IOWA STATE UNIVERSITY

Center for Nondestructive Evaluation

CAAP Update Oct. 8, 2015

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CENTER FOR NDE

Outline

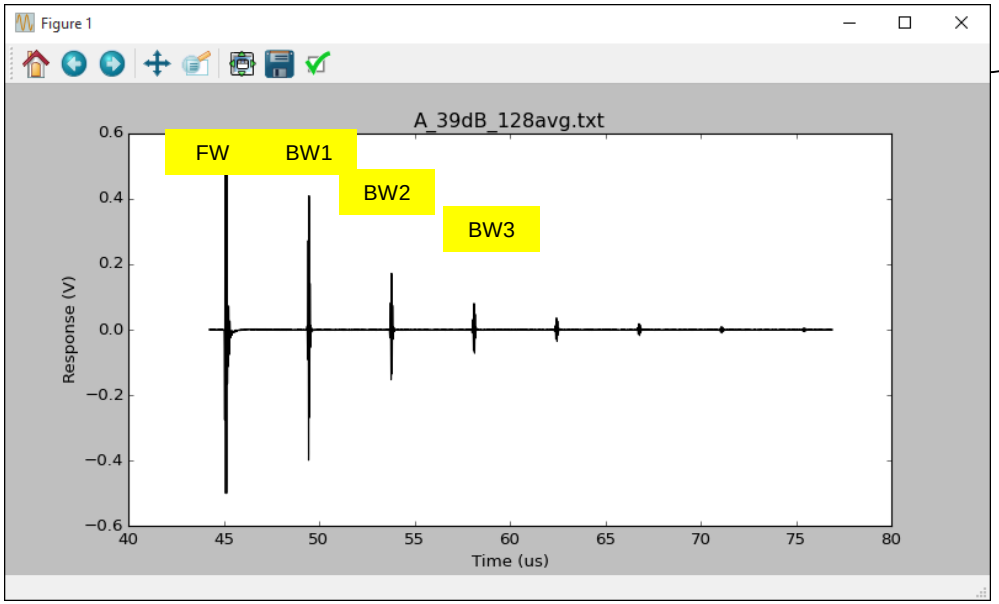
- New Samples
  - Ultrasonic velocity and attenuation measurements
  - Ultrasonic backscatter measurements
  - Barkhausen noise measurements

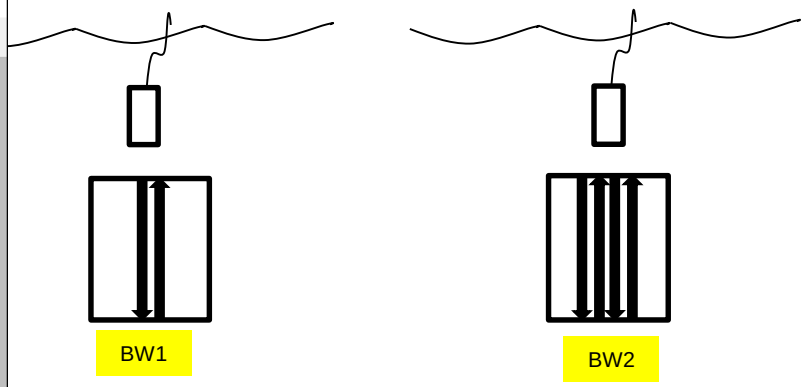
Samples

- X52 plate from Colorado School of Mines
  - Rectangular, ~2”x2”, 0.5” thickness
- 5 samples – one control and four with different heat treatments
  - A: as received by CSM
  - B: Normalized at 950C for 1hr, air cool
  - C: Normalized at 950C for 1hr, furnace cool
  - D: Annealed at inter-critical temp of 800C, air cool
  - E: Annealed at inter-critical temp of 800C, furnace cool
- Expect combination of ferrite and pearlite in inter-critical samples, pearlite in normalized.

Ultrasonic velocity and attenuation

- Estimates of velocity and attenuation obtained using multiple back wall reverberations obtained from a normal incidence immersion test
- 20 MHz 1/4” diameter planar transducer





- Use <u>arrival times</u> of BW signals with <u>thickness</u> to estimate velocity
- Use <u>ratio of BW signal spectra</u> to estimate attenuation as: $\alpha(f) = -\frac{1}{2z}\ln\left(\left|\frac{\Gamma_3(f)}{\Gamma_2(f)}\right|\right)$

  where z is the thickness

SAMPLE A

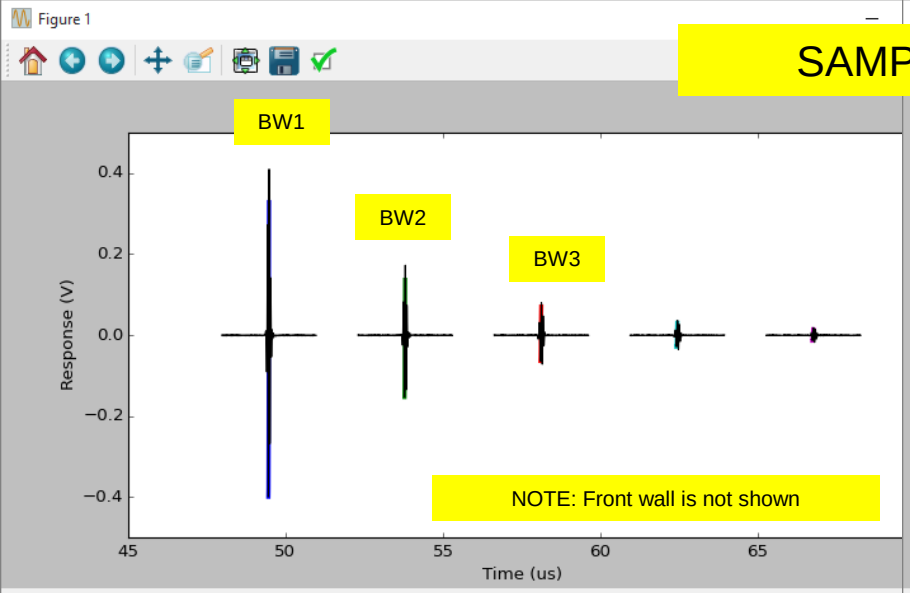


Figure 1
BW1
BW2
BW3
NOTE: Front wall is not shown
Response (V)
Time (us)

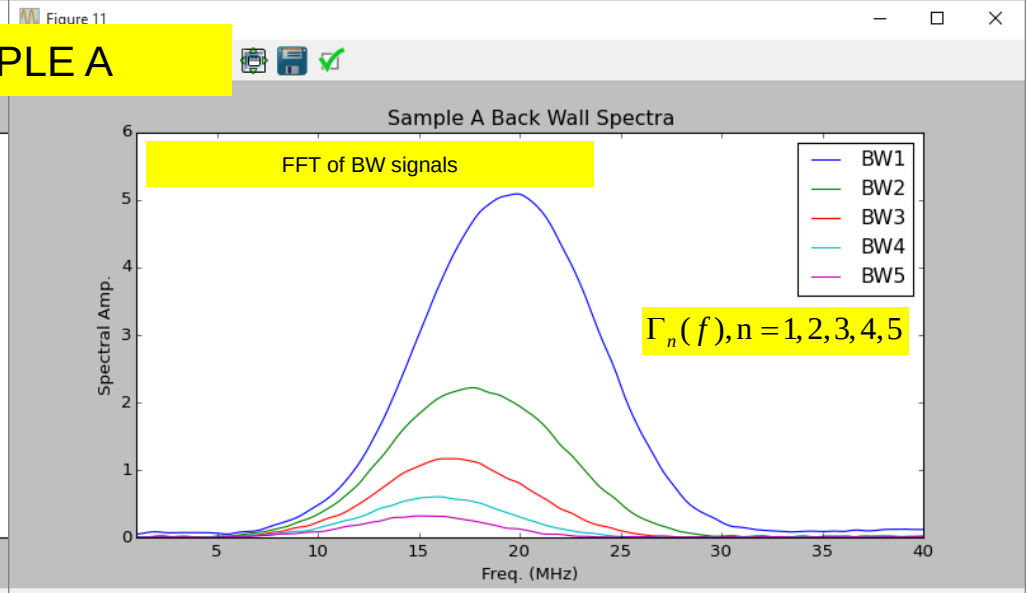


Figure 11
Sample A Back Wall Spectra
FFT of BW signals
BW1
BW2
BW3
BW4
BW5
$\Gamma_n(f), n = 1,2,3,4,5$
Spectral Amp.
Freq. (MHz)

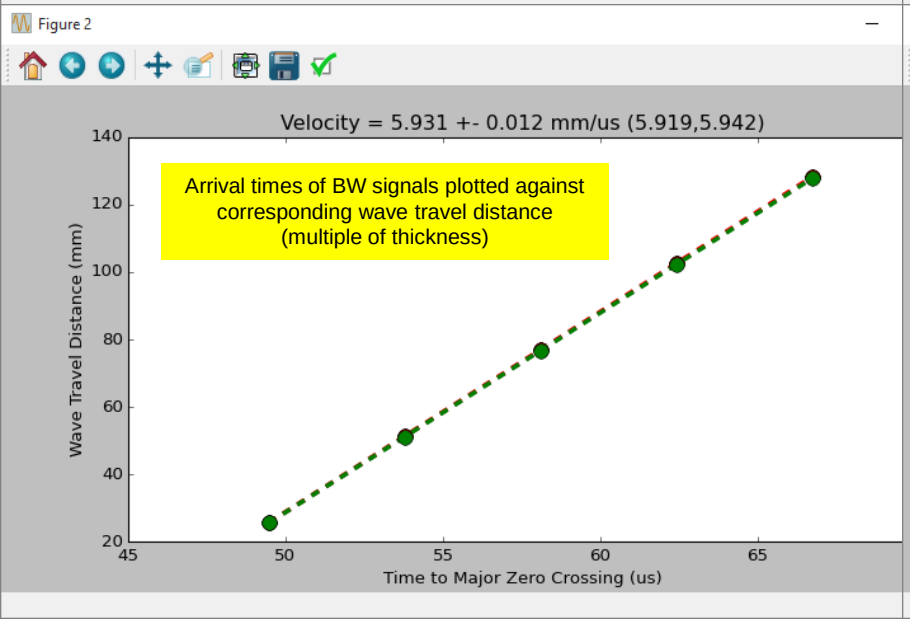


Figure 2
Velocity = 5.931 +- 0.012 mm/us (5.919,5.942)
Arrival times of BW signals plotted against corresponding wave travel distance (multiple of thickness)
Wave Travel Distance (mm)
Time to Major Zero Crossing (us)

