Advanced BME Laboratory (AM5019)
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EXPERIMENT 3:
Speed of sound measurement in a tissue phantom using an ultrasound probe.

OBJECTIVES:
i. To find the speed of sound (m/s) in a tissue mimicking phantom using an ultrasound probe.
ii. Calculate the Acoustic Impedance (kg/m^2s).
iii. Calculate the Amplitude Attenuation Coefficient ($dB/cm^{-1}MHz^{-1}$).

APPARATUS USED:
i. Disc shaped phantom (mixture of 3% Agar and 5% Gelatin in water) mimicking the properties of tissue.
ii. Ultrasound Transducer: V1091 contact ultrasonic transducer by Olympus consisting of a single piezoelectric transducer with a center frequency of 5MHz and 5mm diameter circular surface was used.
iii. Olympus 5077PR ultrasonic square wave pulser/receiver unit.
iv. Cathode ray oscilloscope: The ultrasound signal was acquired at a sampling frequency of 100 MHz.
v. Vernier caliper to measure the dimensions of the tissue phantom.
vi. Weighing machine to measure the weight of aluminum rod and phantom.

THEORY:

1. Introduction
Sound with frequencies higher than the highest audible frequency heard by human beings (20KHz) is considered ultrasound. Ultrasound is a non-invasive modality for imaging human anatomy. Typically, medical ultrasound is operated in the range of 1-15 MHz.
Ultrasound propagation can be explained by using the principles of sound propagation and acoustics. Ultrasound moves in a wavelike fashion by expansion and compression of the medium through which it is moving. The speed of the wave is dependent on the material of the medium. The average speed of sound through most soft human tissues is 1540 m/s. In addition, these waves can be absorbed, refracted, focused, reflected, and scattered. A transducer converts electrical signals to acoustic signals and vice versa. Electric current causes distortion of the crystals, makes them vibrate and produce acoustic waves. The summation of the waves produces an ultrasound beam which is sent through a patient’s body. Organ boundaries and complex tissues produce echoes by reflection or

scattering that return to and are detected by the transducer, which converts the acoustic signal to an electrical signal. The ultrasound imaging system then processes the echoes and presents a grayscale image of human anatomy on a display. Each point in the image corresponds to the anatomic location of the reflecting surface and the intensity corresponds to the echo strength.

2. Speed of Sound:

The speed of sound in a medium depends on the compressibility κ and density ρ of the material and is given by the following formula:

$$\mathbf{c = \sqrt{\frac{1}{\kappa\rho}}}$$

We can assume that t is the time taken for the total time from the start of an ultrasound pulse from the transducer to the receiving of an echo from a reflecting source. If the depth of the reflecting source is known the speed of sound in the medium can be calculated using the formula:

$$\boldsymbol{c} = \frac{\mathbf{2d}}{\mathbf{t}}$$

where c is the speed of sound in the medium, d is the distance of the reflecting source from the US transducer and t is the time taken for the ultrasound transducer to receive the echo from the reflecting source.

3. Attenuation:

The amplitude of a real acoustic wave decreases or attenuates as the wave propagates due to absorption, reflection, scattering, and mode conversion. In soft tissue, 80% of the attenuation is due to absorption. Reflection depends on the difference in acoustic impedances of the tissues at the interface. Acoustic impedance is the resistance offered by the tissues to the transmission of the sound. Higher the difference in impedance greater is the reflection of the wave. Scattering occurs when the ultrasound wave encounters an interface that is not perfectly smooth. Scattering provides most of the information for diagnostic imaging.

Let A_0 be the initial amplitude of the wave, then the actual amplitude A_z of the travelling wave is given by the following equation:

$$\boldsymbol{A_z = A_0 e^{-\mu z}}$$

where $\boldsymbol{\mu}$ (units: cm^{-1}) is the amplitude attenuation factor and **z** is the distance travelled by the wave. Rearranging the above equation,

$$\boldsymbol{\mu = -\frac{1}{z}\ln\frac{Az}{A0}}$$

The attenuation coefficient α is given by:

$$\boldsymbol{\alpha = 20(\log 10\ e)\mu \approx 8.7\mu}$$

which has the units of dB/cm. Dividing the above equation by the transmit frequency in MHz gives the attenuation coefficient in ($dB/cm^{-1}MHz^{-1}$).

PROCEDURE:

i. The ultrasound transducer was connected to the Olympus 5077PR ultrasonic square wave pulser/receiver unit, which in turn was connected to a CRO. This forms the ultrasonic measurement system.

ii. The pulser section of the Olympus 5077PR generates square wave electric pulses which when connected to an ultrasonic transducer produces short ultrasonic pulses. The ultrasonic pulses are received by the transmitting transducer after partial or total reflection (pulse-echo method). The voltage signals produced by the transducer, which represent the received ultrasonic pulses, are amplified by the receiver section. The amplified RF signal is displayed by the CRO.

iii. The settings of the Olympus 5077PR were fixed as follows: Pulse Repetition Frequency PRF=200Hz, Pulser voltage=400V and transducer frequency=5MHz.

iv. The ultrasound transducer was first placed on the surface of the tissue phantom. A small layer of water was used on top of the phantom as a coupling medium. An ultrasound pulse was fired into the phantom by the transducer and the reflected ultrasound pulse was received by the same transducer. The voltage signals produced by the transducer which represent the received ultrasonic pulses were then displayed on the CRO and a snapshot of the signal was saved on the CRO. From the snap shot of the signal, the time duration between the first and second echo was calculated. The amplitude of the first echo peak and the second echo peak were also noted. From this information, the speed of sound in the tissue phantom and the amplitude attenuation factor μ and attenuation coefficient α were calculated. The data from the snap shot was saved in an excel file.

v. Using a Vernier calliper, the depth/thickness of the tissue phantom and the diameter of the circular dish in which the tissue phantom was placed was found. The weight of the tissue phantom was found by using a weighing balance. From this information, the volume and density of the tissue phantom was calculated.

