Making a Matching Layer for Acoustic Sensors

Data Book

Justin P. Skycak

November 1, 2012: I met with Professor Levine. We first attended a presentation from his students regarding various ways they are trying to improve the COUPP experiment, which involves using bubble chambers to search for dark matter in the form of Weakly Interacting Massive Particles (WIMPs). Then, I was given a tour of his laboratory. Finally, Professor Levine and I had a discussion. He agreed to be my mentor and help me put together a project, we decided on research days (Tuesday, Thursday, and Friday), and he signed the release approval contract. Afterward, he e-mailed me some documents to peruse. He will have some more materials for me to read next meeting

November 2, 2012: Professor Levine and I discussed the reading materials from our last meeting and he assigned a paper on evidence for dark matter. He let me borrow The Cosmic Perspective, a textbook that might help with my paper. Cale, one of the students, gave me an in-depth tour of the lab materials and explained how the PVS (Pressure Vessel Simulator) works. He also showed me a few test transducers and the effects of different epoxies on transducer durability.

November 3, 2012: Professor Levine emailed me an introduction to oscilloscopes to be read by our next meeting.

November 4, 2012: Ed, one of the lab workers, gave me an introduction to oscilloscopes and helped me create a research plan

November 5, 2012: Professor Levine and I discussed and the research plan, and he signed the ISEF forms. We also discussed my paper on evidence for dark matter, and I need to revise it before our next meeting. He assigned me another paper on dark matter candidates, direct dark matter searches, and COUPP.

November 6, 2012: Professor Levine and I met to discuss my revised paper. There are a few slight details I need to fix, and I should find a few figures to insert as well. My second paper should be done by Thursday, and I should read up on acoustics. We also talked about my project a bit more. I will be constructing the piezoelectric transducers with Professor Levine before experimentation, and after the correct material is determined it will be tested to see how much it improves the acoustic transducers' sensitivities.

November 9, 2012: Professor Levine and I met to discuss my paper on dark matter candidates and searches. Like the first paper, there are some revisions I must make and I need to find a few figures to insert. I should also begin a paper on acoustics and have some type of outline done by Tuesday. Professor Levine also helped me edit my grant application, and gave me a signed letter of support to include in my grant.

November 12, 2012: Professor Levine and I met to discuss my Detecting Dark Matter paper revision and he demonstrated a procedure for making the epoxy molds. This is a procedure for making the pure epoxy mold (100% MAS epoxy, 0% tungsten carbide powder).

1. Make pipe mold
    - 1a. Use chop saw to cut small end portion off of 2 inch plastic pipe (2" CRESLINE PVC DUV NSF ASTM D 2665 SCH 40 280 PSI PR WATER AT 73°F PVC 1120 NSF ....ASTM D 1785 PPFA)
    - 1b. Place small end part of plastic pipe in plastic bag so one opening is covered.
    - 1c. Secure the plastic bag to the pipe part with duct tape on the sides and on the bottom.
    - 1d. Coat the inside of the pipe mold with release agent (Slide EpoXease Mold Release Agent For Epoxy Molding ISO 9001:2000) so the epoxy will not stick to the mold.

2. Measure epoxy resin and epoxy hardener
    - 2a. Place plastic cup on scale and pour a mass of epoxy hardener (MAS Epoxies Fast Non-Blushing Epoxy Hardener) in cup (71.4 grams were used)
    - 2b. Place another plastic cup on scale and pour a twice the mass of epoxy resin (MAS Epoxies Epoxy Resin) in cup (143.0 grams were used - this is slightly more than 142.8 grams but it is okay)

3. De-gas epoxy resin and epoxy hardener to remove dissolve gases from the resin and hardener
    - 3a. Put on gloves (on shelf by the door)
    - 3b. Remove de-gasser cover, place both cups in the de-gasser, and replace cover.
    - 3c. Run de-gasser
        - 3ci. Attach pump
        - 3cii. Open valve (turn parallel)
        - 3cii. Flip switch
    - 3d. Bubbles form in resin and hardener
    - 3e. Stop de-gasser evacuation when bubble density begins to decrease
        - 3ei. Turn off switch
        - 3eii. Close valve (turn perpendicular)

3eiii. Remove pump
3f. Slowly open valve (turn parallel) to let air in and dissipate bubbles

4. Mix epoxy and hardener
4a. Obtain wooden stirrer (located in back left shelf)
4b. Pour epoxy and hardener into single cup
4c. Manually mix the epoxy and hardener with the stirrer for 60 seconds.