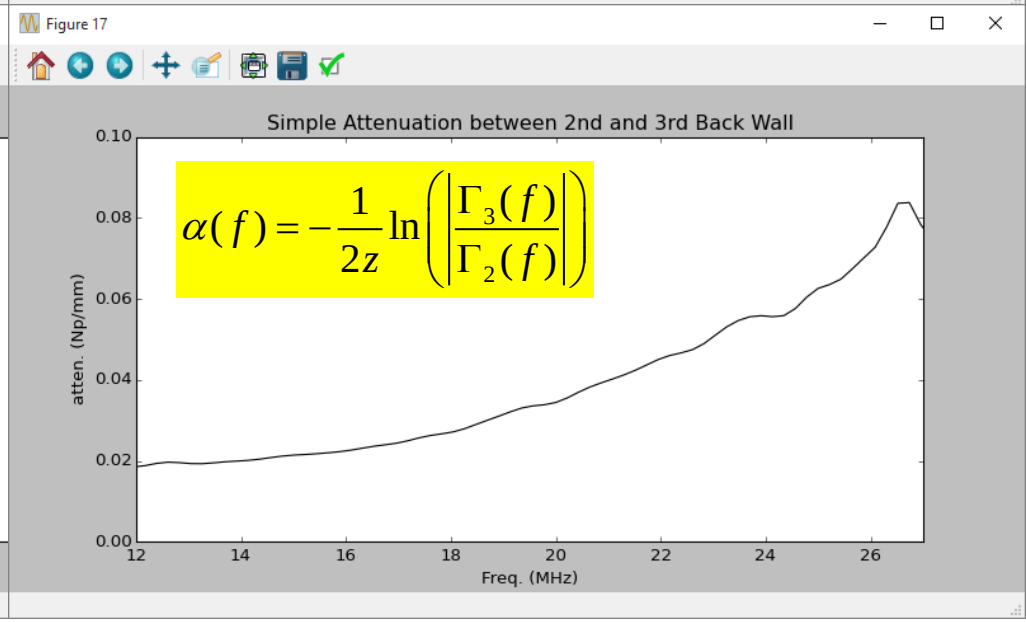


Figure 17
Simple Attenuation between 2nd and 3rd Back Wall
$\alpha(f) = -\frac{1}{2z}\ln\left(\left|\frac{\Gamma_3(f)}{\Gamma_2(f)}\right|\right)$
atten. (Np/mm)
Freq. (MHz)

SAMPLE B

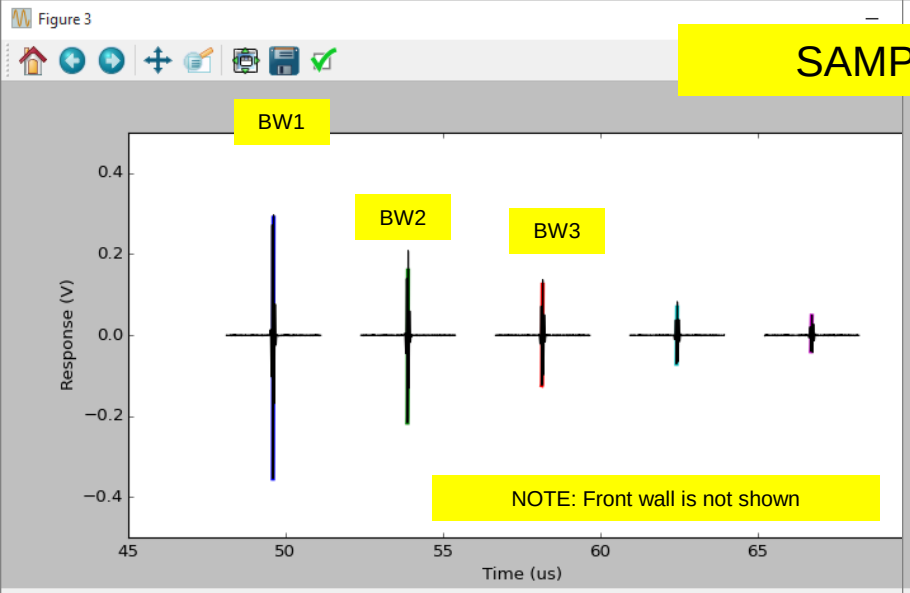


Figure 3
BW1
BW2
BW3
NOTE: Front wall is not shown
Response (V)
Time (us)

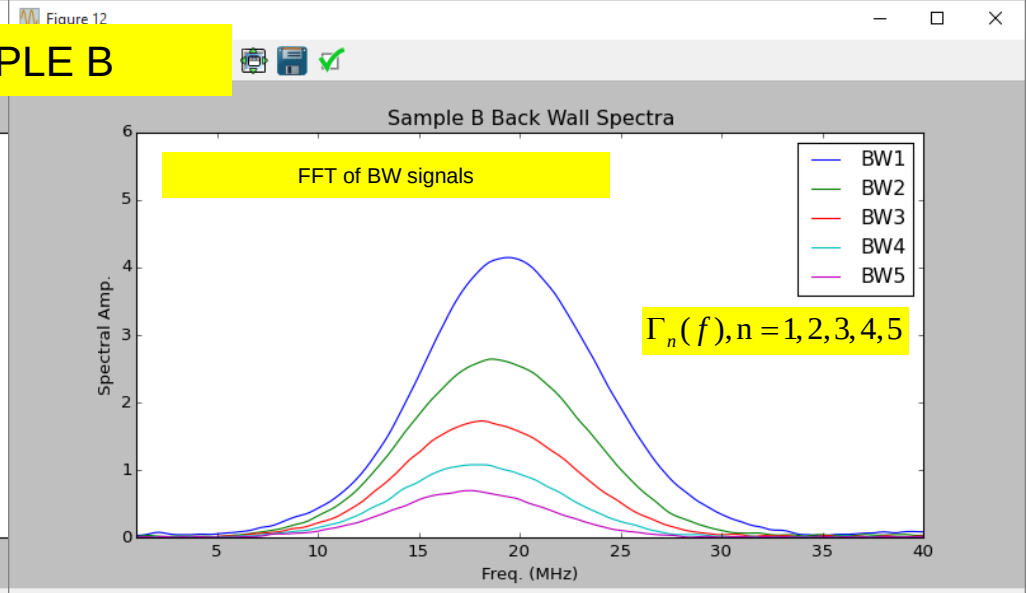


Figure 12
Sample B Back Wall Spectra
FFT of BW signals
BW1
BW2
BW3
BW4
BW5
$\Gamma_n(f), n = 1,2,3,4,5$
Spectral Amp.
Freq. (MHz)

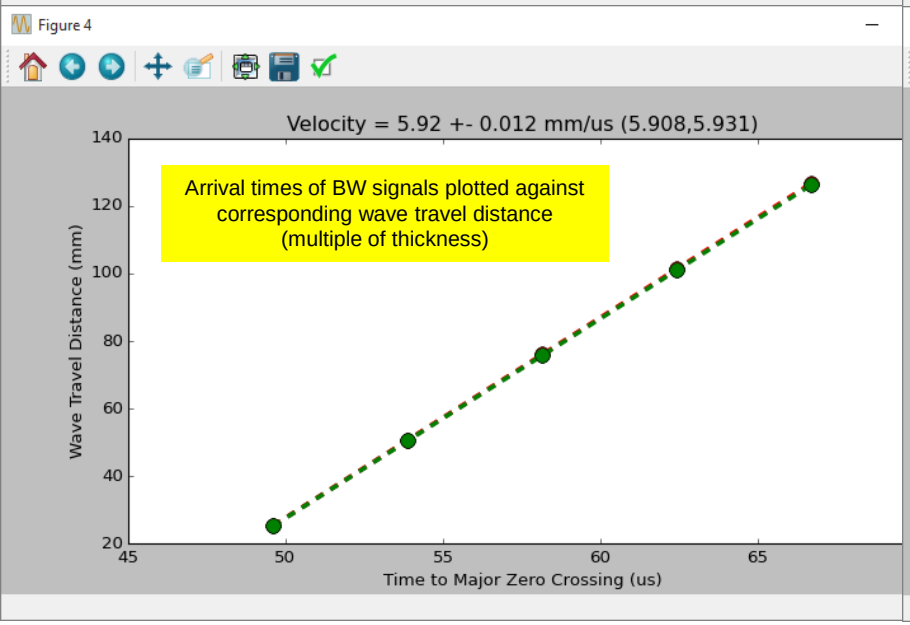


Figure 4
Velocity = 5.92 +- 0.012 mm/us (5.908,5.931)
Arrival times of BW signals plotted against corresponding wave travel distance (multiple of thickness)
Wave Travel Distance (mm)
Time to Major Zero Crossing (us)

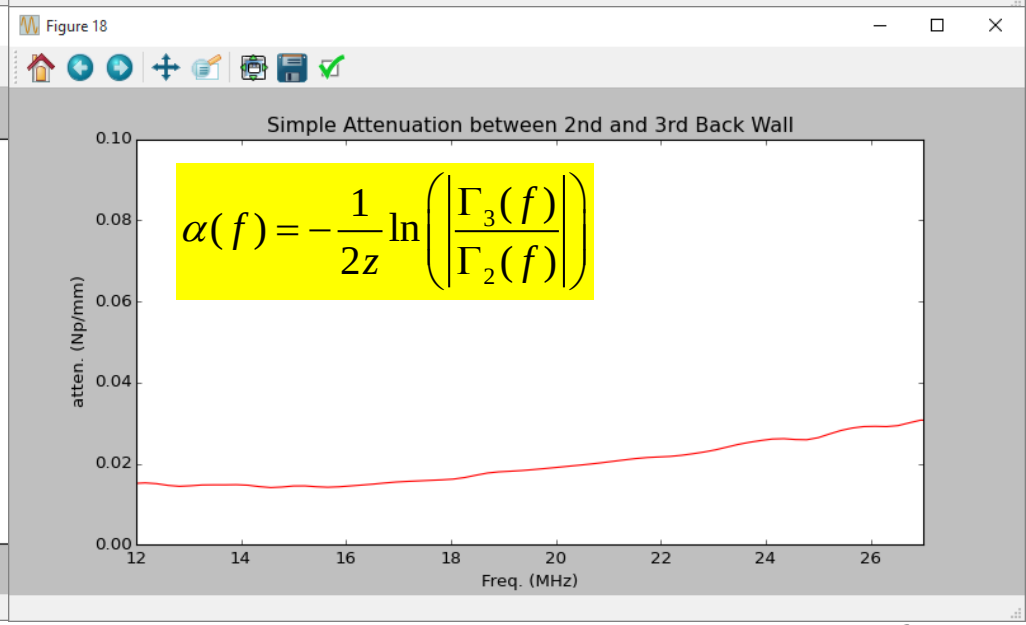


Figure 18
Simple Attenuation between 2nd and 3rd Back Wall
$\alpha(f) = -\frac{1}{2z}\ln\left(\left|\frac{\Gamma_3(f)}{\Gamma_2(f)}\right|\right)$
atten. (Np/mm)
Freq. (MHz)

SAMPLE C

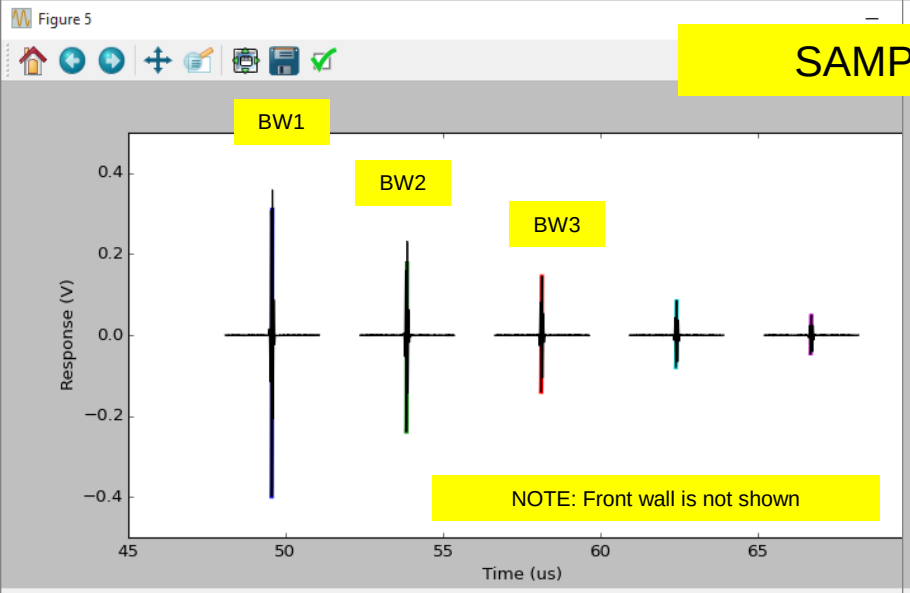


Figure 5
BW1
BW2
BW3
NOTE: Front wall is not shown
Response (V)
Time (us)

