EE101 Homework 4

Submit: Blackboard   Due: Nov. 28th

Your Name: ______________ Student ID: __________________

1. Calculate the distance at which the intensity of a 1 MHz and 8 MHz ultrasound beam will be reduced by half traveling through (a) bone, (b) air, and (c) muscle. (The attenuation coefficient for muscle, bone and air are 1, 8.7 and 45 dB cm^{-1} MHz^{-1}, respectively.dB $= 10\log_{10}(\frac{I_x}{I_0})$)

   Solution. (16 points)
   As stated in the text the values of μ for muscle, bone and air are 1, 8.7 and 45 dB cm^{-1} MHz^{-1}, respectively. For the intensity to be reduced by half, the value of (μx) must be ~3 dB. Hence, the distance is $\mathrm{d} = \frac{3}{\mu}$.

   Therefore, at 1 MHz,

   The half value distance for bone is $\mathrm{d_{bone}} = \frac{3}{\mu_{bone}} = \frac{3}{8.7} = 0.34cm$,

   The half value distance for air is $\mathrm{d_{air}} = \frac{3}{\mu_{air}} = \frac{3}{45} = 0.067cm$,

   The half value distance for muscle is $\mathrm{d_{muscle}} = \frac{3}{\mu_{muscle}} = \frac{3}{1} = 3cm$.

   At 8 MHz, the distances are one-eighth those at 1 MHz, thus,
   0.0425 cm for bone, 0.008375 cm for air and 0.375 cm for muscle.

   Tips: If you confuse the intensity attenuation coefficient and frequency dependence, half of the points will be deducted. Note: μ(dB/cm)=4.343μ(/cm)

2. The three ultrasound images in Figure 2 are acquired from the same object.

(a) (b) (c)

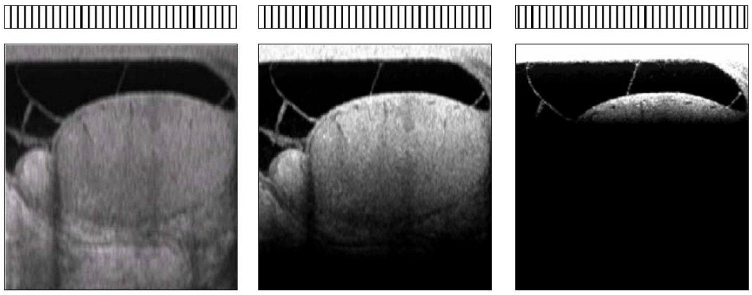


Figure 2

Answer the following questions:

(1) Please analyze the difference among the three images referring to image characteristics, for example image depth, SNR, etc.

(2) If only a single operating parameter changes and causes the difference among image (a), (b) and (c), which parameter could it be? Explain why.

Solution. (18points)

(1) There are three image features to note:
   (a) the penetration depth decreases from A to B to C.
   (b) the signal-to-noise decreases from A to B to C.
   (c) the axial spatial resolution increases from A to B to C. (optional)

(2) The only operating parameter that could give rise to all three of these effects is an increase in the ultrasound frequency.
   (a) The higher the frequency of the ultrasound wave, the larger the attenuation it will experience and the less deep it will penetrate.
   (b) The higher the frequency, the lower SNR.
   (c) Axial resolution $=\frac{1}{2}p_d c$. The higher the frequency f, the smaller the pulse duration p_d will become. Thus, the axial resolution will become better.

3. Given the transmitted frequency spectrum of an ultrasound beam from a transducer operating at a central frequency of 1.5 MHz and assume that the transducer is damped.

   (a) Please plot the beam returning to the transducer after having passed through tissue and been reflected.

   (b) Explain the reason why your draw the reflected spectrum like this.

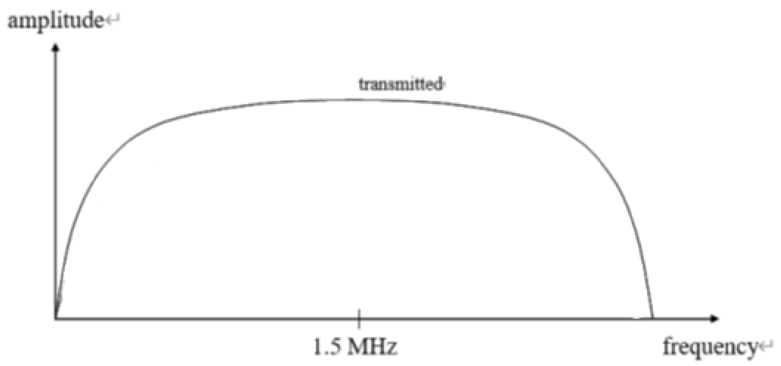
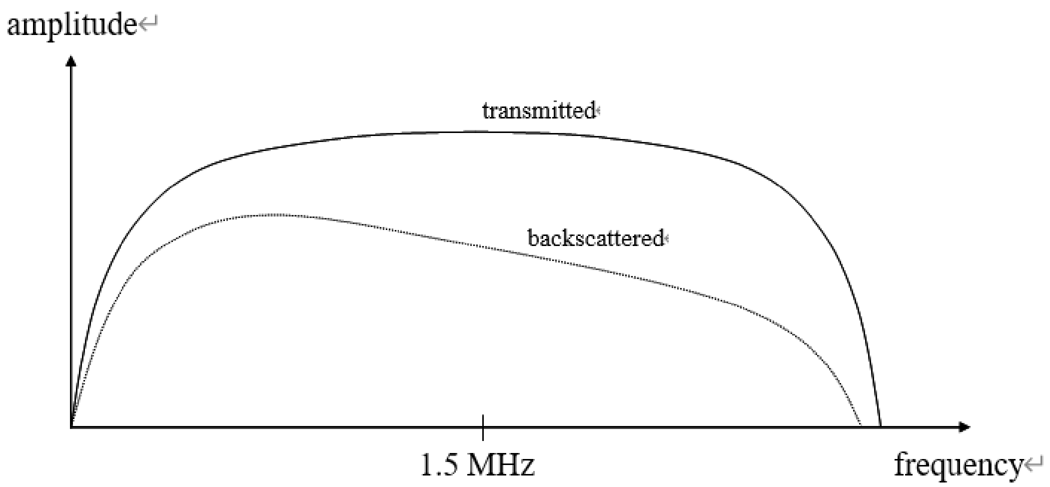