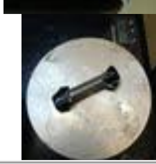
5. De-gas the mixture using the same method as step 3

6. Create mold
6a. Place pipe mold in de-gasser
6b. Pour mixture into pipe mold
6c. De-gas mold
6ci. ?Stop when mold starts to boil and emit vapor? (this happens because the reaction generates a great amount of heat)
6cii. This should take roughly 7 minutes (the de-gasser was started at 3:55 P.M. and stopped at 4:02 P.M.)
6d. Carefully transport mold to water bath to cool

The ends of the mold will be sanded during the next meeting, and Professor Levine gave me a lab notebook to record information from every meeting. I had been keeping computerized records of each meeting, but it is important that I have an original copy of my lab notes. I am to re-revise my paper on dark matter detection/searches and write a paper on acoustics by Friday.

November 17, 2012: Today, the density of the tungsten carbide powder was measured to allow for conversions between volume and mass later in the experiment. Then, the testing of the acoustic impedance of copper was begun.

1. The first density measurement came from the type of mold that will be used in the experiment:
1A. A plastic tube was measured to 10 cm with a caliper and then cut. Masks, goggles, and gloves were worn when the chop-saw was operated.
1B. The ends of the tube were filed until they were even and smooth
1C. The dimensions of the tube were measured with the caliper. The measurements were repeated 3 times from different angles each time and the average was calculated.
1D. Tape was put on both ends of the tube and the taped tube was massed
1E. Tape was removed from one end and a funnel was used to fill the tube with tungsten carbide powder.
1F. The tape was reapplied and the filled taped tube was massed



<u>Measured Quantity</u>	<u>Measurements</u>	<u>Average</u>
Length of tube	10.113 cm, 10.185 cm, 10.150 cm	10.149 cm
Inner diameter of tube	1.827 cm, 1.823 cm, 1.821 cm	1.824 cm
Mass of empty taped tube	4 g	4 g
Mass of filled taped tube	252 g, 250 g, 252 g	251.33 g

1G. The volume of the tube and the mass of the tungsten carbide powder were calculated and used to calculate the density of the tungsten carbide powder

<u>Calculated Quantity</u>	<u>Expression</u>	<u>Result</u>
Volume of empty tube	(pi)*((inner diameter of tube)/2)^2*(length of tube)	26.519 cm^3
Mass of tungsten carbide powder	(mass of filled tube)-(mass of empty tube)	247.33 g
Density of tungsten carbide powder	(mass of tungsten carbide powder)/(volume of empty tube)	9.33 g/cm^3

2. The second density measurement came from a graduated cylinder
2A. The graduated cylinder was filled with 40 cm^3 of tungsten carbide powder
2B. The graduated cylinder was massed
2C. A cup was placed on the balance and the balance was zeroed
2D. The contents of the graduated cylinder were poured into the cup and massed
2E. The empty graduated cylinder was massed

Measured Quantity	Measurements	Average
Volume tungsten carbide powder	40 cm^3	40 cm^3
Mass of filled graduated cylinder	454 g, 454 g, 454 g	454 g
Mass of empty graduated cylinder	40 g, 40 g, 40 g	40 g

2F. The mass of the tungsten carbide powder and the volume of the tungsten carbide powder to calculate the density of the tungsten carbide powder

Calculated Quantity	Expression	Result
Density of tungsten carbide powder	(mass of tungsten carbide powder)/(volume of tungsten carbide powder)	10.35 g/cm^3

3. The third density measurement came from a graduated cylinder but a more precise scale was used

Measured Quantity	Measurements	Average
Mass of empty graduated cylinder	41.19 g, 41.18 g, 41.18 g	41.183 g
Volume of tungsten carbide powder	10 cm^3	10 cm^3
Mass of filled graduated cylinder	145.08 g, 145.09 g, 145.08 g	145.083 g