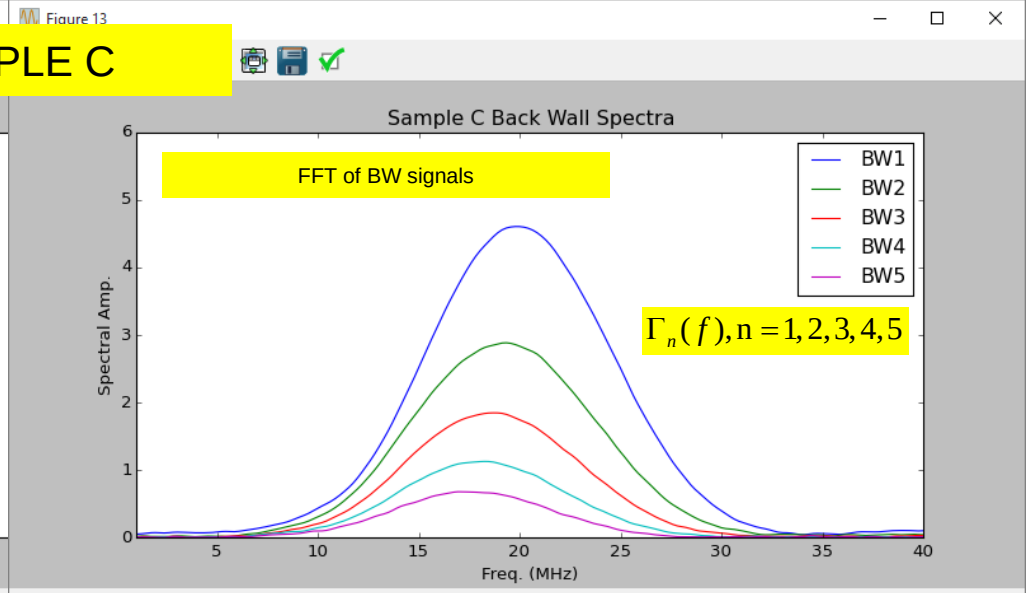


Figure 13
Sample C Back Wall Spectra
FFT of BW signals
BW1
BW2
BW3
BW4
BW5
$\Gamma_n(f), n = 1,2,3,4,5$
Spectral Amp.
Freq. (MHz)

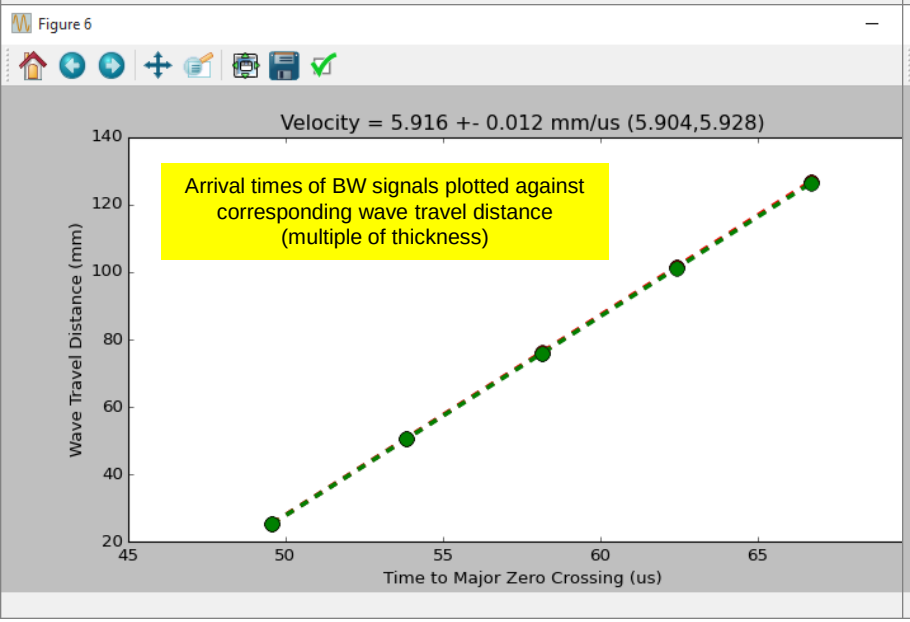


Figure 6
Velocity = 5.916 +- 0.012 mm/us (5.904,5.928)
Arrival times of BW signals plotted against corresponding wave travel distance (multiple of thickness)
Wave Travel Distance (mm)
Time to Major Zero Crossing (us)

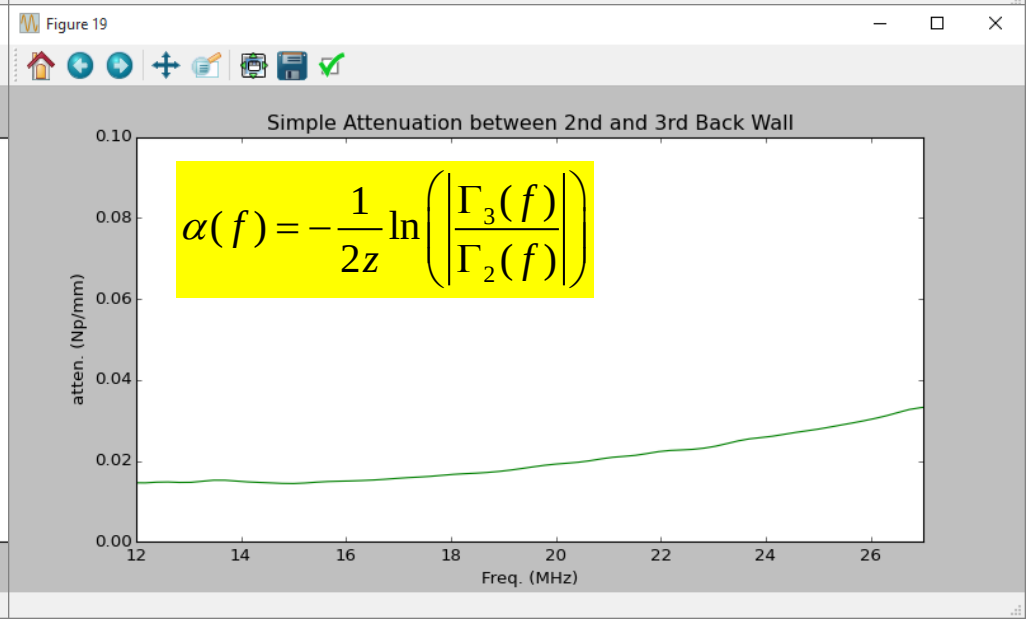


Figure 19
Simple Attenuation between 2nd and 3rd Back Wall
$\alpha(f) = -\frac{1}{2z}\ln\left(\left|\frac{\Gamma_3(f)}{\Gamma_2(f)}\right|\right)$
atten. (Np/mm)
Freq. (MHz)

SAMPLE D

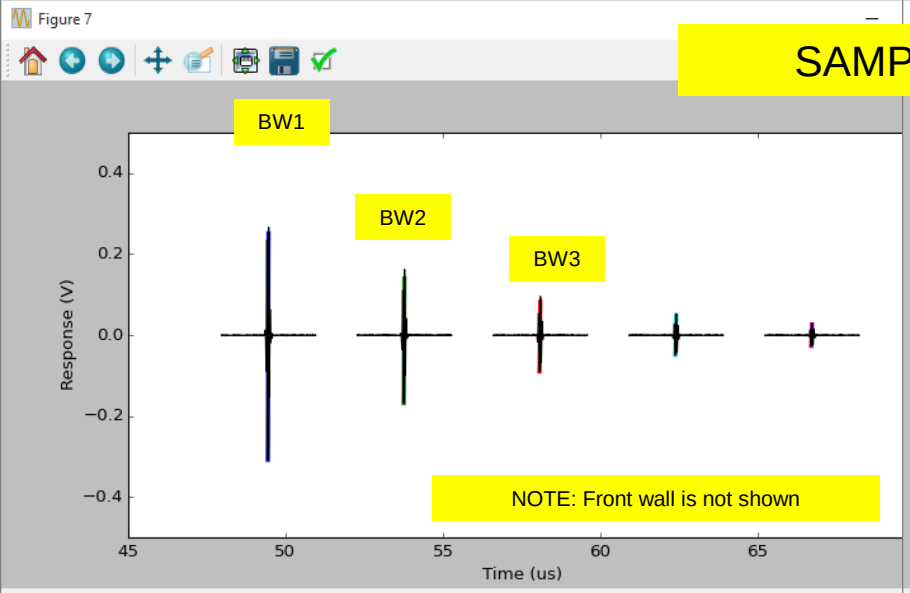


Figure 7
BW1
BW2
BW3
NOTE: Front wall is not shown
Response (V)
Time (us)

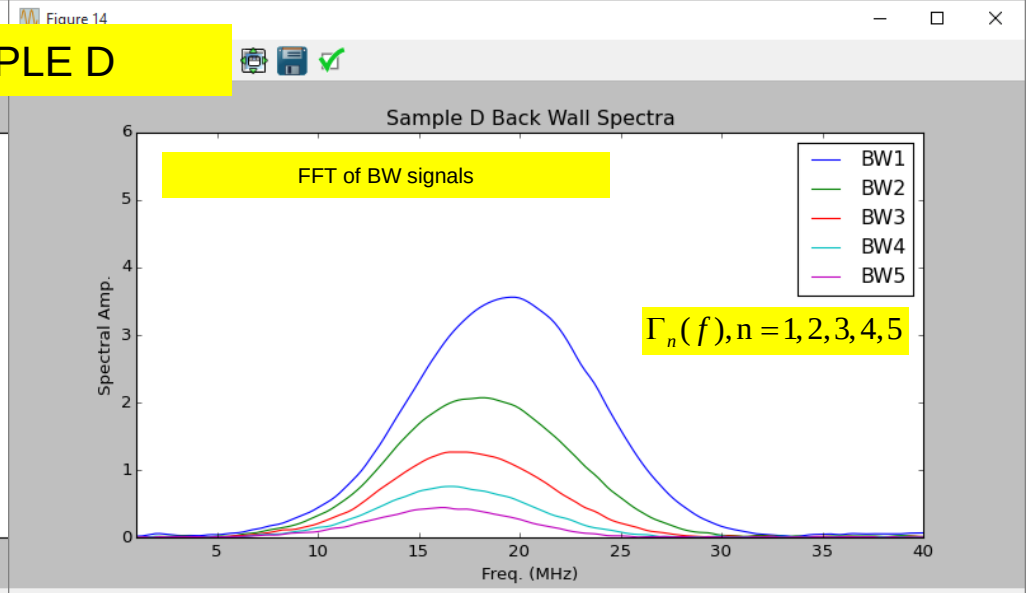


Figure 14
Sample D Back Wall Spectra
FFT of BW signals
BW1
BW2
BW3
BW4
BW5
$\Gamma_n(f), n = 1,2,3,4,5$
Spectral Amp.
Freq. (MHz)

