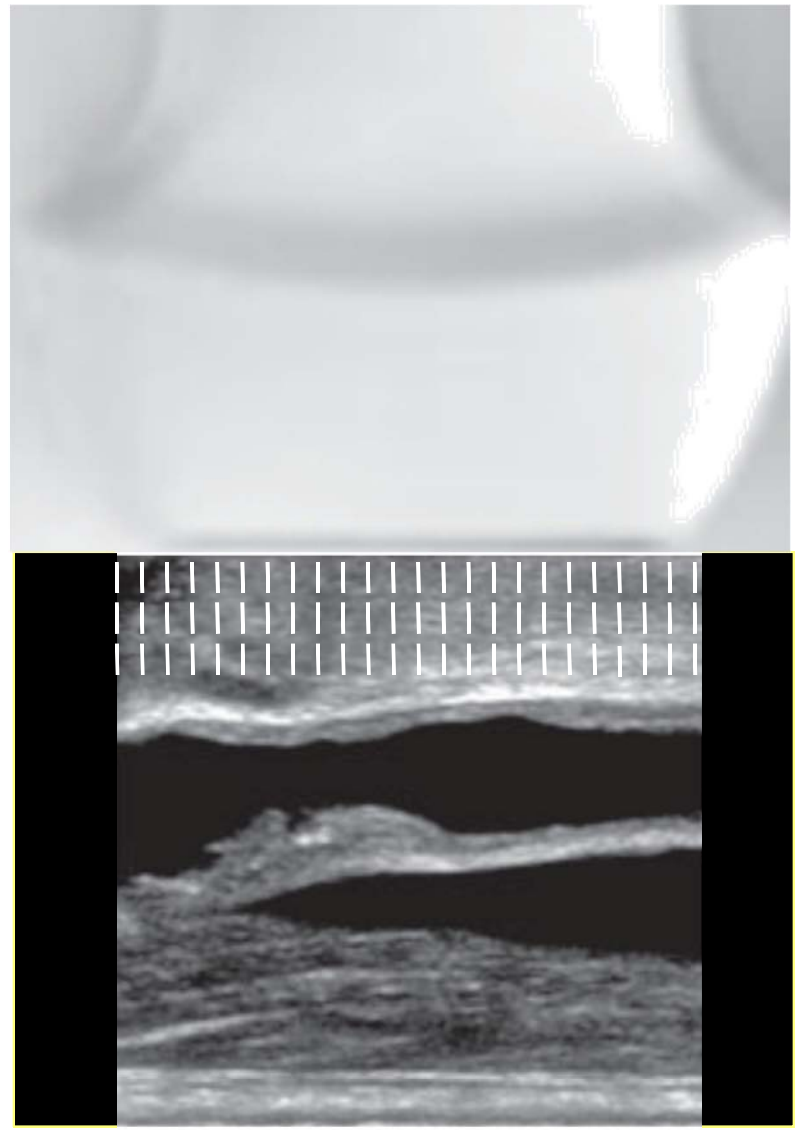
- flat (unfocused)
- mutually isolated (mechanically, electrically)
- operated independently

Linear Array

Individual operation

- One transducer at a time
- Sweep left-to-right
- Sequential
- Calculate image line by line

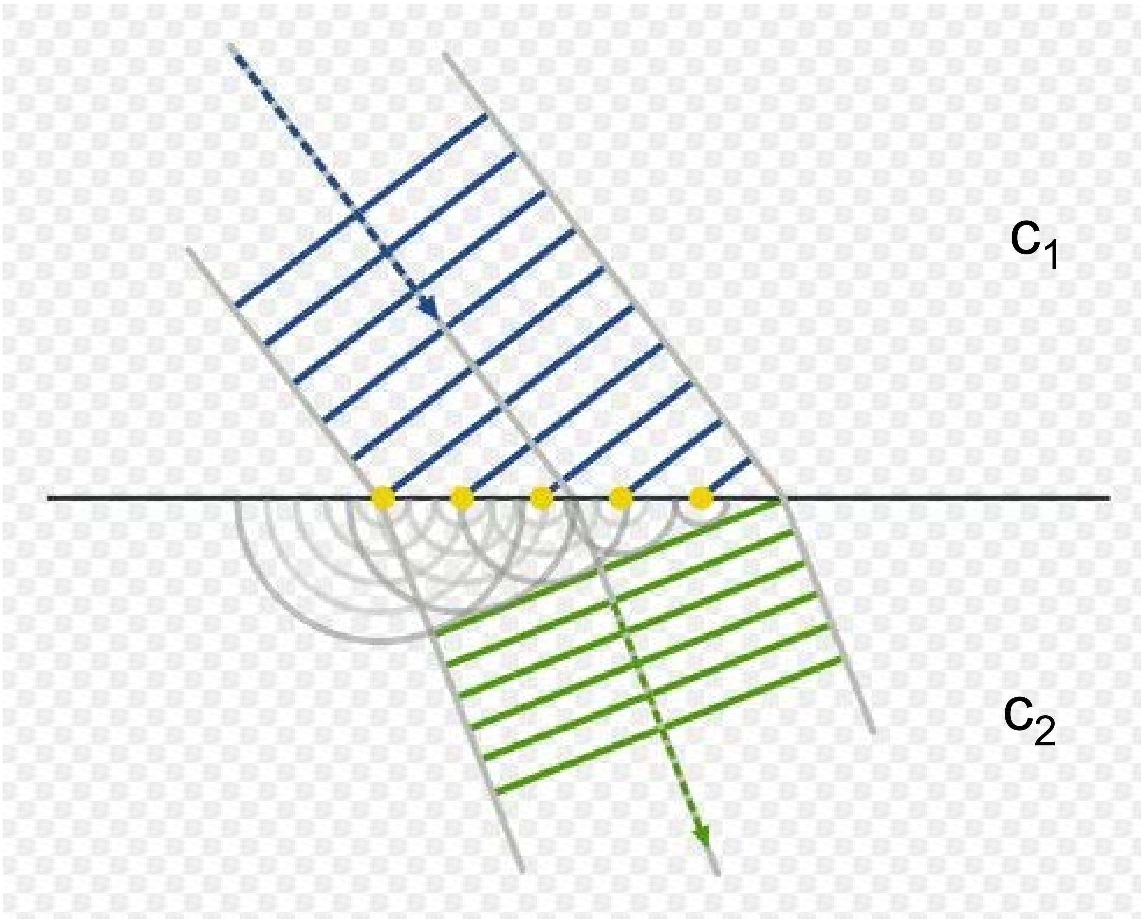
- lateral resolution limited by pitch
- small pitch → large θ



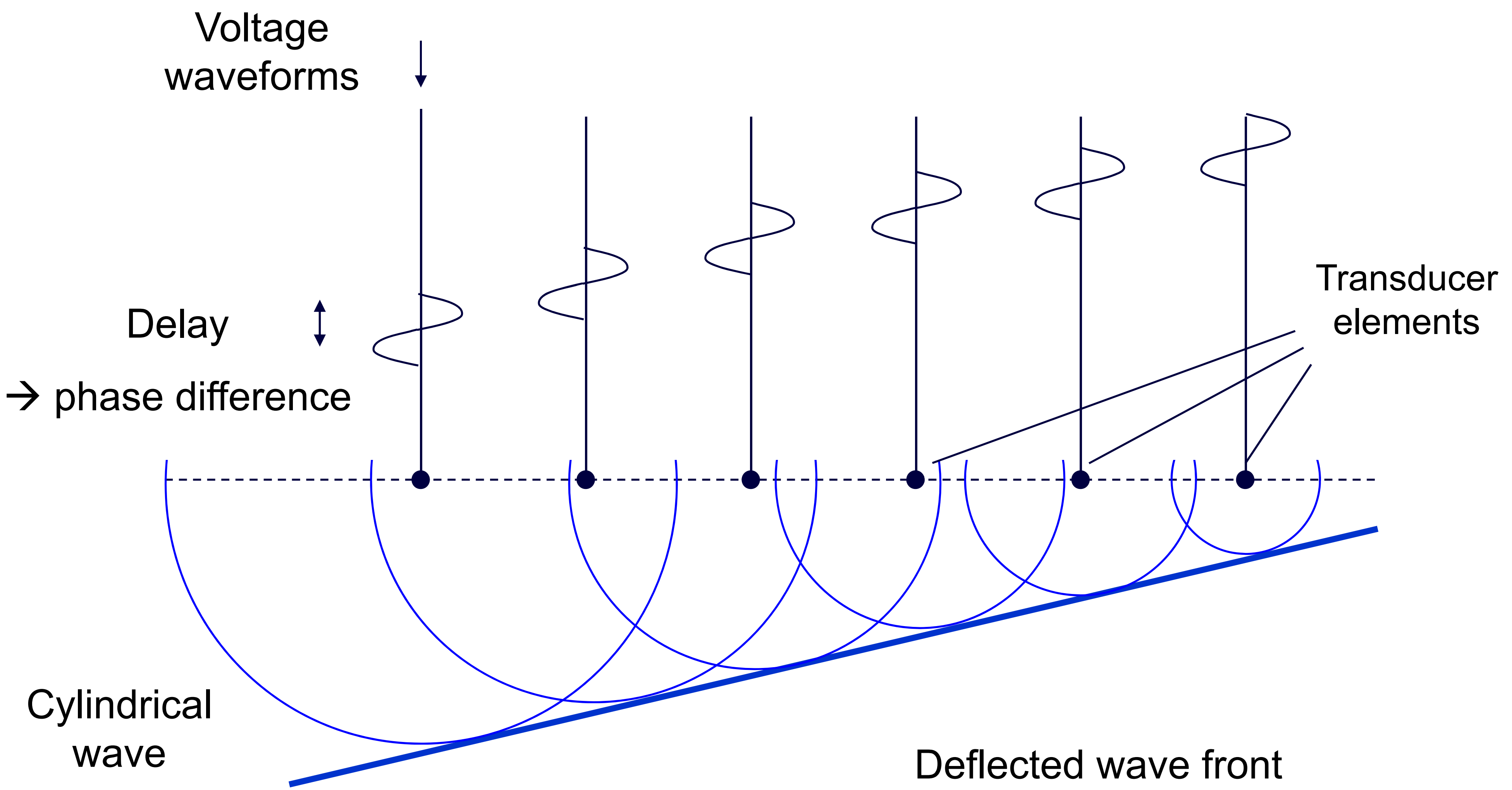
Huygens' Principle

Each point of a wavefront is origin of partial wave

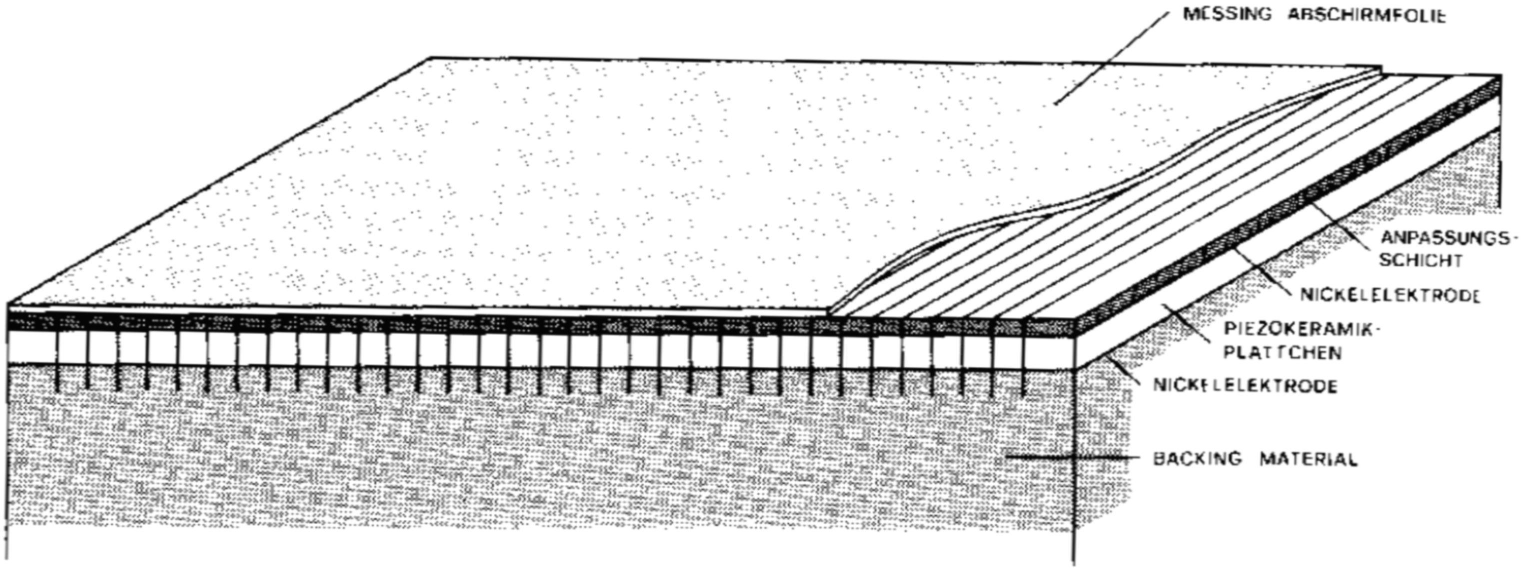
Refraction



Phased Parallel Operation

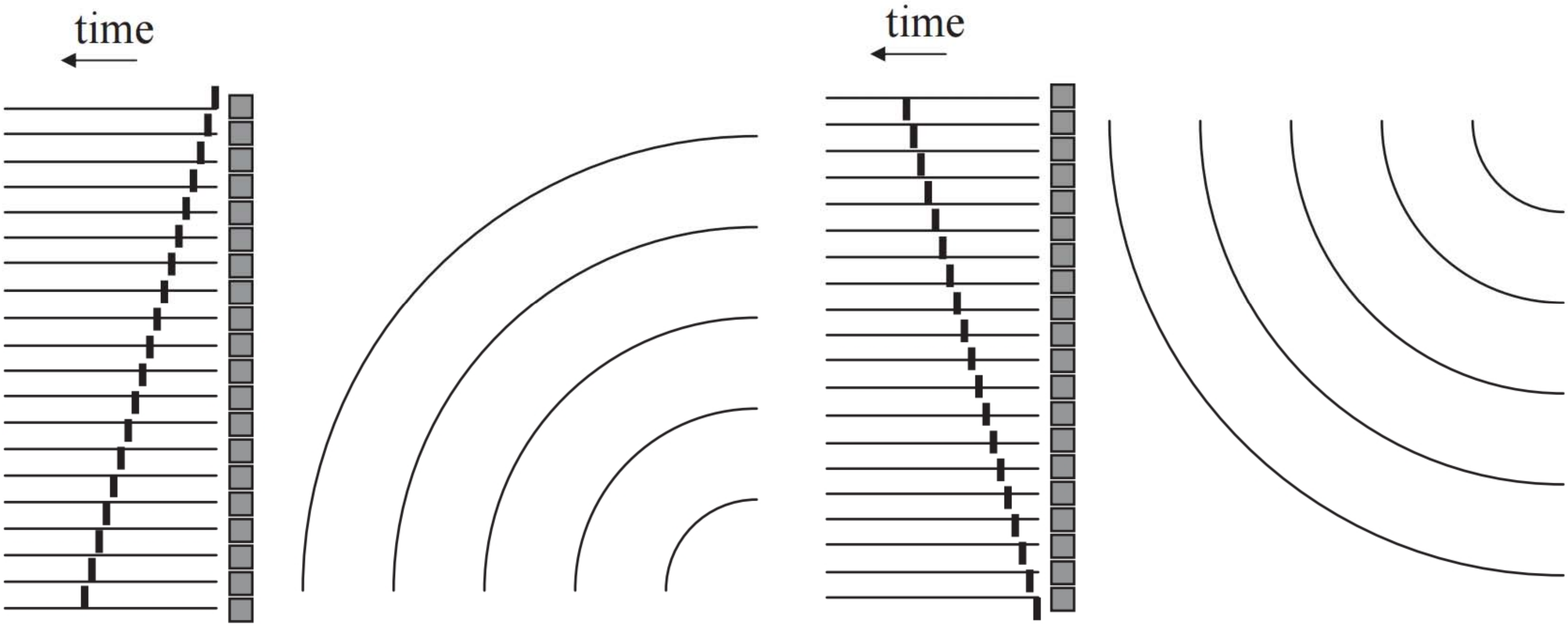


Phased Array

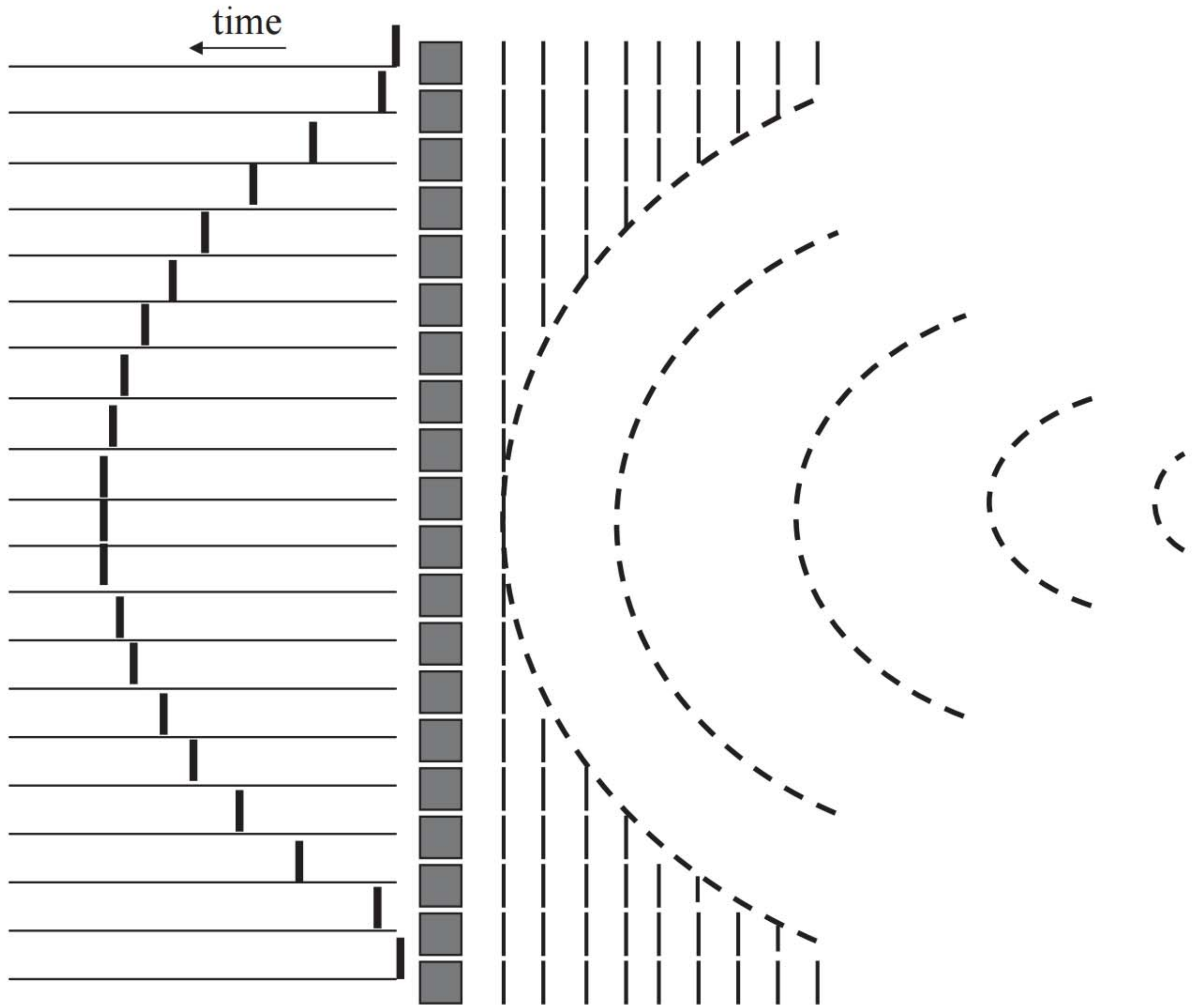


- Smaller transducer elements
- Denser packing
- Pitch < $\lambda/2$
- Adjustable individual delays

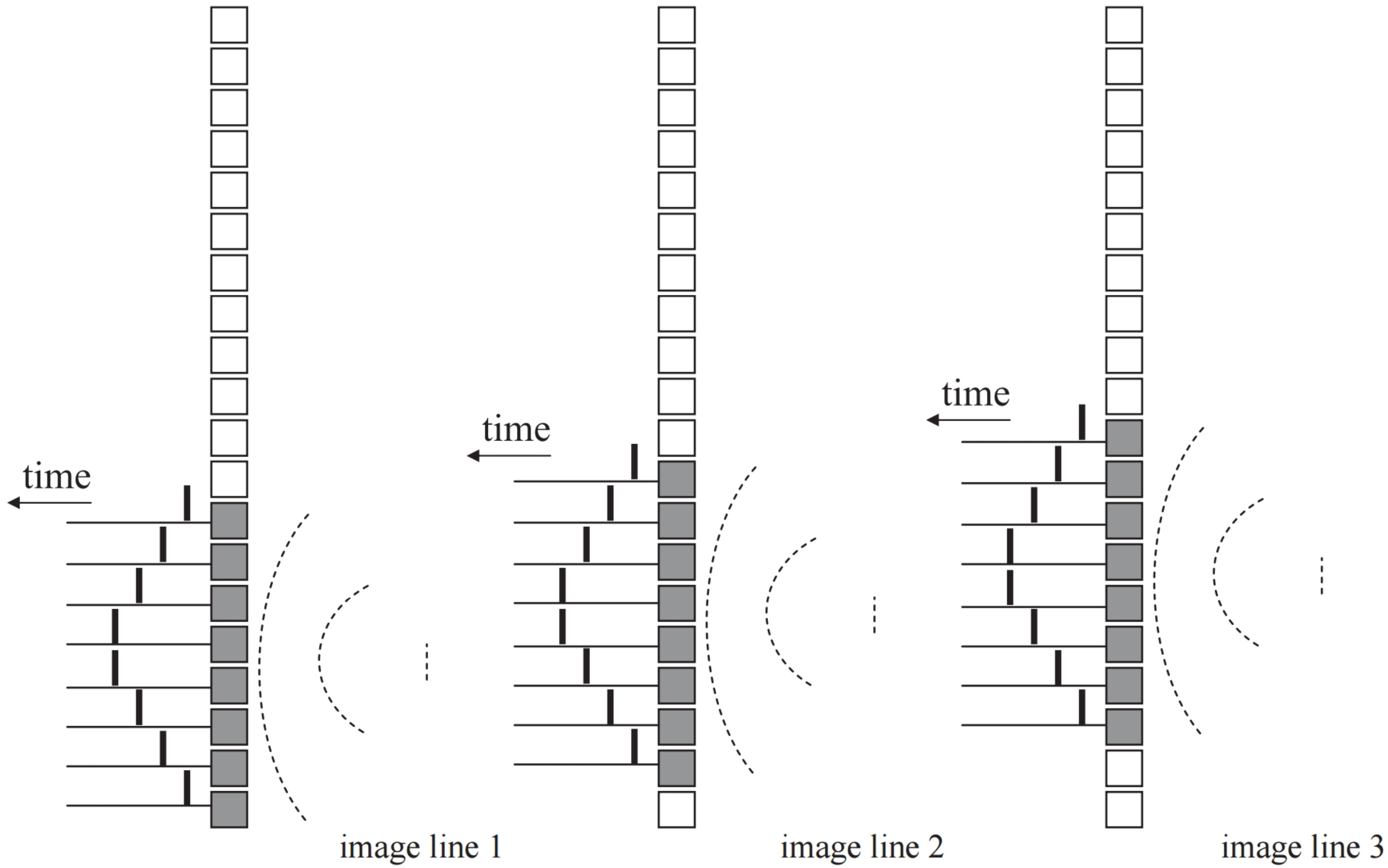
Beam Deflection



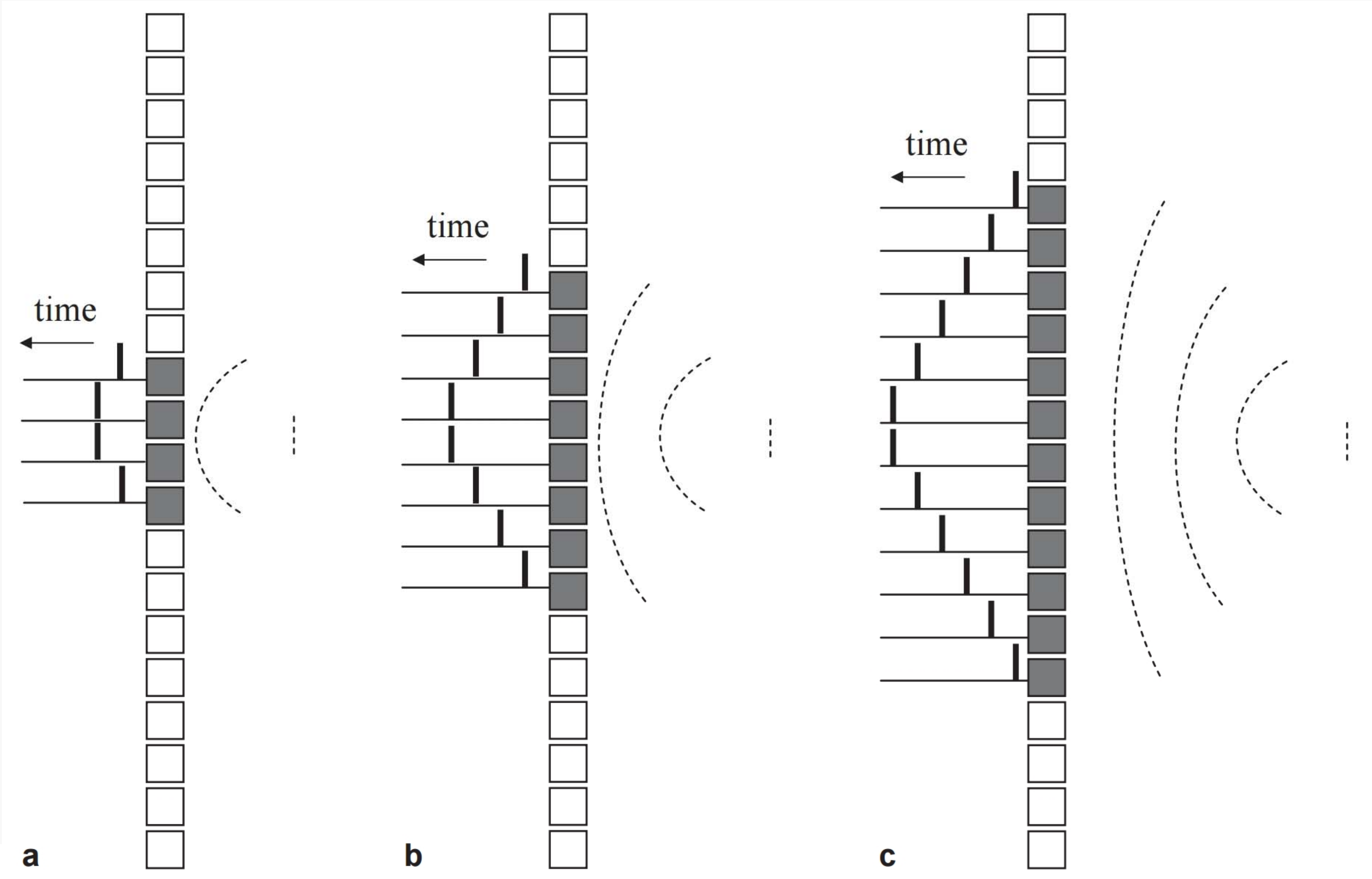
Focusing



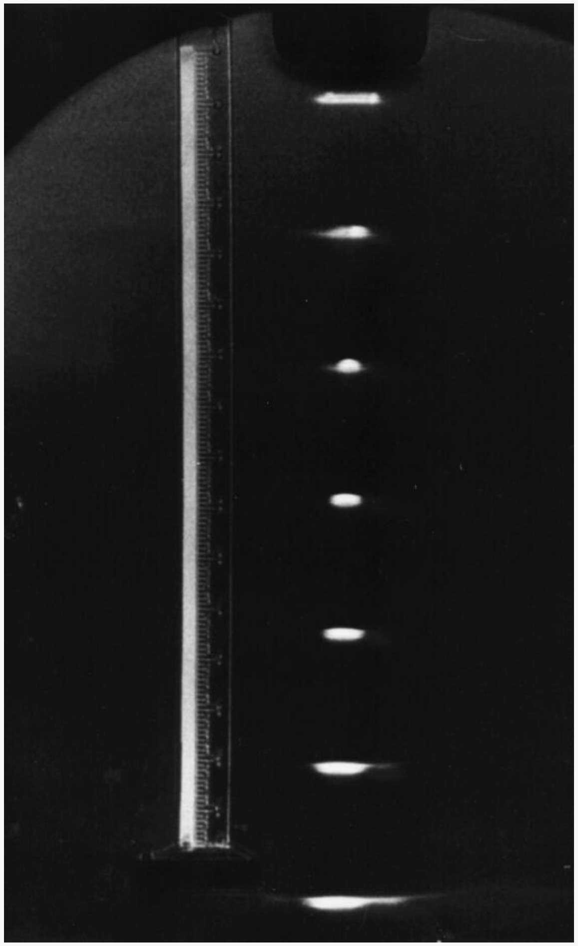
Focusing and Shifting



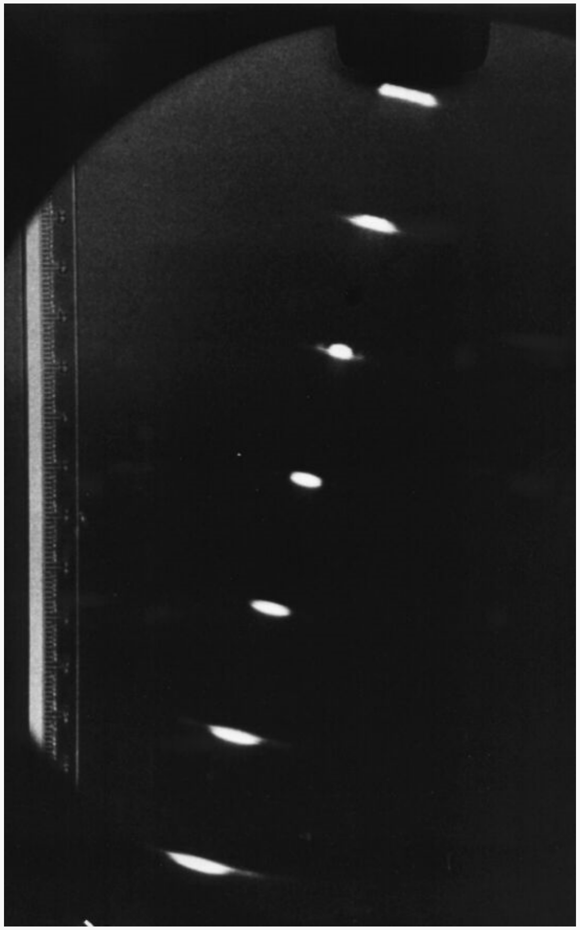
Variable Focusing



Phased Array: 'Schlieren' Photographs

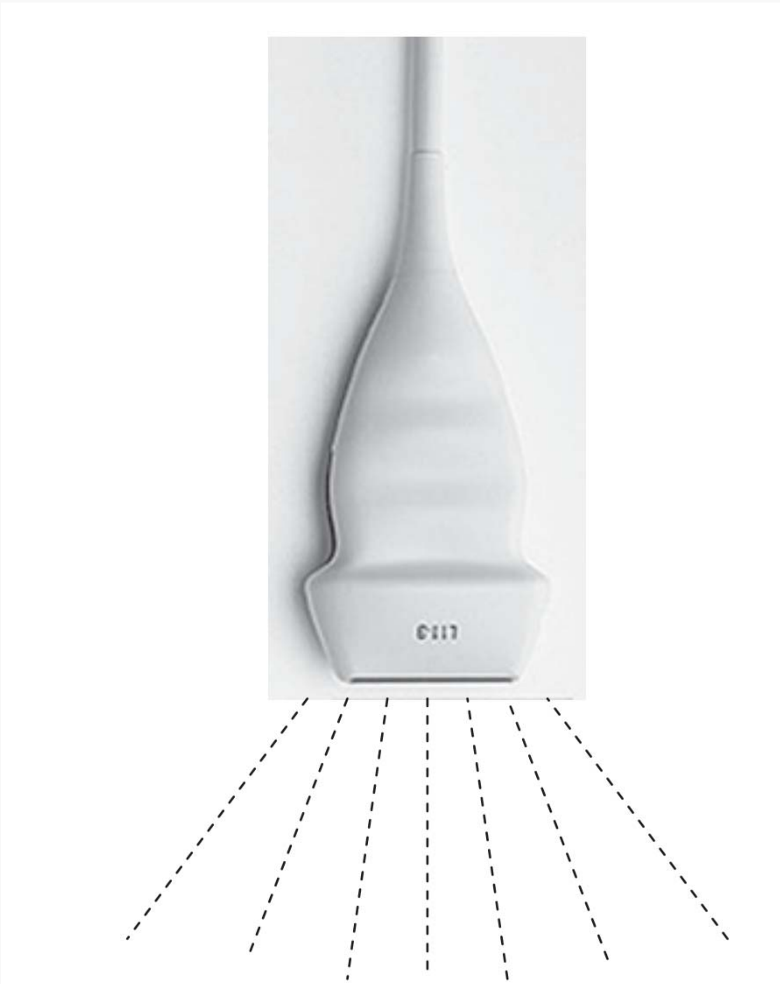


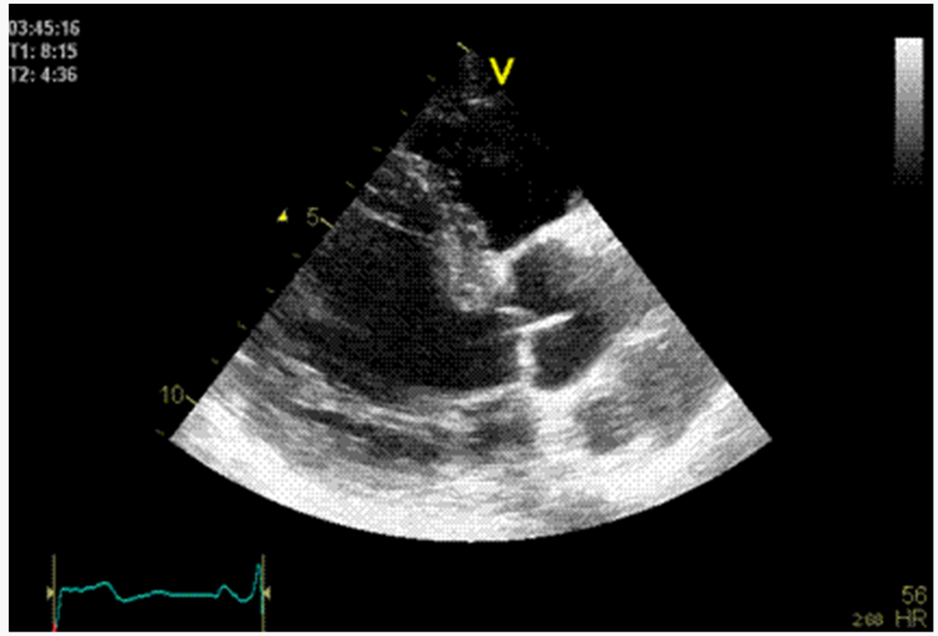
Focusing only



Focusing and deflection

Acoustic Windows



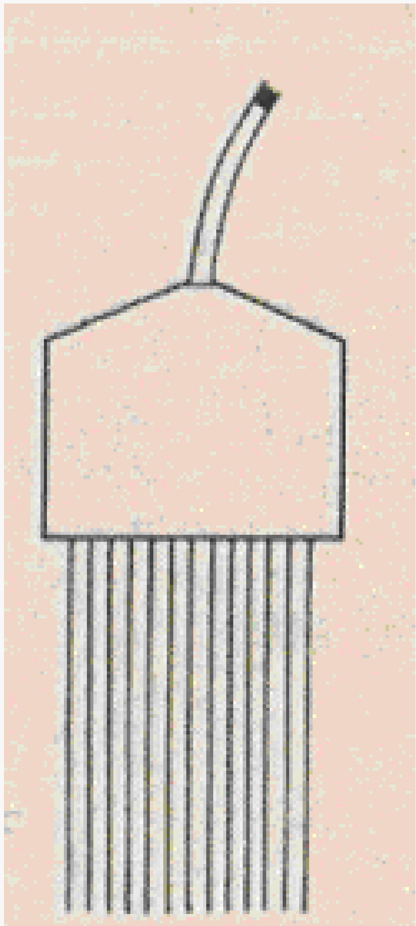


Small aperture + beam steering

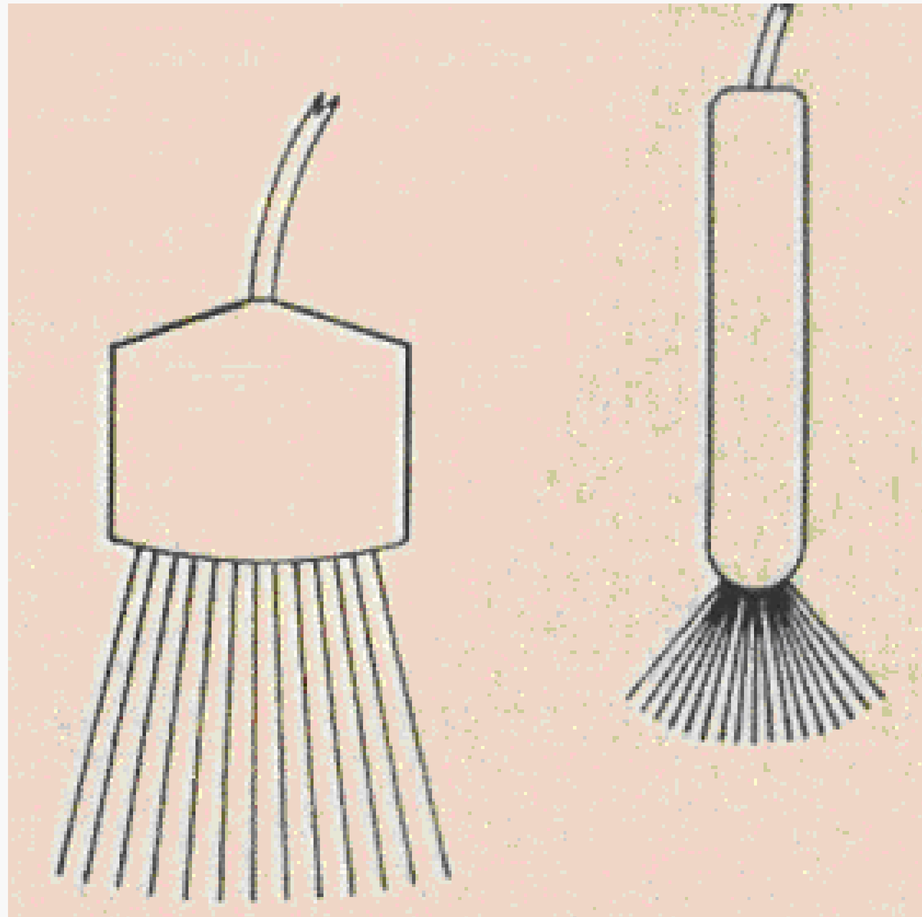
→ see through acoustic windows

→ particularly for cardiac scanning

Linear and Curved Phased Arrays

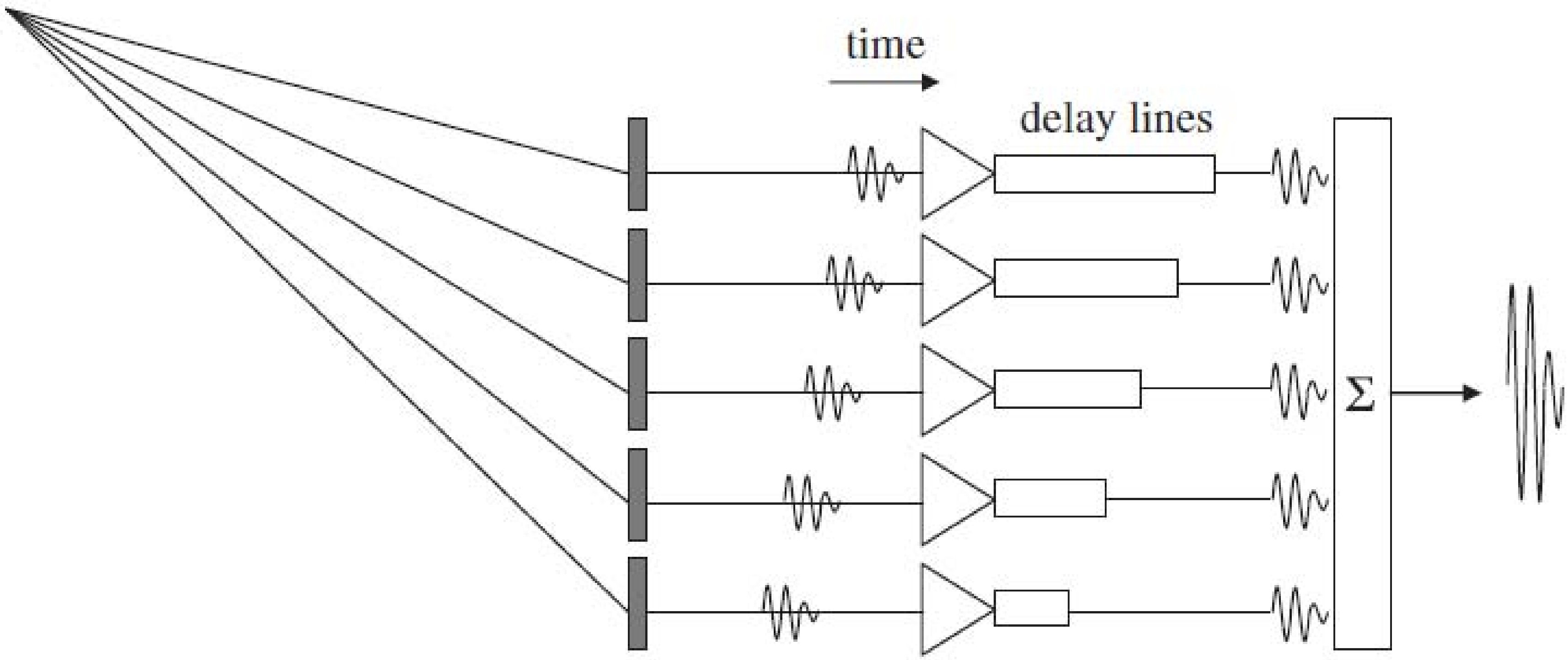


Flat array



Curved arrays

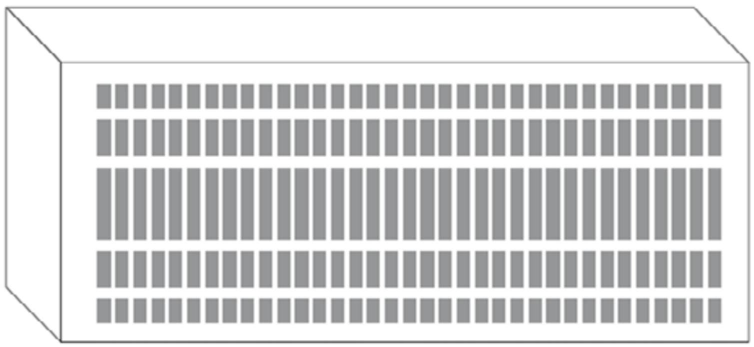
Receiver Beam-Forming



Reciprocity: Transmit and receive with same beam direction and focus

- analog: run-time phased combination, one output
- digital: record all channels, combine later, more flexible