Fig3

Solution: (16 points)



For the backscattered energy, the intensity is lower, and the higher frequencies are preferentially attenuated, meaning that the frequency spectrum becomes skewed towards the lower frequencies.

4. If we only consider the transmission process of ultrasound wave and neglect the multiple reflection in different boundaries, please answer the following questions:
(1) Given values of Z_{PZT} and Z_{skin} of $25 \times 10^5\ g\ cm^{-2}s^{-1}$ and $2.7 \times 10^5\ g\ cm^{-2}s^{-1}$, respectively, calculate what fraction of the energy from the transducer is actually transmitted into the patient if one matching layer is used.
(2) If two matching layers are used instead of one, and the respective acoustic impedances are given by the analogues of the equation above, then calculate the increase in efficiency in transmitting power into the patient.

Solution. (16 points)

(1) The value of Z_{ML} is given by:

$$Z_{ML} = \sqrt{(25 \times 10^5)(2.7 \times 10^5)} = 8.22 \times 10^5 \mathrm{gcm}^{-2}\mathrm{s}^{-1}$$

The value of T_I is now calculated:

$$T_I = \frac{4(25)(8.22)}{(25+8.22)^2}\frac{4(2.7)(8.22)}{(2.7+8.22)^2} = 0.55$$

(2) If the two matching layers have Z values Z_{ML1} and Z_{ML2}, then two equ15ations can be written to solve for these values:

$$Z_{ML1} = \sqrt{25 Z_{ML2}}$$

$$Z_{ML2} = \sqrt{2.7\sqrt{25 Z_{ML2}}}$$

These equations can be solved easily to give $Z_{ML1}=11.91 \times 10^5 \mathrm{gcm}^{-2}\mathrm{s}^{-1}$ and $Z_{ML2}=5.67 \times 10^5 \mathrm{gcm}^{-2}\mathrm{s}^{-1}$. Calculating TI across the two boundaries gives:

$$T_I = \frac{4(25)(11.91)}{(25+11.91)^2}\frac{4(11.91)(5.67)}{(11.91+5.67)^2}\frac{4(5.67)(2.7)}{(5.67+2.7)^2} = 0.67$$

Increase = 0.67-0.55 = 0.12

5. A B-mode scan is taken of the object in Figure 5.a with a linear array. There are four tissue components, ***a*** and ***b*** with a boundary in-between and two spherical tumors ***c*** and ***d***. Given the corresponding ultrasound image shown on Figure 5.b, which is the enlargement of the blue region in Figure 5.a. What can you deduce about the acoustic characteristics of components ***a***, ***b***, ***c*** and ***d***?

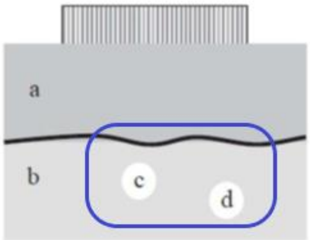


Figure 5.a

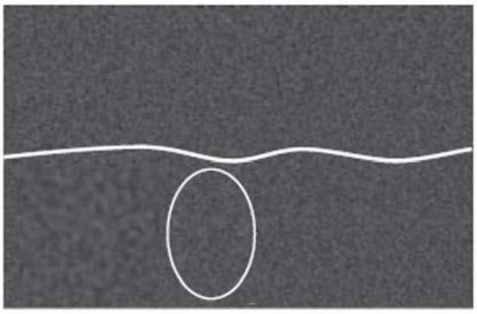


Figure 5.b

Solution: (16 points)

There are five different things that can be determined.

(i) Since the boundary between a and b is visible, $Z_a \neq Z_b$.

(ii) Since tumor d is not visible, $Z_b = Z_d$.

(iii) Since tumor c is visible, $Z_c \neq Z_b$.

(iv) Since tumor c is elongated, $c_c < c_b$.

6. Sketch the Doppler spectral patterns at points 1, 2, and 3 below in a stenotic artery, shown in Figure 6. (All of the plots are made over one cardiac cycle)

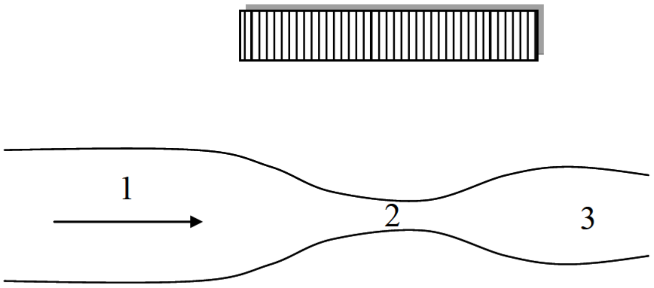


Figure 6

Solution. *(18 points)*

At position 1 the flow is characterized by a range of relatively low velocities predominantly flowing towards the transducer. At 2, since the vessel narrows, the velocities become much higher. However, there are equal contributions from flow towards and away from the transducer, and so equal positive and negative frequencies. At 3, there will be a broad range of velocities, probably including turbulent flow. The Doppler spectral patterns will have the general appearance shown below.