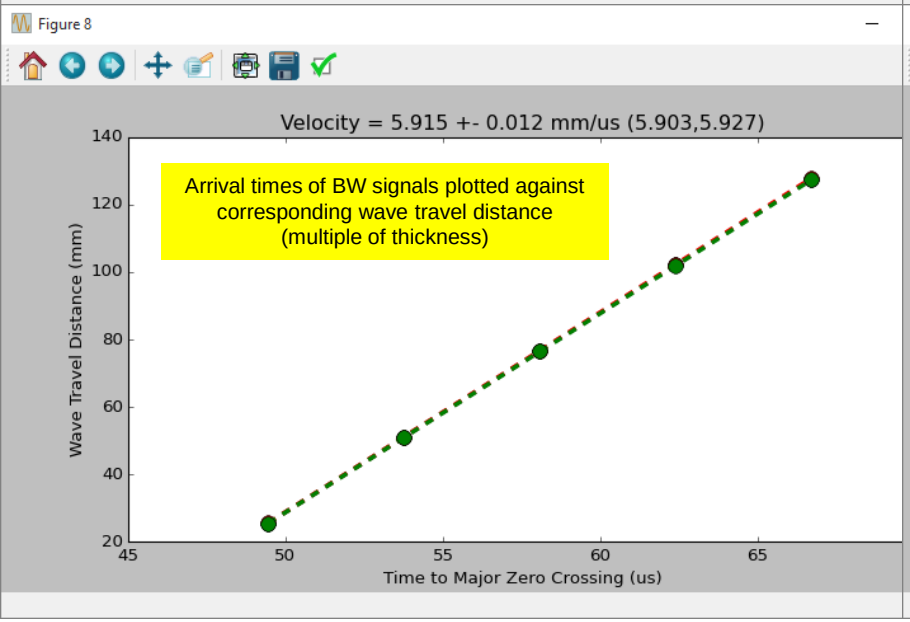


Figure 8
Velocity = 5.915 +- 0.012 mm/us (5.903,5.927)
Arrival times of BW signals plotted against corresponding wave travel distance (multiple of thickness)
Wave Travel Distance (mm)
Time to Major Zero Crossing (us)

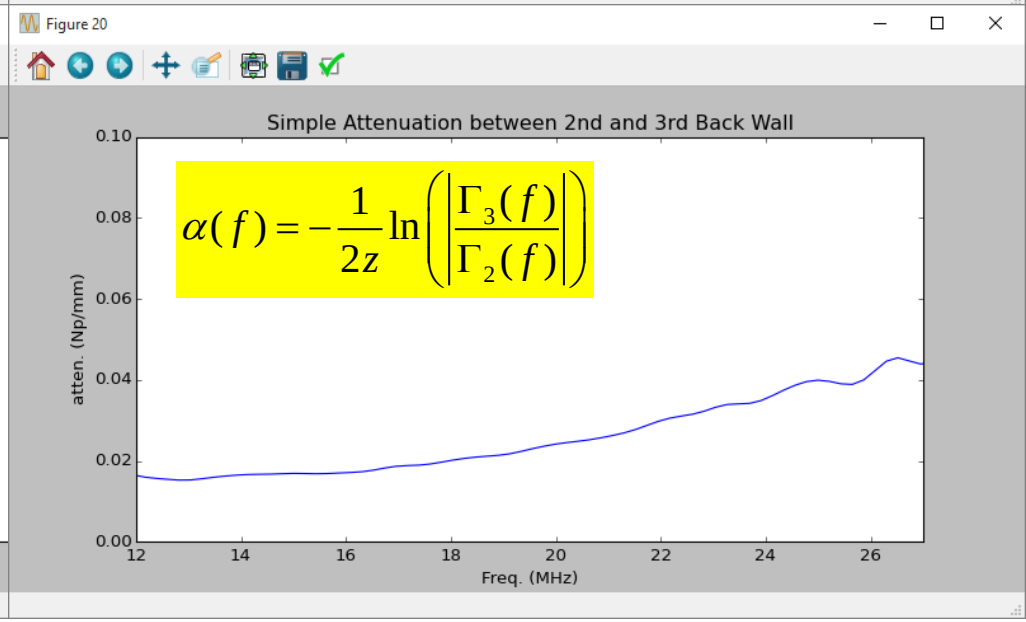


Figure 20
Simple Attenuation between 2nd and 3rd Back Wall
$\alpha(f) = -\frac{1}{2z}\ln\left(\left|\frac{\Gamma_3(f)}{\Gamma_2(f)}\right|\right)$
atten. (Np/mm)
Freq. (MHz)

SAMPLE E

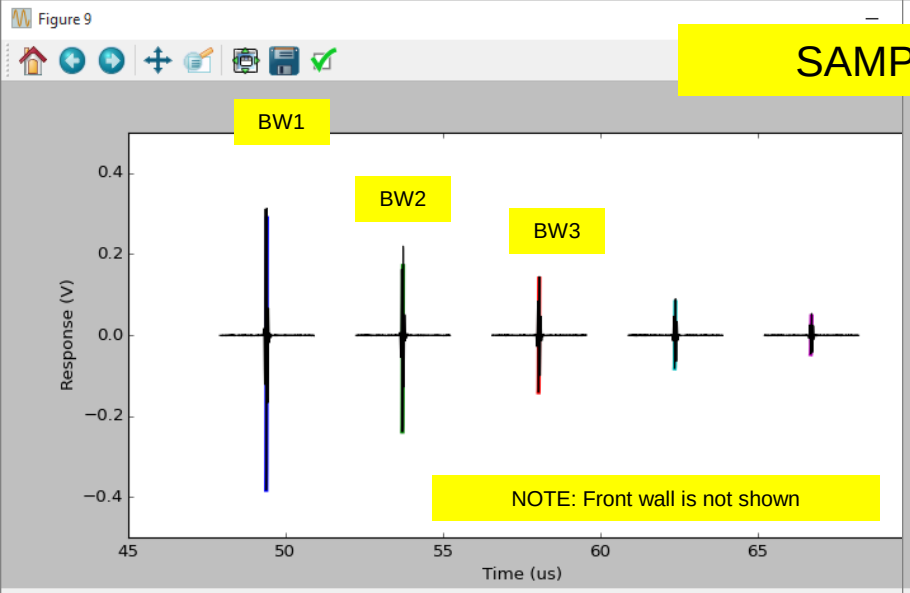


Figure 9
BW1
BW2
BW3
NOTE: Front wall is not shown
Response (V)
Time (us)

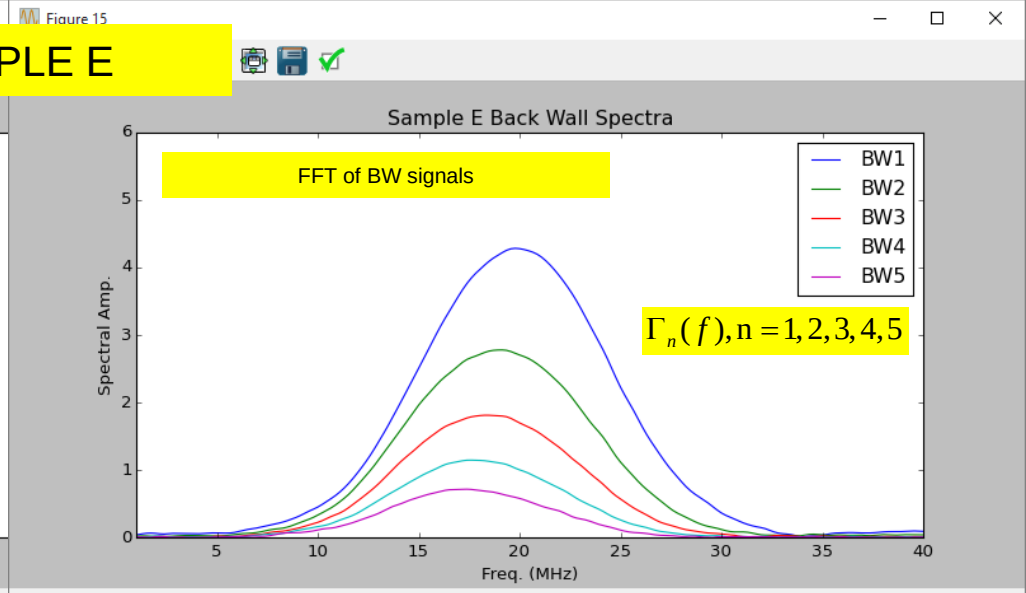


Figure 15
Sample E Back Wall Spectra
FFT of BW signals
BW1
BW2
BW3
BW4
BW5
$\Gamma_n(f), n = 1,2,3,4,5$
Spectral Amp.
Freq. (MHz)

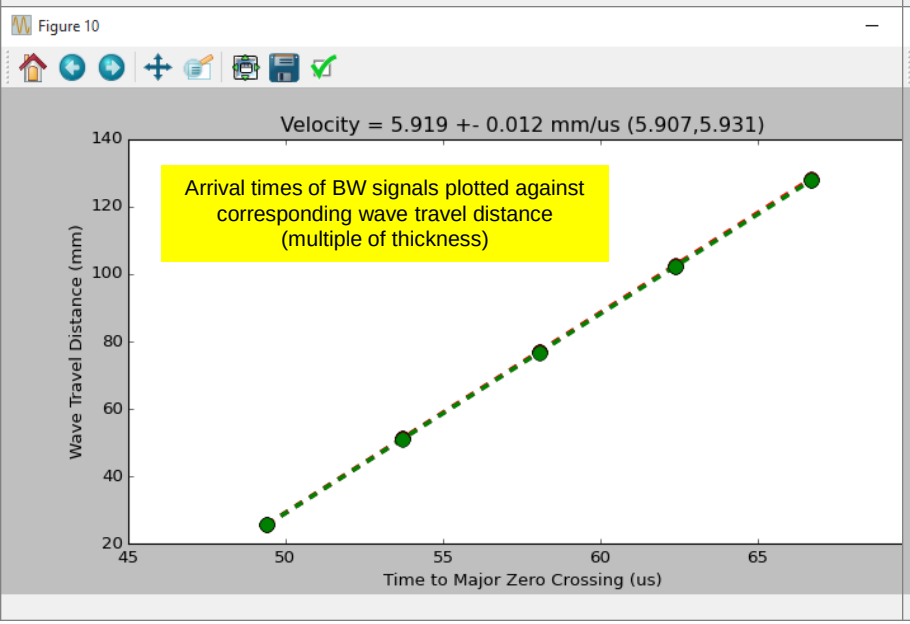


Figure 10
Velocity = 5.919 +- 0.012 mm/us (5.907,5.931)
Arrival times of BW signals plotted against corresponding wave travel distance (multiple of thickness)
Wave Travel Distance (mm)
Time to Major Zero Crossing (us)