Calculated Quantity	Expression	Result
Mass of tungsten carbide powder	(mass of filled graduated cylinder)-(mass of empty graduated cylinder)	103.9 g
Density of tungsten carbide powder	(mass of tungsten carbide powder)/(volume of tungsten carbide powder)	10.39 g/cm^3

The third density calculation was very close to the second density calculation (both were equal to 10.4 g/cm^3 when rounded to 3 significant figures) and still fell below the accepted value of 11.25 g/cm^3. This means that there was a significant amount of volume occupied by the air pockets in the powder, and the company made the powder settle more before they measured its volume. Because much of the volume was caused by air pockets, the percent tungsten carbide powder in the samples was calculated as a percent by mass instead of a percent by volume.

4. The testing of the speed of sound through copper was begun.
   - 4A. Background information: The speed of sound through copper should be roughly 4600-4700m/s
   - 4B. Coupling grease was spread on the surface of the transducer
   - 4C. The transducer was secured to the middle of the copper sample with tape
   - 4D. The copper sample was set in the sound detonator, close to the air source
   - 4E. The air pump was attached to the sound detonator and the door was closed
   - 4F. The air pump was opened to allow air through, and the oscilloscope settings were adjusted so the waveform was visible: 5.00mV, 400ms
   - 4G. A test was ran and a Fast Fourier Transform was conducted and saved
   - 4H. The air pump was closed
   - 4I. The transducer was removed from the copper sample and the coupling grease was wiped off.
   - 4J. The testing procedure was repeated with the transducer only (no copper sample)
     - 4Ji. Oscilloscope settings: 20.0mV, 400ms

The frequency scale on the FFT was too broad to see the peaks clearly, so next time the test will be repeated and the ms/div setting on the oscilloscope will be adjusted to specify the frequency scale on the FFT.

November 19, 2012: Today, the density of the sample of pure MAS epoxy resin and hardener mixture was calculated using 2 different methods. Also, the approximate frequency of the copper sample was predicted, but due to computer issues the copper sample was not able to be tested.

1. The density of the sample made from a mixture of MAS epoxy resin and hardener (2 parts epoxy and 1 part hardener, 100% epoxy and 0% tungsten carbide powder) was calculated using the water displacement method.
   - 1A. The pure epoxy sample was massed using a scale
   - 1B. The volume of the sample was calculated by observing how much water it displaced
     - 1Bi. A graduated cylinder was filled with volume and the volume was recorded

1Bii. The pure epoxy sample was placed in the graduated cylinder (this was done carefully so that no water splashed) and the new volume was recorded.
1Biii. The final volume was subtracted from the initial volume to calculate the volume of water displaced, which was equal to the volume of the sample.
1Biv. The volume of the sample was calculated three times and the average volume was used in the density calculation.

Water Displacement Test	Initial Volume	Final Volume	Volume of Sample
1	60.6 cm^3	76.9 cm^3	16.3 cm^3
2	54.3 cm^3	70.6 cm^3	16.3 cm^3
3	50.0 cm^3	66.5 cm^3	16.5 cm^3

Measured Quantity	Measurements	Average
Mass of pure epoxy sample	18.37 g, 18.37 g, 18.37 g	18.37 g
Volume of pure epoxy sample	16.3 cm^3, 16.3 cm^3, 16.5 cm^3	16.37 cm^3

Quantity to be Calculated	Calculation	Result
Density of pure epoxy sample	(mass of pure epoxy sample)/(volume of pure epoxy sample)	1.122 g/cm^3

2. The density of the sample made from a mixture of MAS epoxy resin and hardener (2 parts resin and 1 part hardener, 100% epoxy and 0% tungsten carbide powder) was calculated using the densities found on the labels of the epoxy and hardener containers.

