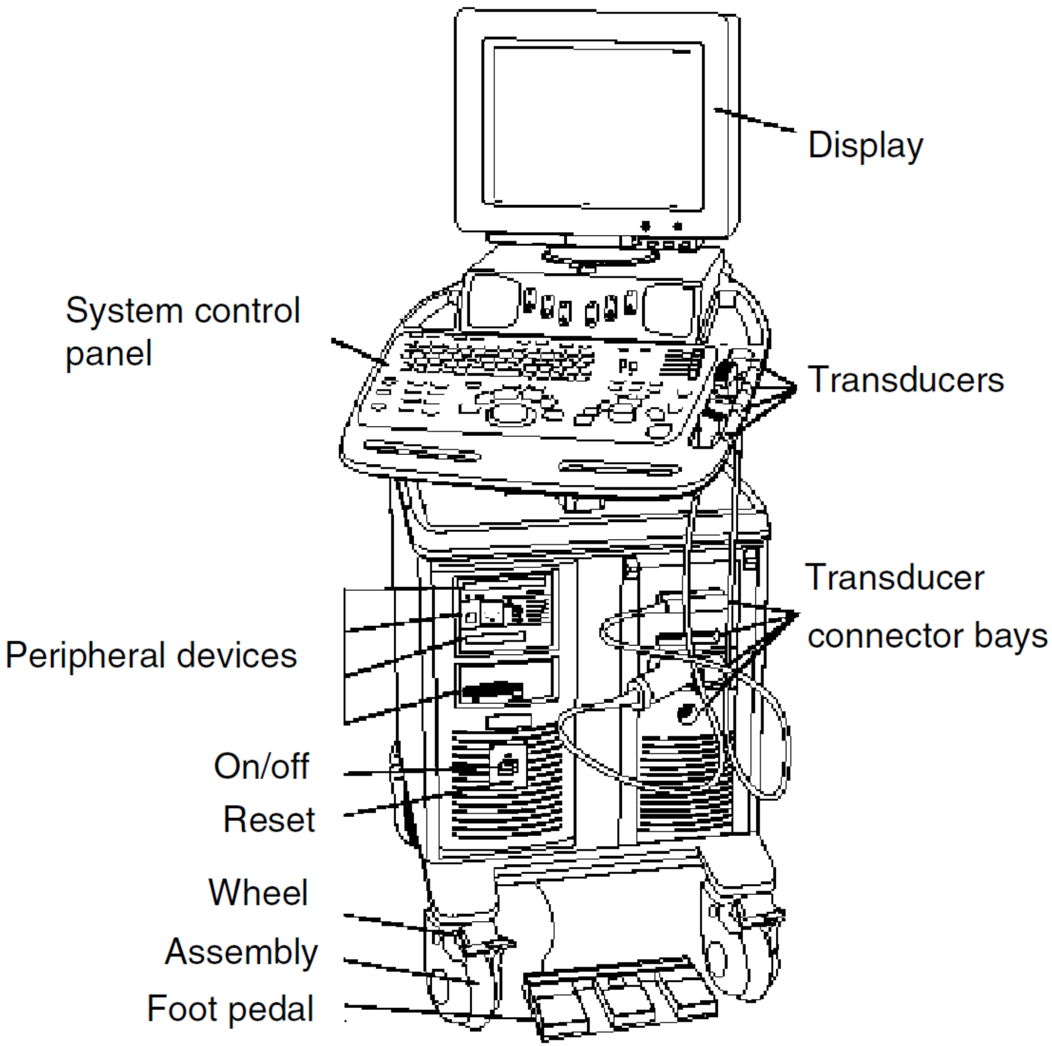
MEDICAL EQUIPMENT (4)
TOPIC 1: ULTRASOUND IMAGING

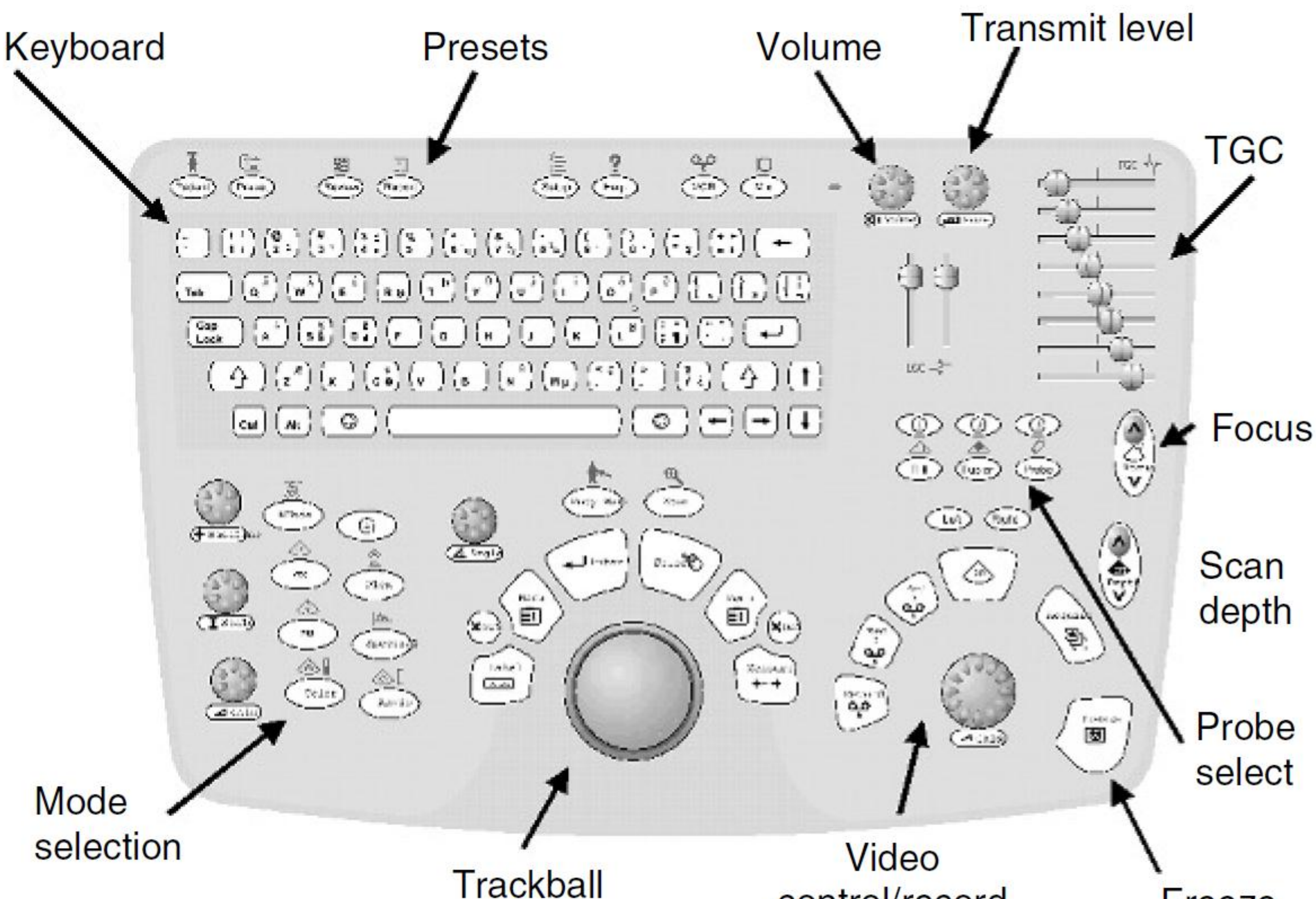
Term 2 - 2013

Prof. Yasser Mostafa Kadah

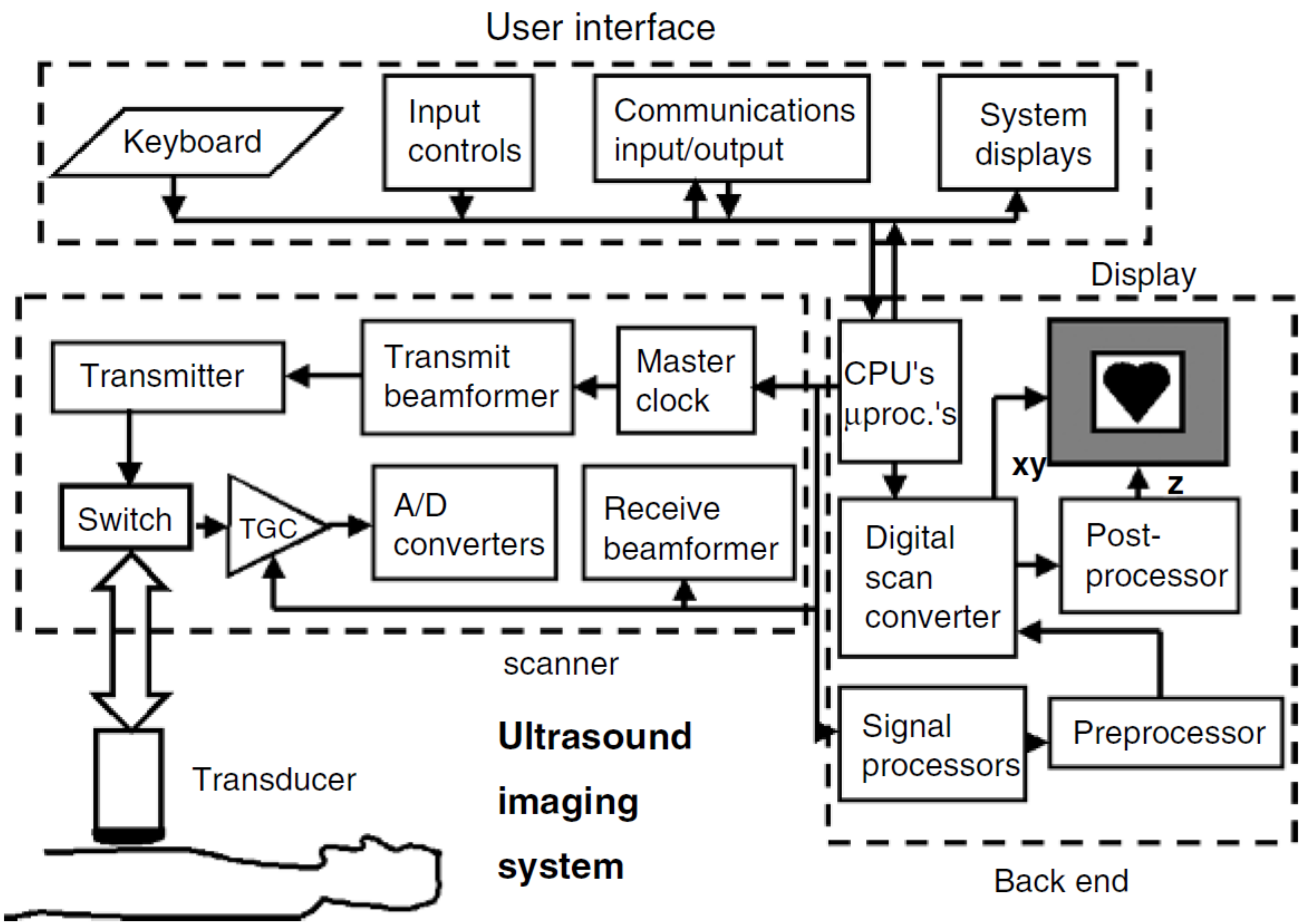
Ultrasound Imaging System: External Look



Keyboard Controls



Block Diagram



Ultrasound Transducers

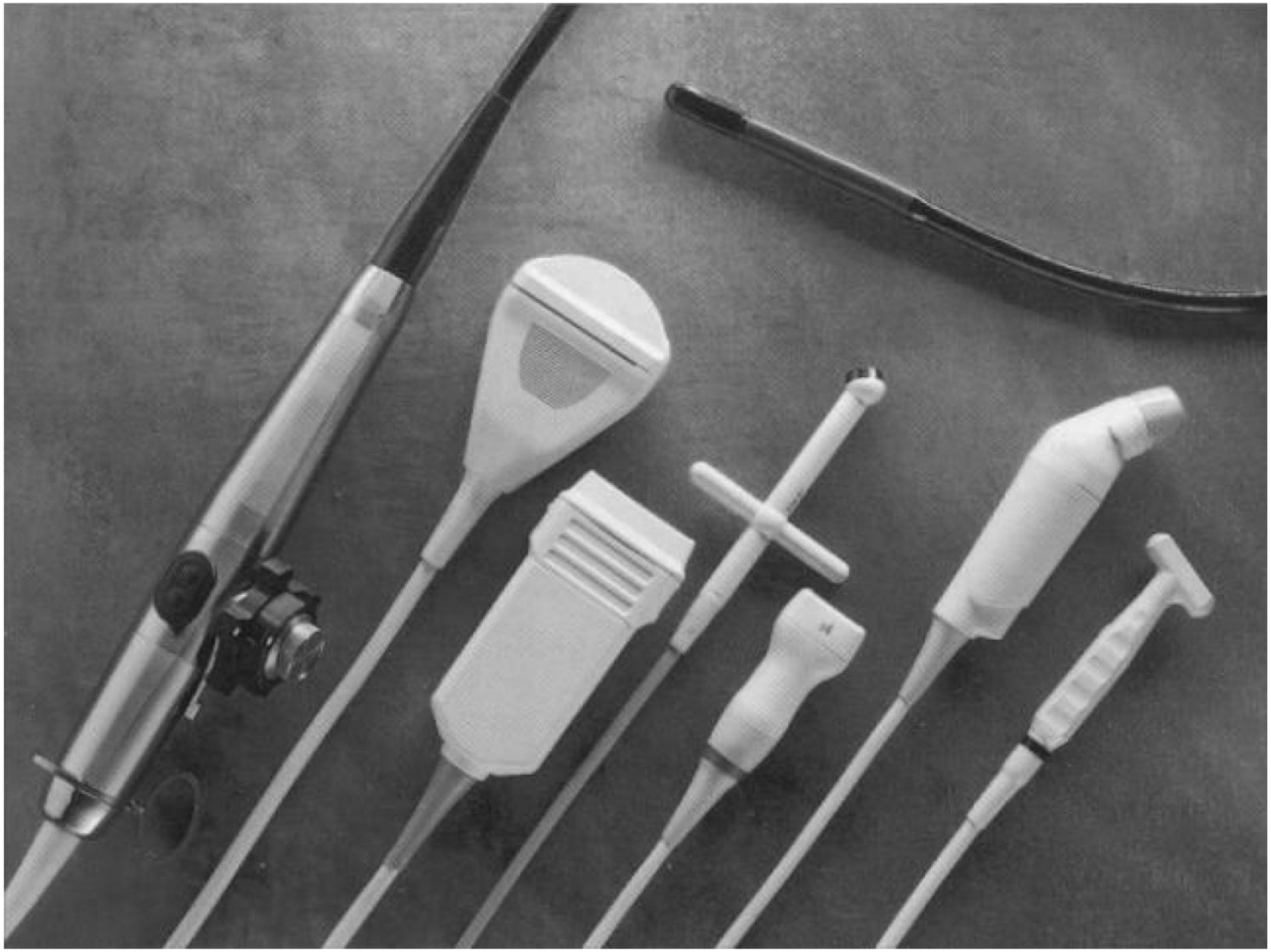
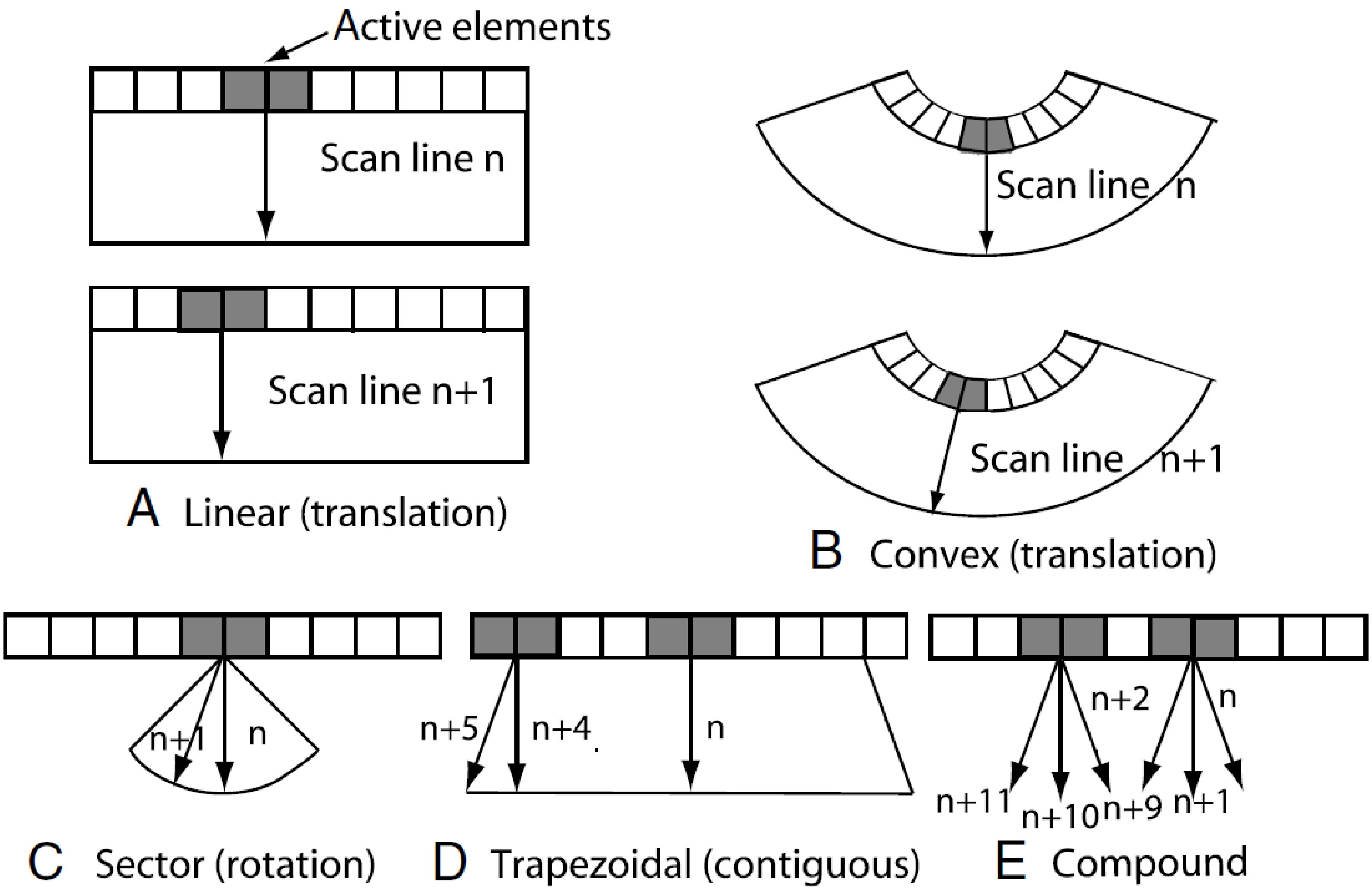