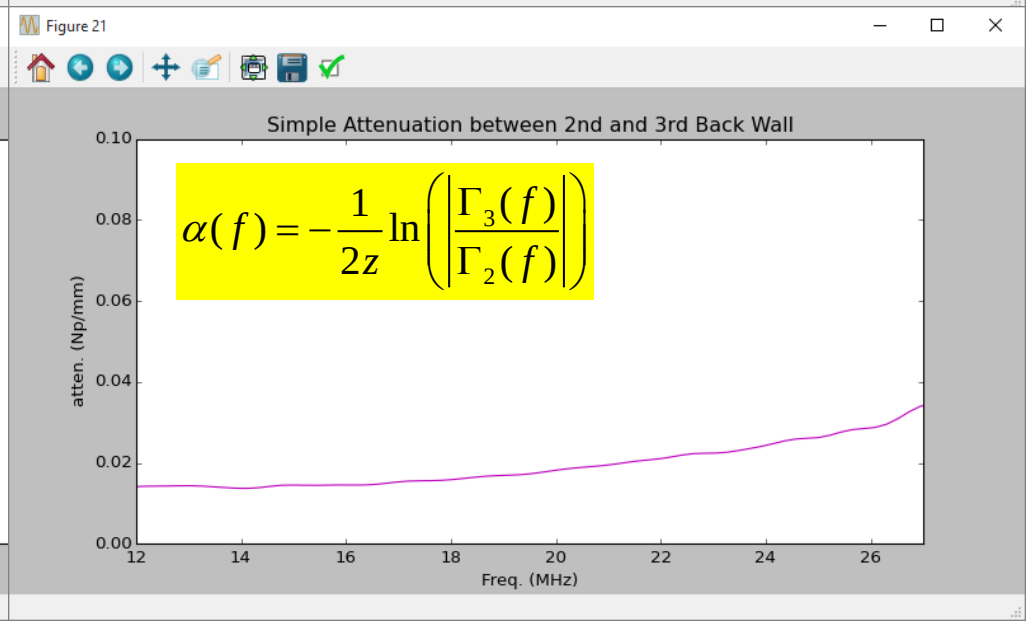
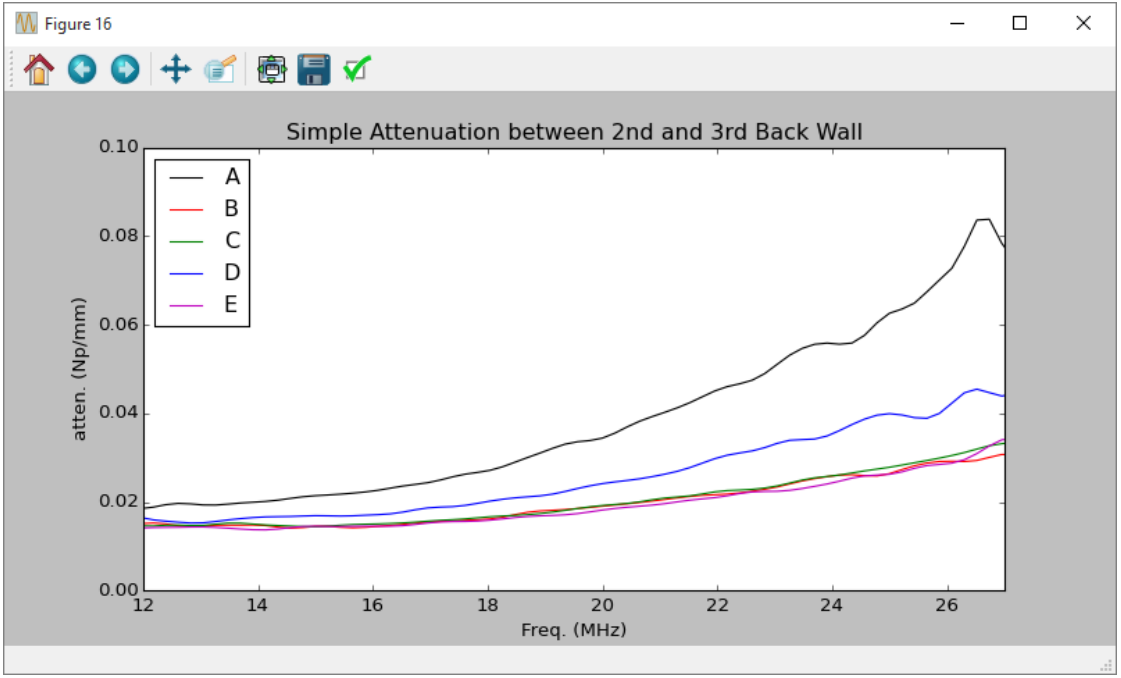
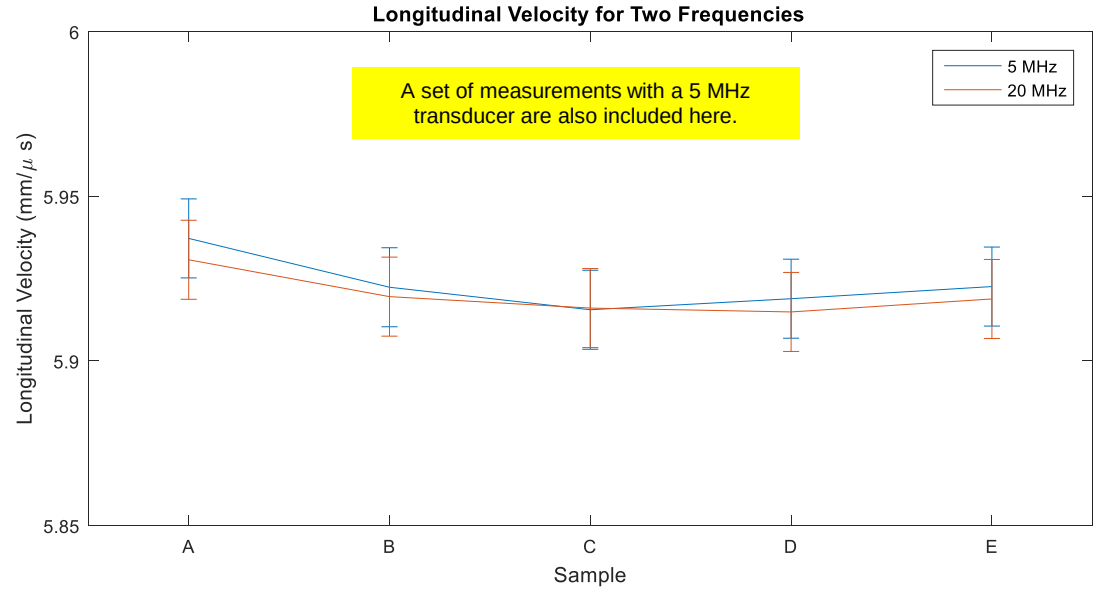


Figure 21
Simple Attenuation between 2nd and 3rd Back Wall
$\alpha(f) = -\frac{1}{2z}\ln\left(\left|\frac{\Gamma_3(f)}{\Gamma_2(f)}\right|\right)$
atten. (Np/mm)
Freq. (MHz)



Attenuation of A clearly the largest, followed by D. Samples B, C, and E have roughly the same attenuation.

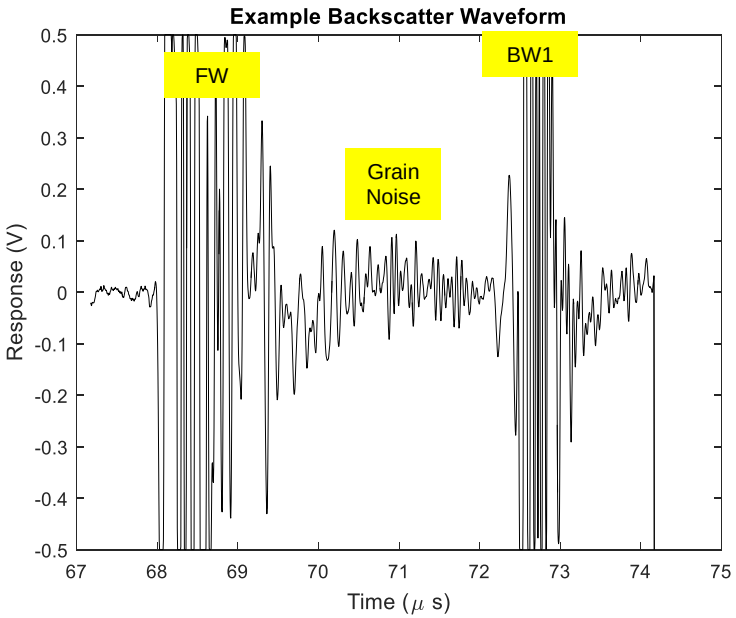


No substantial variation in velocity. Error bars are +- 0.2%. Largest variation between samples is about 0.2%.

Ultrasonic backscatter measurements

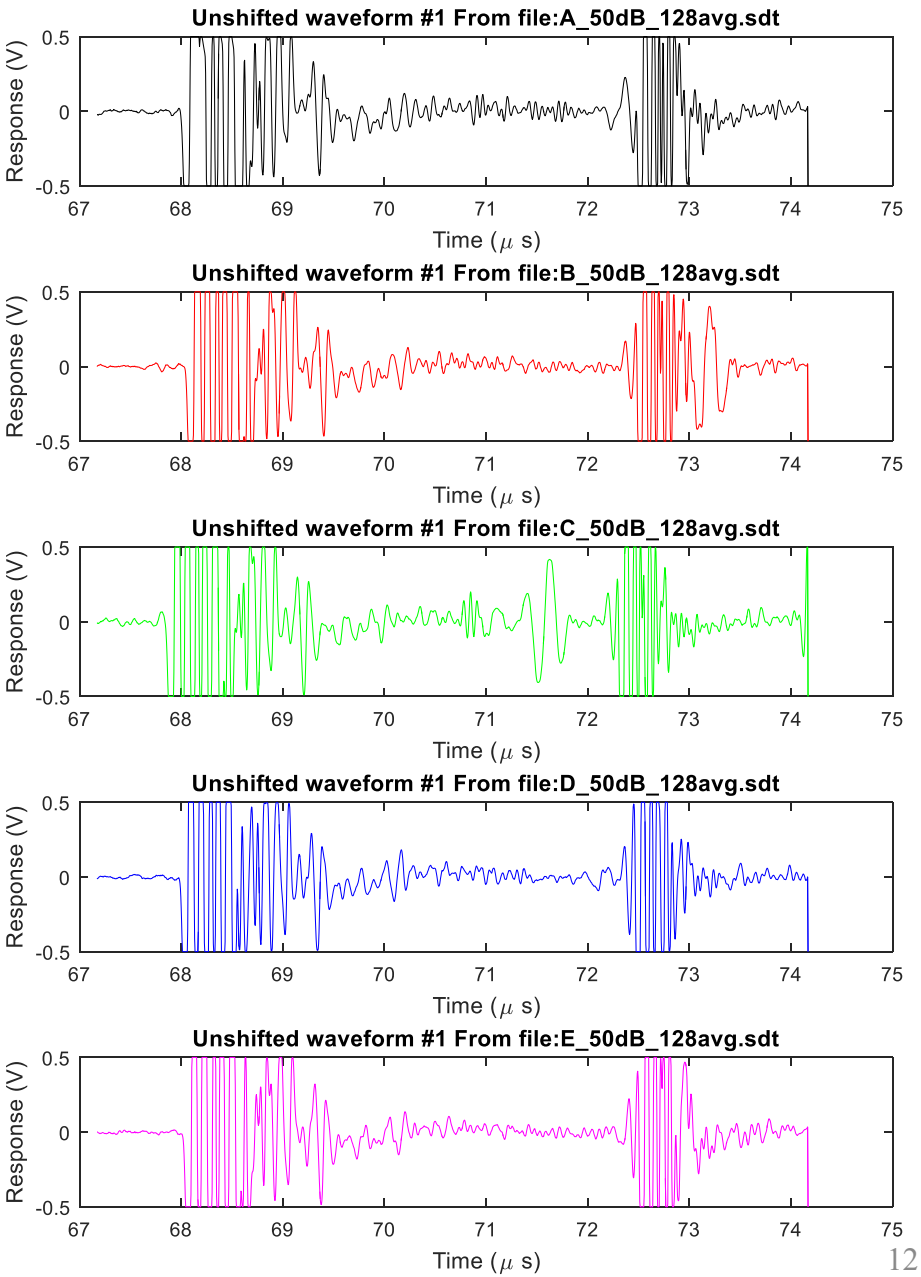
- Normal incidence, immersion test
- 10 MHz, 3/8” focused transducer, 3” focal length
- Focused roughly halfway through the thickness
- High gain measurements to measure response from microstructure between the FW and BW1