Substance	Density found on Container
MAS Epoxy Resin	9.2 lb/gal = 1.102 g/cm^3 (at 77 deg. F)
MAS Epoxy Hardener	1.08 g/cm^3 (at 77 deg. F)

Calculated Quantity	Calculation	Result
Density of pure epoxy sample	(2/3)(density of resin) + (1/3)(density of hardener)	1.095 g/cm^3

The calculations were extremely similar - equivalent, actually, when rounded to 2 significant figures. The density for the pure epoxy sample is 1.1 g/cm^3.

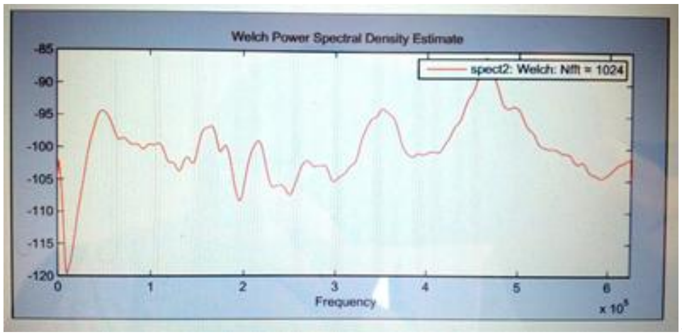
3. The approximate frequency of the copper sample was predicted.
3A. The length of the copper sample was measured using a caliper.
3B. The approximate speed of sound through copper was found in an online database.
3C. The length and approximate speed of sound through the sample were used to predict the approximate frequency of the copper sample.

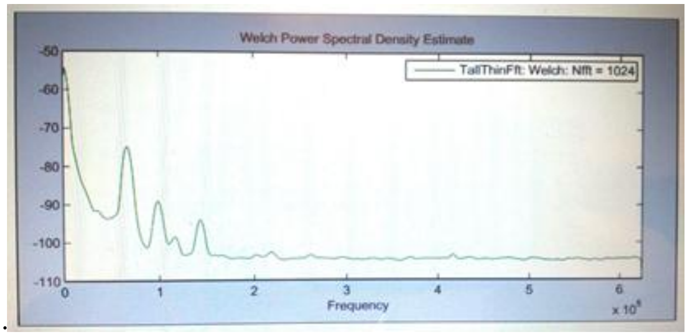
Measured Quantity	Measurement
Length of copper sample	.1488m

Calculated Quantity	Calculation	Result
Approximate frequency of copper sample	(speed of sound through sample)/(wavelength) = (speed of sound through sample)/(2*(sample length))	15-16 kHz

Approximate speed of sound through copper	4600-4700 m/s

November 21, 2012: Repeating the procedure given on October 26, the FFTs of the transducer with the copper sample and without the copper sample were taken. The oscilloscope was set at 10.00mV and 40.0ms/div to ensure that the frequency scale on the FFT would be specific enough to display the peaks clearly. However, both FFTs looked exactly the same. Furthermore, the FFT for the transducer without the copper sample looked nothing like an FFT for the same transducer taken during a previous experiment. This was obviously not correct.

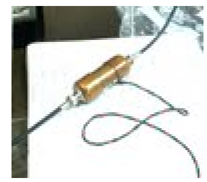




Resulting FFT (left) and correct FFT (right)

The oscilloscope settings were adjusted to 20.0mV and 40.0ms/div, but the FFTs were still not correct.

November 15, 2012: Professor Levine revised my paper with me, and experimentation was continued.
1. The transducer FFT was reconstructed with and without the copper sample.



1A. An amplifier was used to amplify the transducer's signal. (Last session's problems may have occurred because an unamplified transducer was used.)
1B. Oscilloscope settings: 20.0mV, 100ms/div
1C. Oscilloscope glitched and gave incorrect FFT
1D. Oscilloscope settings: 20.0mV, 40ms/div
1E. Oscilloscope glitched and gave incorrect FFT again
1F. Oscilloscope settings: 20.0mV, 20ms/div
1G. Oscilloscope did not glitch, and it gave the correct FFT. However, the frequency scale on the FFT was not specific enough to display the peaks clearly.

The oscilloscope seems to glitch when it is set at over 20ms/div, and in order to display the peaks clearly on the FFT, it needs to be set at over 20ms/div. Ed will help find a solution to this problem, and next session some samples will be made.