Image Formats



Major Modes:
B-Mode (2D Mode)

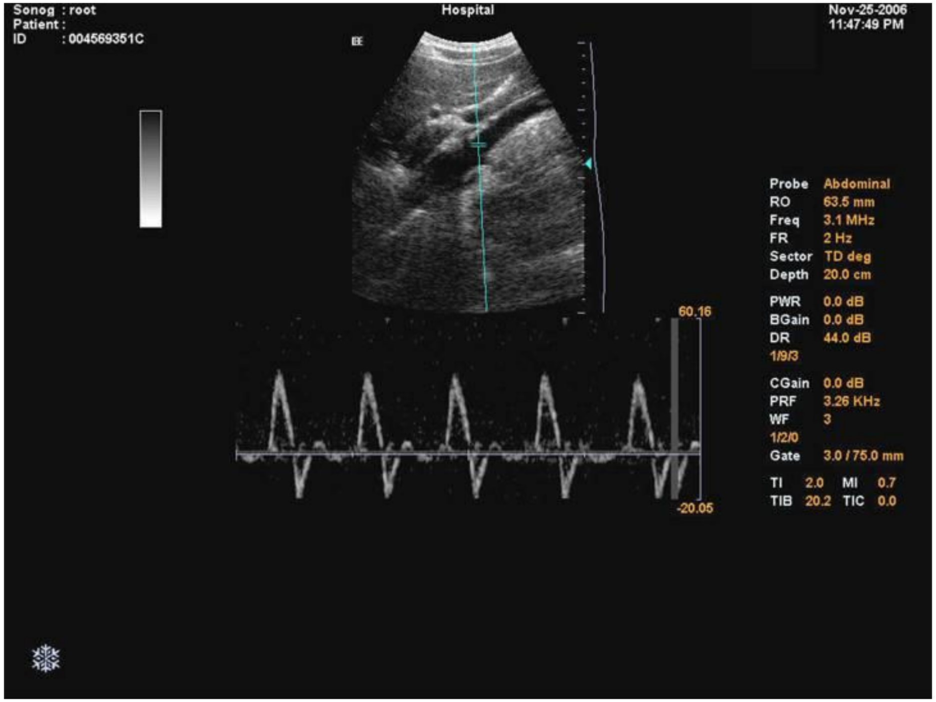
- Brightness-modulated image in which depth is along the z axis and azimuth is along the x axis.
  - The position of the echo is determined by its acoustic transit time and beam direction in the plane.

Major Modes:
M-Mode

- Brightness modulated, where depth is the y deflection (fast time), and the x deflection is the same imaging line shown as a function of slow time.
  - Time history of single line at the same position over time

Major Modes: Doppler-Mode

- This is the presentation of the Doppler spectrum
  - Continuous wave (CW) Doppler
  - Pulsed wave (PW) Doppler

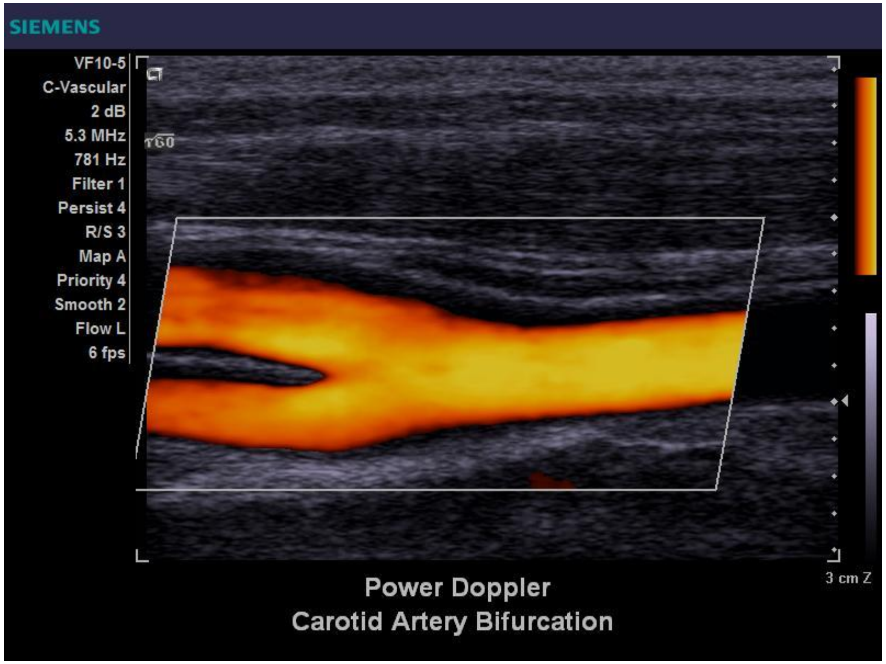


Major Modes:
Color Flow Mapping Mode (CFM)

- Spatial map overlaid on a B-mode gray-scale image that depicts an estimate of blood flow mean velocity
  - Direction of flow encoded in colors (blue away from the transducer and red toward it)
  - Amplitude of mean velocity by brightness, and turbulence by a third color (often green).

Major Modes:
Power Doppler Mode

- This color-coded image of blood flow is based on intensity rather than on direction of flow, with a paler color representing higher intensity.
  - It is also known as “angio”

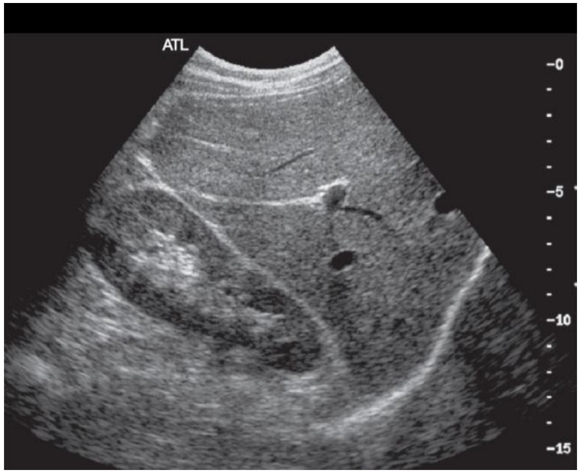


Secondary Modes

- Duplex
  - Presentation of two modes simultaneously: usually 2D and pulsed (wave) Doppler
- Triplex
  - Presentation of three modes simultaneously: usually 2D, color flow, and pulsed Doppler
- 3D
  - Display or Surface/volume rendering used to visualize volume composed of multiple 2D slices.
- 4D
  - A 3D image moving in time

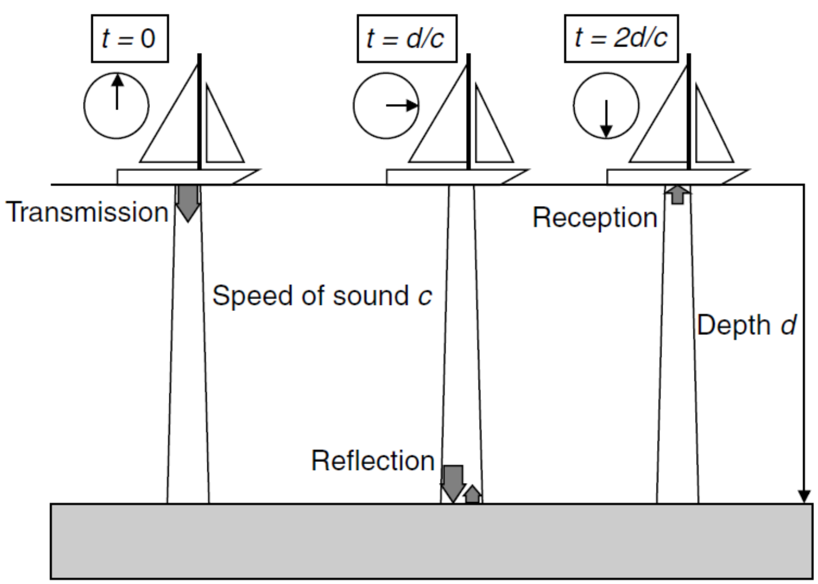
Introduction to B-mode imaging

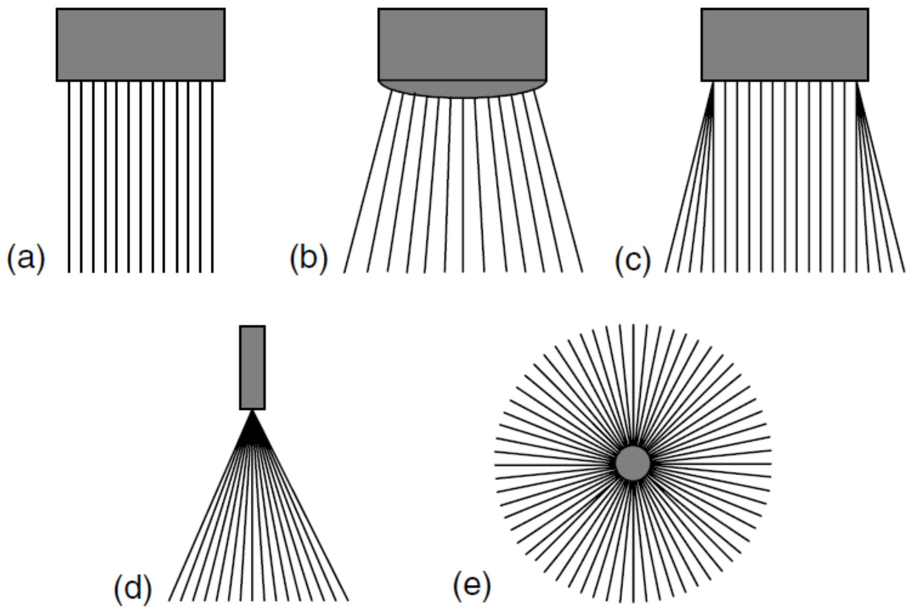
- B-mode image is an anatomic cross-sectional image
- Constructed from echoes (reflection and scattering) of waves
- Echo is displayed at a point in image, which corresponds to relative position of its origin within the body cross section
- Brightness of image at each point is related to strength of echo
  - Term B-mode stands for Brightness-mode



Echo Ranging

- To display each echo in a position corresponding to that of the interface or feature (known as a target) that caused it, the B-mode system needs two pieces of information:
  - (1) Range (distance) of the target from the transducer
  - (2) Position and orientation of the ultrasound beam





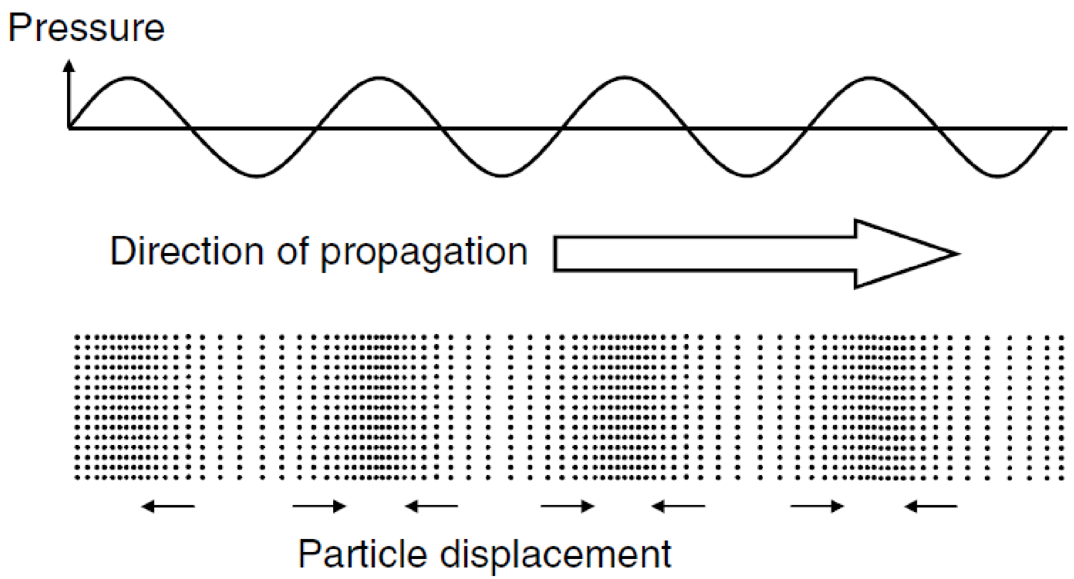
Ultrasound Physics

- Sound waves used to form medical images are longitudinal waves, which propagate (travel) only through a physical medium (usually tissue or liquid)
  - Characterized by frequency, wavelength, speed and phase

$$c = f\lambda$$

$$\text{Speed of sound } c = \sqrt{k/\rho}$$

Material	c (m s^{-1})
Liver	1578
Kidney	1560
Amniotic fluid	1534
Fat	1430
Average tissue	1540
Water	1480
Bone	3190–3406
Air	333



Ultrasound Physics

- Medical ultrasound frequencies used in the range 2–15 MHz
  - Higher frequencies are now utilized for special applications
  - Resolution proportional to wavelegth

f (MHz)	λ (mm)
2	0.77
5	0.31
10	0.15
15	0.1

- Acoustic impedance
  - p is the local pressure $z = p/v$ he local particle velocity.
  - Analogous to electrical impedance (or resistance R)

$$z = \sqrt{\rho k} \quad = \rho c$$

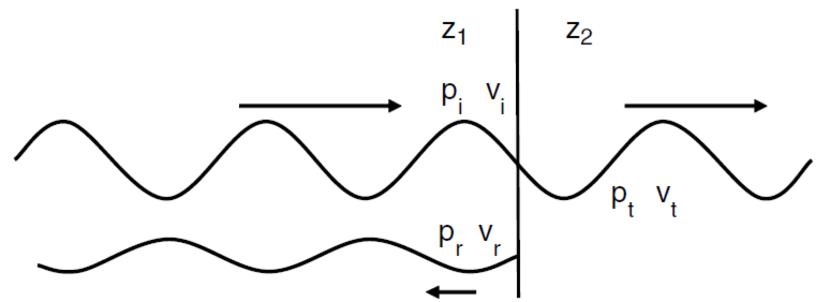
Material	z (kg m^{-2} s^{-1})
Liver	1.66×10^6
Kidney	1.64×10^6
Blood	1.67×10^6
Fat	1.33×10^6
Water	1.48×10^6
Air	430
Bone	6.47×10^6