A 2D scan over a 0.6”x0.6” area was performed, collecting a waveform such as the one at right every 0.02”, for 900 total waveforms per sample



Backscatter Data Processing

- 900 waveforms per sample. V_j, j=1,2,…M, where M=900 here
- Example from each sample shown
- Time domain processing
  - For each time, spatially average the square of the response
- Outcome will be what we call the RMS Noise Voltage



Backscatter Time Domain Processing

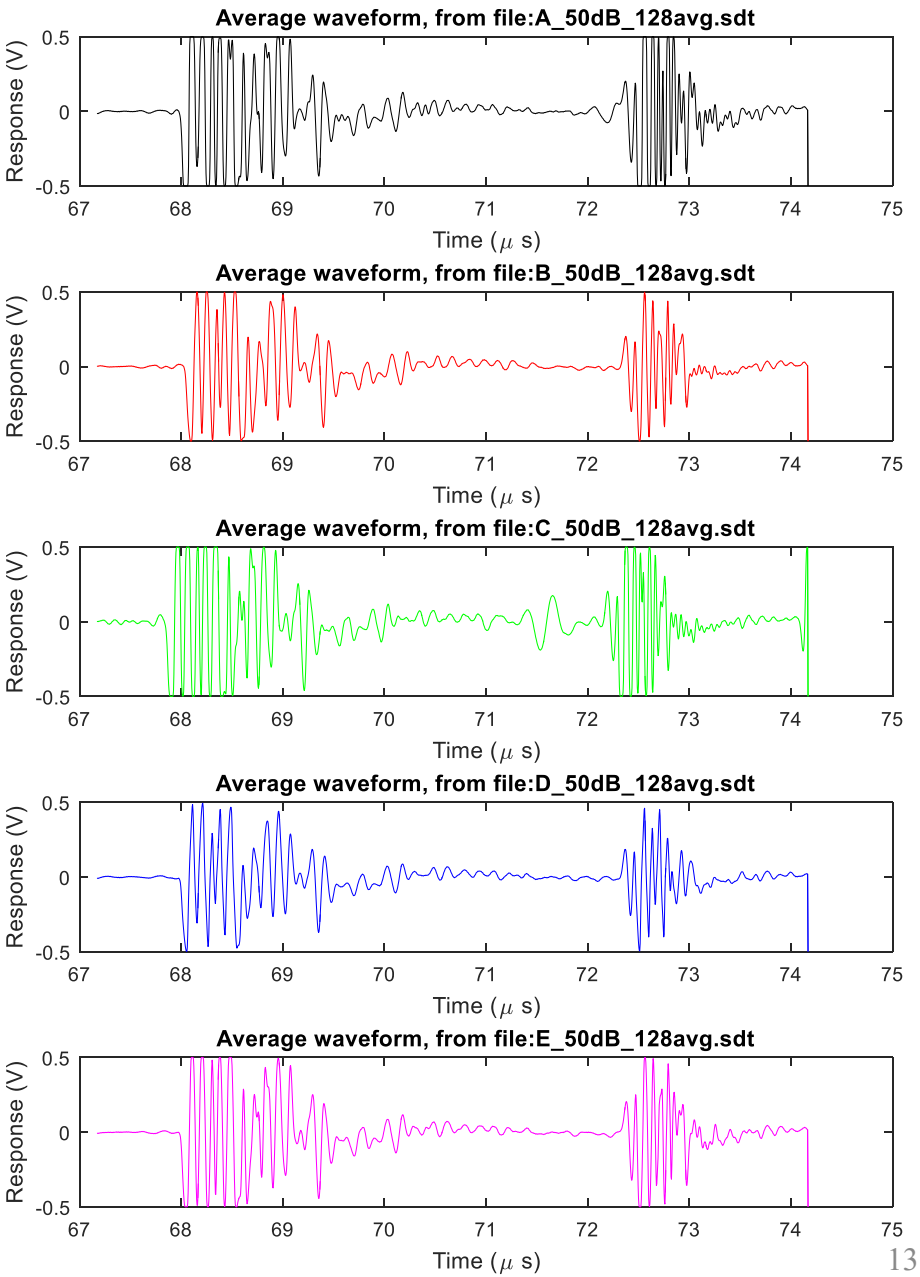
Calculate RMS Noise as

$$V_{rms}(t) = \left[\frac{1}{M} \sum_{j=1}^{M} \left(V_j(t) - V_{avg}(t) \right)^2 \right]^{1/2}$$

Where

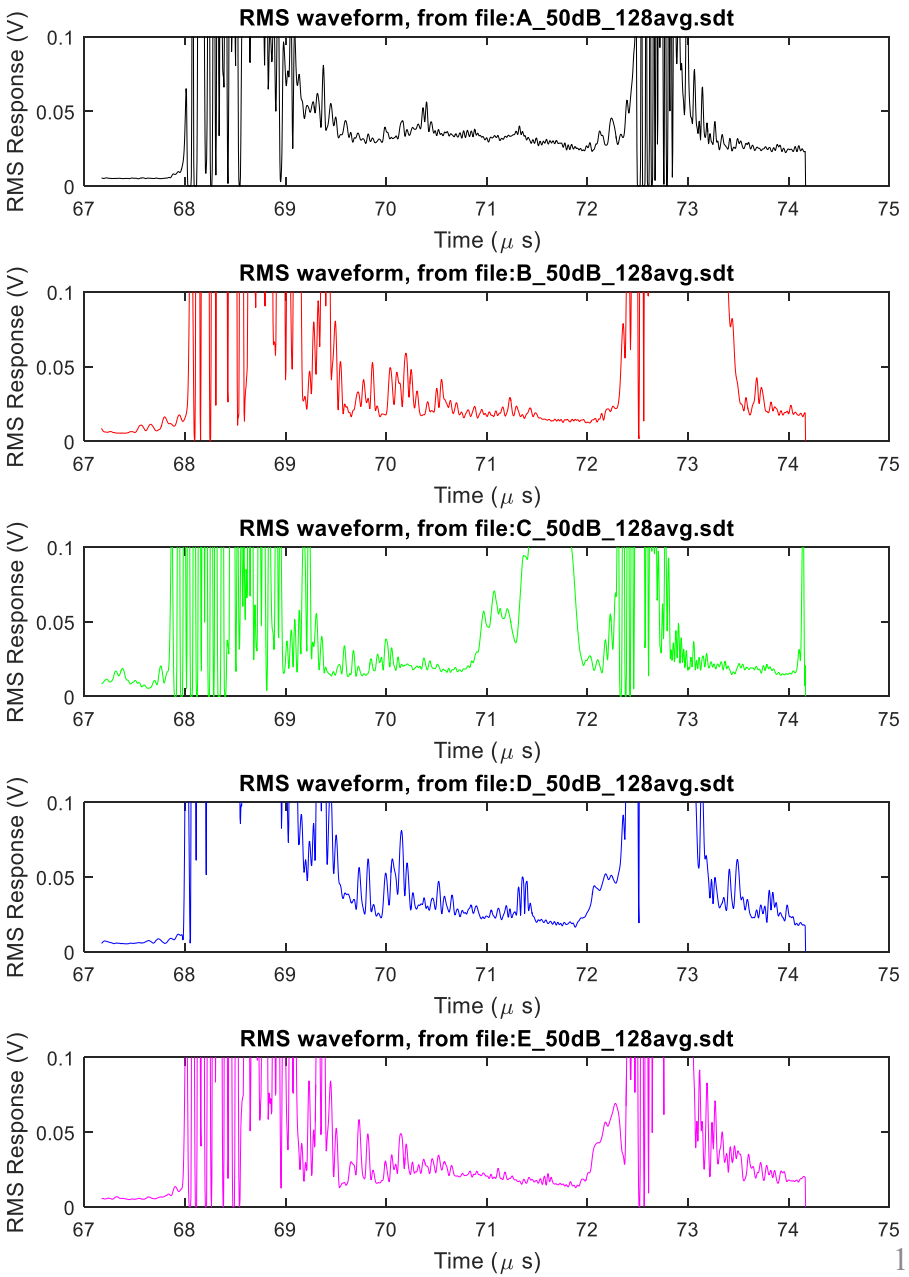
$$V_{avg} = \frac{1}{M} \sum_{j=1}^{M} V_j(t)$$

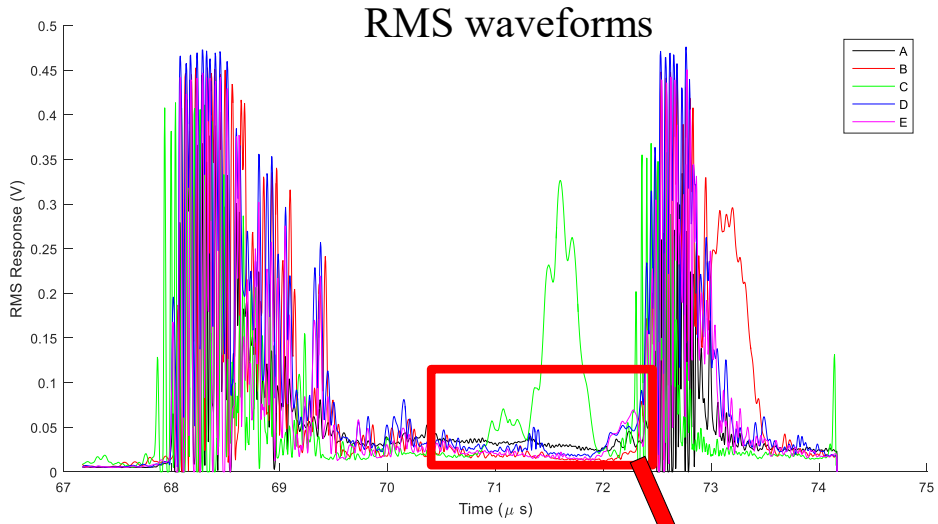
The V_{avg} for each sample is shown to the right



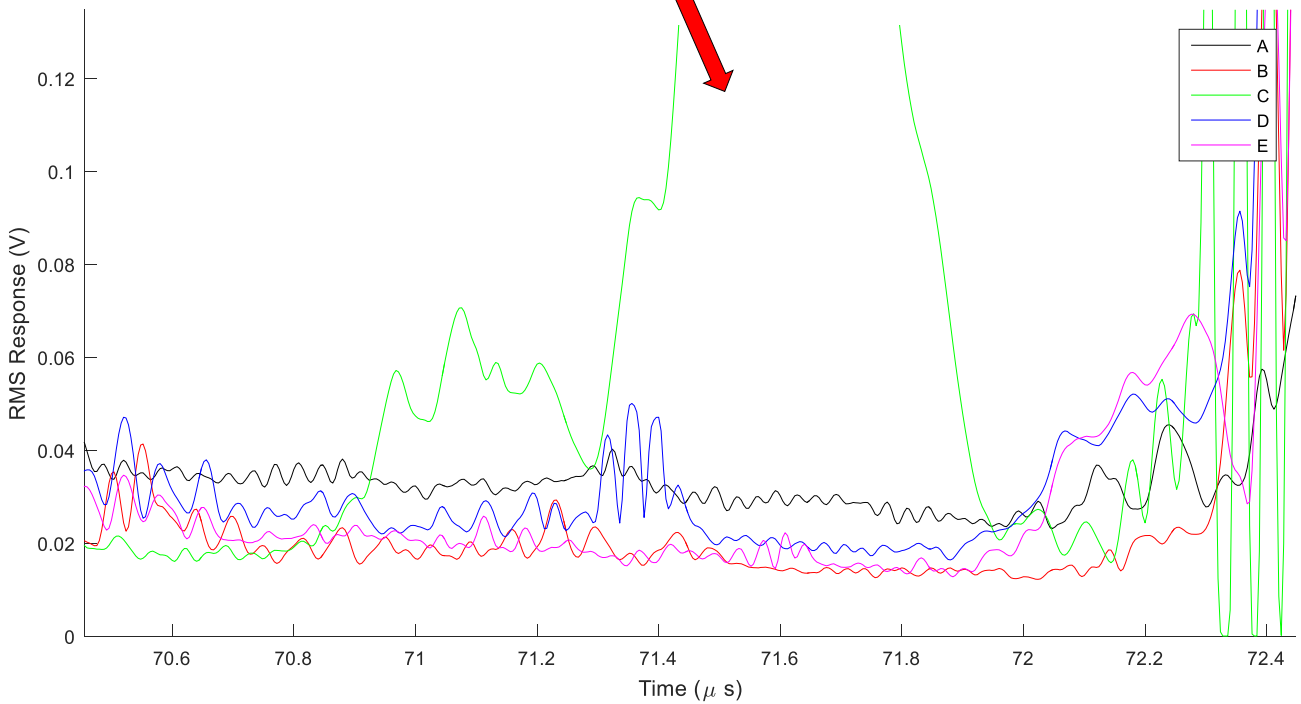
Backscatter: RMS Noise Voltage

- The V_{rms} is shown at right for each sample
- Noteworthy items:
  - Up until t=70.5us, there looks to be effects of the front wall signal
  - Sample C had a persistent signal around 71.5us that greatly affected the V_{rms}





Overlaying the Vrms curves from each sample we can focus on the area of interest, shown below.



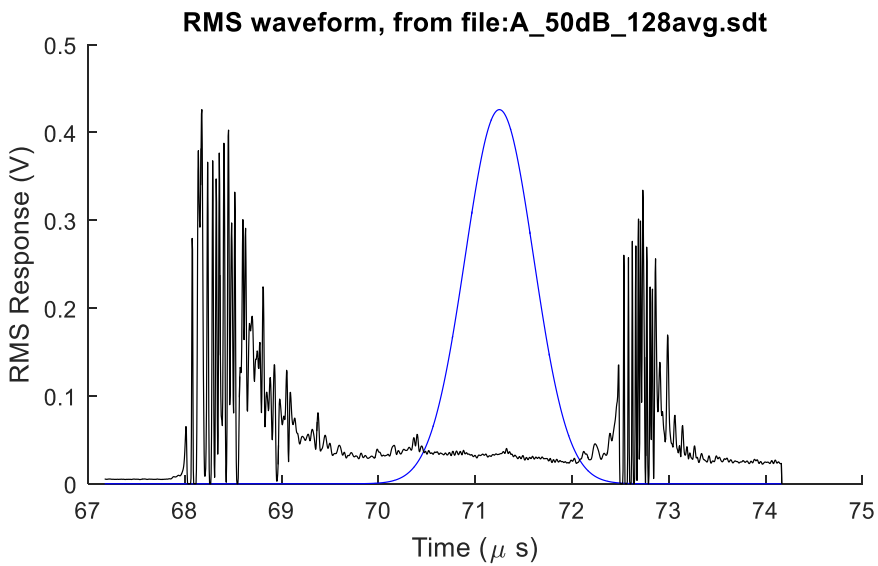
Looking at the curves overall, A has the largest response, with D having a medium response, and B and E having a smaller response. C should not be directly compared to the others until the source of the persistent signal is identified.

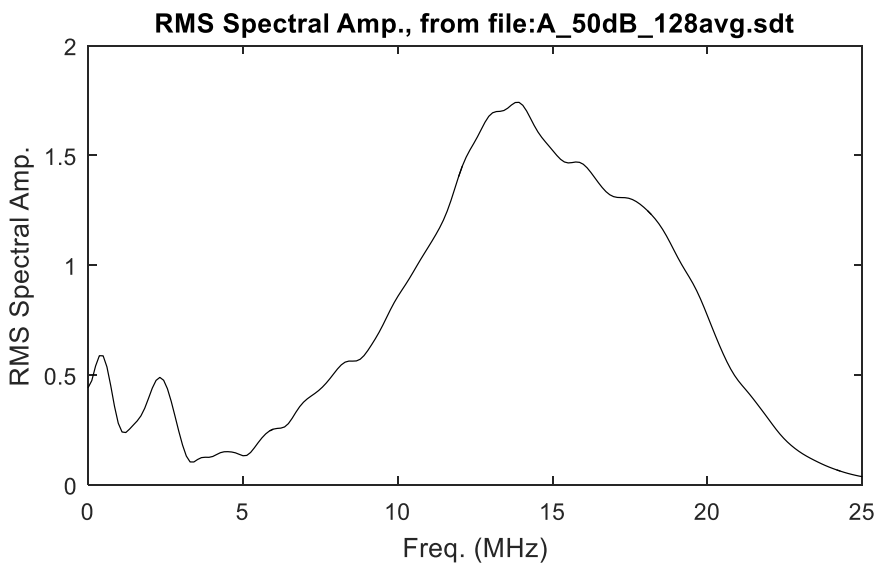
Backscatter: Frequency Domain Processing

- Take the FFT of each (V_j-V_{avg}) after windowing with a Gaussian function
- Spatially average in a similar way as the V_{rms}

SAMPLE A

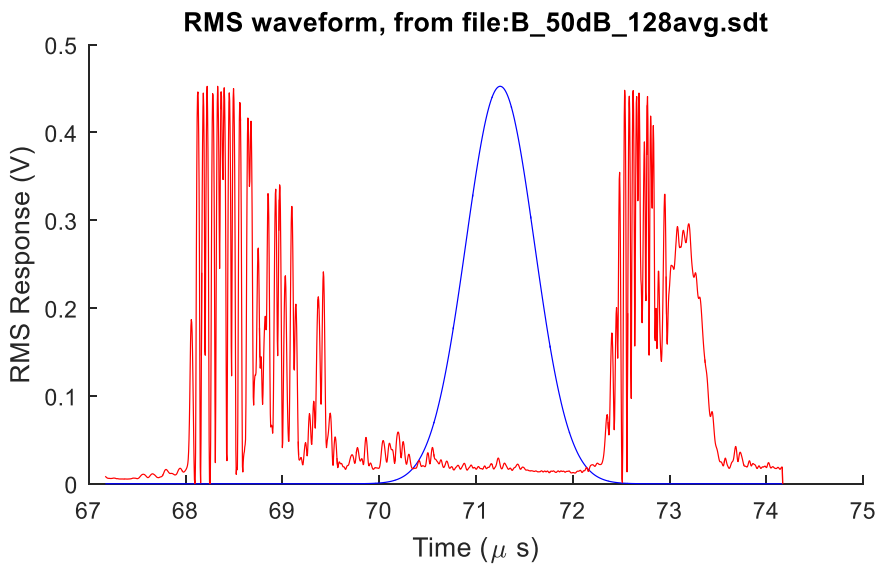
Gaussian gate (in blue) is applied to each individual time-domain waveform; it is shown on the V_{rms} here for convenience.

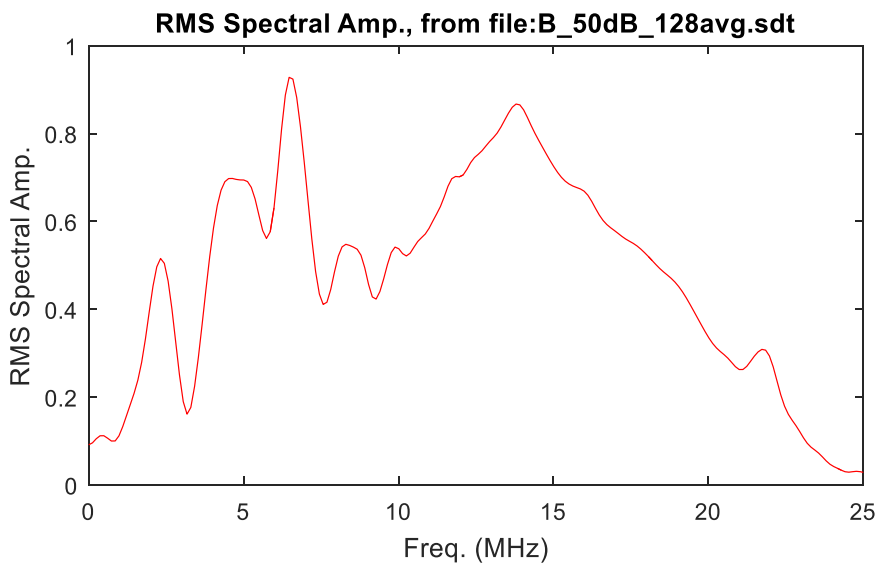




SAMPLE B

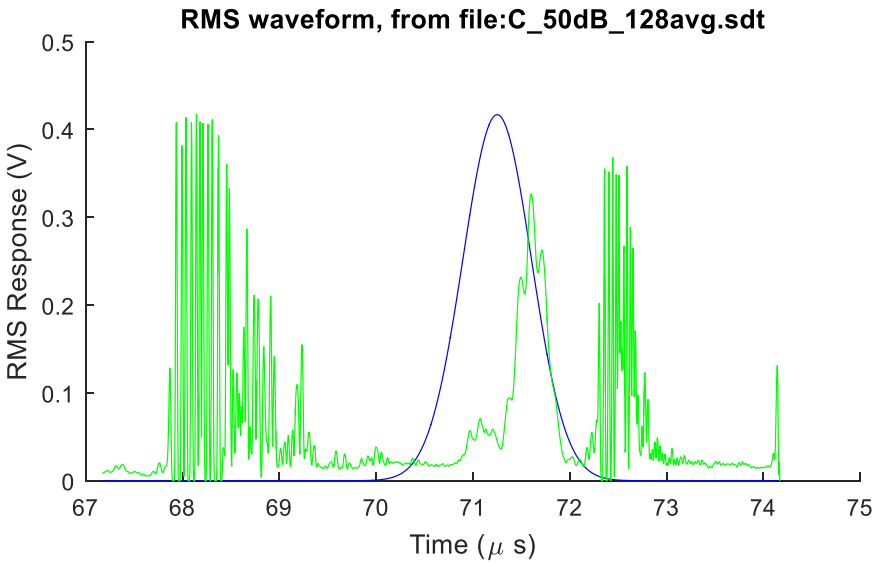
Gaussian gate (in blue) is applied to each individual time-domain waveform; it is shown on the V_{rms} here for convenience.

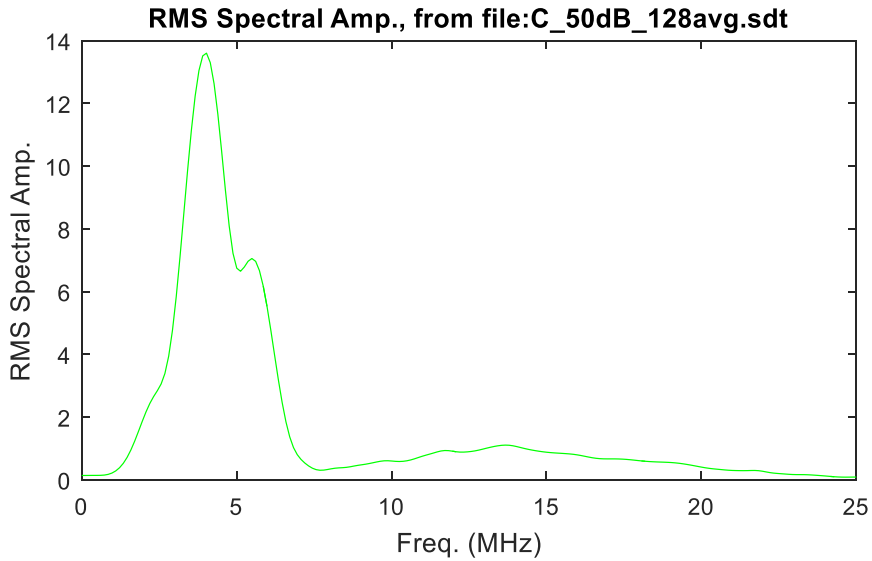




SAMPLE C

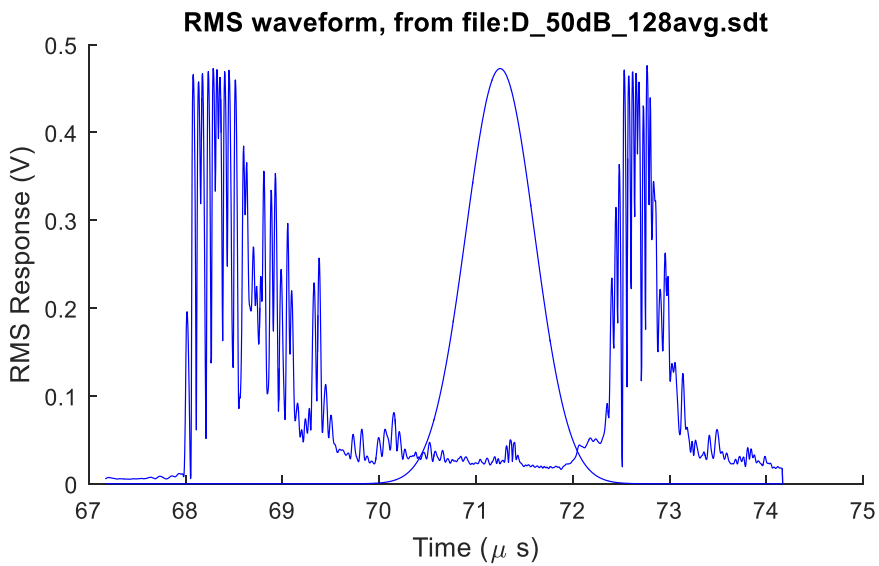
Gaussian gate (in blue) is applied to each individual time-domain waveform; it is shown on the V_{rms} here for convenience.

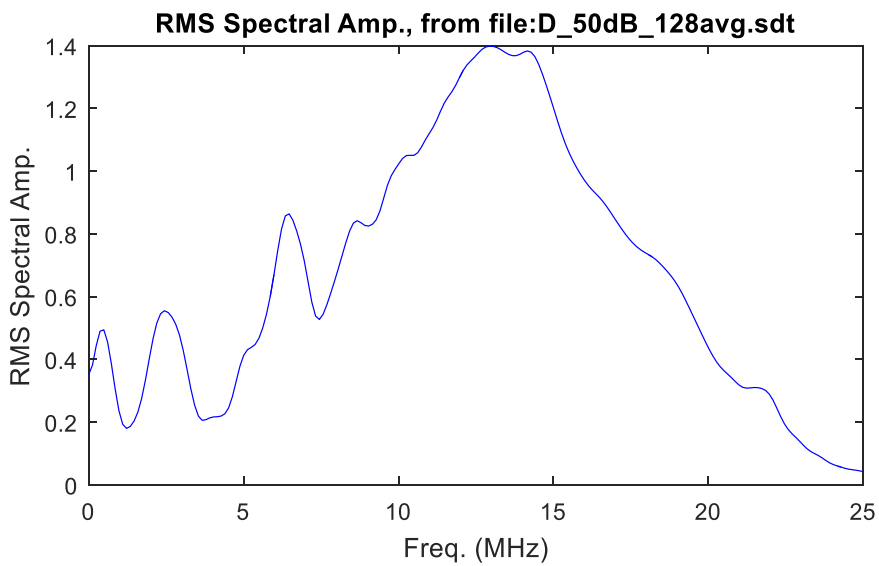




SAMPLE D

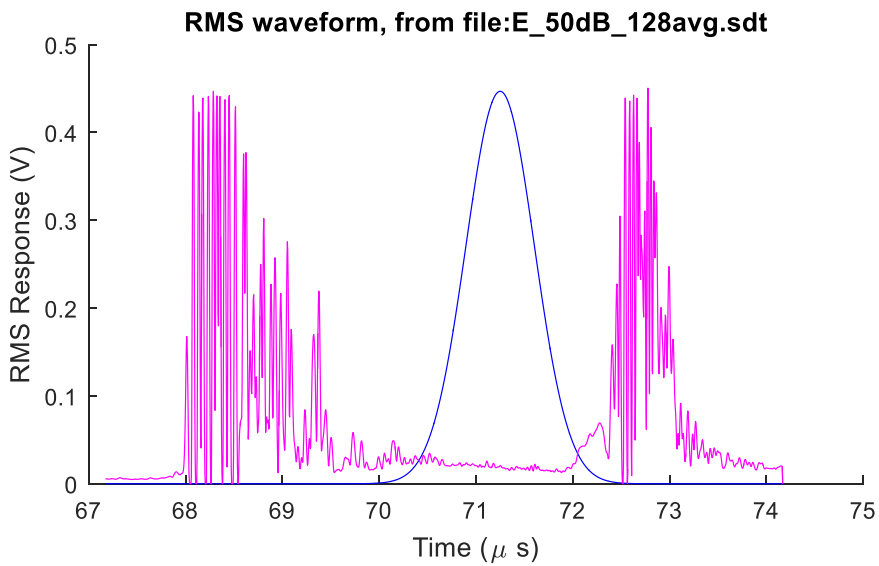
Gaussian gate (in blue) is applied to each individual time-domain waveform; it is shown on the V_{rms} here for convenience.

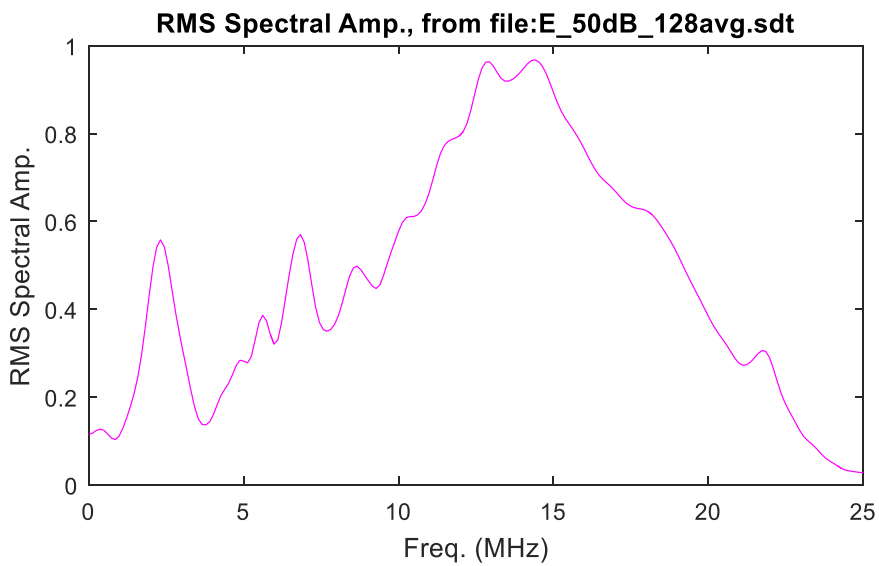




SAMPLE E

Gaussian gate (in blue) is applied to each individual time-domain waveform; it is shown on the V_{rms} here for convenience.

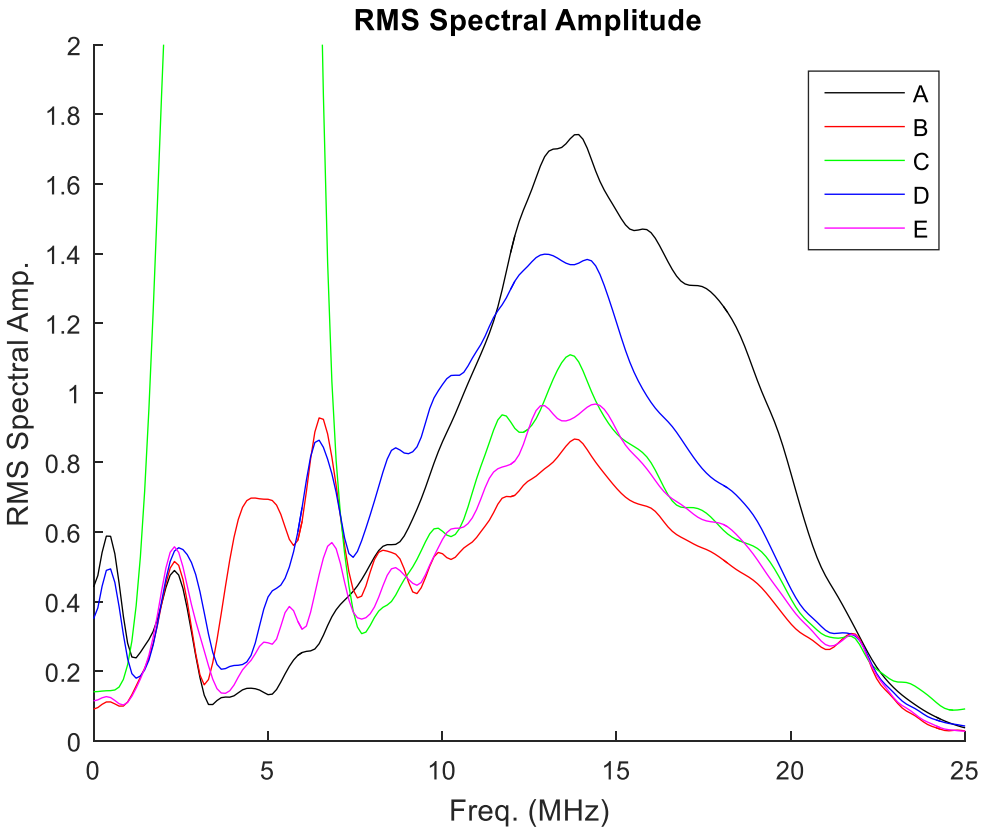




Frequency Domain Results

A generally has largest response, followed by D, with B and E smaller still.

C has a similar response to E for frequencies above 10 MHz, but has a very large peak around 5 MHz due to the persistent signal.



Barkhausen Noise

- Barkhausen measurements done on commercial Stresstech Rollscan system
  - Signal taken at three points per sample, used to get error bars
- The average RMS signal for each sample is shown
- A, B, and C have roughly the same, and largest, response, while D has a medium response, and E has the smallest response

Conclusions

- Measurements were done on set of X52 plate samples that have had different heat treatments
- Little variation in the ultrasonic velocity was seen between the samples
- For ultrasonic attenuation, the relation seen between samples was A>D>B=C=E
- For ultrasonic backscatter, the relation was A>D>B=E, though some distinction between B and E could be seen in the frequency domain processing
  - C exhibited anomalous behavior
- For the Barkhausen measurements, the relation seen was roughly A=B=C>D>E
- Samples B and E had similar responses in every ultrasonic measurement, but largely varying Barkhausen responses