November 29, 2012:
1. The pure epoxy (0% tungsten carbide powder) sample was created
1A. The epoxy mold was created using the same procedure as for the first density measurement of the tungsten carbide powder, except a rubber stoppers were used in place of tape and the tube was cut to 12 cm instead of 10 cm to account for the extra space occupied by the rubber stoppers. This procedure was used instead of the first procedure demonstrated by Professor Levine because it results in fewer air bubbles and the tube does not need to be waxed.
1B. The epoxy mixture was made using the same procedure as demonstrated by Professor Levine. 18g hardener were used and 36g resin were used.
1C. The sample was made
1Ci. The epoxy mixture was poured into the mold
1Cii. The ends were plugged with stoppers
1Ciii. The sample was put in the rotator to settle.

2. A solution to the oscilloscope glitch was found. The waveform will be saved to a flashdrive connected to the oscilloscope and the flashdrive will be transferred to the computer so the waveform data can be used to run a FFT on MATLAB.

November 30, 2012: Ed ran me through the procedure for working around the oscilloscope glitch
1. Gather waveform from oscilloscope
1A. Put flashdrive directly in oscilloscope
1B. Save waveform to flashdrive

2. Transfer flashdrive to computer

3. Create Fast Fourier Transform
3A. Import data
3B. Click on device (CSV)
3C. Import selection -> Import data, waveform data will go to workspace
3D. Enter sampling frequency formula in command window: Fs=length(CH1)/(max(TIME)-min(TIME))
3E. Applications -> signal analysis -> import
3F. Type in value for sampling frequency, use Fs, click ok
3G. Create FFT

December 1, 2012:

1. The 50%, 60%, 70%, 80%, and 90% tungsten carbide powder by mass samples were created using the same procedure as for the pure epoxy (0% tungsten carbide powder) sample.

Percent Tungsten carbide by Mass	Mass of Epoxy Resin	Mass of Epoxy Hardener	Mass of Tungsten carbide Powder
60%	20 g	10 g	45 g
70%	20 g	10 g	70 g
80%	20 g	10 g	120 g
90%	20 g	10 g	270 g

2. The sound detonator was tested

 2A. An FFT was created for the transducer

  2Ai. The setup was the same as before

  2Aii. The air was turned on and the oscilloscope settings were adjusted to 2.00mV, 40.0ms

  2Aiii. The waveform was saved and the data was transferred to MATLAB via flashdrive

  2Aiv. An FFT was created

 2B. An FFT was created for the copper sample

  2Bi. The setup was the same as before

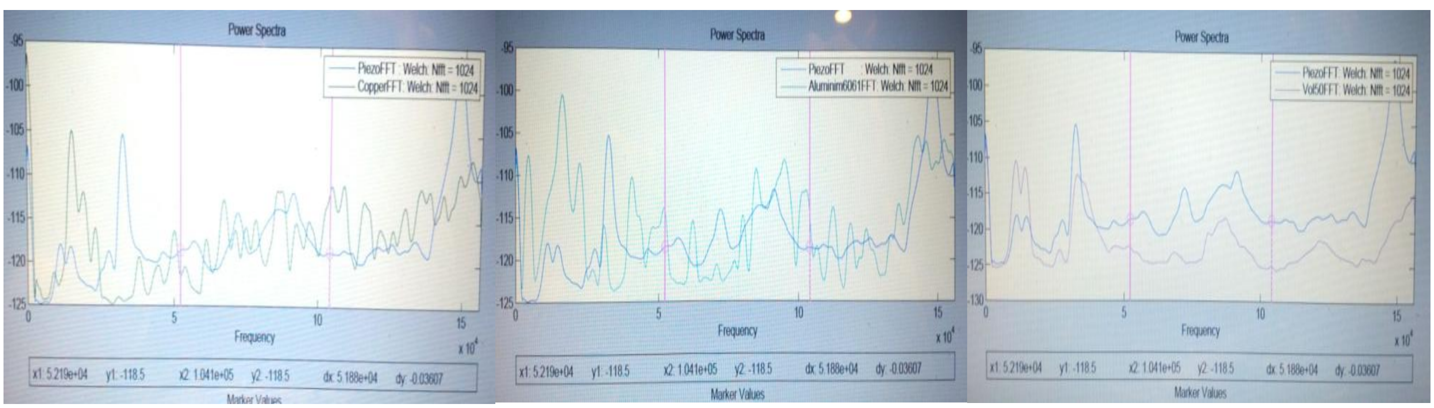
  2Bii. The data was transfered just as it was for the transducer

