

**NC STATE UNIVERSITY**

**College of Engineering**

**Department of Mechanical and Aerospace Engineering**



MAE 496 - Undergraduate Research

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**Development and Testing of lung phantoms to mimic  
pulmonary fibrosis and edema.**

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## **1. Introduction**

The primary objective of this project is to develop and evaluate lung phantoms capable of accurately replicating the characteristics of pulmonary fibrosis and edema. Lung phantoms are artificial models in medical imaging and research to mimic the properties of human lungs. By creating these phantoms, the aim is to establish a controlled and standardized environment for studying and diagnosing pulmonary fibrosis and edema using ultrasound.

In pursuit of our objective, the initial strategy is a series of experiments with a diverse range of materials and designs for lung phantoms. This will help us towards the development of lung phantoms whose stiffness can be customized to closely mimic the properties of human lung tissues, particularly in cases of conditions such as pulmonary fibrosis and edema. This research paper focuses on the utilization of hydrogel-based phantoms. We aim to assess the speed of sound and attenuation characteristics within these phantoms. The primary goal of this study is to ascertain the effectiveness of hydrogel phantoms as a tool for ultrasound-based diagnostic procedures.

The significance of this project lies in its potential to revolutionize the identification of lung diseases, including fibrosis, and medical conditions like edema. By providing a faster and more cost-effective means of diagnosis, it promises greater accessibility than traditional diagnostic methods. Further, the success of this project could pave the way for the development of wearable devices utilizing ultrasound technology, potentially transforming the field of ultrasound imaging.

## 2. Methodology

In the experiment we measured the speed of sound through a solid hydrogel block using a water tank setup, function generator, and Pico scope in the laboratory. This setup was helped in establishing a baseline for sound transmission in the medium. The hydrogel block, supported by a gelatin base, was positioned between two transducers for data collection.

The speed of sound through the hydrogel medium was measured to be 1529.48 m/s, closely aligning with that in water, suggesting hydrogel's suitability for mimicking human tissue acoustics. The next step was to find the attenuation in the hydrogel block using the data collected.

The sampling frequency (fs) was determined from the time interval (dt), and a time vector (timevec) was established for signal plotting. The data collection involved two scenarios: with the hydrogel sample (signal A) and without it (signal Aref), the latter representing just the water in the tank. Fourier Transform analyses were conducted on both datasets to derive frequency components and subsequently calculate attenuation coefficients.

Using the formula provided in [1] the frequency-dependent attenuation coefficient  $\alpha(f)$  can be derived from the ratio of the magnitude spectrum of the measured pulse  $|A_b(f)|$  with the magnitude spectrum of the reference wave  $|A_r(f)|$ . Magnitude spectra were obtained using a fast Fourier transform algorithm (FFT). The quantity  $\alpha(f)$  expressed in decibel, is given by:

$$\alpha(f) = 20 \log_{10}(e) \left( \frac{1}{L} \ln \frac{|A_b(f)|}{|A_r(f)|} + \ln(T(f)) \right), \quad (1)$$

where  $L$  is the sample length in cm which in our case was 1 cm. The term  $T(f)$  is introduced to correct for losses due to transmission and corresponds to the transmission coefficient of the pulse through the sample:

$$T(f) = \frac{4Z_r(f)Z_b(f)}{|Z_r(f) + Z_b(f)|^2}, \quad (2)$$

where  $Z_r(f) = \rho V_b(f)$  and  $Z_b(f) = \rho V_b(f)$  are respectively the acoustic impedance of the reference medium. Since in our case hydrogels have similar acoustic impedance as compared to water (our reference medium) we can assume  $Z_r(f) = Z_b(f)$ .

### 3. Code Review & Analysis

The following code was written in MATLAB to calculate the attenuation in the sample using (1).

```
1 % Define time interval for sampling
2 dt=Tinterval * 1000000;
3
4 % Calculate the sampling frequency
5 fs=1/dt;
6 timevec=0: dt: dt*length(A)-dt;
7
8 % Plot the original signal A over time
9 figure;
10 plot(timevec,A);
11 xlabel('Time (micro sec)');
12 ylabel('Amplitude');
13 title('Time Series of Signal A');
14
15 % Select a subset of the signal A and Aref starting from the 450000th element
16 AA=A(450000:end);
17 AAref=Aref(450000:end);
18
19 % Plot the subset signal AA over time
20 figure;
21 plot(timevec(450000:end),AA)
22 xlabel('Time (micro sec)');
23 ylabel('Amplitude');
24 title('Time Series of Subset Signal AA');
25
26 % Perform and plot the Fourier Transform of the subset signal AA
27 figure;
28 plot(abs(fft(AA)));
29 xlabel('Frequency');
30 ylabel('Magnitude');
31 title('Fourier Transform of Subset Signal AA');
32
33 % Create a frequency vector for plotting
34 freqvec=0:fs/length(AA):fs-fs/length(AA);
35 fftaa=abs(fft(AA));
36 fftaar=abs(fft(AAref));
37
38 % Plot the first 100 components of the Fourier Transform of AA in decibels
39 figure;
40 plot(freqvec(1:100),20 * log10(fftaa(1:100)/ max(fftaa(1:100))))
41 xlabel('Frequency (MHz)');
42 ylabel('Magnitude');
43 title('First 100 Components of Fourier Transform of AA');
44
```

```
45 % Plot the first 100 components of the Fourier Transform of Aaref in decibels
46 figure;
47 plot(freqvec(1:100),20 * log10(fftaar(1:100)/ max(fftaar(1:100))))
48 xlabel('Frequency (MHz)');
49 ylabel('Magnitude');
50 title('First 100 Components of Fourier Transform of Aaref');
51
52 % Define a constant for conversion from ln to log10
53 log10e = 20*log10(exp(1));
54
55 L = 1;
56
57 % Calculate attenuation
58 alpha_f = log10e .* ( (1/L) .* log(fftaa(1:100) ./fftaar(1:100)));
59
60 %alpha_mean = mean(alpha_f)
61
62
63 figure;
64 % Plot
65 plot(freqvec(1:100), alpha_f);
66 xlabel('Frequency (MHz)');
67 ylabel('Attenuation Coefficient (dB)');
68 title('Frequency Dependent Attenuation');
69 grid on;
```

Code (1), MATLAB implementation to find attenuation.

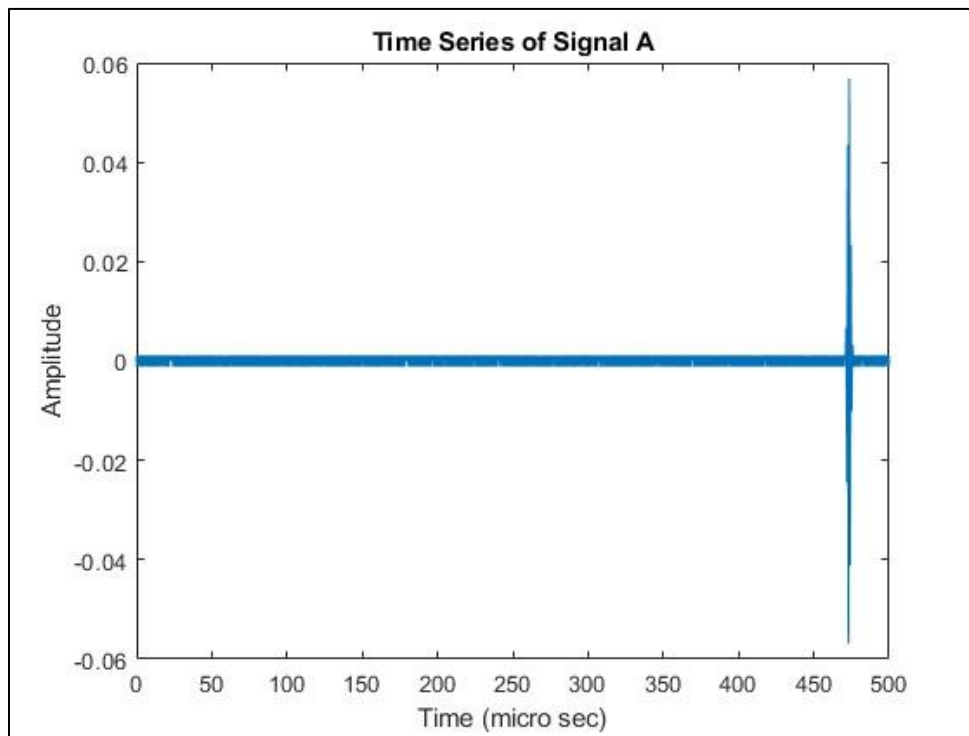


Figure (1), Plot for Time series of signal.

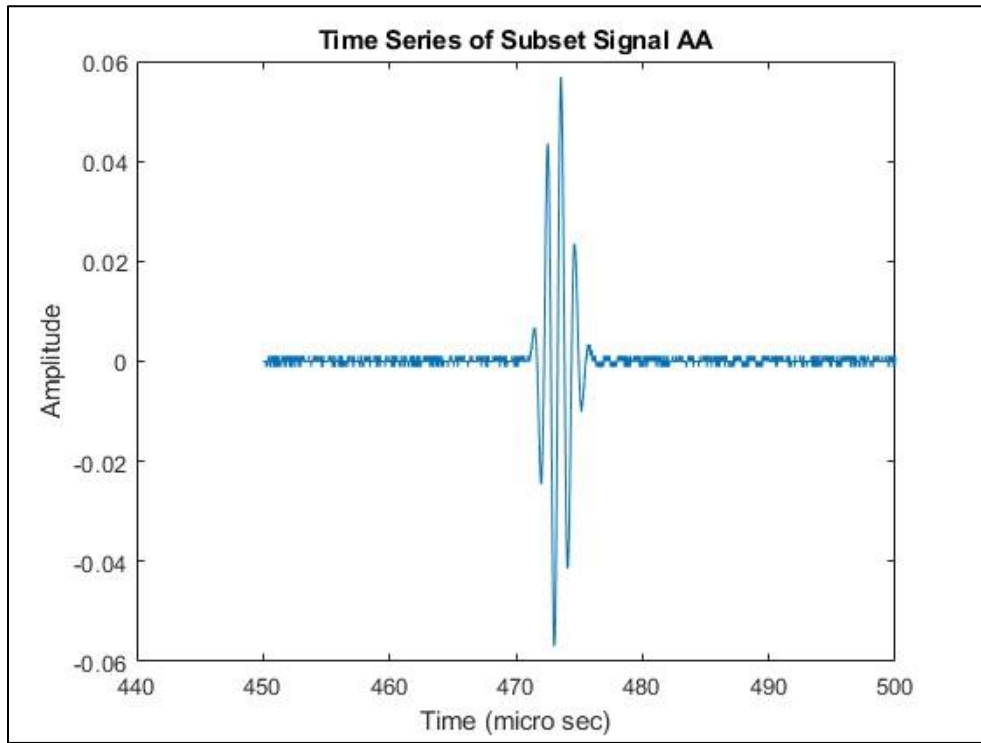


Figure (2), Plot for Time series of signal zoomed in.

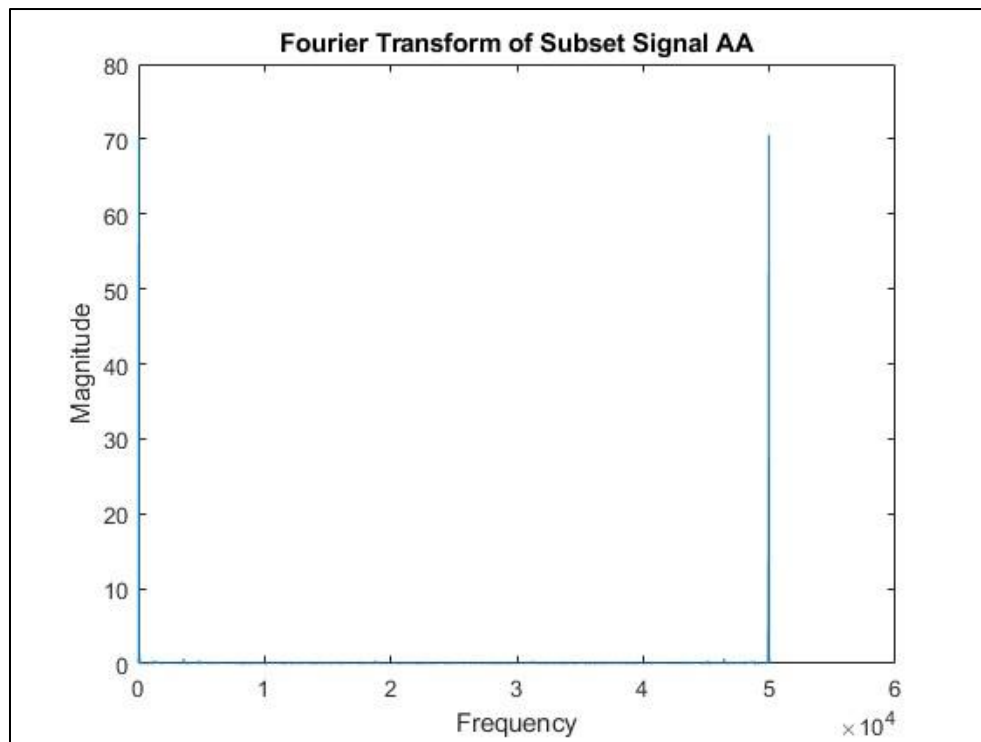


Figure (3), Plot for Fourier Transform of the signal.

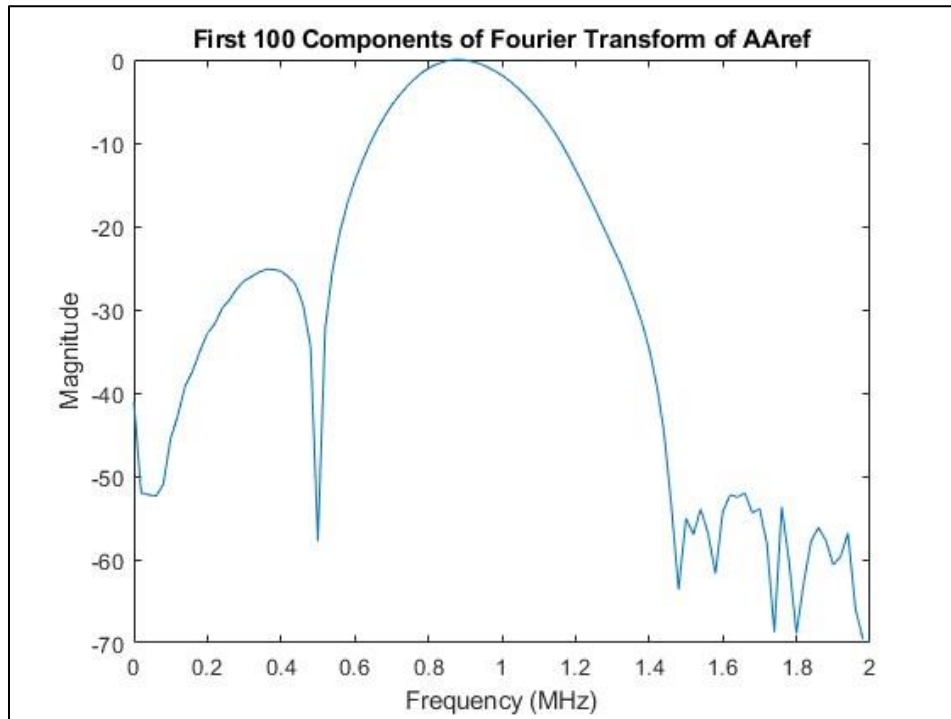


Figure (4), Plot for first 100 components in the Fourier Transform of the reference signal.

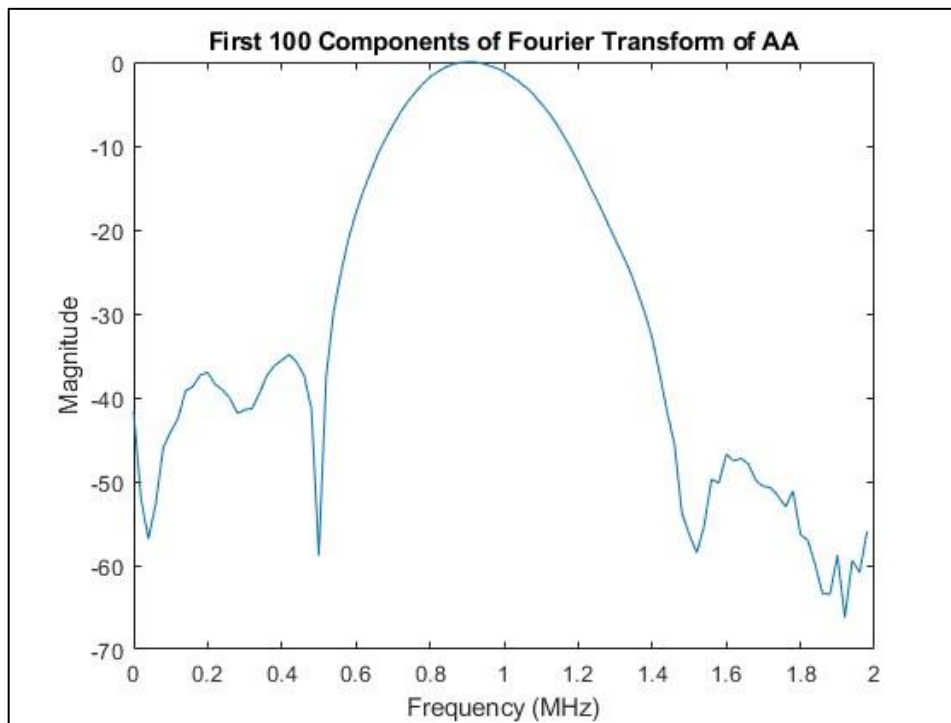


Figure (5), Plot for first 100 components in the Fourier Transform of the signal.

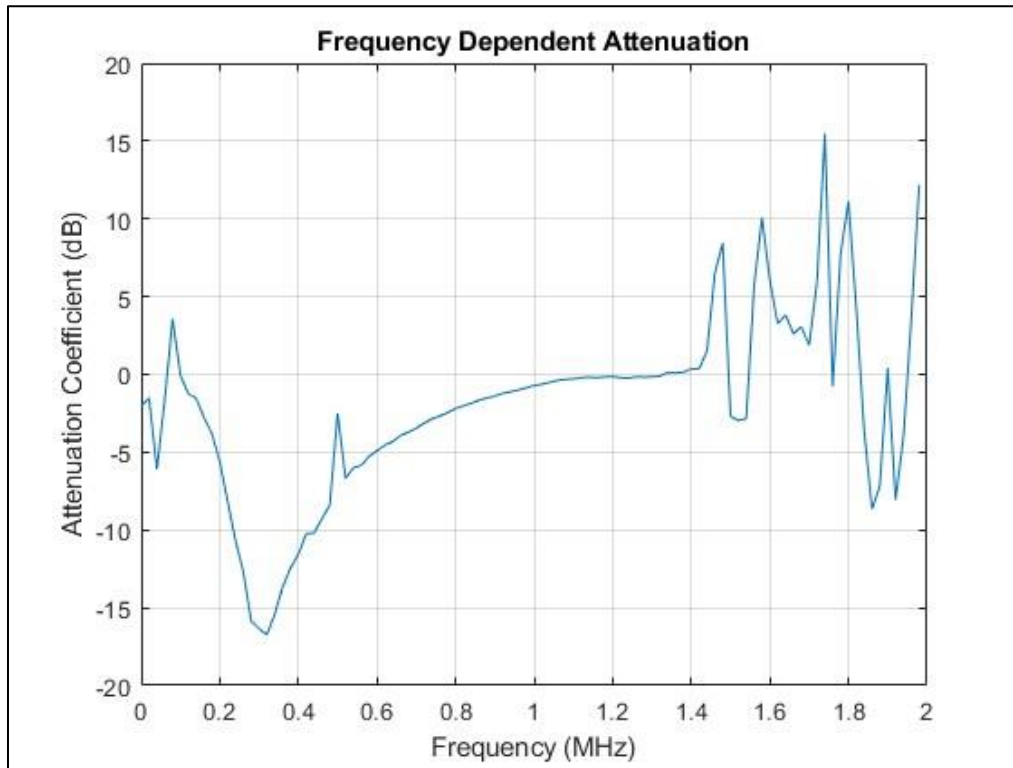


Figure (6), Plot for Frequency Dependent Attenuation

The observed attenuation, particularly in the frequency range of 0.7 – 1.1 MHz as depicted in Figure 6, was found to be minimal. This was determined by graphing the initial 100 elements of the Fourier Transforms of both AA and AArefer, with their values in decibels. The focus on the 0.7 – 1.1 MHz range was due to its relevance to our study, while other data were regarded as noise. The attenuation coefficient was computed based on the logarithmic comparison of the Fourier components of AA and AArefer, with appropriate adjustments made for converting into decibels.

## **4. Conclusion**

The acoustic characteristics of the hydrogel phantoms, particularly their sound speed and minimal attenuation, show similarity to human lung tissue. This observation highlights the potential of these hydrogel-based models in ultrasound imaging, especially for the uses in pulmonary conditions like fibrosis and edema. The hydrogel phantoms can be used in replicating lung acoustics indicates their utility as a dependable and controlled medium for ultrasound imaging research and development.

In the next phase of the research, I plan to further conduct experiments on the phantoms. To simulate fibrosis, we will create hydrogel lattice structures with initially empty lattices that will progressively absorb water, leading to a denser structure. For emulating edema, we intend to use hydrogel lattice structures with partially filled lattices. These approaches are designed to closely mimic the respective pulmonary conditions.

Additionally, the next steps involve the utilization of the Verasonics system for ultrasound data collection on these hydrogel lattices.

## **5. References**

- [1] Sasso, M., Haiat, G., Yamato, Y., Naili, S., & Matsukawa, M. (2007). "Frequency Dependence of Ultrasonic Attenuation in Bovine Cortical Bone: An In Vitro Study". *Ultrasound in Medicine & Biology*, 33(12), 1933-1942.01