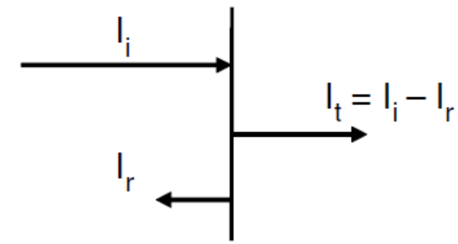
Ultrasound Physics

- Reflection: Large Interfaces

$$R_A = \frac{p_r}{p_i} = \frac{z_2 - z_1}{z_2 + z_1}$$

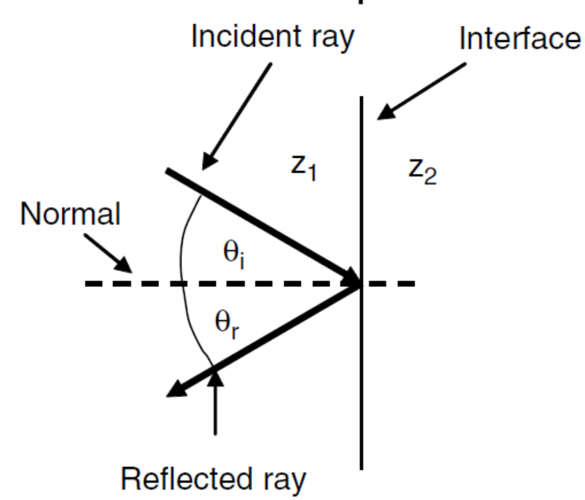
$$\frac{I_r}{I_i} = R_i = R_A^2$$





Interface	R_A
Liver–kidney	0.006
Kidney–spleen	0.003
Blood–kidney	0.009
Liver–fat	0.11
Liver–bone	0.59
Liver–air	0.9995

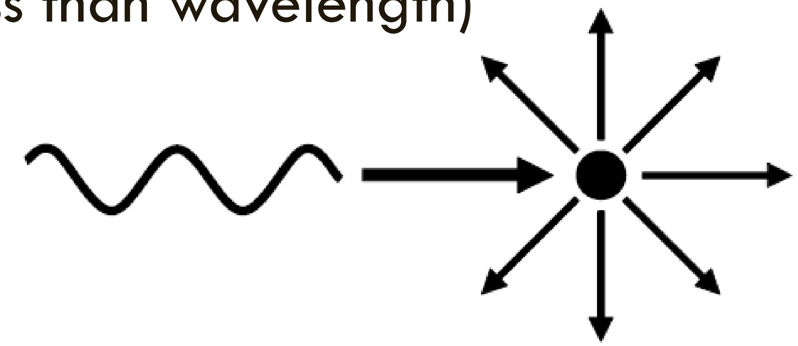
$$\theta_r = \theta_i$$



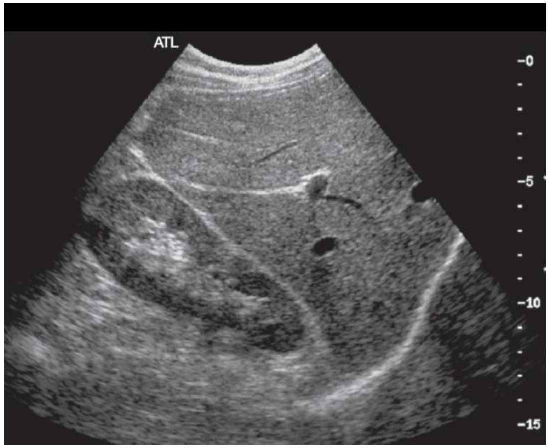
Ultrasound Physics

- Scattering: Small Interfaces (size less than wavelength)

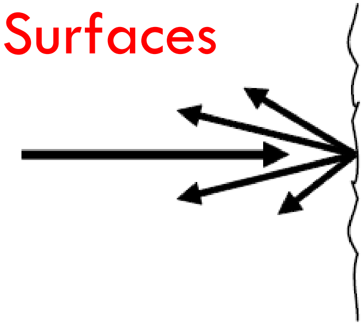
$$W_s \propto \frac{d^6}{\lambda^4} \propto d^6 f^4$$



- Two important aspects of scattering:
  - Ultrasonic power scattered back is small compared to reflections
  - Beam angle-independent appearance in the image unlike reflections



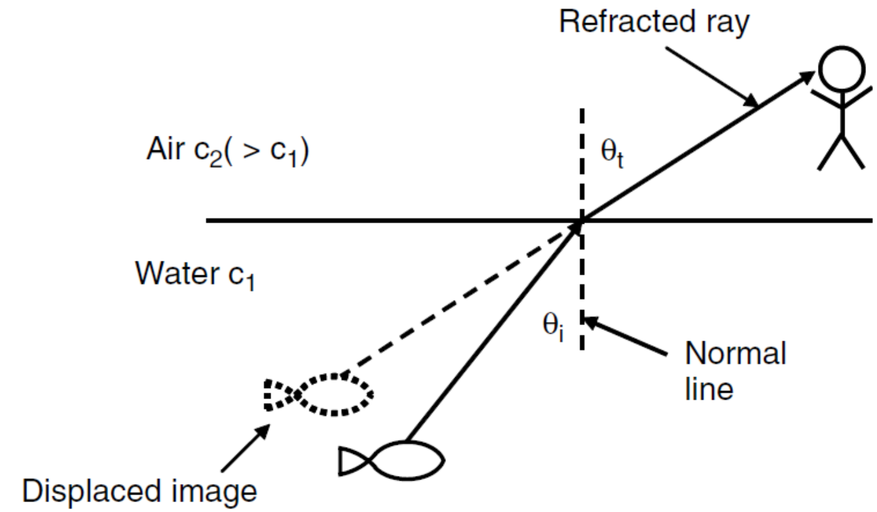
- Diffuse Reflection: Rough Surfaces



Ultrasound Physics

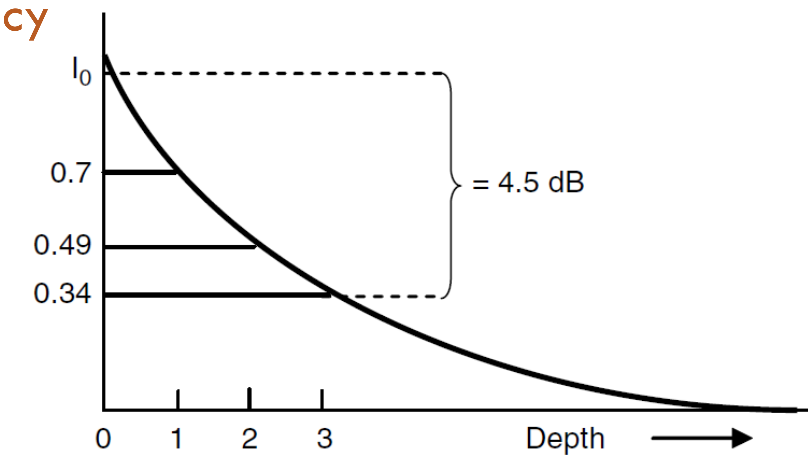
- Refraction: Snell's law

$$\frac{\sin\theta_i}{\sin\theta_t} = \frac{c_1}{c_2}$$



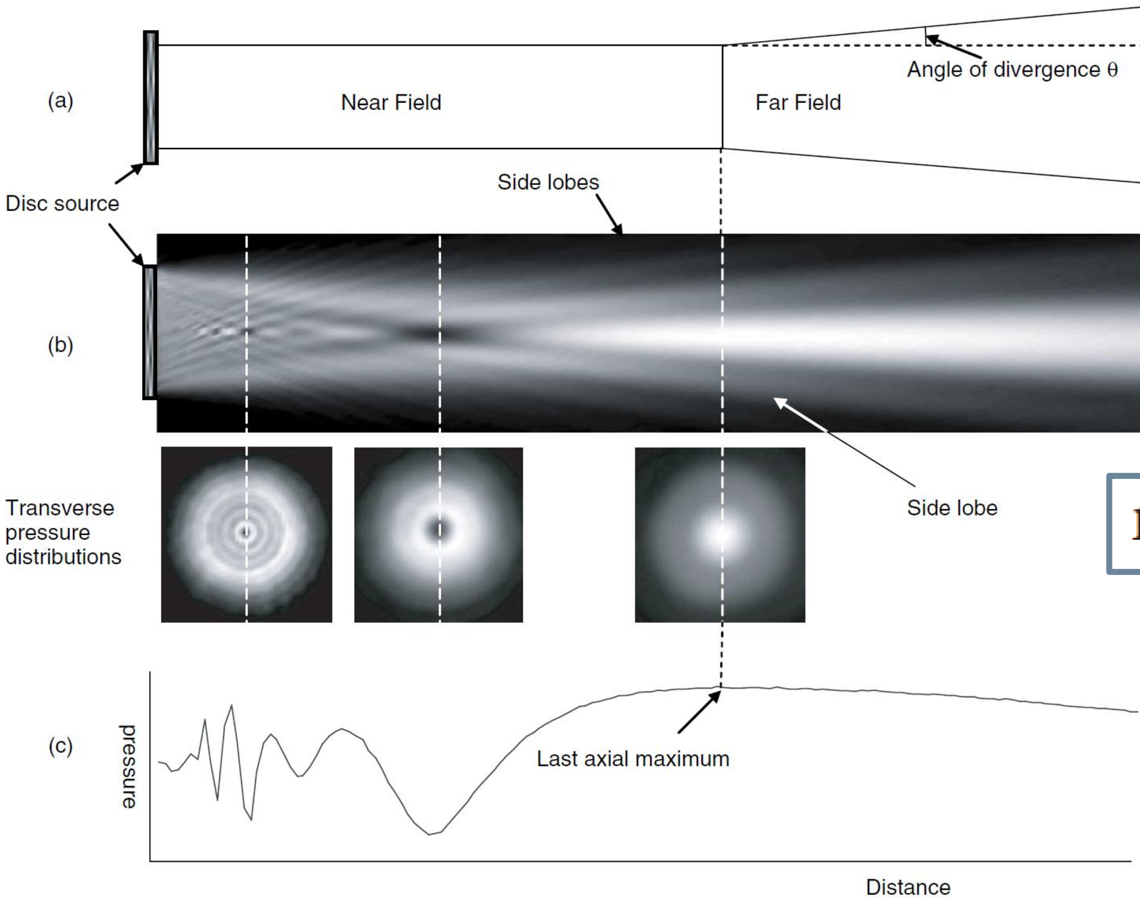
- Attenuation: gradual loss of beam energy
  - Depends on both distance and frequency

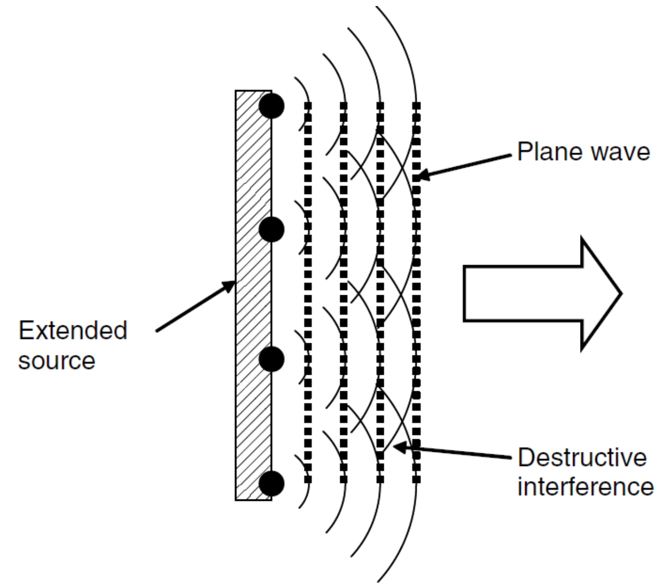
Tissue	Attenuation (dB cm^{-1} MHz^{-1})
Liver	0.399
Brain	0.435
Muscle	0.57
Blood	0.15
Water	0.02
Bone	22



Ultrasound Physics

- Interference and diffraction
  - Constructive/Destructive interference



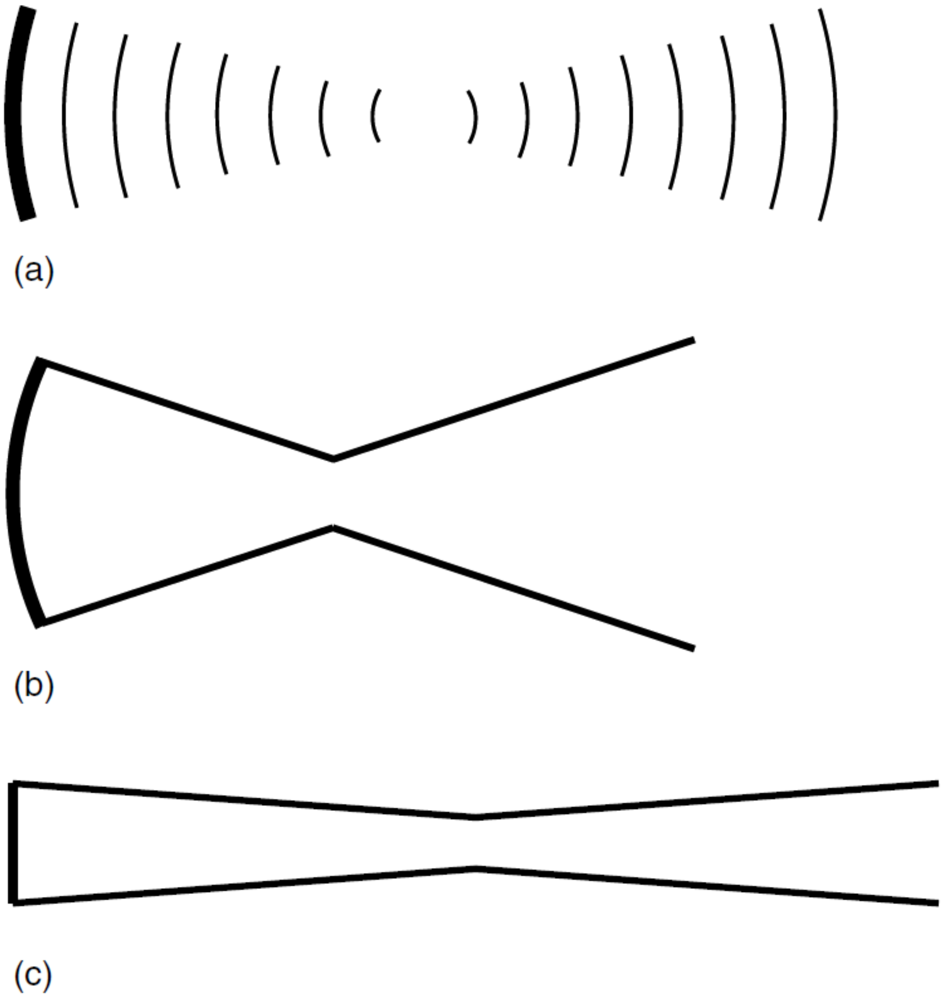


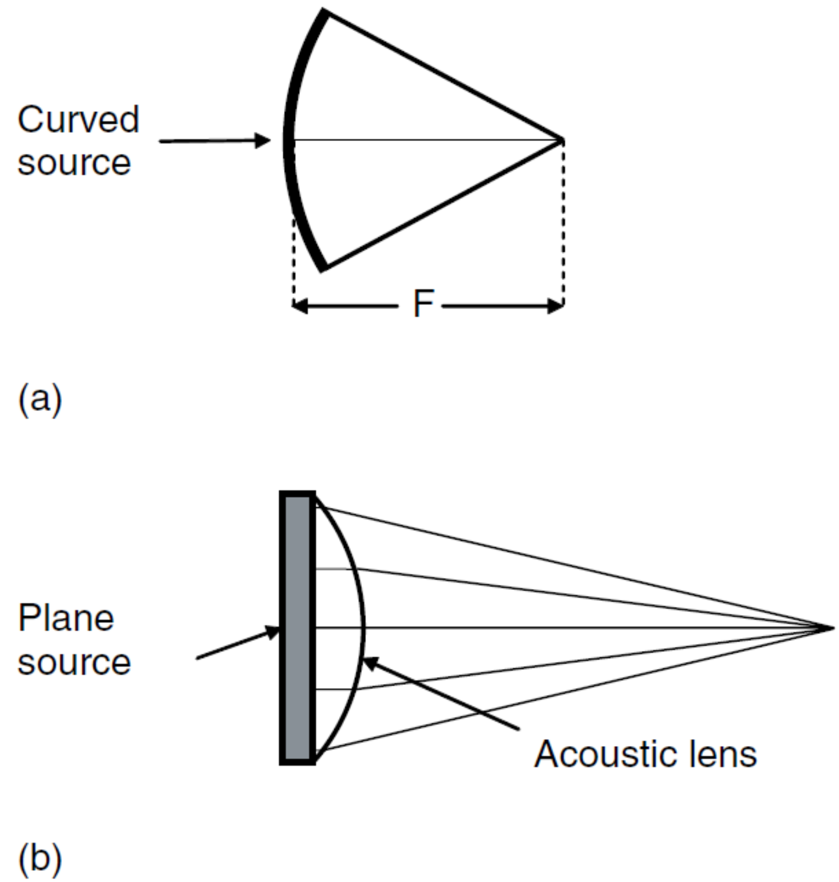
$$\text{near field length} = a^2/\lambda$$

$$\sin\ \theta = 0.61\ (\lambda/a)$$

Ultrasound Physics

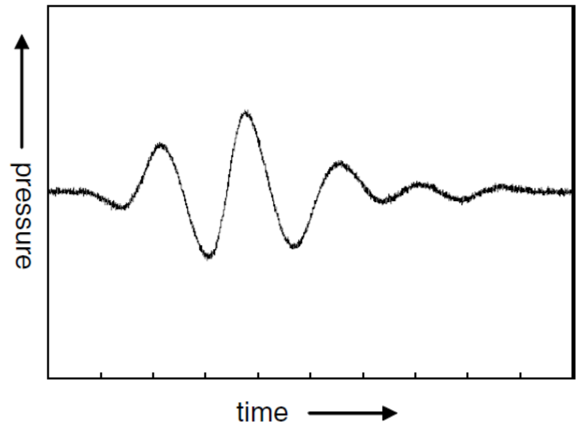
- Focusing: narrower ultrasound beam

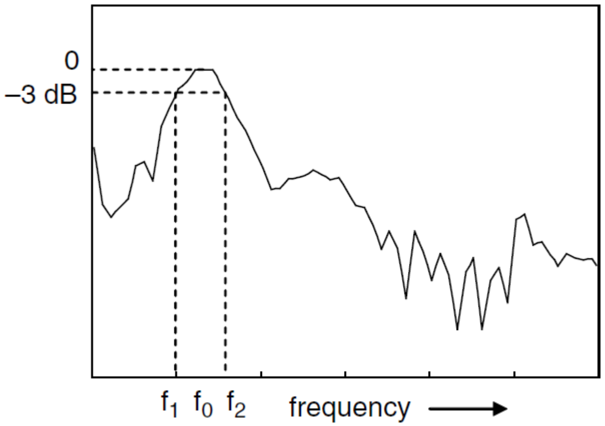




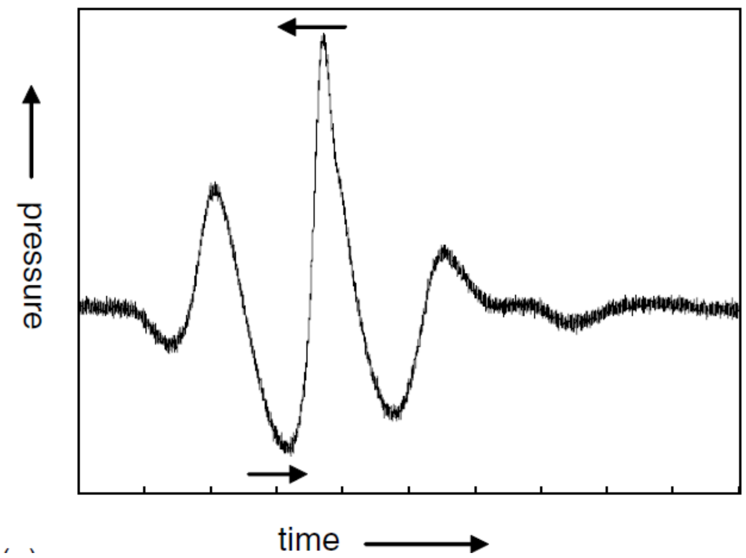
Ultrasound Physics

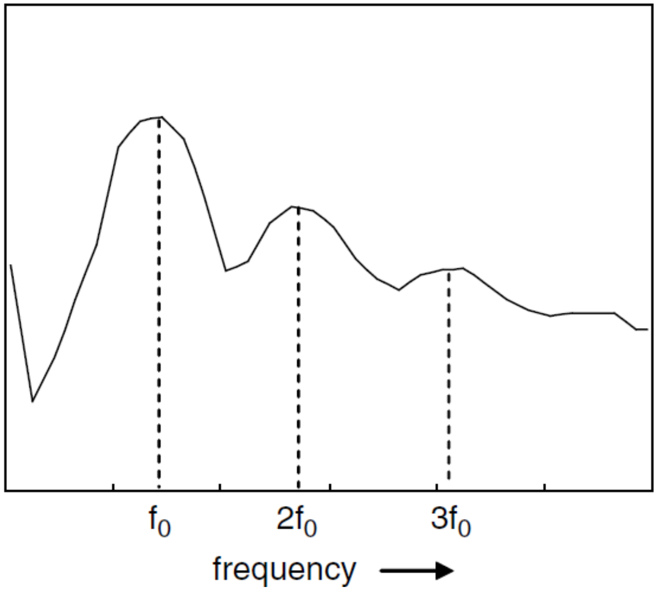
- Ultrasound pulse





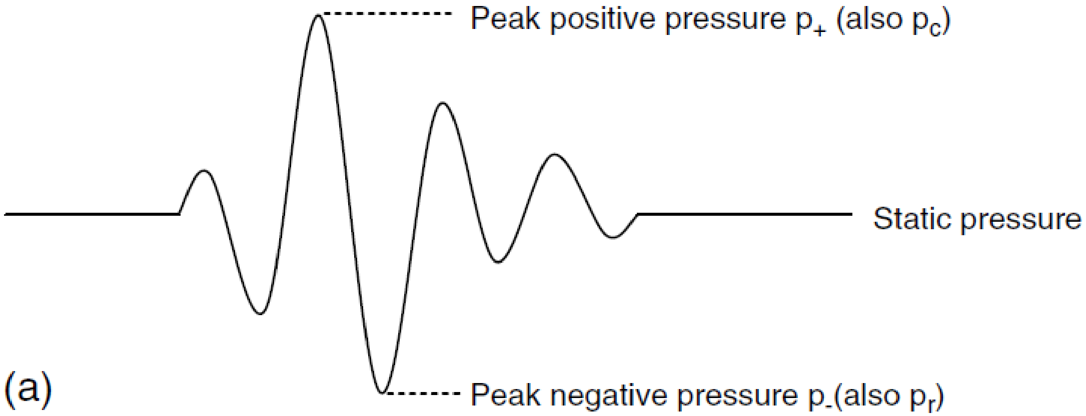
- Harmonic Imaging



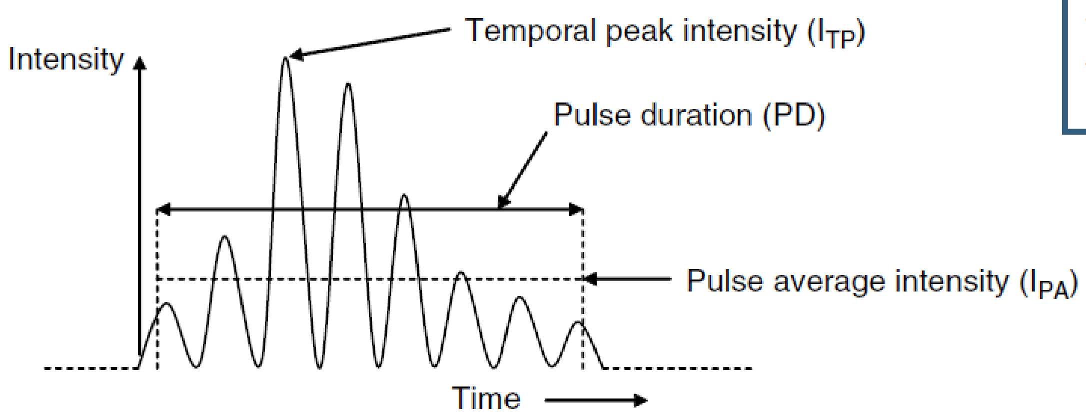


Ultrasound Physics

- Acoustic pressure and intensities within ultrasound beam



$$I = \frac{p^2}{z}$$



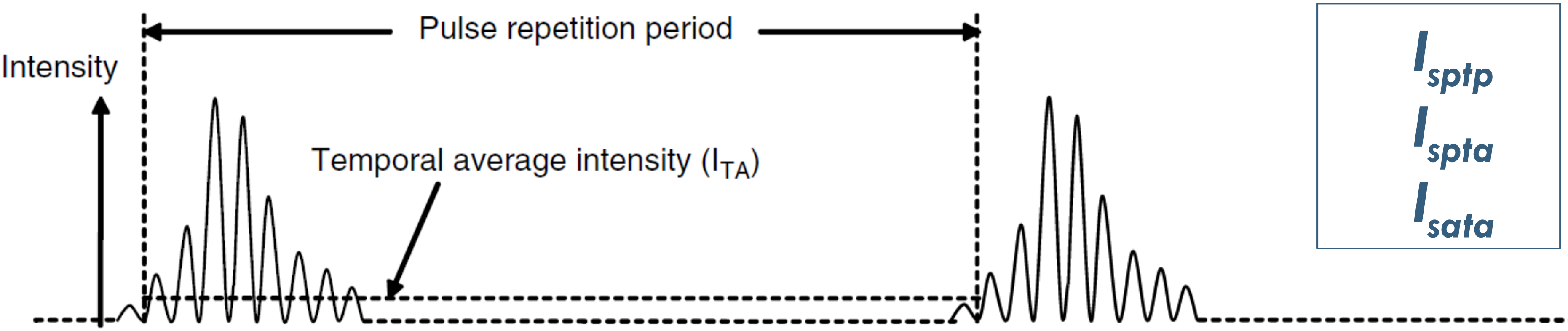
(b)

$$PD = 1.25 \times (T_{90} - T_{10})$$

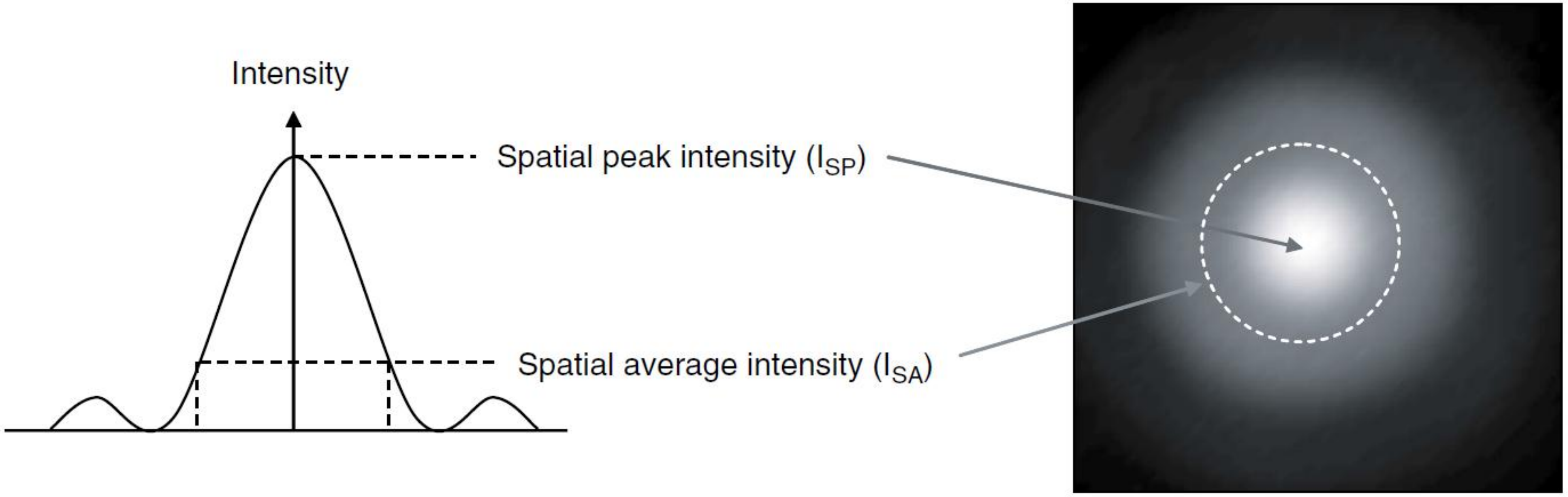
$$I_{PA} = PII / PD$$

Ultrasound Physics

- Acoustic pressure and intensities within ultrasound beam

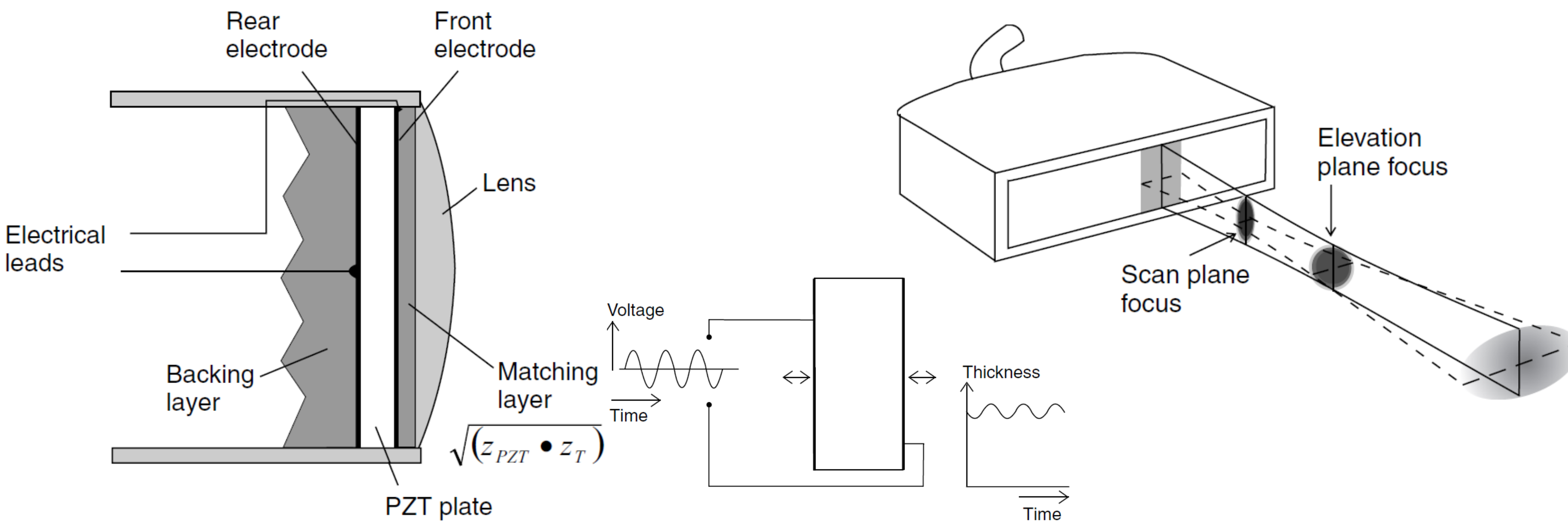


I_{sptp}
I_{spta}
I_{sata}



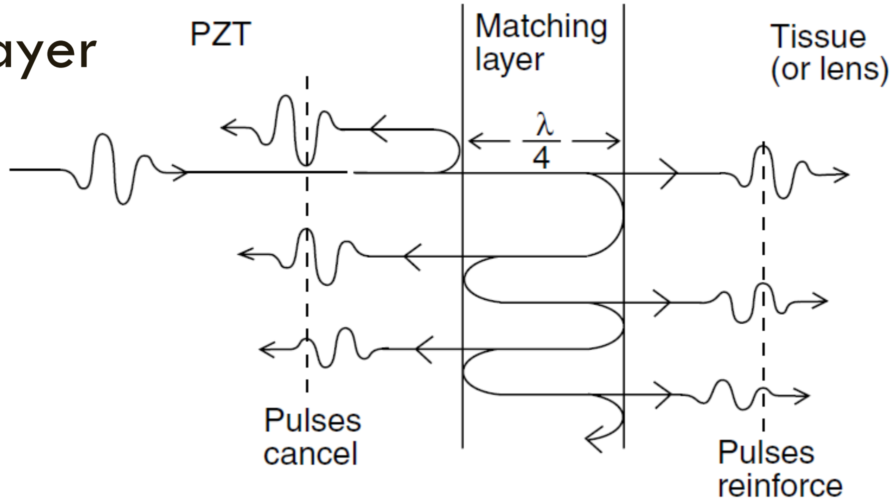
Transducers and Beamforming

- Transducer: device that actually converts electrical transmission pulses into ultrasonic pulses and, conversely, ultrasonic echo pulses into electrical echo signals
- Beamformer: part of scanner that determines the shape, size and position of the interrogating beams by controlling electrical signals to and from the transducer array elements