Multi-dimensional arrays



50x50
transducers

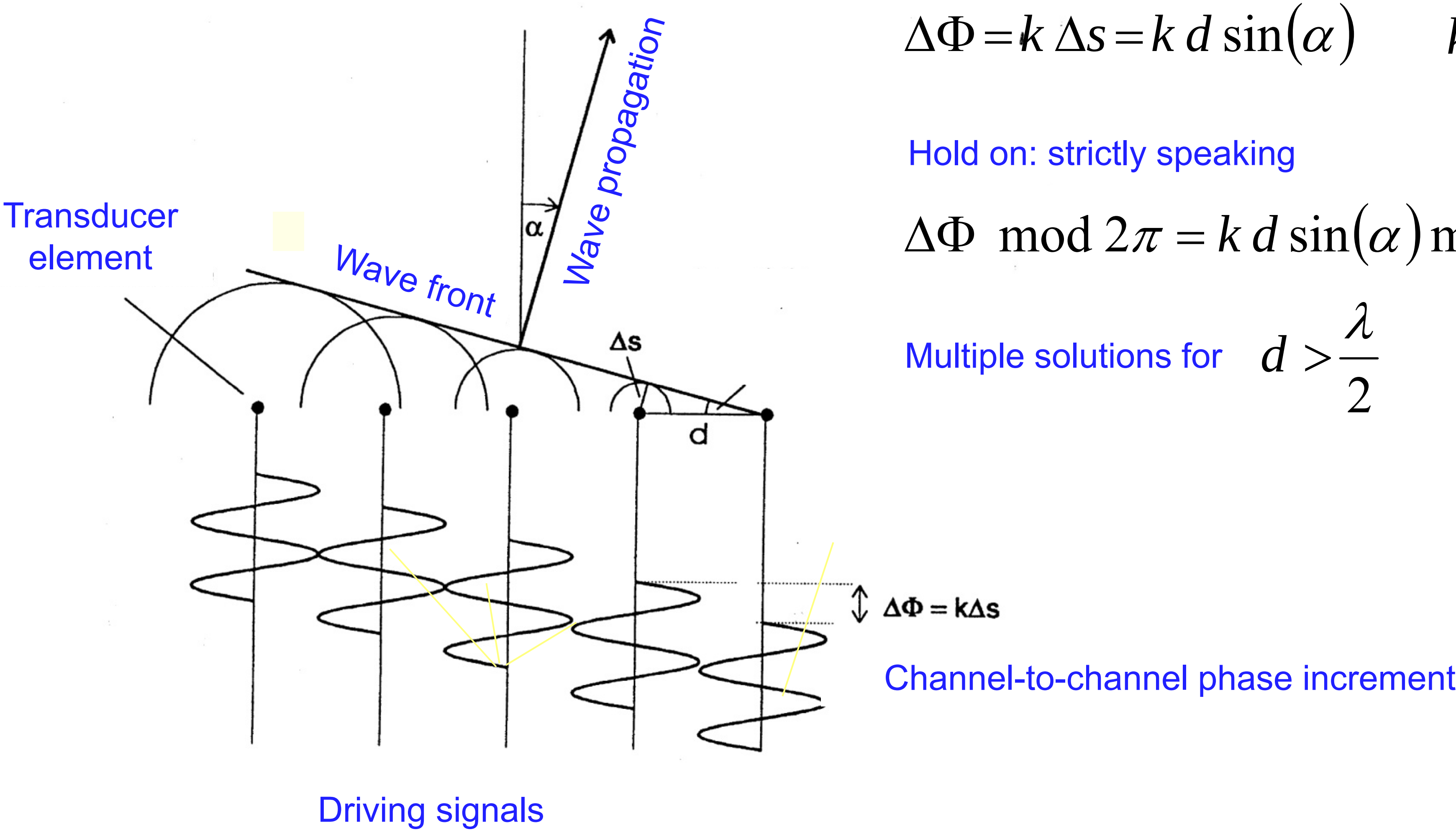
'1.5D' array:

- few elements in third dimension
- Permits some beam control in the third dimension
- Third dimension = 'elevation' dimension

2D array:

- Permits full 3D beam control

Grating Lobes



Wave front: partial waves in-phase

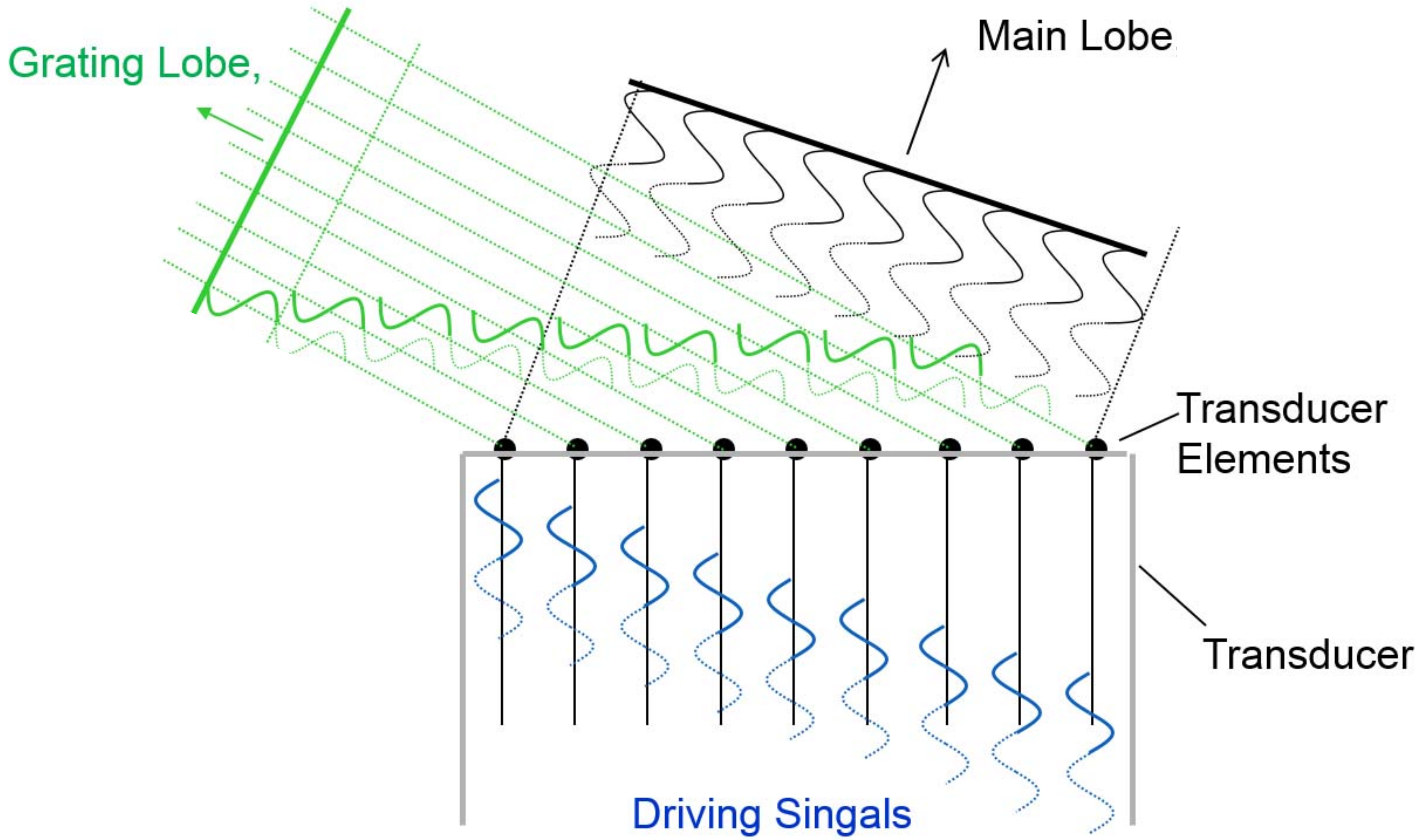
$$\Delta\Phi = k\,\Delta s = k\,d\,\sin(\alpha) \qquad k = \frac{2\pi}{\lambda}$$

Hold on: strictly speaking

$$\Delta\Phi \mod 2\pi = k\,d\,\sin(\alpha) \mod 2\pi$$

Multiple solutions for $d > \dfrac{\lambda}{2}$

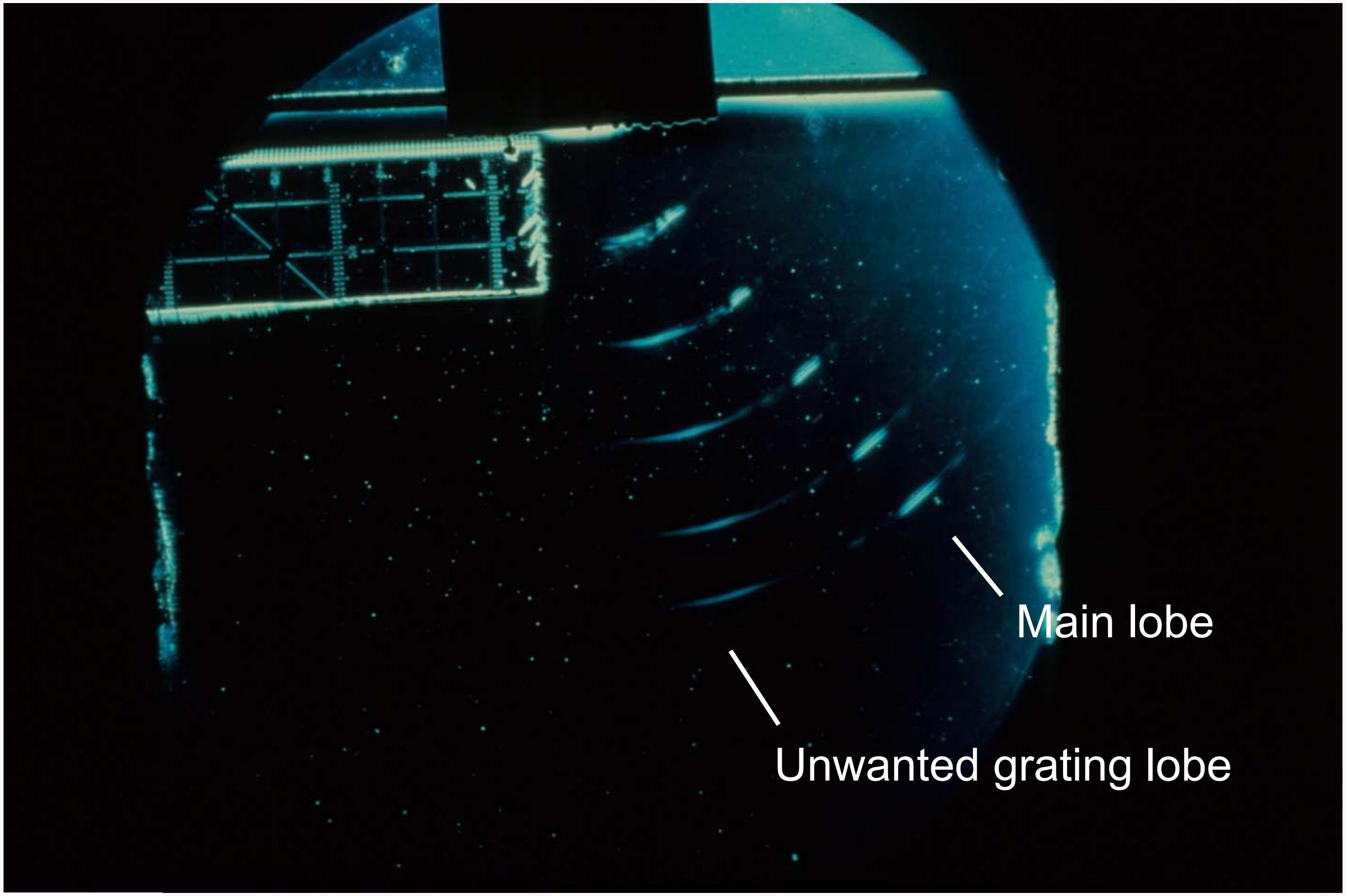
Grating Lobes



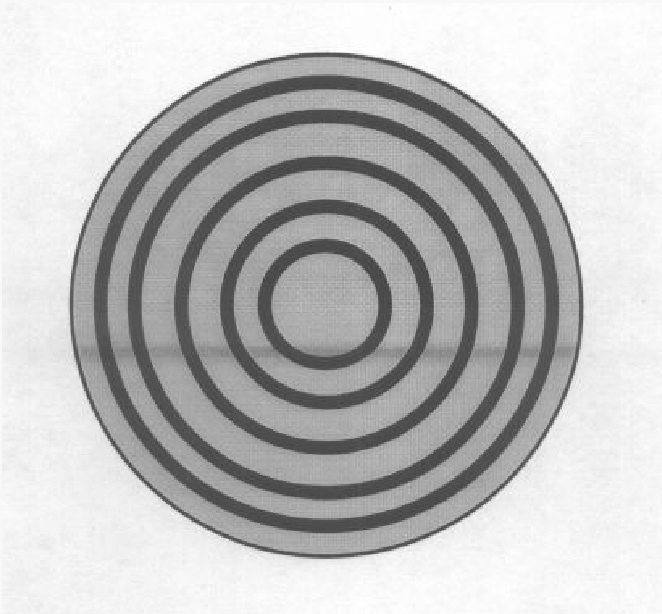
Must ensure $d \leq \lambda / 2$!

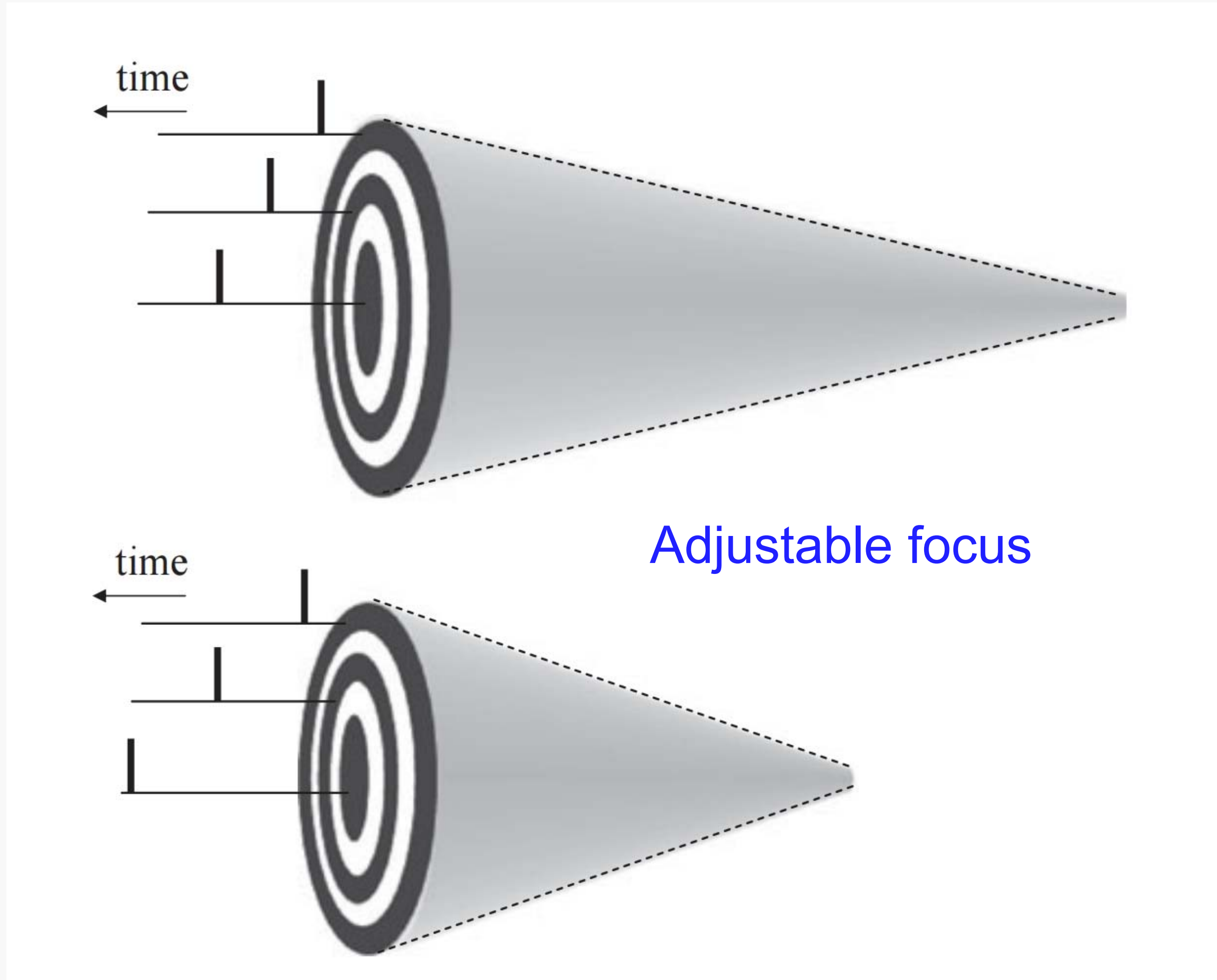
E.g., 5 MHz, $\lambda/2$ = 0.15 mm, 2D array of 1.5cm x 1.5cm require 10'000 elements !

Schlieren Picture of Grating Lobes



Annular Array

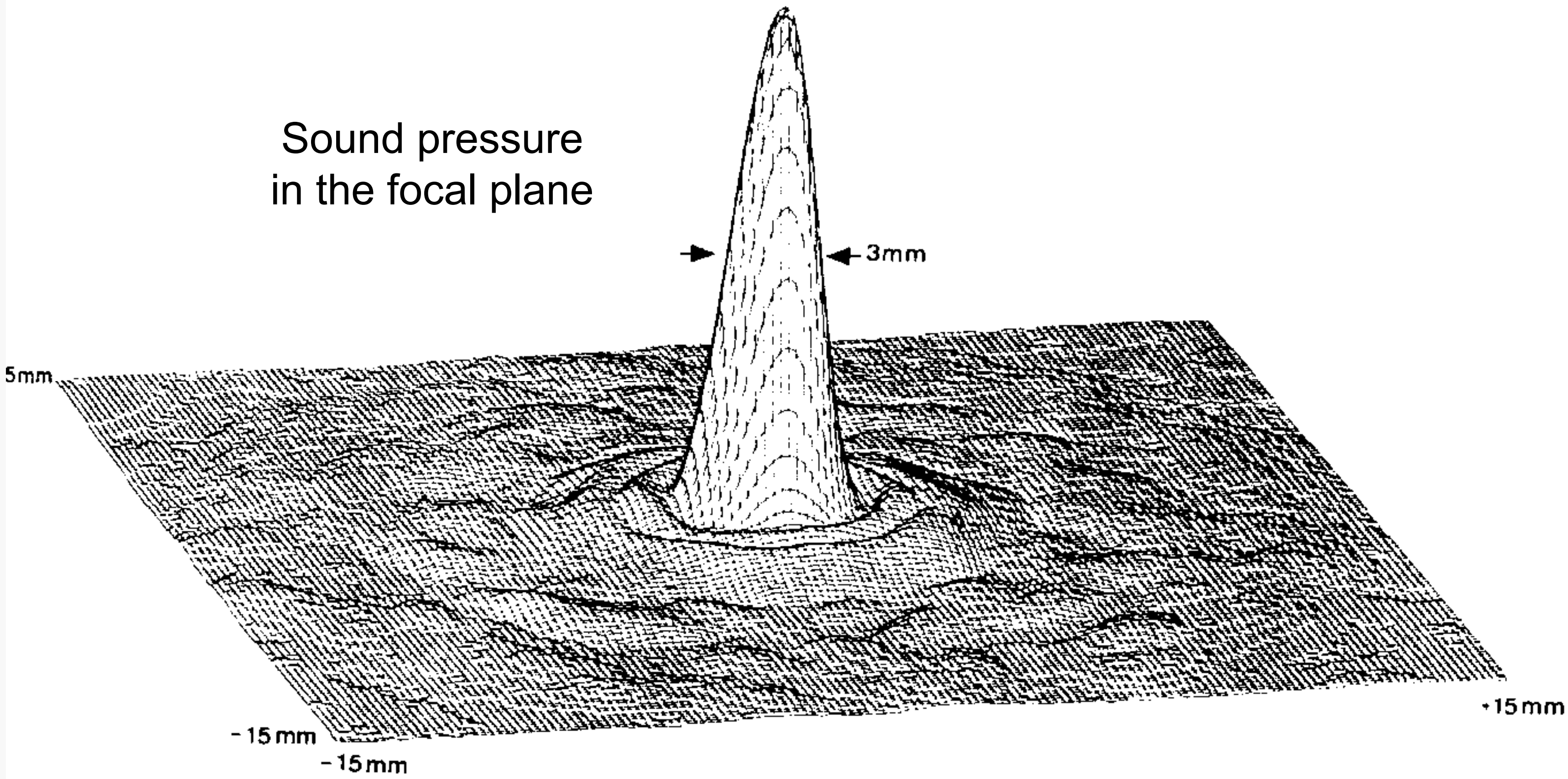




Advantage: Much fewer channels, still permit dynamic focusing

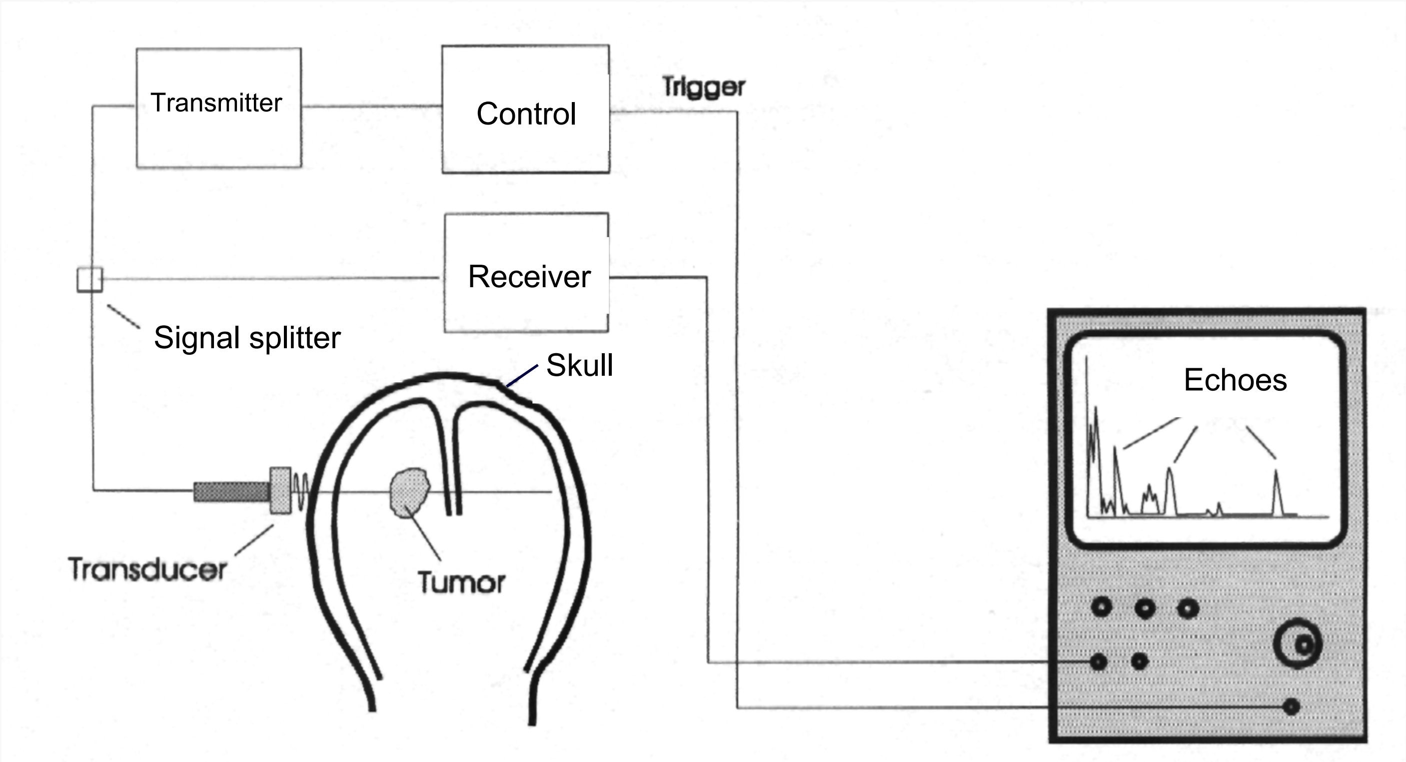
Disadvantage: No electronic direction control, must be mechanical

Sound Field of an Annular Array



Further advantage: circular symmetry = more isotropic depiction

Scanning Modes: A-Mode

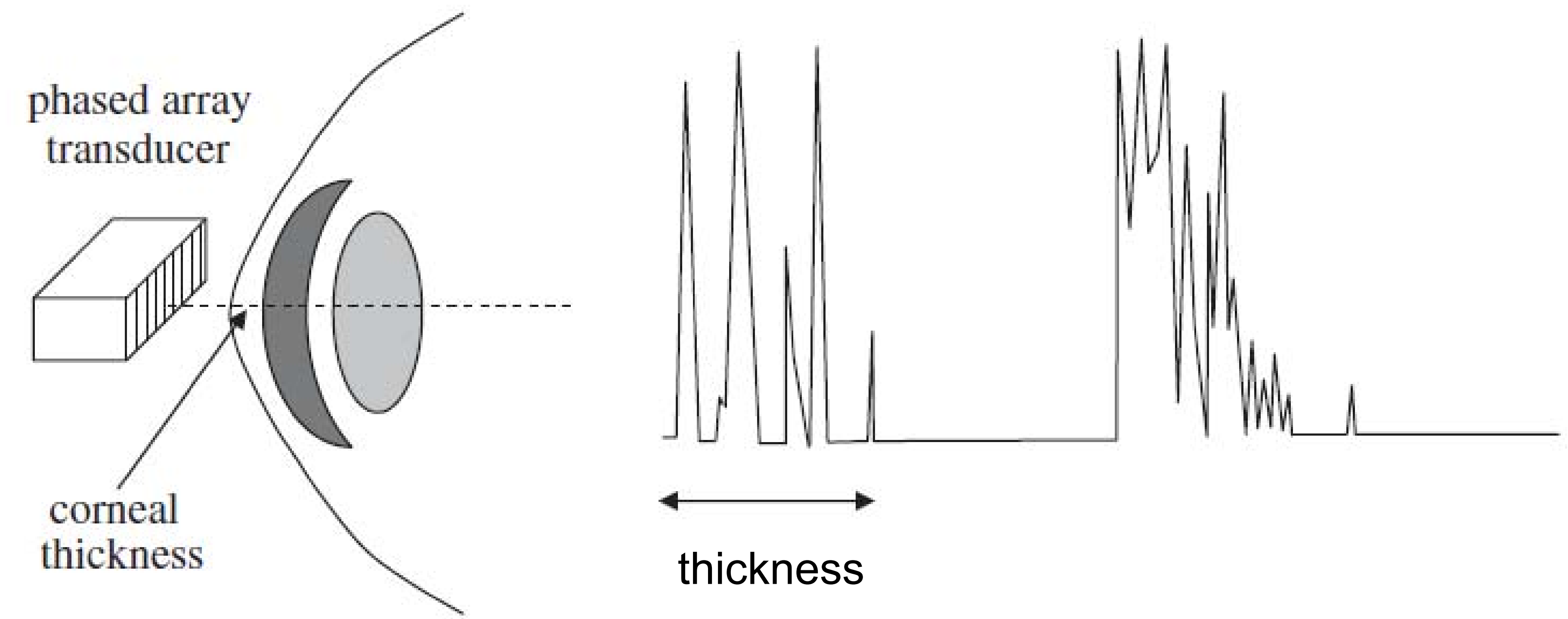


A-Mode (Amplitude)

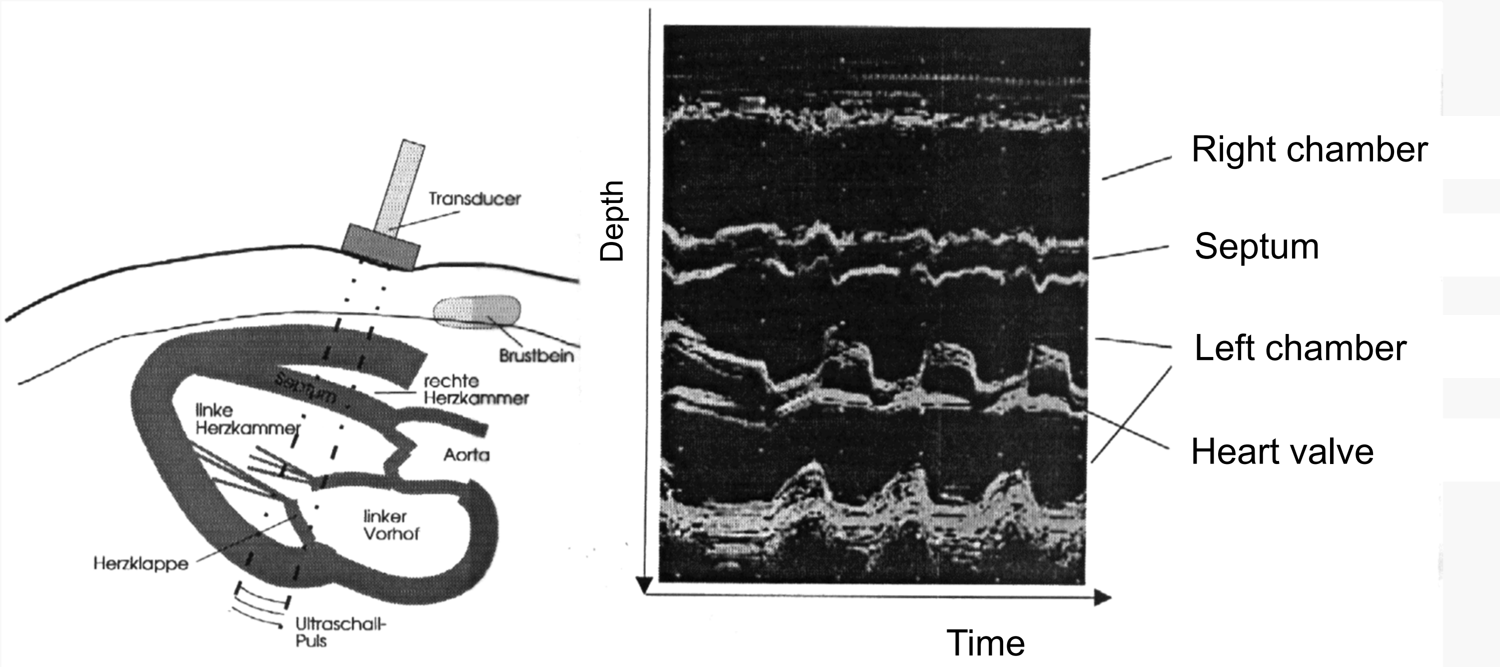
→ one spatial dimension

Corneal Pachymetry

= Measuring the thickness of the cornea



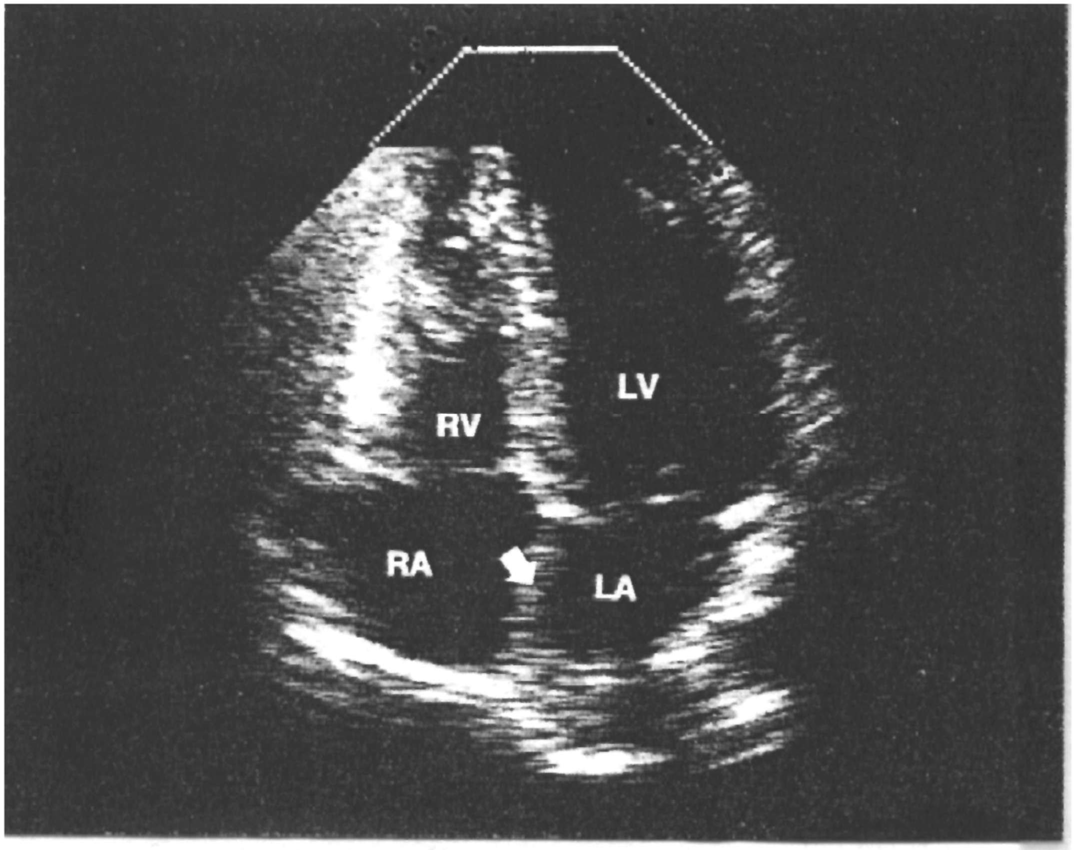
M-Mode



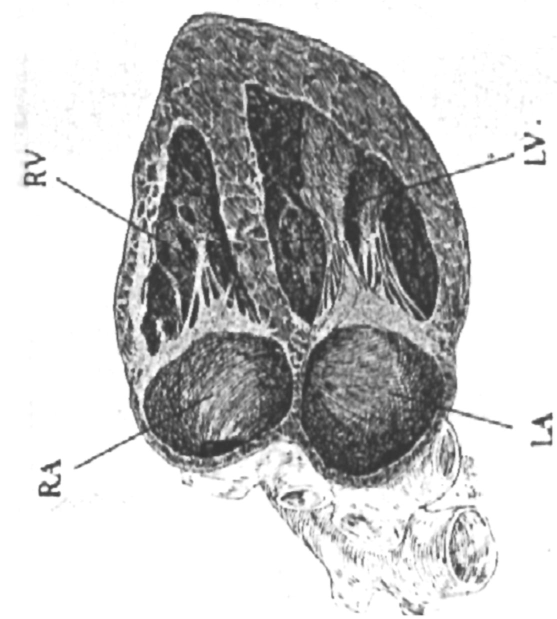
M- Mode (Motion)

→ one spatial dimension, one temporal dimension

B-Mode



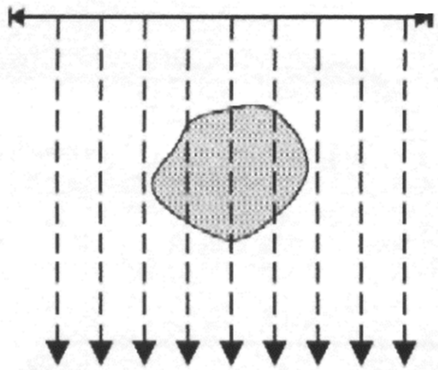
Human heart (upside down)



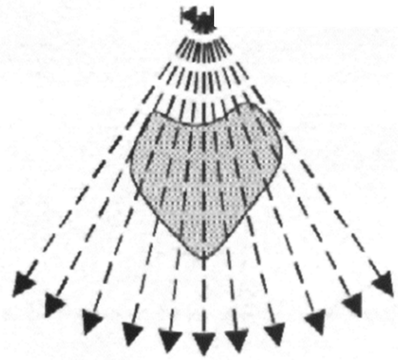
B-mode (Brightness)

→ two spatial dimensions

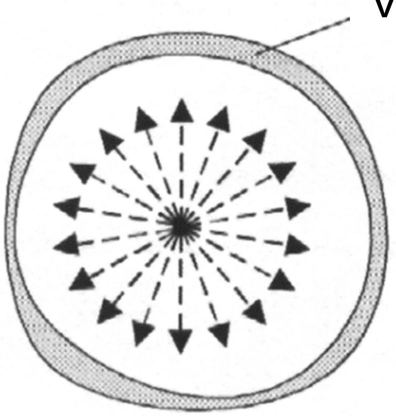
Scanning Procedures



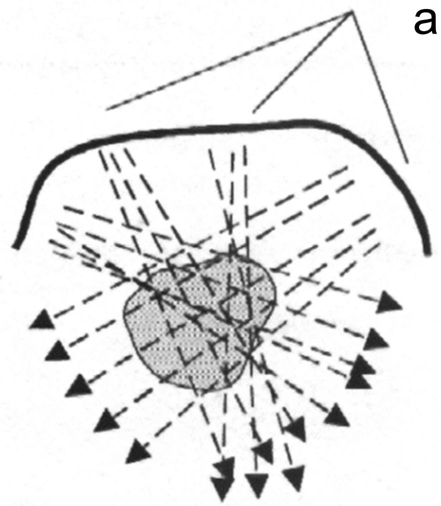
Parallel Scan



Sector Scan



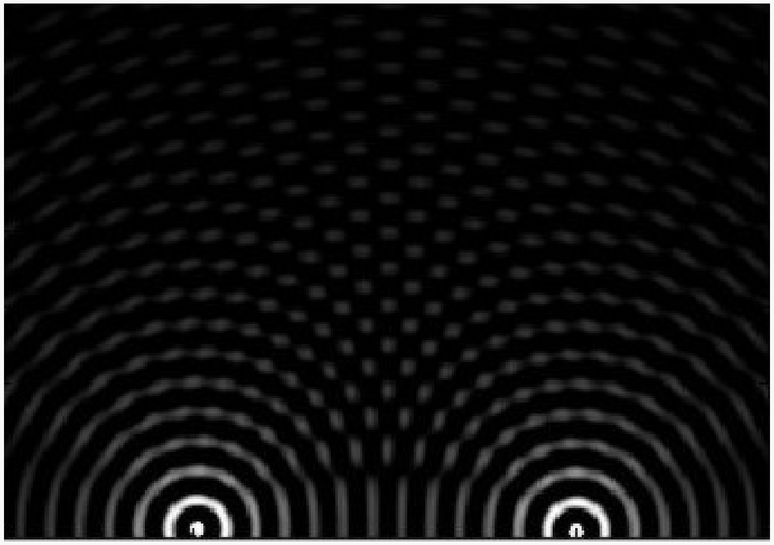
Radial Scan



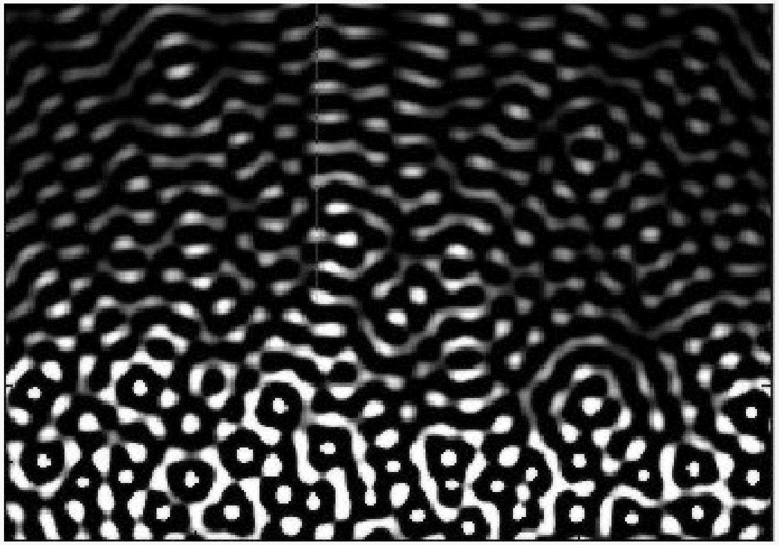
Compound Scan

Speckle

Sound interference patterns



Two sources



Many sources

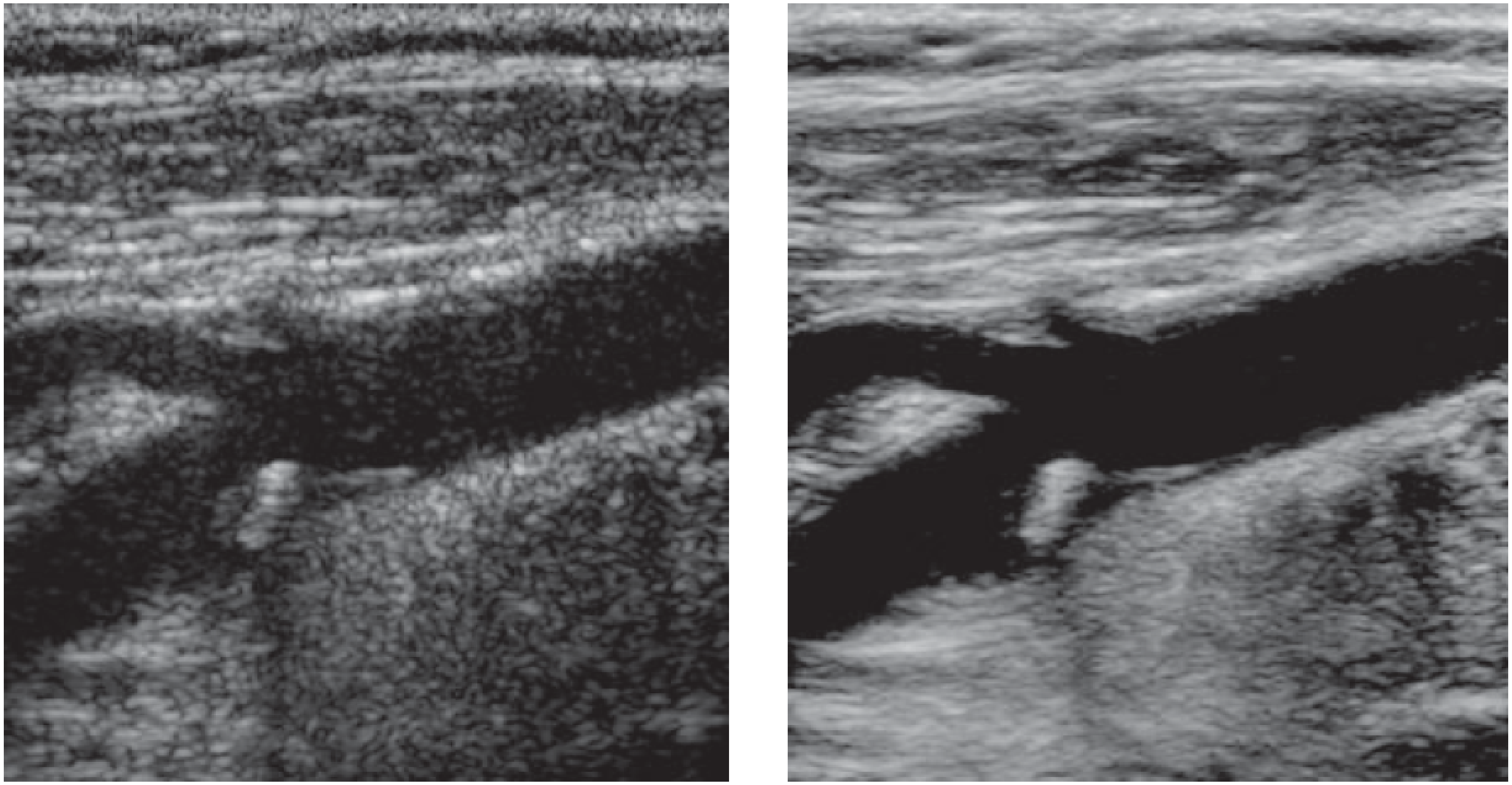
Speckle = interference of scattered waves

→ characteristic length = $\lambda / 2$

Speckle Reduction with Compound Imaging

Standard B-mode

Compound =
multiple angles, images averaged



Carotid bifurcation