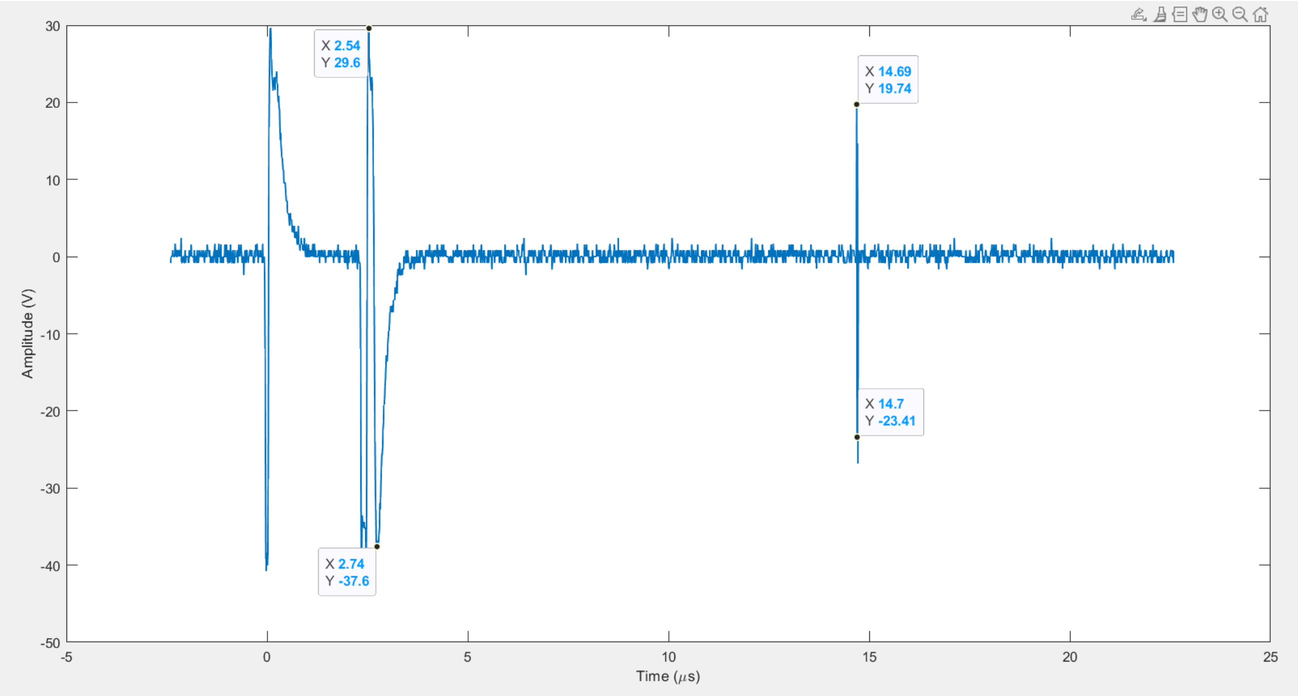
vi. The data stored in the excel file was then loaded onto MATLAB and plotted as shown in the Figure below.

RESULTS & CALCULATIONS:

Sampling frequency = 100 MHz
Transmit frequency = 5 MHz

Dimensions of the cylindrical phantom used:
1. Height of phantom = 9.1 mm (direction of ultrasound propagation)
2. Radius of phantom = 15 mm
3. Mass of phantom= 6.52 grams

Density = $\frac{mass}{volume} = \frac{6.52 \text{ x } 10^{-3}}{\pi(0.015)^2 \text{x}(0.0091)}$ = 1014.13 kg/m^3.



Time taken to reach the bottom surface of the phantom = (14.69 – 2.54)/2 = 6.075 µs.

A2 = 19.74 + 23.41 = 43.15 V

A1 = 29.6 + 37.6 = 67.2 V

Distance = 9.1 mm

Speed (c) = Distance/time = 0.0091/(6.075 x 10^{-6}) = **1497.94 (m/s)**

Acoustic impedance (Z) = Density x Speed = **1.519 x 10^6 (kg/m²s).**

Transmit frequency= 5 MHz

Amplitude attenuation factor (μ_A) = $-\frac{1}{z}\left(\ln\frac{A2}{A1}\right) = \frac{-1}{1.82cm}\left(\ln\frac{43.15}{67.1}\right)$ = **0.2434 cm^{-1}.**

Amplitude attenuation coefficient = $20\,(\log e)\,(\mu_A)$ = 8.686x (0.2434) = **2.114 dB/cm**

= 0.423 (dB/cm/MHz)

CONCLUSIONS:

The speed of sound (c) in the medium, acoustic impedance (Z), amplitude attenuation factor (μ_A) and the amplitude attenuation coefficient has been estimated for the tissue phantom.

CRITICAL REMARKS:

The accuracy in the speed of sound measurement depends on the proper placement of the probe perpendicular to the surface.

In addition, the phantom may not have a uniform height over the entire surface area. There could be slight variations in the height and thus the distance travelled by the sound wave may vary depending on where the probe is placed on the phantom.