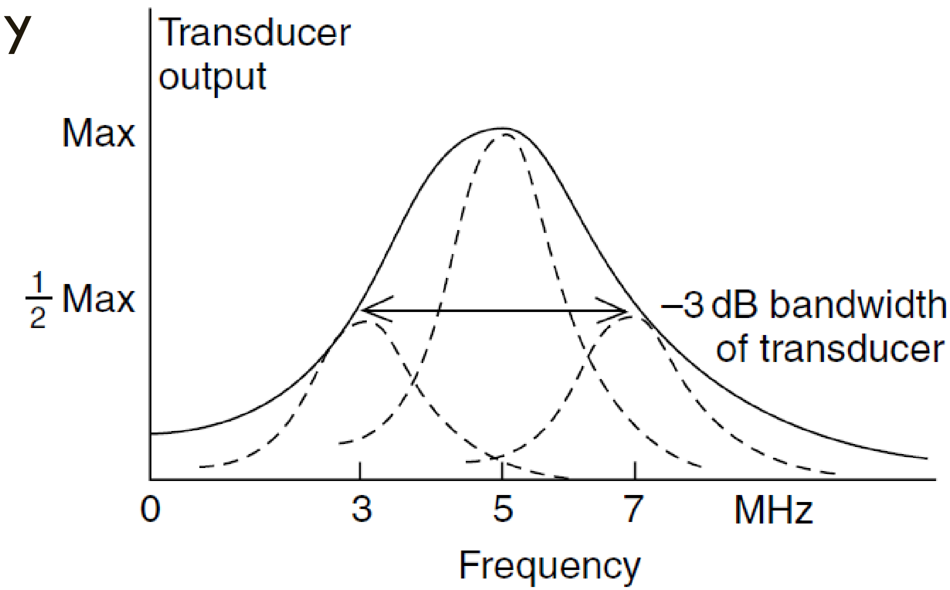


Transducers and Beamforming

- Quarter-wavelength matching layer

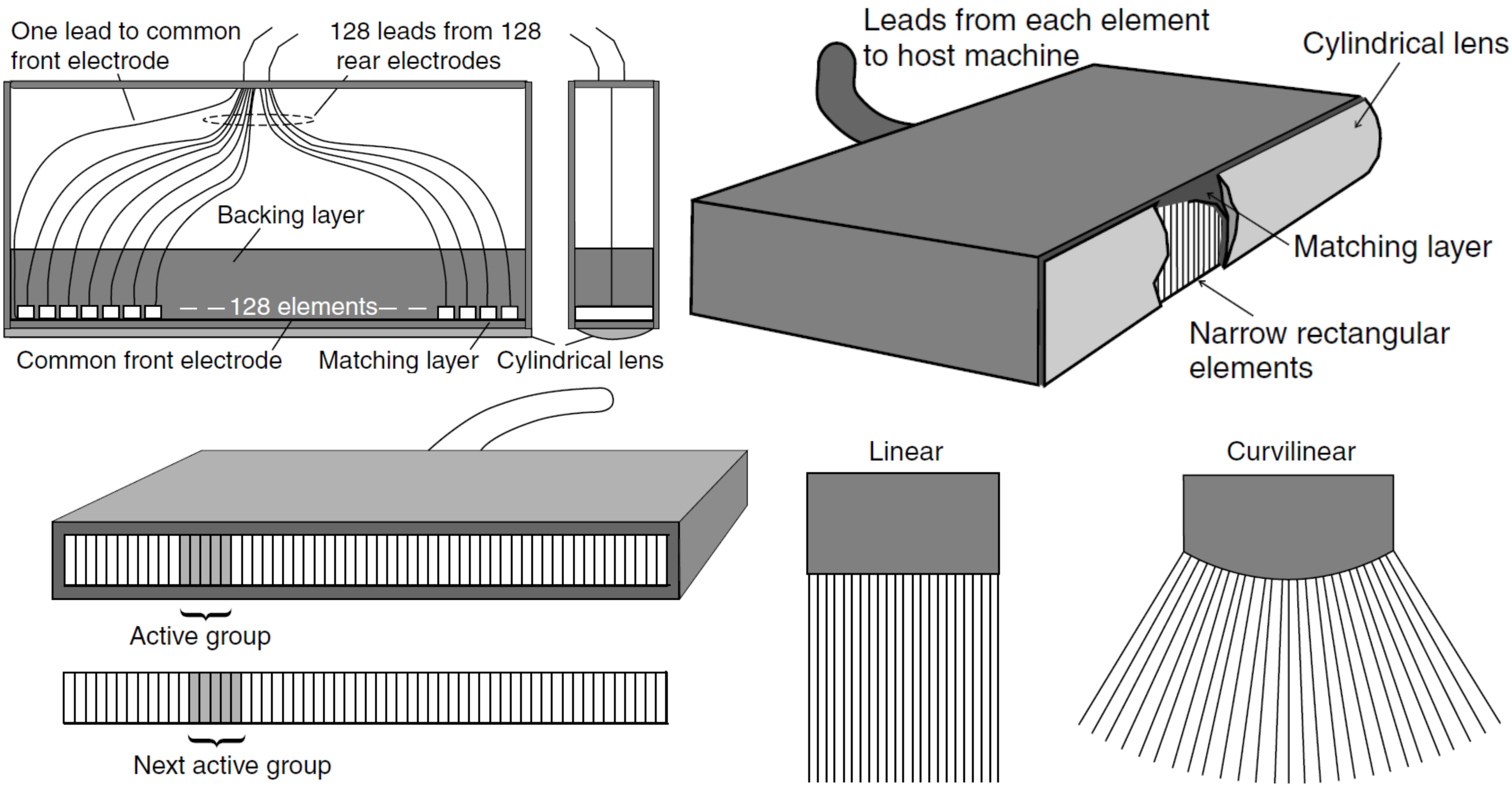


- Bandwidth for multi-frequency transducers



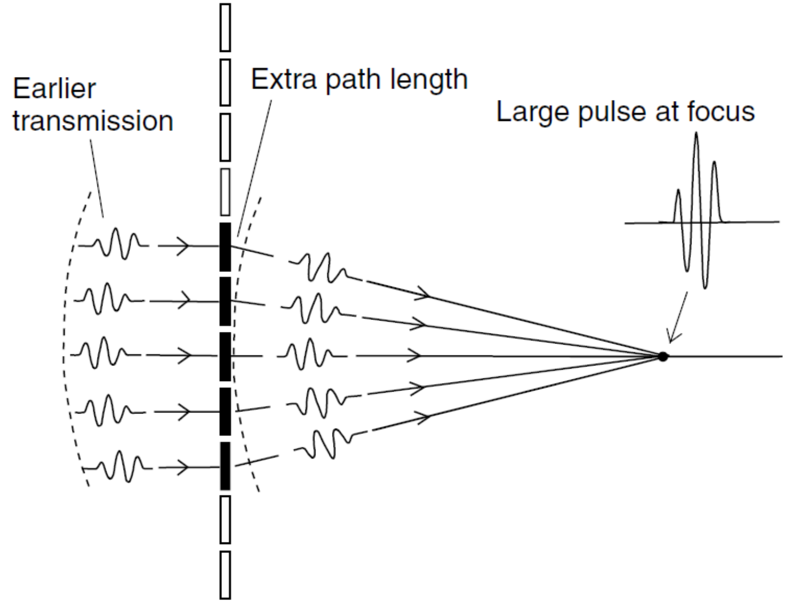
Transducers and Beamforming

- Linear- and curvilinear-array transducers

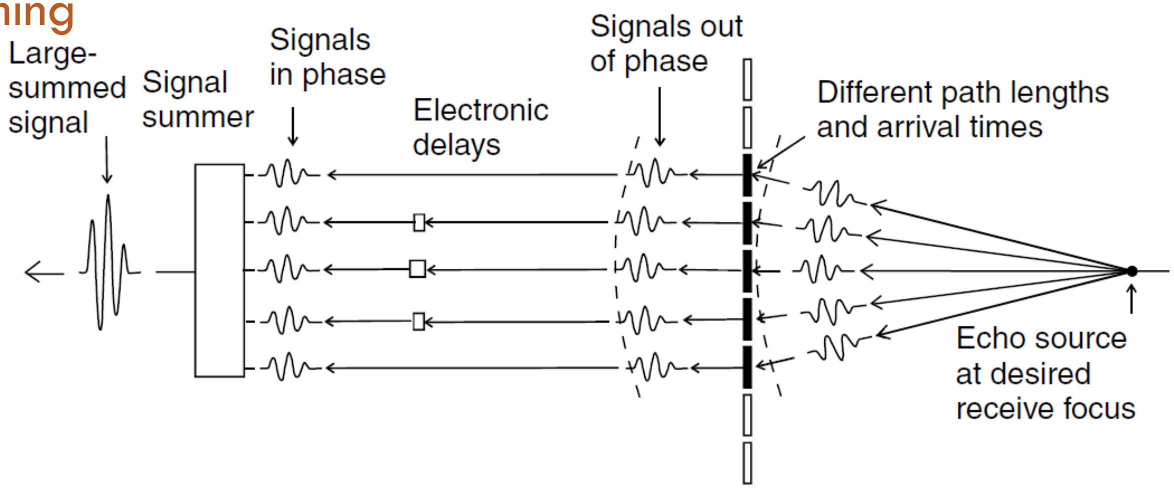


Transducers and Beamforming

- Transmission Focusing

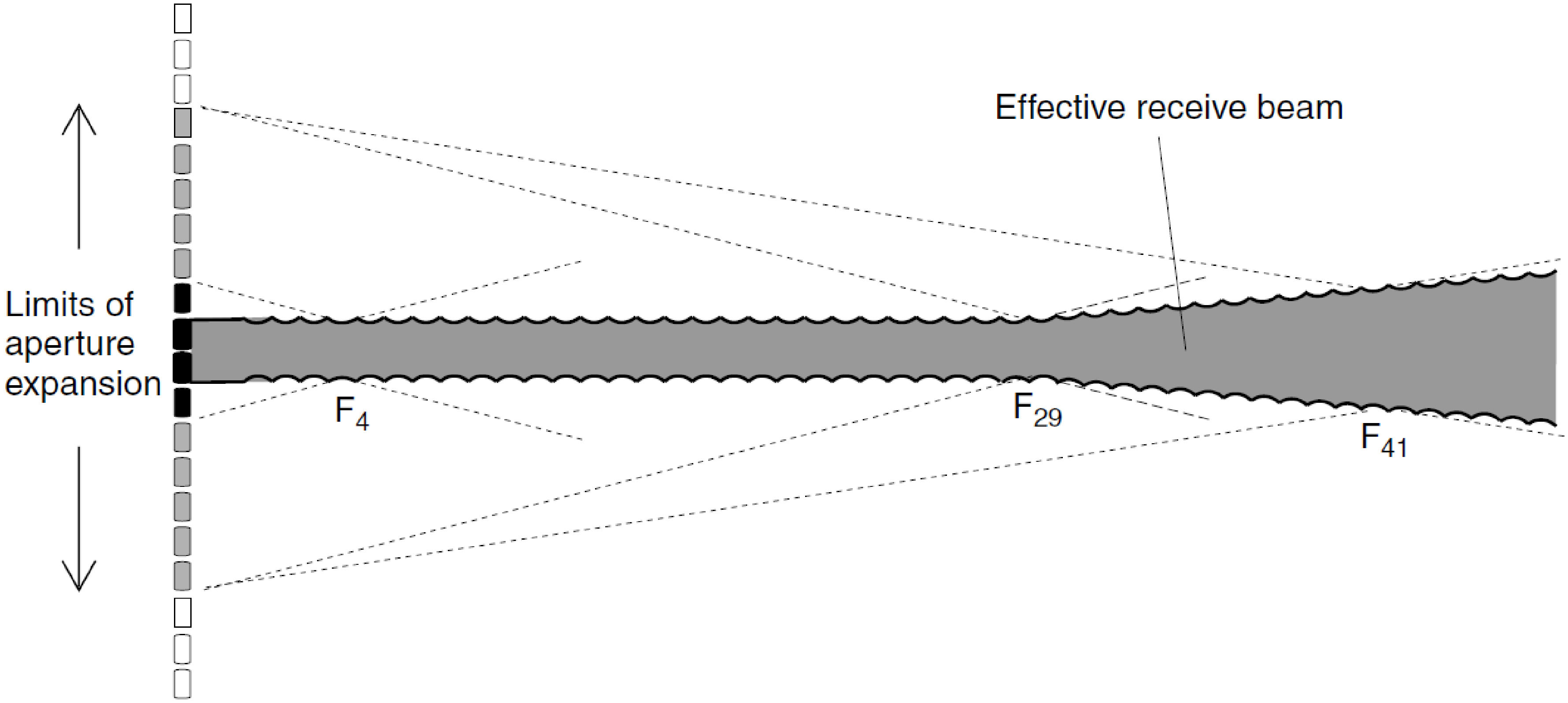


- Reception focusing
  - Delay-Sum beamforming



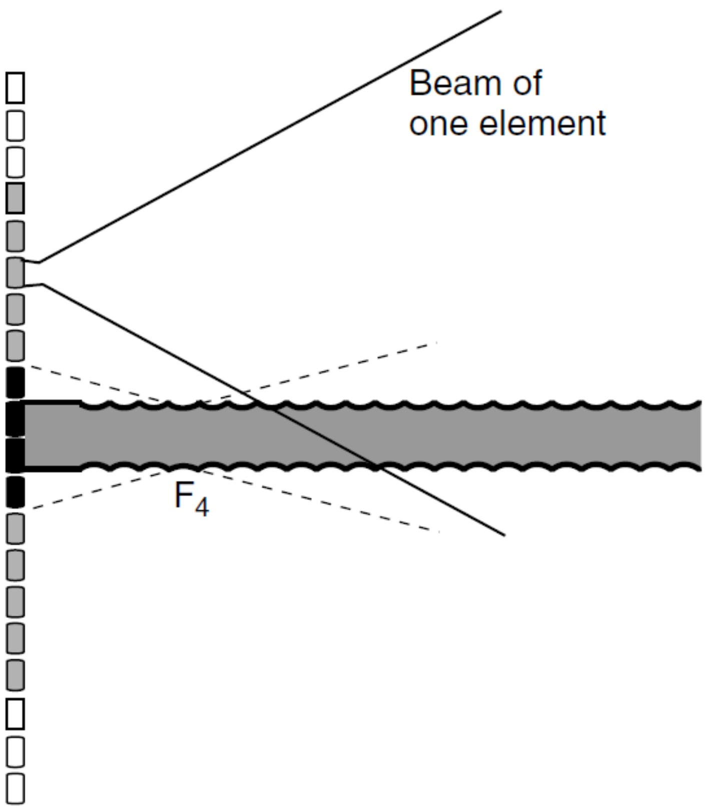
Transducers and Beamforming

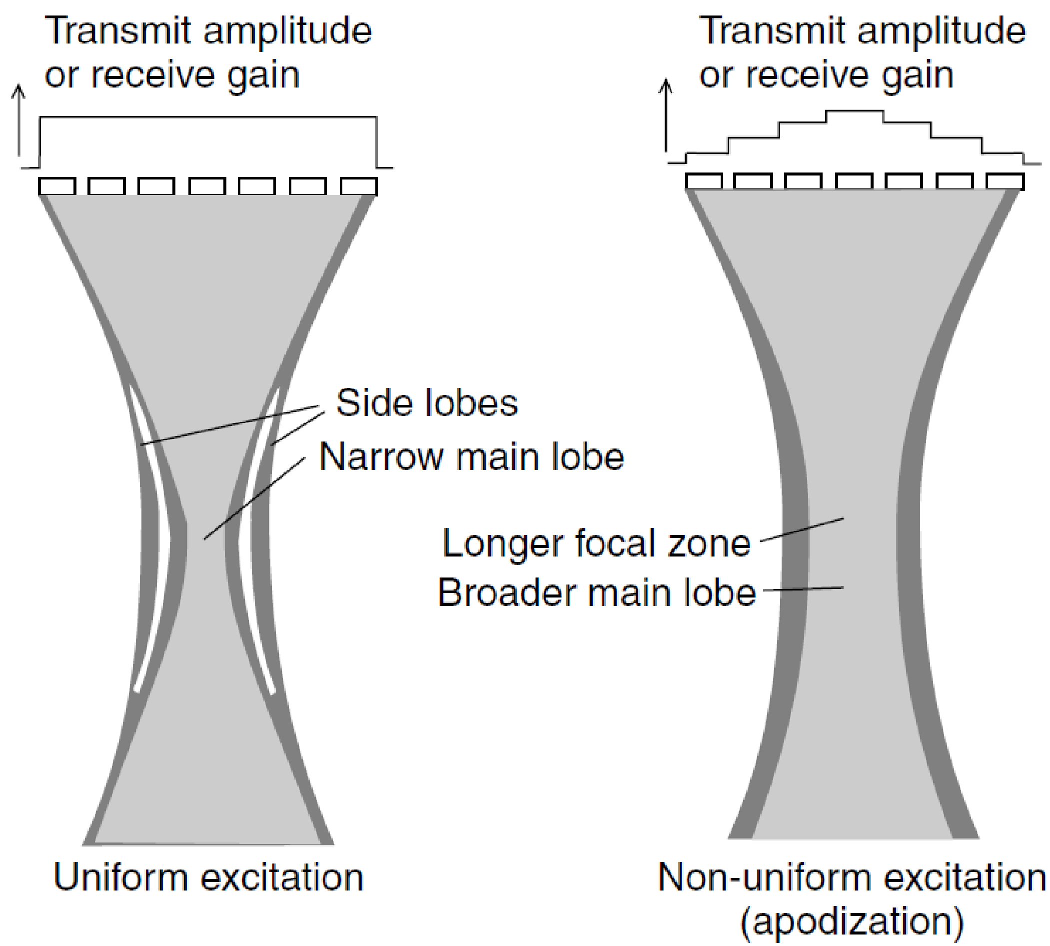
- Dynamic reception focusing



Transducers and Beamforming

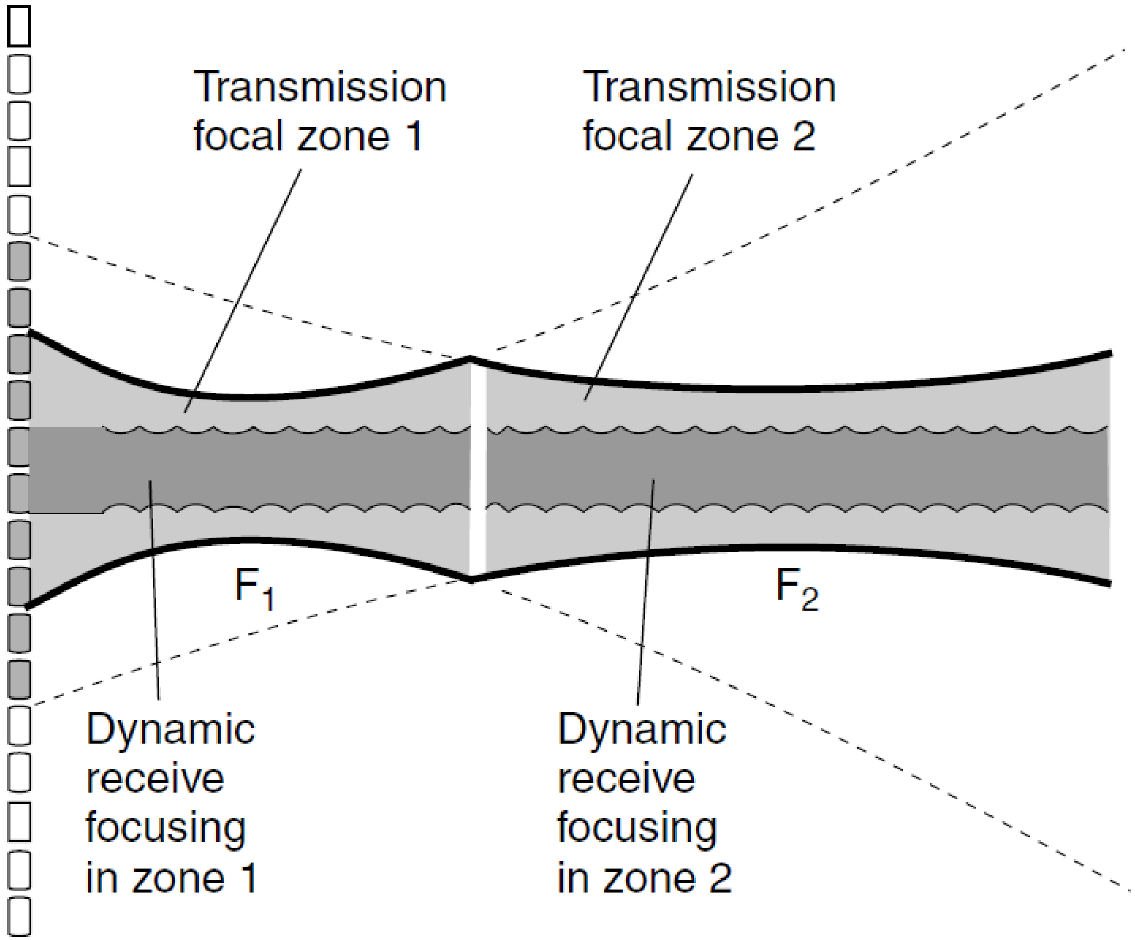
- Beamforming: selecting active elements and apodization





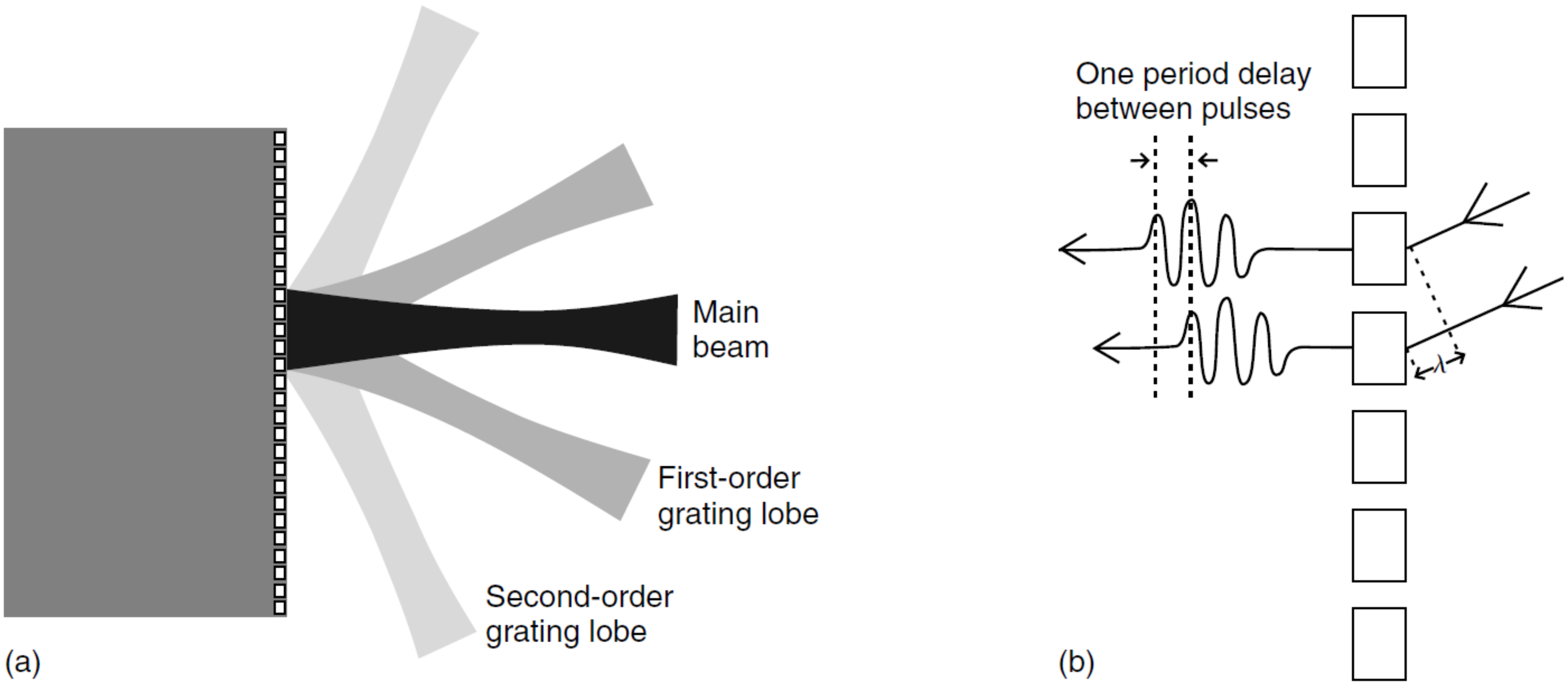
Transducers and Beamforming

- Beamforming: Multiple Transmission zones



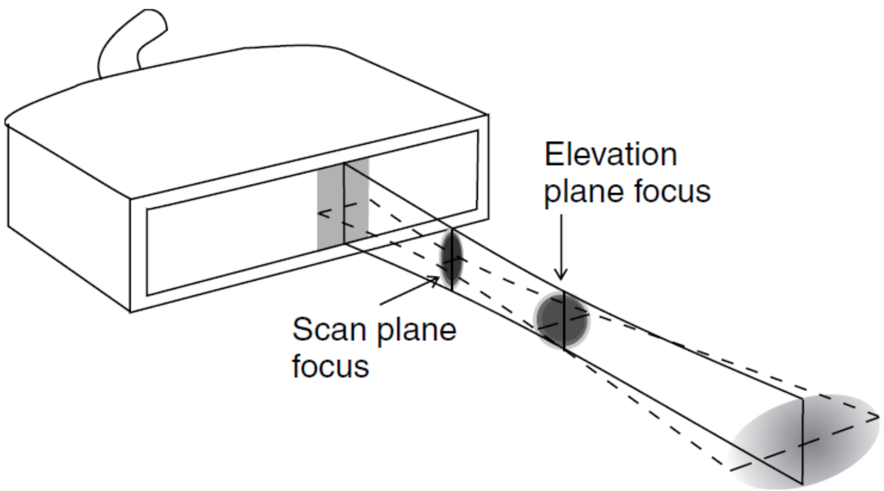
Transducers and Beamforming

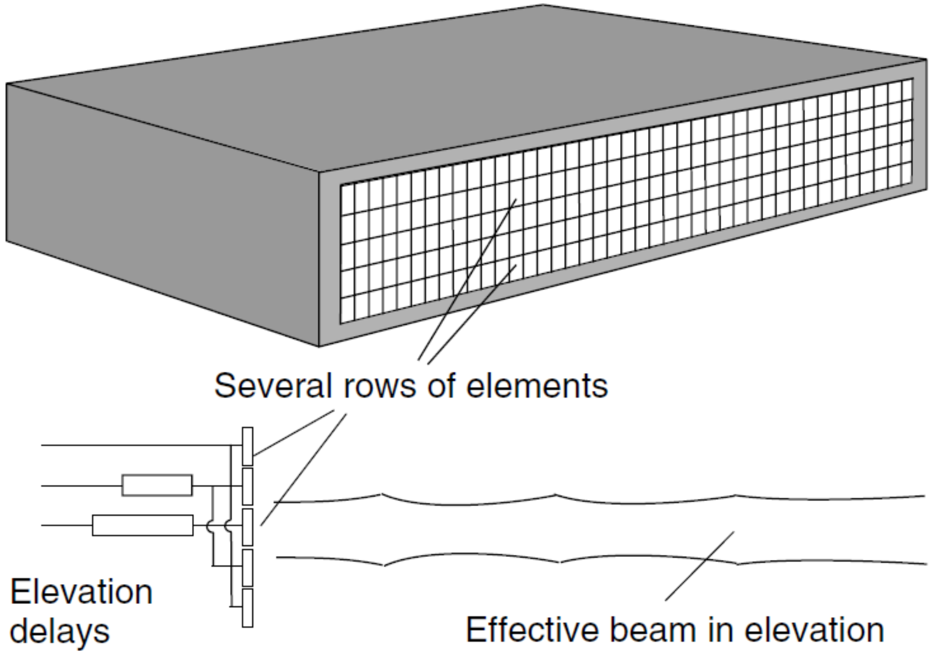
- Beamforming: Grating lobes
  - No grating lobes, if the center-to-center distance between elements is half a wavelength or less



Transducers and Beamforming

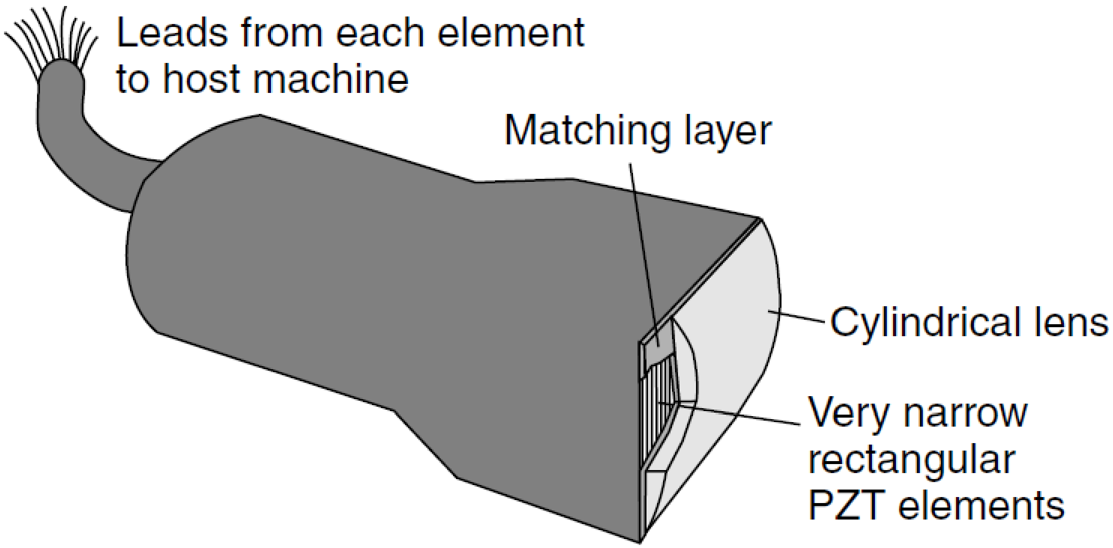
- Slice thickness: elevation direction
  - 1.5D or 2D arrays

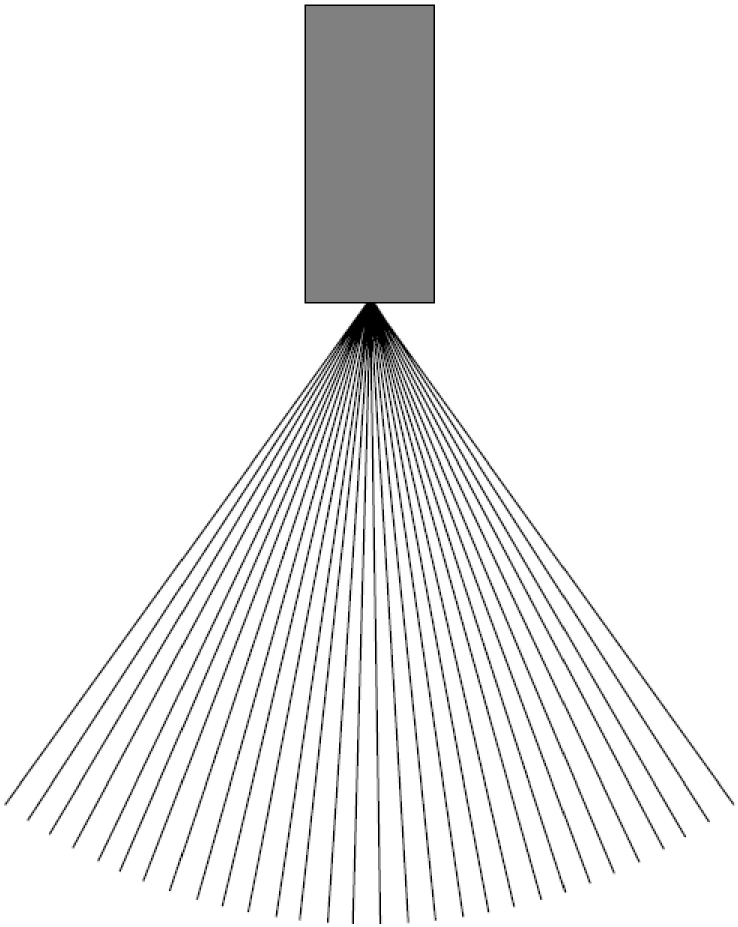




Transducers and Beamforming

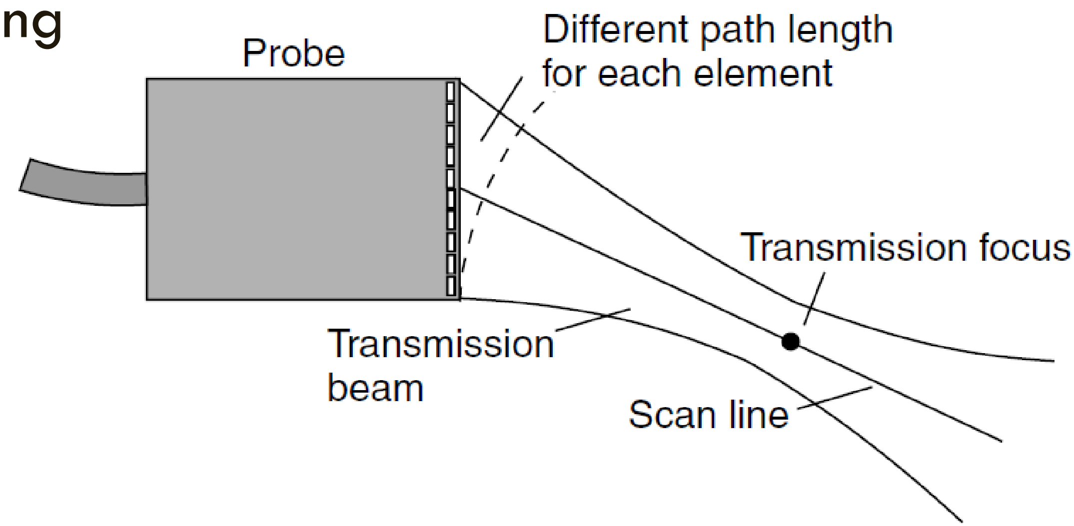
- Phased Array transducers

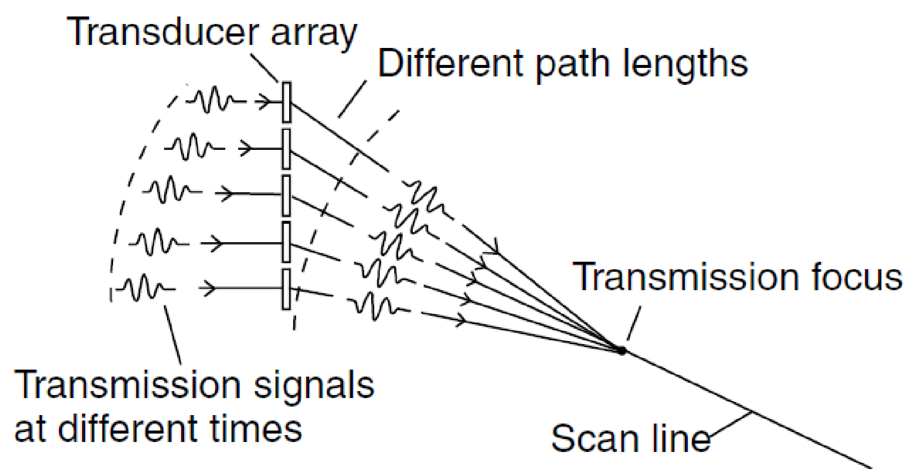




Transducers and Beamforming

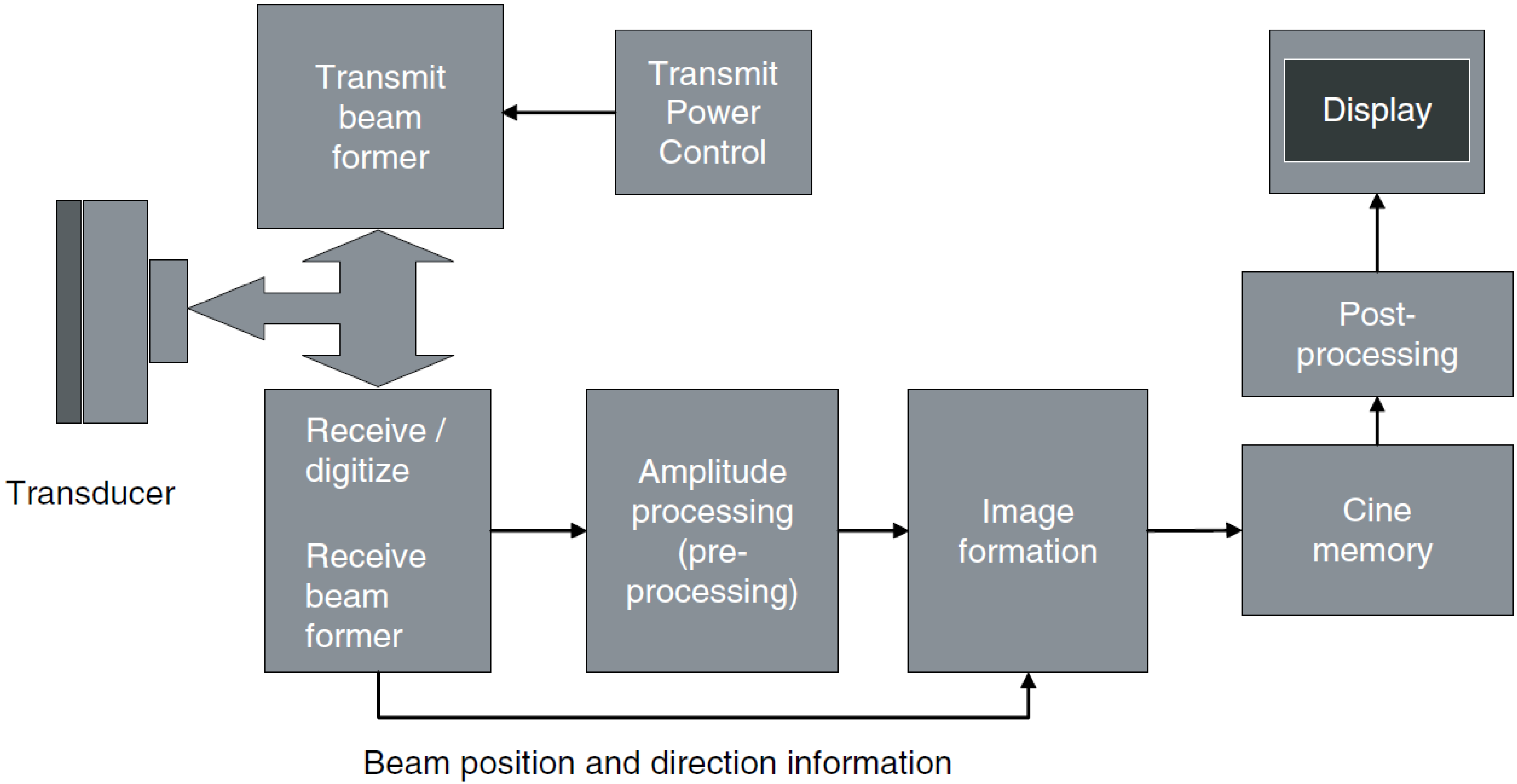
- Electronic steering/focusing





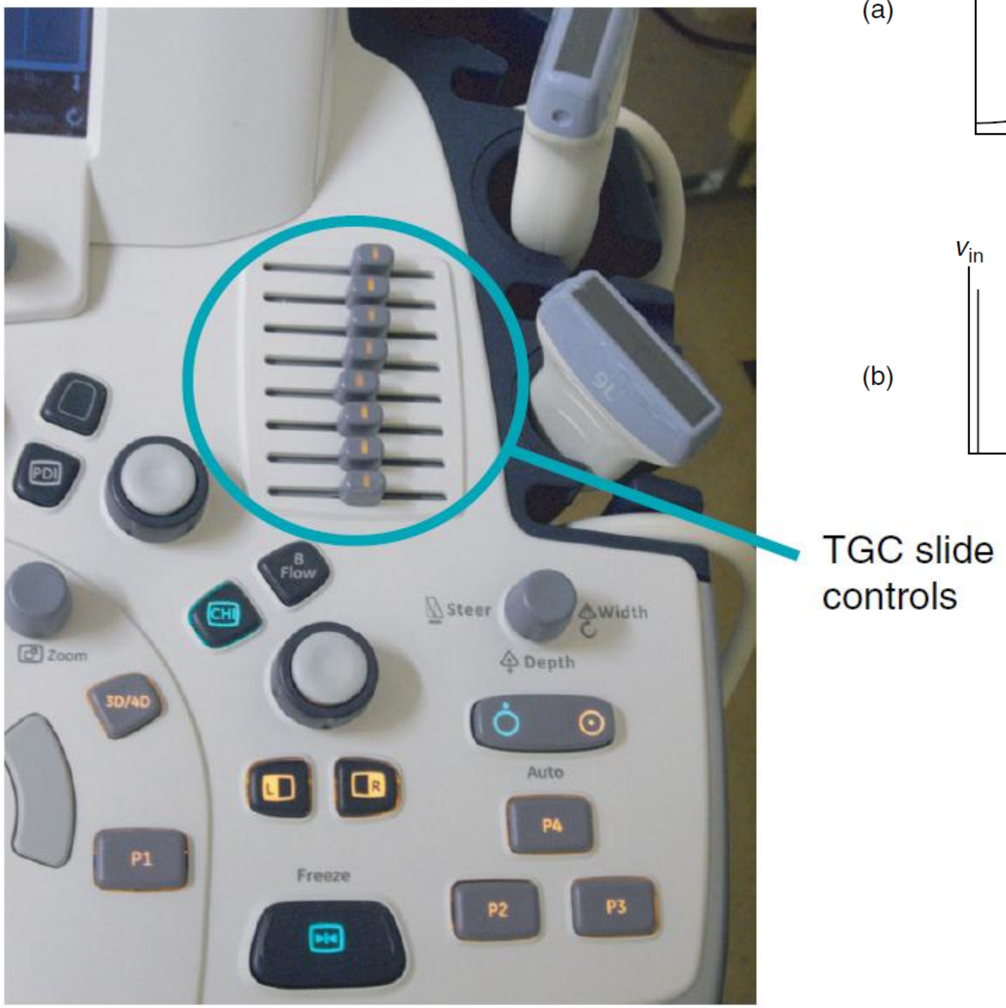
B-Mode Instrumentation

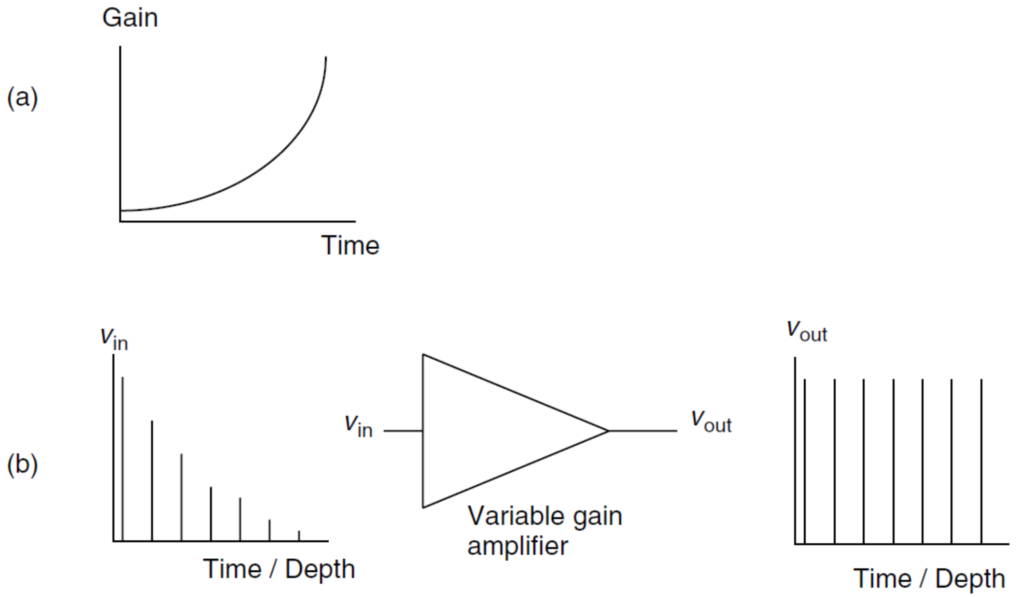
- Processing block diagram



B-Mode Instrumentation

- Time-Gain Compensation





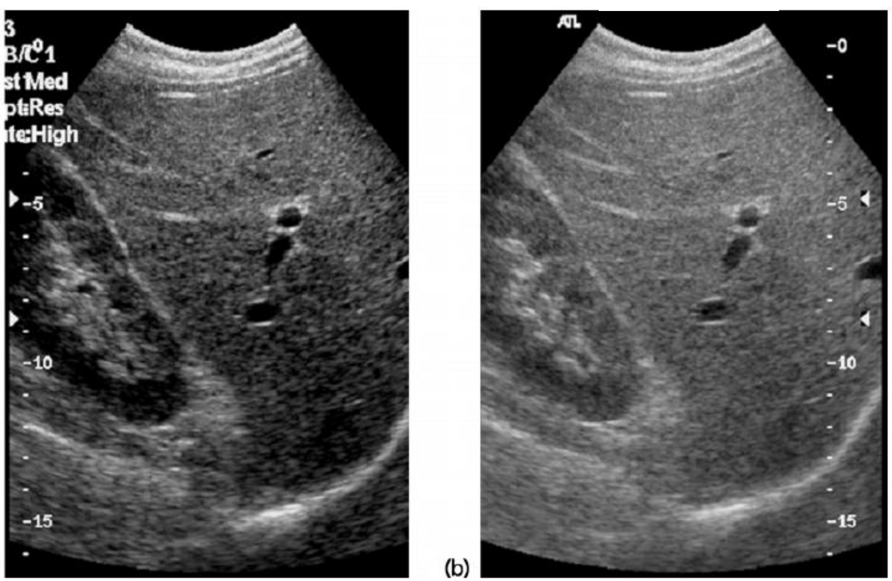
B-Mode Instrumentation

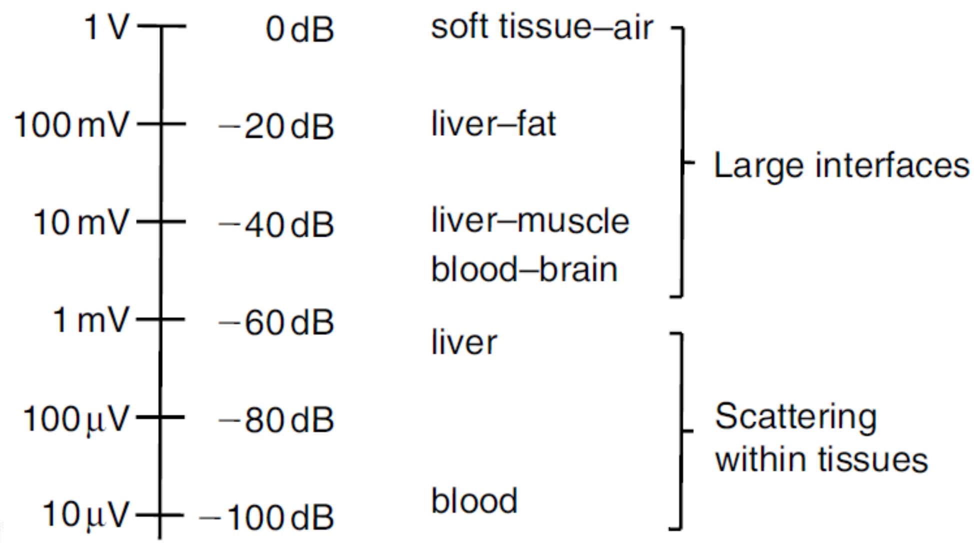
- Dynamic range of echoes

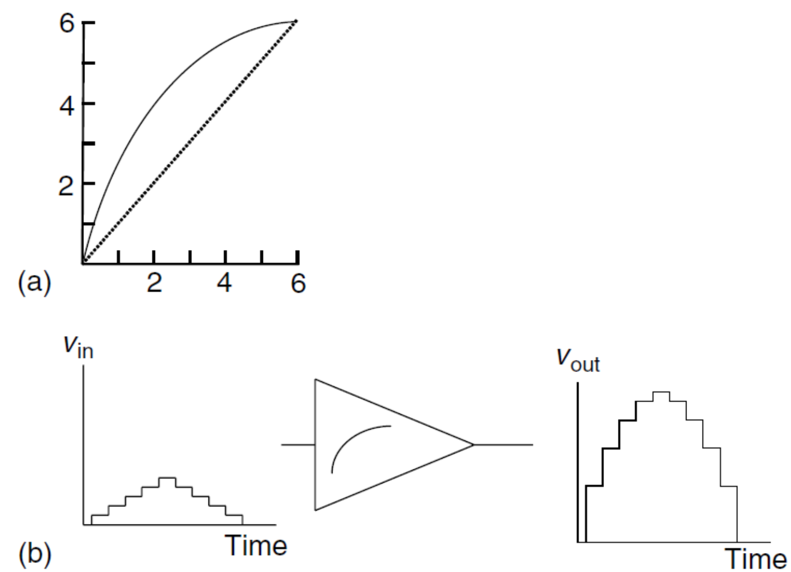
Bits	Max count	DR (dB)
4	15	24
8	255	48
10	1023	60
12	4095	72

40 dB

80 dB

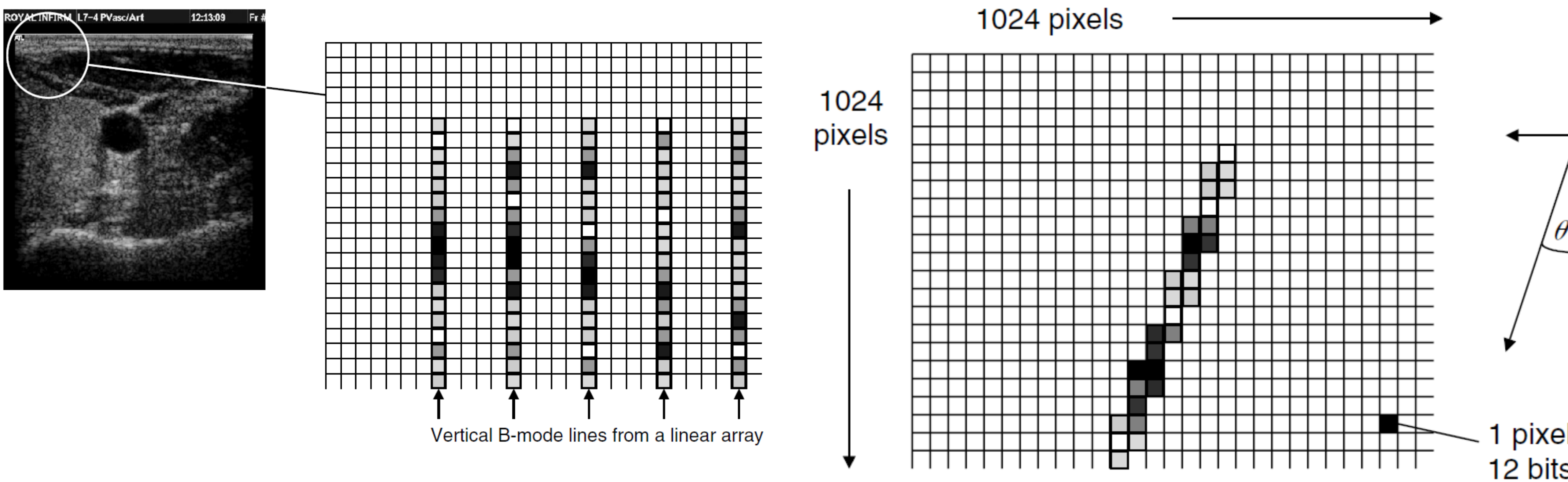






B-Mode Instrumentation

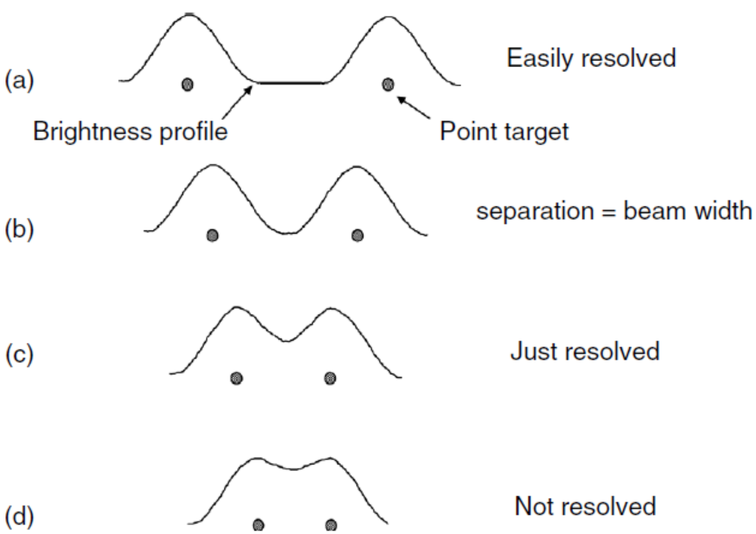
- Image reconstruction: scan conversion and interpolation

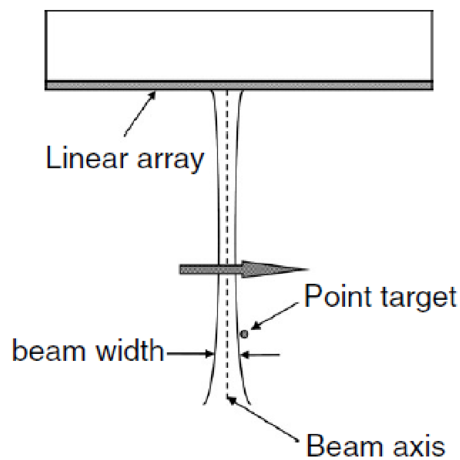


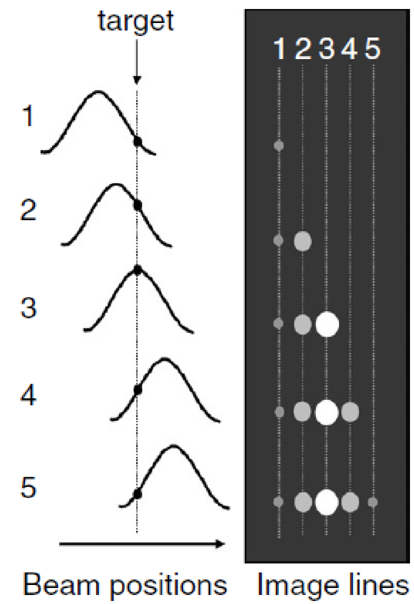
- Real-time display: frame every 1/25 s
- Freeze: updating frame stops
- Cine Loop: recording of real-time scan as a movie
- Frame Averaging: moving average filter to improve SNR

B-Mode Image Properties

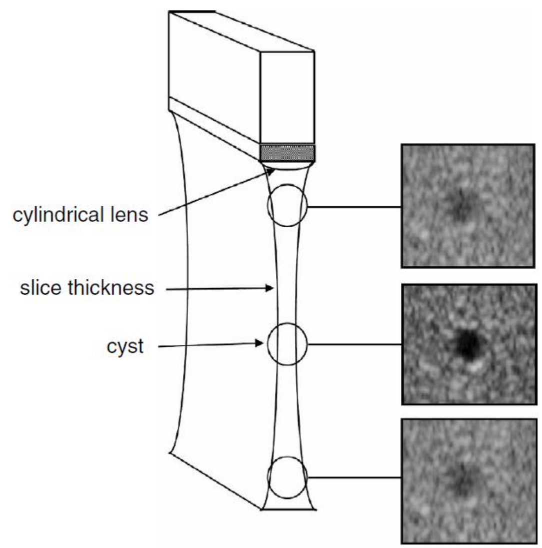
- Lateral Resolution





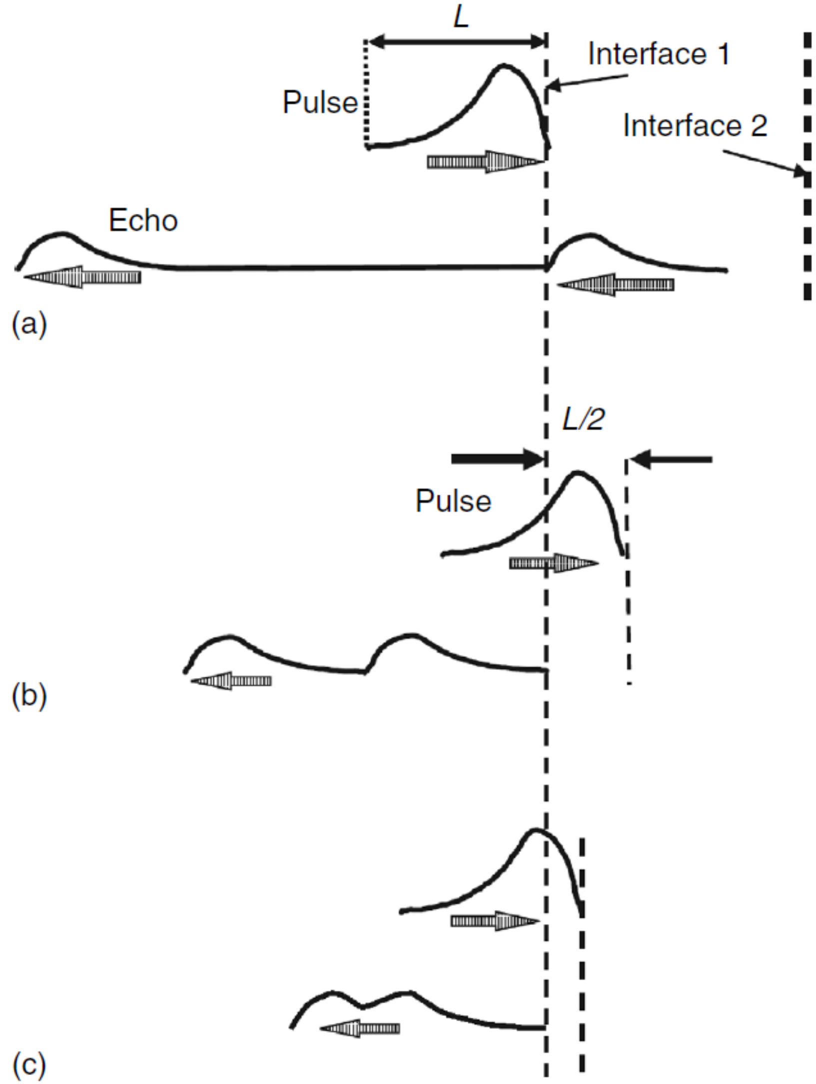


- Thickness resolution
  - Elevation

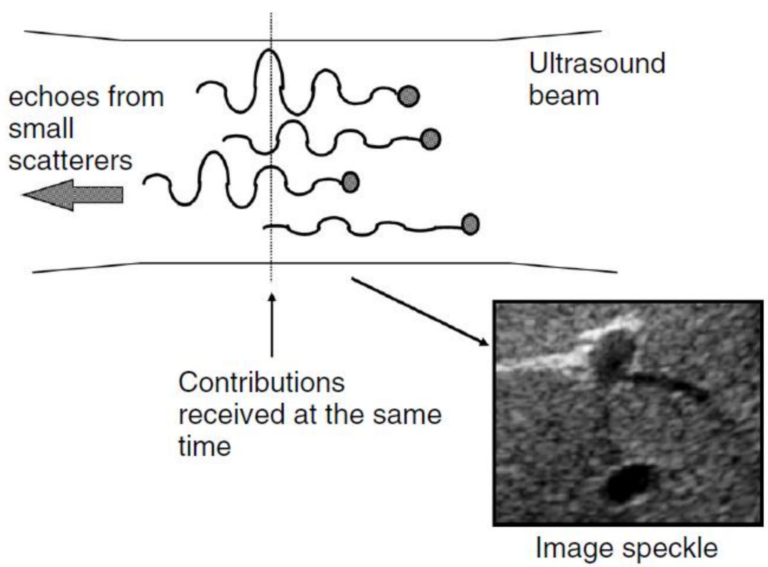


B-Mode Image Properties

- Axial resolution
  - Half pulse length



- Speckle
  - Random yet stationary pattern

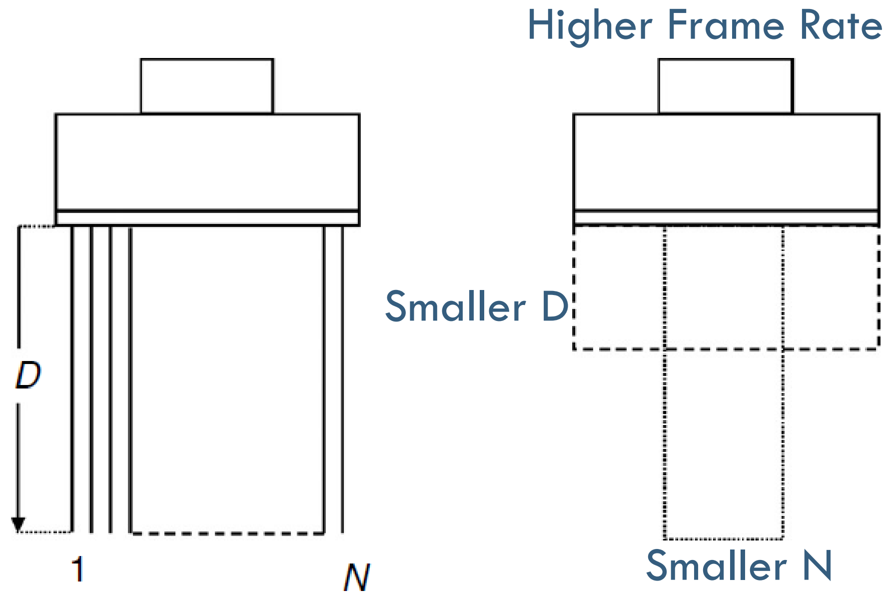


B-Mode Image Properties

- Frame time / Frame rate
  - Time to scan a complete image

$$\text{frame time} = 2DN/c$$

$$\text{frame rate} = (c/2DN)$$



- Example: time to scan 1 cm= 2x1cm/c= 2 cm/(1540 m/s) = 13 μs

Then, frame time to scan a 20 cm depth with 128 lines=13 μs x20 x128

Frame rate = 1/ frame time = 30 frames/s

Assignments

- Chapter 2: problems 3, 4, 5, 7, 10
- Chapter 3: problems 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
- Chapter 4: problems 1, 2, 3, 4, 5