  2Biii. An FFT was created

 2C. An FFT was created for the aluminum sample using the same method as for the copper sample

 2D. An FFT was created for the 50% tungsten carbide powder by volume sample that had been created for previous experiments. In the previous experiments, its resonant frequency was shown to be about 12 kHz.

Sample	Speed of Sound Through Sample	Length of Sample	Calculated Resonant Frequency	Peak on FFT
Copper	4600-4700 m/s	0.1488 m	15-16 kHz	15 kHz
Aluminum	5000-6500 m/s	.150 m	16-22 kHz	16.5 kHz
50% Tungsten carbide powder by mass	-	-	12 kHz (previous experiments)	12 kHz



Since FFT peaks lie within the calculated resonant frequency ranges for all three samples, the oscilloscope and sound detonator are working properly.

December 2, 2012:

1. The samples were taken out of their molds and the edges were buffed

2. The densities of the samples were calculated

 2A. The samples were massed

 2B. The samples' volumes were calculated

  2Bi. The volume was calculated using length and diameter measurements taken with a caliper

2Bii. The volume was calculated using water displacement in a graduated cylinder
2Biii. The dimension and water displacement volumes were averaged

Percent Tungsten carbide Powder by Mass	Mass Measurements	Average Mass	Diameter Measurements	Average Diameter	Length Measurements	Average Length	Initial water level	Final water level
0%	22 g, 24 g	23 g	1.799 cm, 1.805 cm, 1.768 cm	1.791 cm	8.527 cm, 8.532 cm, 8.585 cm	8.548 cm	60.9 mL	82.5 mL
60%	52 g, 52 g	52 g	1.836 cm, 1.808 cm, 1.811 cm	1.818 cm	8.492 cm, 8.486 cm, 8.488 cm	8.489 cm	59.1 mL	80.9 mL
70%	64 g, 64 g	64 g	1.803 cm, 1.810 cm, 1.808 cm	1.807 cm	8.323 cm, 8.364 cm, 8.331 cm	8.339 cm	69.0 mL	90.1 mL
80%	98 g, 98 g	98 g	1.802 cm, 1.850 cm, 1.801 cm	1.818 cm	8.261 cm, 8.271cm, 8.248 cm	8.260 cm	45.0 mL	66.1 mL
90%	140 g, 140 g	140 g	1.814 cm, 1.796 cm, 1.793 cm	1.801 cm	8.271 cm, 8.252 cm, 8.273 cm	8.265 cm	60.6 mL	81.5 mL

Percent Tungsten carbide Powder by Mass	Dimension Volume (pi)*(diameter/2)^2*(length)	Displacement Volume ((final water level)-(initial water level))*(cm^3/mL)	Average Volume	Density (average mass)/(average volume)*((kg/10^3g)*(m/10^2cm))^3
0%	21.54 cm^3	21.6 cm^3	21.6 cm^3	1.06 x 10^3 kg/m^3
60%	22.04 cm^3	21.8 cm^3	21.9 cm^3	2.37 x 10^3 kg/m^3
70%	21.45 cm^3	21.1 cm^3	21.3 cm^3	4.61 x 10^3 kg/m^3
80%	21.46 cm^3	21.1 cm^3	21.3 cm^3	4.61 x 10^3 kg/m^3
90%	21.02 cm^3	20.9 cm^3	21.0 cm^3	6.68 x 10^3 kg/m^3

3. The speed of sound through the aluminum sample was calculated using the sonoclamp and oscilloscope to make sure it was working properly

3A. Coupling grease was spread on the ends of the sample and it was secured in the sonoclamp
3B. A 25 Hz signal was sent from the emitting transducer, through the sample, and to the receiving transducer
3C. The time interval on the oscilloscope was adjusted so it began when the emitting transducer sent the signal and ended when the receiving transducer received the signal.

