10. Medical ultrasound employs the use of:

- ❑ Sound waves with wavelength greater than 0.8 mm
- ❑ Sound waves of frequency less than 20 kHz
- ❑ Light waves of wavelength less than 2 µm
- ❑ Shear waves
- ❑ Sound waves of frequency greater than 2 MHz

Pressure waves of frequency greater than 2 MHz.
(wavelength < c/f = 1500/2e6 = 0.75 mm)

12. Assume a speed-of-sound equal to 1 500 m/s. Which of the following statements are correct?

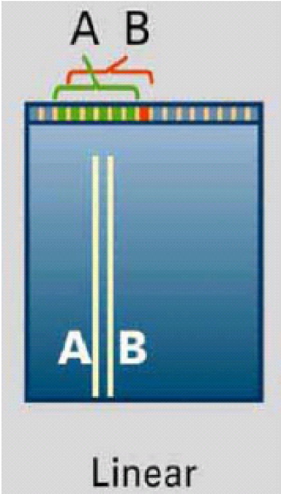
- ❑ Ultrasound with frequency less than 3 MHz has wavelength less than 3 mm
- ❑ Ultrasound with wavelength 1 cm has frequency 1.5 MHz
- ❑ Ultrasound with frequency 8 MHz has wavelength longer than 2 mm
- ❑ Ultrasound with wavelength 0.005 m has frequency 3 MHz
- ❑ Ultrasound with frequency 7 MHz has wavelength less than 2 mm

c=1500 m/s and λ=c/f, so

a. *f<3 MHz <=> λ>0.5 mm: False*
b. *f=1.5 MHz <=> λ=1 mm: False*
c. *f=8 MHz <=> λ=0.19 mm: False*
d. *f=3 MHz <=> λ=0.5 mm = 0.0005 m: False*
e. *f=7 MHz <=> λ=0.21 mm< 2 mm: True*

33. Medical ultrasound imaging (30 points).

Consider a linear array of 100 flat, rectangular, 3.0 MHz transducers, each 0.5 mm wide. Assume for simplicity that they are packed tightly together so that the array is 5 cm long. The transducer array is tested in a medium having a speed of sound of 1500 m/s.



a) If 30 consecutive transducers on the transducer array are electronically grouped (A in drawing) on each transmit and receive, what depths (or ranges) are considered to be in the far field?

*Aperture D=30*0.5 mm = 15 mm, λ = 1500/3e6 = 0.5 mm. Rc > D^2/ λ = 15*15/0.5 = <u>450 mm</u> (alternatives: D^2/4λ = 112 mm or D^2/2λ = 225 mm).*

b) A B-mode image is created by successively grouping 30 transducers on the array, sliding one transducer at a time down the length of the array (from A to B and so on). Suppose the depth of penetration is 20 cm, and that there are no overlapping pulses in this range. What is the maximum frame rate for this linear array image?

*Travel time: 2*d/c = 2*0.2/1500 = 267 μs. PRF is the inverse: 3750 Hz. Number of beams: N=100 – 30 + 1 = 71, FR = PRF/N = <u>52.8 frames per second.</u>*

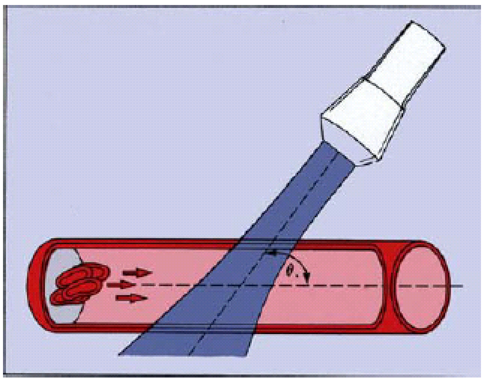
c) Assume that neighboring beams should be spaced less than half a beamwidth apart for a good image. Discuss whether the system outlined above will give acceptable image quality.

Beamwidth: $\theta = \lambda/D$ = 0.033 rad. Distance between beams: 0.5 mm, beamwidth = beam distance for 0.033R=0.5 mm => R=15.2 cm. The system is undersampled since distance between beams should be p= 0.5 x beamwidth (often less in practice). Therefore <u>the system is undersampled in the lateral direction</u> for all ranges < 15.2/0.5 = 30.4 cm, i.e. everywhere.

11. **Given a linear *N*-element array with dimensions *(N•b) x h*, where *(N•b)* is the length of the array (lateral dimension) and *h* is the height of the array (elevation dimension). Each element has size *b x h*. How can we improve the array's elevation resolution?**
   - ❑ We can send a shorter pulse (increase the bandwidth of the pulse).
   - ❑ We can send a longer pulse (decrease the bandwidth of the pulse).
   - ❑ We can increase the number of elements (larger *N*).
   - ❑ We can increase the frequency of the pulse.
   - ❑ We can reduce the height *h*.

12. **Given an annular array with a given radius and curvature. How can we increase (expand the length of) the array's focal zone?**
   - ❑ We can increase the curvature of the array (i.e. make it more curved).
   - ❑ We can decrease the curvature of the array (i.e. make it flatter).
   - ❑ We can increase the frequency of the transmitted pulse.
   - ❑ We can send a longer pulse (decrease the bandwidth of the pulse).
   - ❑ We can send a shorter pulse (increase the bandwidth of the pulse).

13. **We shall estimate the velocity of a blood flow in a blood vessel by means of a Doppler measurement. The measurement setup is shown in the figure. The blood flow is assumed to have a velocity *v* and the angle between the sound beam and the blood flow is given by θ. How can we minimize the relative error in the measurement in relation to the estimated velocity?**



   - ❑ We can increase the frequency of the emitted signal.
   - ❑ We can decrease the frequency of the emitted signal.
   - ❑ We can estimate velocity to a blood flow with larger velocity *v*.
   - ❑ We can decrease the angle θ.
   - ❑ We can increase the angle θ.

29. Medical ultrasound imaging (30 points).

A 128-element linear array is used for real-time imaging of a fetus in the mother's womb. An uterus (with abdomen) in the final stages of pregnancy can be up to 50 cm thick. Assume that four non-overlapping elements are used to form a group and are fired sequentially to create an image of the fetus.

a) How many scan lines can you get in each image?

Number of scanlines: 128 elements / (4 elements/scan line) = 32 scan lines.

b) What is the frame rate if one assumes a speed of sound of 1500 m/s and that one need to receive an echo from depth 50 cm, sent from one group of elements before the next group sends out its pulse?

Framerate: The time for the pulse to travel from the transducer, to depth 0.5 m and back to the transducer is given as: t=s/c, where s = 2 * 0.5 m and c = 1500 m/s.

Then: t = (1/1500) s/line
prf = 1/t = 1500 lines/s
frame rate = 1500 lines/s / (32 lines/frame) = (1500 / 32) frames/s

c) What can be done to increase the frame rate? Please suggest at least two possibilities, and describe briefly what effect the choice one makes will have on the image and image quality.

- Reduce 's', i.e. imaging depth ==> Might not see the whole baby. Might get problems with echoes from lower lying areas when imaging points which are close to the transducer.
- Reduce aperture, i.e. the number of scan lines ==> reduced image sector.
- Increase the distance between groups of elements ==> sparser sampling of the image.

13. Say you want to image a beating heart with ultrasound. In this application, frame rate is essential in order to capture the dynamics of the heart. What can you do to increase the frame rate?

- ❑ Increase the maximum depth over which the image is unambiguous
- ❑ Increase the number of lines in the image
- ❑ Increase the emitted frequency
- ❑ Increase the number of parallel receive beams
- ❑ Increase the size of the aperture in the azimuth dimension

14. Imaging of a fetus may require an unambiguous depth of 30 cm. The image is made with a curved array with a radius of 40 mm and 128 elements and operates at frequency 5 MHz. Assume that the speed of sound is c=1540 m/s. What is the maximum pulse repetition (PRF) frequency (rounded off)?

- ❑ 1925
- ❑ 6494
- ❑ 2567
- ❑ 3247
- ❑ 1283

30. Medical ultrasound imaging (25 points).

An ultrasound probe is used for B-mode imaging. It requires 256 lines per image to scan the desired sector and runs at a pulse repetition frequency of 3840 frames per second.

a) What is the frame rate?

Frame rate: FPS = PRF/ Nlines = 3840/256 = 15 fps

b) Assume that the one-way attenuation is α=0.5 dB/cm/MHz and increases linearly with frequency. What is the maximum frequency that can be used if the system is sensitive to maximum 80 dB loss? Assume that c=1540 m/s.

Imaging depth: d=c/(2*PRF) = 1540/(2*3840)=0.2005 m = 20.05 cm

f is in MHz, d is in cm:
80 = f*α*2d => f=80/(α*2*d) = 80/(0.5*2*20.05) =3.99 $\approx$ 4 MHz

c) The same frame rate can be achieved in a medium with twice the attenuation when half the frequency is used. Assume that this is the case, and that the number of required beams is the same due to sampling criteria. How must the imaging system be modified and how will the properties change for this case (aperture, number of elements, resolution,…)?

At half the frequency, the wavelength is doubled. Since the number of beams is the same, the azimuth resolution is unchanged. The aperture is doubled since $\theta=\lambda/D$ is constant. Assuming the same pitch, e.g. half wavelength between elements, the number of elements and thus the number of channels in the system is unchanged. Since the frequency is half the original, and bandwidth of a probe usually scales with the frequency, the range resolution is worse by a factor of two.