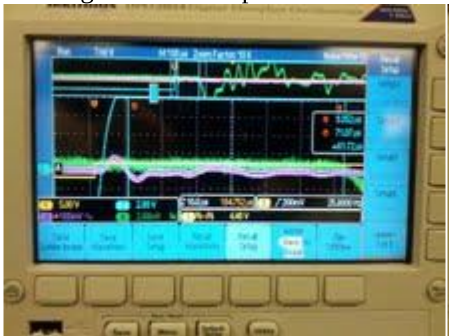
Sample	Time Interval	Length of Sample	Calculated Speed of Sound Through Sample	Known Speed of Sound Through Sample	Percent Error
Aluminum	23.72microsec	14.960 cm	6307 m/s	6320 m/s	0.2070%

4. The speeds of sound through the test samples were calculated using the same procedure as for the aluminum sample, and the acoustic impedance was calculated for each sample.

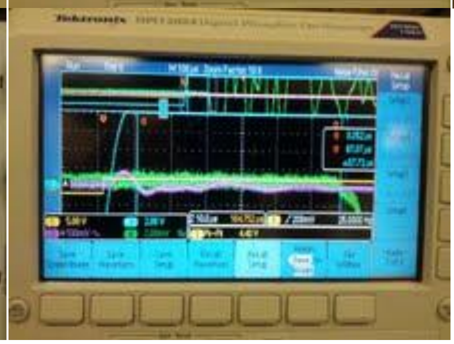
Percent Tungsten carbide Powder	Time Interval	Speed of Sound Through Sample ((length of sample)/(time interval))*(m/10^2cm)*(10^6microsec/sec)	Acoustic Impedance (density of sample)*(speed of sound through sample)*(Rayl/(kg/(m^2*s)))*(MRayl/10^6Rayl)
0%	41.72 microsec	2049 m/s	2.17 MRayl
60%	49.72 microsec	1707 m/s	4.05 MRayl
70%	51.72 microsec	1612 m/s	4.85 MRayl
80%	57.72 microsec	1431 m/s	6.59 MRayl
90%	61.72	1339 m/s	8.94 MRayl

	microsec		

The target acoustic impedance is about 15 MRayl, so higher percent tungsten carbide powder samples need to be made.







Red = emitting transducer, blue = amplifier, green = receiving transducer, yellow = square wave

5. 92.5% and 95% tungsten carbide powder samples were made using the same procedure as before

Percent Tungsten carbide Powder	Mass Epoxy Mixture	Mass Tungsten carbide Powder
92.5%	16g	198g
95%	16g	304g

December 3, 2012:
1. The 92.5% and 95% tungsten carbide powder samples were actually made with 18g epoxy, not 16g. This means that the samples were actually 91.7% and 94.4% tungsten carbide powder.

2. The density and acoustic impedances of the 91.7% and 94.4% samples were calculated using the same method as before

Percent Tungsten carbide Powder by Mass	Mass Measurements	Average Mass	Diameter Measurements	Average Diameter	Length Measurements	Average Length	Initial Water Level	Final Water Level
91.7%	152 g, 152g	152 g	1.811 cm, 1.803 cm, 1.789 cm	1.801 cm	8.029 cm, 8.043 cm, 8.048 cm	8.040 cm	61.0 mL	81.6 mL
94.4%	188 g, 188 g	188 g	1.810 cm, 1.806 cm, 1.804 cm	1.807 cm	8.127 cm, 8.136 cm, 8.121 cm	8.128 cm	55.7 mL	76.3 mL

Percent Tungsten carbide Powder by Mass	Dimension Volume (pi)*(diameter/2)^2*(length)	Displacement Volume ((final water level)-(initial water level))*(cm^3/mL)	Average Volume	Density (average mass)/(average volume)*((kg/10^3g)*(m/10^2cm))^3
91.7%	20.48 cm^3	20.6 cm^3	20.5 cm^3	7.41 x 10^3 kg/m^3
94.4%	20.84 cm^3	20.6 cm^3	20.7 cm^3	9.08 x 10^3 kg/m^3

Percent Tungsten carbide Powder by Mass	Time Interval	Speed of Sound Through Sample ((length of sample)/(time interval))*(m/10^2cm)*(10^6microsec/sec)	Acoustic Impedance (density of sample)*(speed of sound through sample)*(Rayl/(kg/(m^2*s)))*(MRayl/10^6Rayl)
91.7%	52.92 microsec	1519 m/s	11.3 MRayl
94.4%	51.12 microsec	1590 m/s	14.4 MRayl

3. The 94.4% sample was still under 15Mrayl, so 95% and a 95.5% samples were made

Percent Tungsten carbide Powder by Mass	Mass Epoxy	Mass Tungsten carbide Powder
95%	18g	342g
95.5%	18g	382g

December 4, 2012:
The density, speed of sound, and acoustic impedance were calculated for the 95% and 95.5% samples.

Percent Tungsten carbide Powder by Mass	Mass Measurements	Average Mass	Diameter Measurements	Average Diameter	Length Measurements	Average Length	Initial Water Level	Final Water Level
95%	204 g, 204g	204 g	1.803 cm, 1.804 cm, 1.803 cm	1.803 cm	8.668 cm, 8.655 cm, 8.669 cm	8.664 cm	59.9 mL	82.0 mL
95.5%	228 g, 228 g	228 g	1.810 cm, 1.804 cm, 1.805 cm	1.805 cm	8.548 cm, 8.343 cm, 8.458 cm	8.516 cm	58.0 mL	79.8 mL

Percent Tungsten carbide Powder by Mass	Dimension Volume (pi)*(diameter/2)^2*(length)	Displacement Volume ((final water level)-(initial water level))*(cm^3/mL)	Average Volume	Density (average mass)/(average volume)*((kg/10^3g)*(m/10^2cm))^3
95%	22.12 cm^3	22.1 cm^3	22.1 cm^3	9.23 x 10^3 kg/m^3
95.5%	21.79 cm^3	21.8 cm^3	21.8 cm^3	10.5 x 10^3 kg/m^3

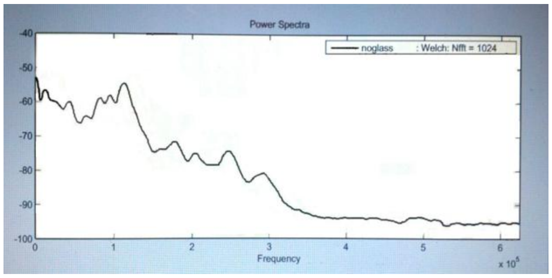
Percent Tungsten carbide Powder by Mass	Time Interval	Speed of Sound Through Sample ((length of sample)/(time interval))*(m/10^2cm)*(10^6microsec/sec)	Acoustic Impedance (density of sample)*(speed of sound through sample)*(Rayl/(kg/(m^2*s)))*(MRayl/10^6Rayl)
95%	53.72 microsec	1613 m/s	14.9 MRayl
95.5%	50.52 microsec	1686 m/s	17.7 MRayl

December 8, 2012: The data was recalculated using a computer program to ensure that rounding errors did not come into play. This data was the data used in place of the data which was rounded between calculations.

December 18, 2012: 20% and 40% tungsten carbide by mass samples were created.

February 5, 2013: Ed discussed how to calculate the required thickness for the matching layer with me.

February 7, 2013: A WPD was created for transducer 403:



Resonant frequency = 111 kHz

Calculated Quantity	Calculation	Result
Goal thickness	$\frac{\lambda}{4} = \frac{1}{4} * \frac{speed\ of\ sound\ through\ sample}{resonant\ frequency\ of\ transducer}$	3.2 mm

A WPD was created for the transducer and glass without the matching layer and with the matching layer.

February 8, 2012: A larger matching layer was made to cover the whole transducer

February 12, 2012 and February 14, 2012: The larger matching layer was tested and multiple WPDs were compared: