Carleton UNIVERSITY

Monitoring the Propagation of Lung Sounds using Electronic Stethoscope Arrays

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What problems are we trying to solve?

- Breath Variability between Auscultation Points
- Auditory Training Variability between Physicians
- Reduce Ventilator Induced Lung Injury (VILI)
- Effectiveness of Respiratory System Treatments
- Current technology cannot deliver both regional (SpO_2) and temporal information (X-ray)

What is stethoscope auscultation?

Respiratory Disease

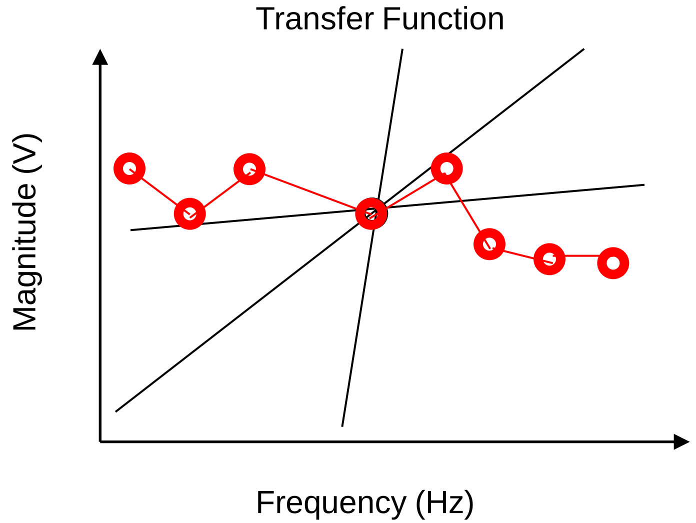
- Pneumonia
- Bronchitis
- Emphysema
- Asthma

Airway Obstructions Due to Excess Mucus Production

White Gaussian Noise

- Injected into the mouth
- Random signal across a range of frequencies
- Useful for system identification due to wide frequency band and linear phase

Input Signal Frequency	Output Signal Frequency
1 Value (500 Hz)	1 Value (500 Hz)
Range (0 – 4 kHz)	Range (0 – 4kHz)



Solution

- Breath Variability between Auscultation Points

Array of Stethoscopes

- Auditory Training Variability between Physicians

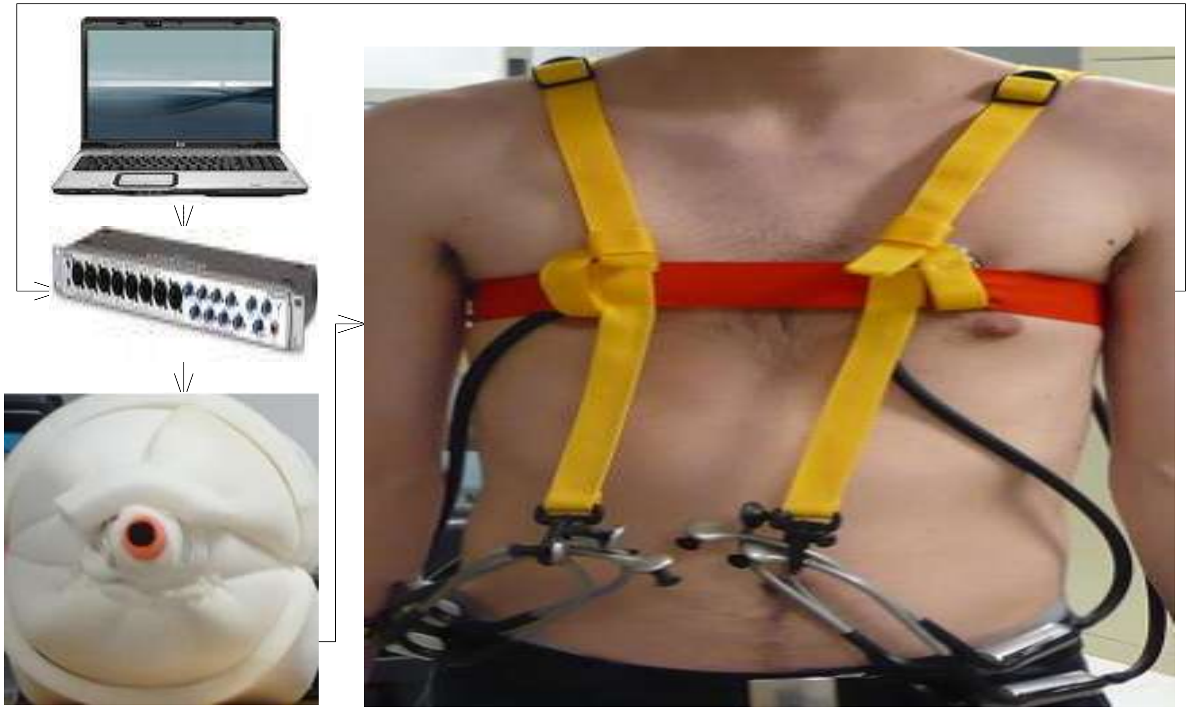
Focus on Signals and Computers

- Reduce Ventilator Induced Lung Injury (VILI) & Effectiveness of Respiratory System Treatments

Develop a medical instrument capable of measuring both regional and temporal information within the respiratory system

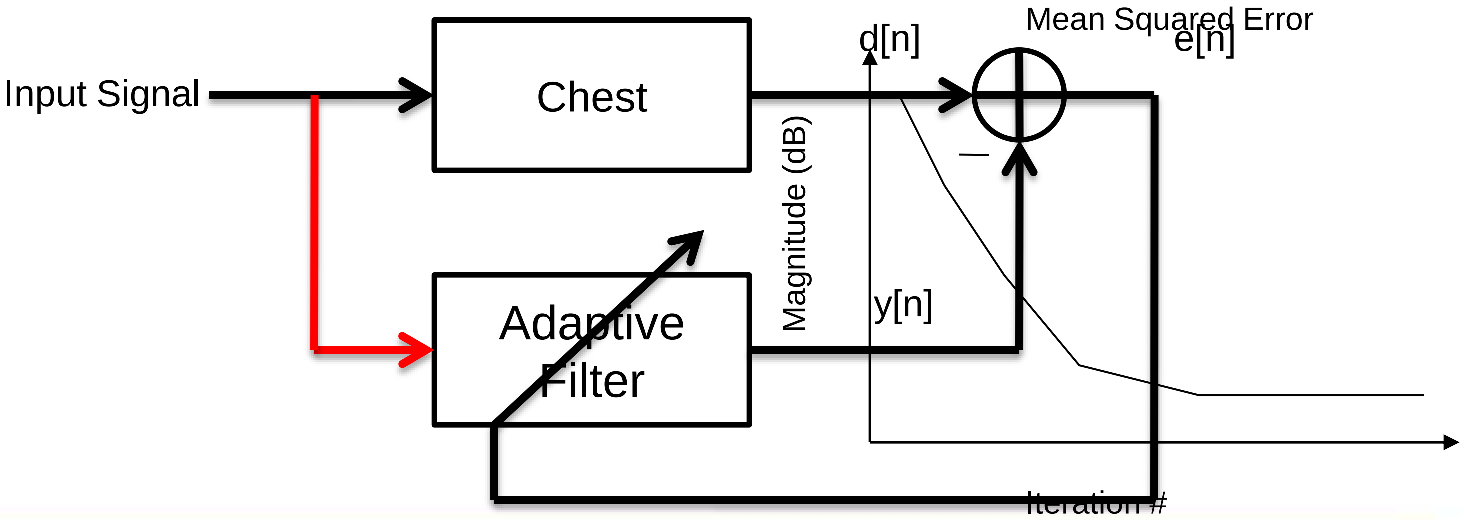
Instrument Apparatus

- Basic Structure



Data Processing Algorithm

- Adaptive Filter implemented the Normalized Least Mean Squared (NLMS) coefficient update algorithm
- Number of Coefficients = 1500
- Step Size μ = 0.296
- Input Signal = Reference Signal = WGN (0 – 4 KHz)



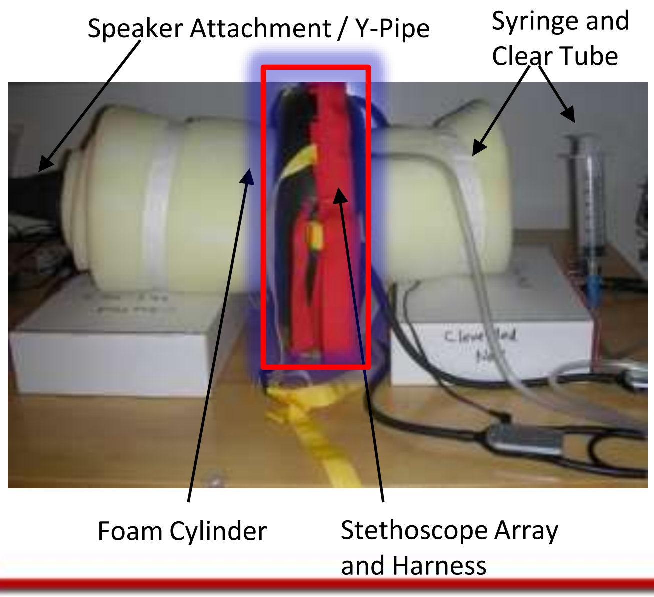
In vitro Experiments (Phantom Models)

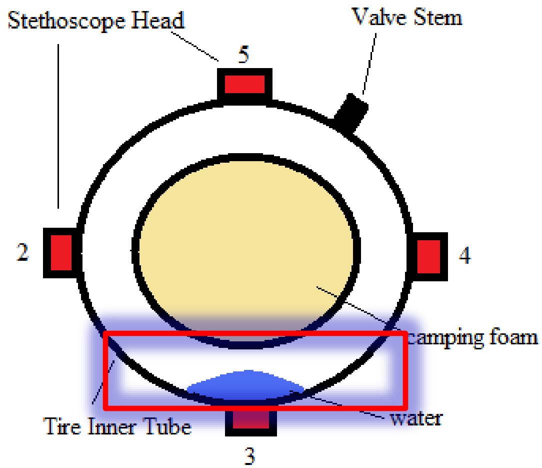
- Verify algorithm functionality using known predictable sound propagation models (open air column model)

- Add complexity in an effort to simulate actual human chests (plastic bucket model, chest phantom model)

Chest Phantom Experiment

- Modified Plastic Bucket Model to provide a better phantom-stethoscope head interface.
- Inject sound into model
- Increase the volume of water inside the inner tube by 5cc until saturation
- Run NLMS Algorithm for 195 trials and plot average impulse response and retrieved delay

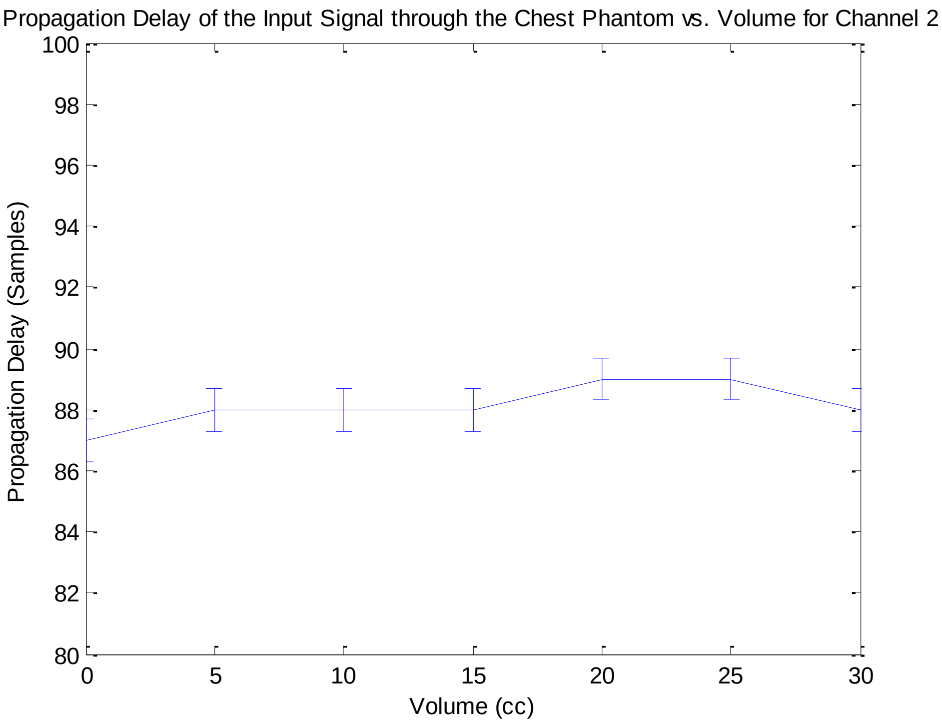




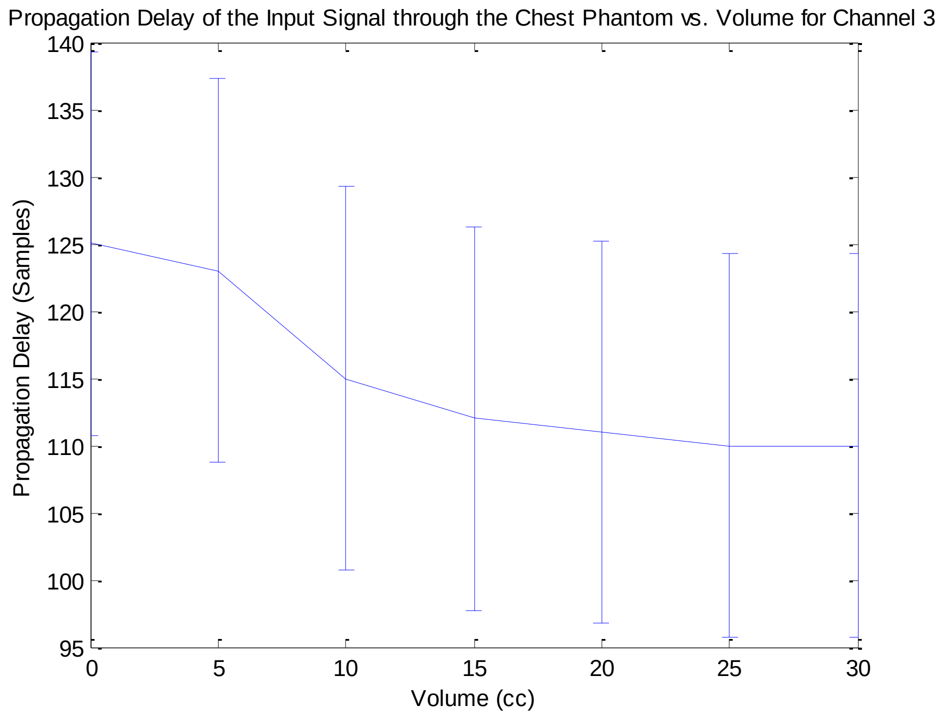
Delay Estimation and Volume Location using the Impulse Response

Mulligan K, Adler A, Goubran R.A, Monitoring Lung Disease using Electronic Stethoscope Arrays, *Canadian Medical and Biological Engineering Society Conference,* Calgary, AB, May 2009

No Water in FOV

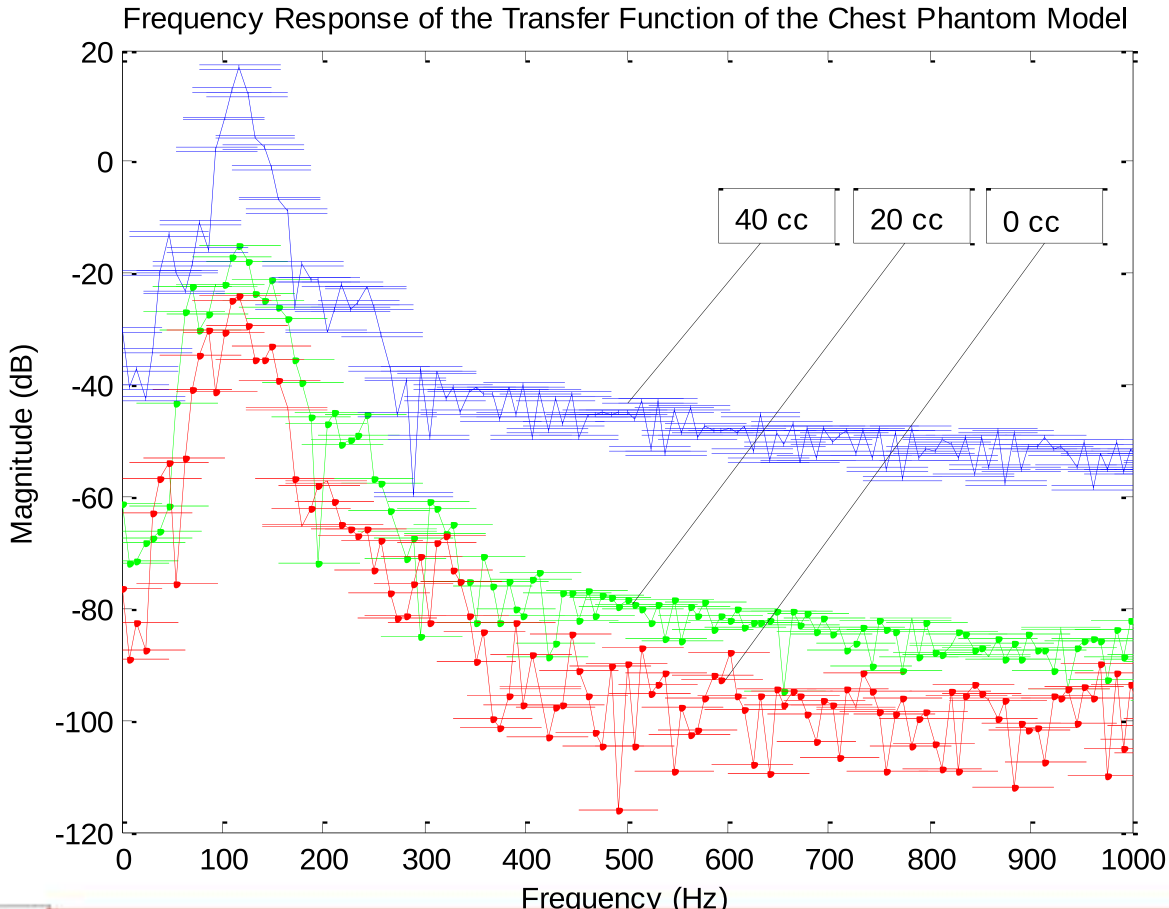


Water in FOV



Frequency Response for Varying Volumes of Water

Mulligan K, Adler A, Goubran R A, Detecting Regional Lung Properties using the Audio Transfer Function of the Respiratory System, *International Conference of the IEEE Engineering in Medicine and Biology Society,* Minneapolis, MN, September 2009

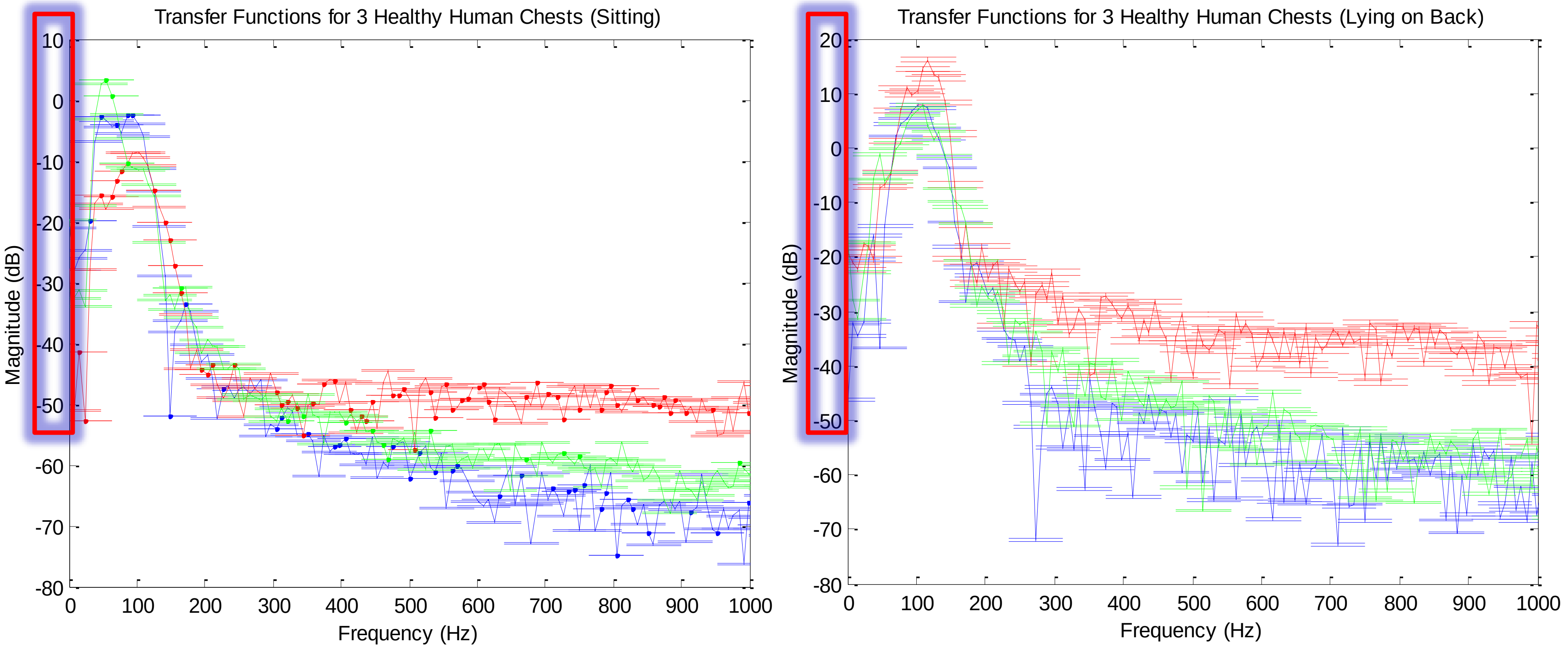


- Two peak frequencies at 86.0 45.6Hz and 172.0 45.6Hz
- Cut-off frequency of 175.0 17.7Hz

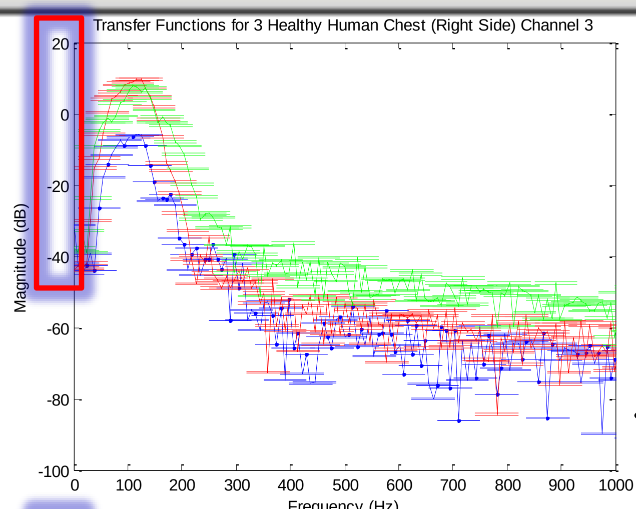
In vivo Experiments

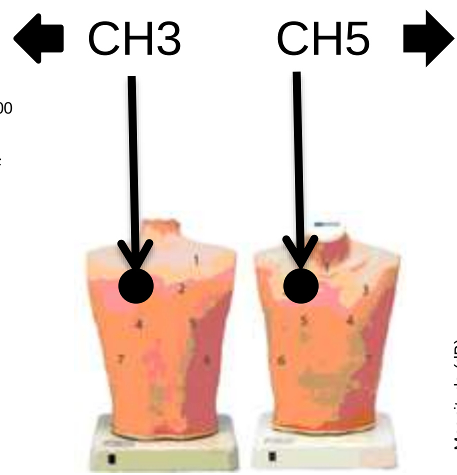
- 3 Healthy Male Participants (20 – 23 yrs. old)
- 5 Postures (Sitting, Lying Right, Lying Left, Flat on Back, Flat on Stomach)
- 15 Trials per Posture
- Plot Chest Transfer Functions

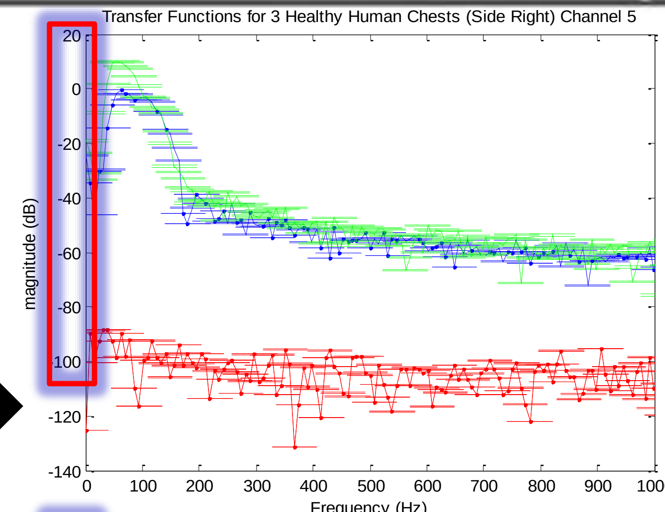
All 3 Participants Sitting vs. Flat

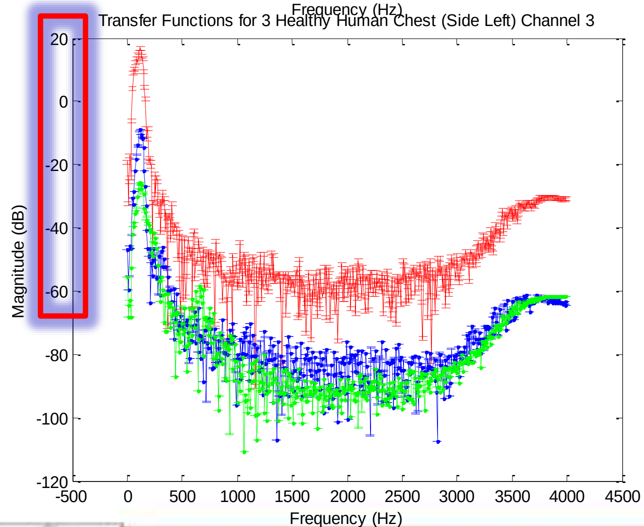


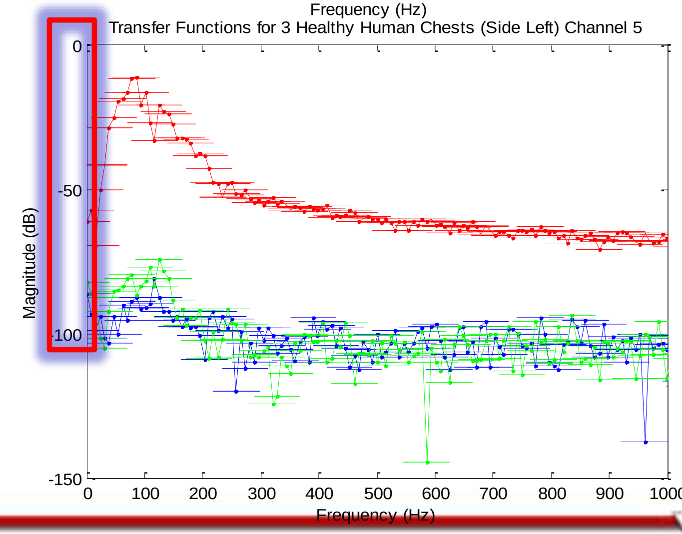
Comparing Lying on the Sides



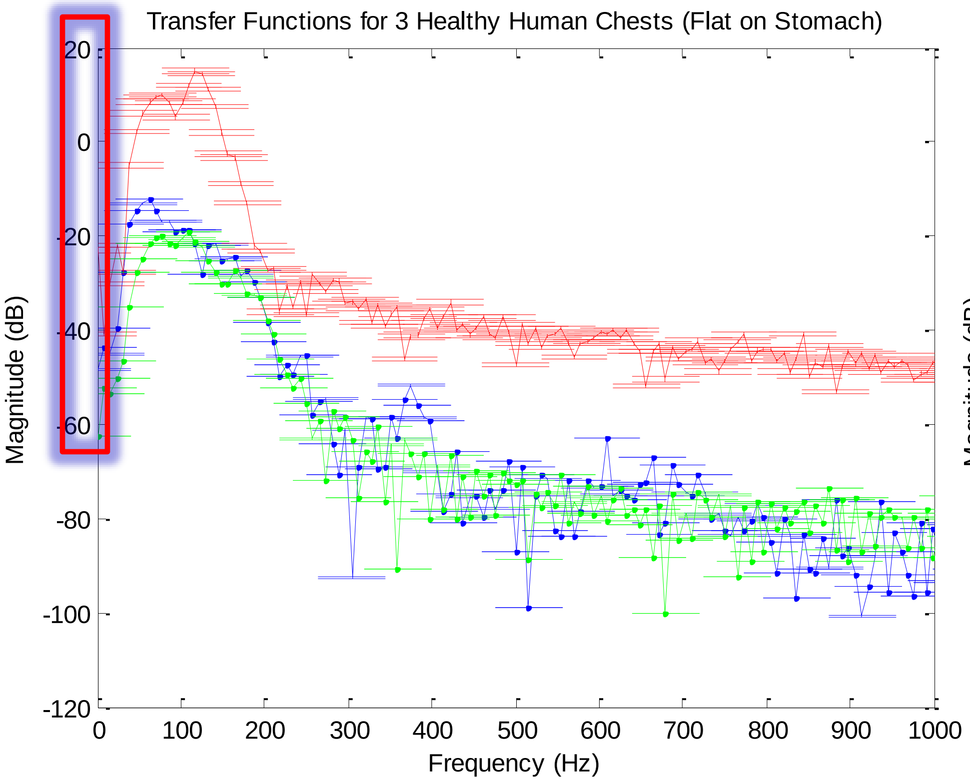


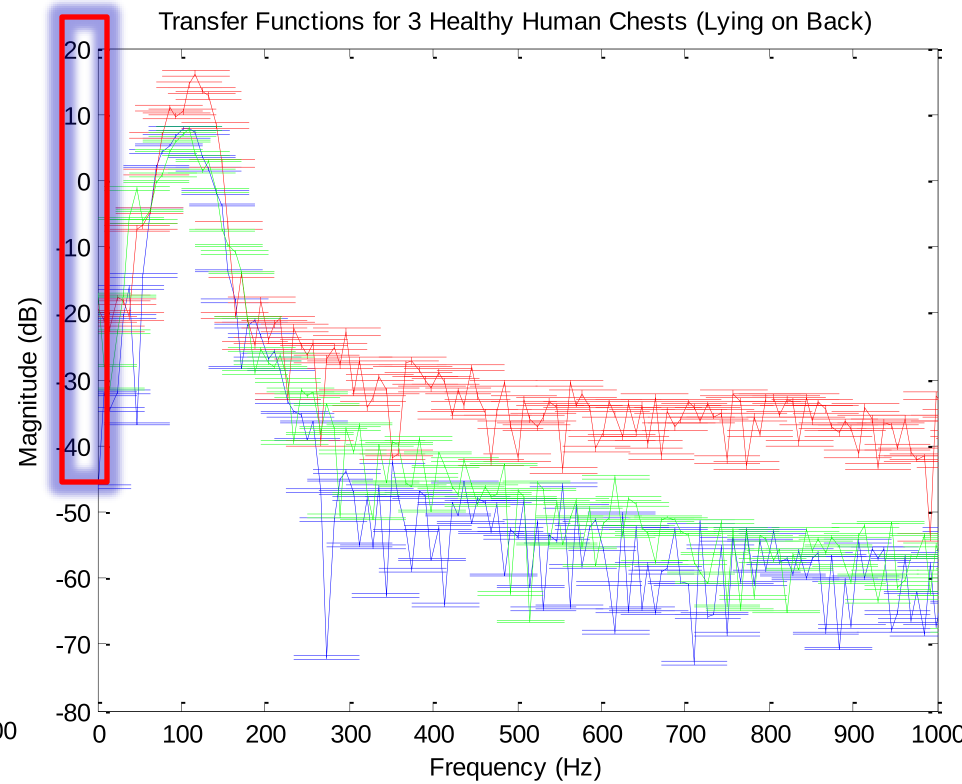




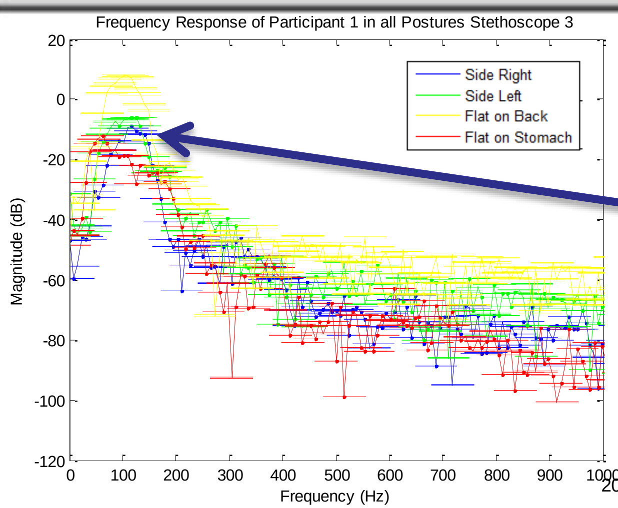


All 3 Participants Stomach vs. Back

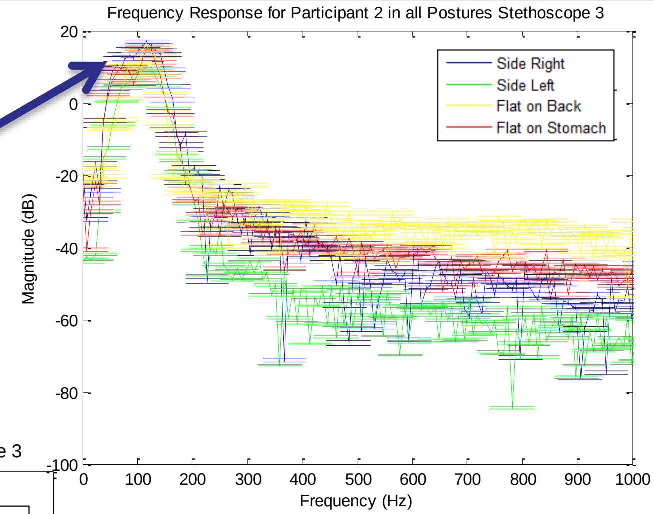




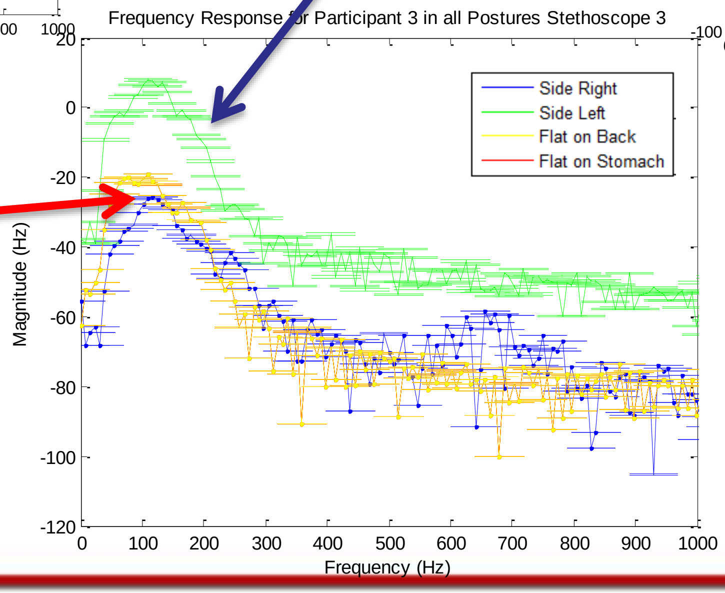
All 3 Participants – 4 Postures – 1 Stethoscope

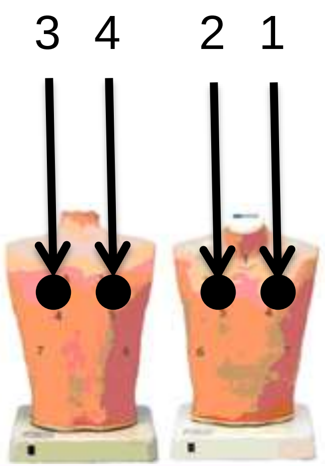


We see the Effect!!

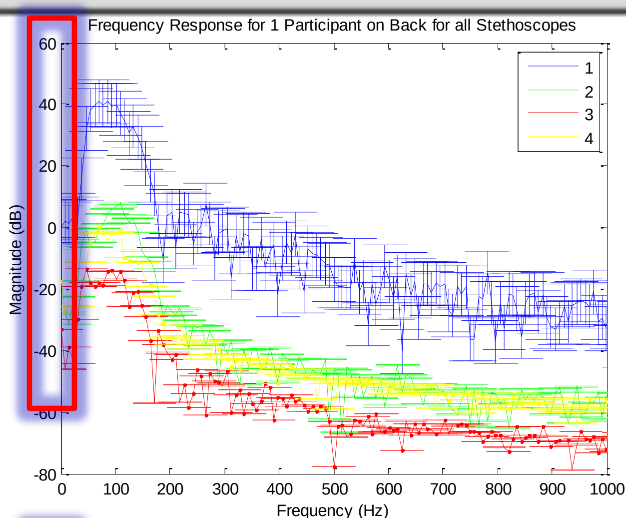


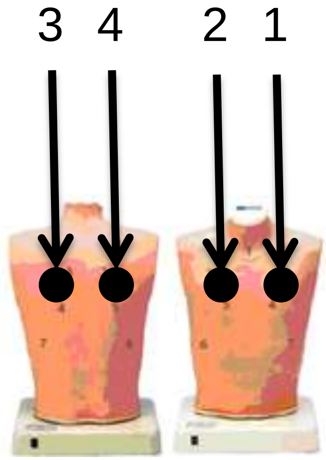
SAME

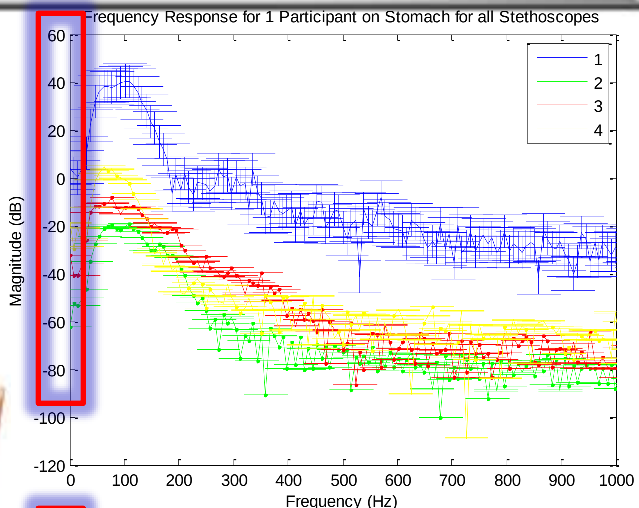


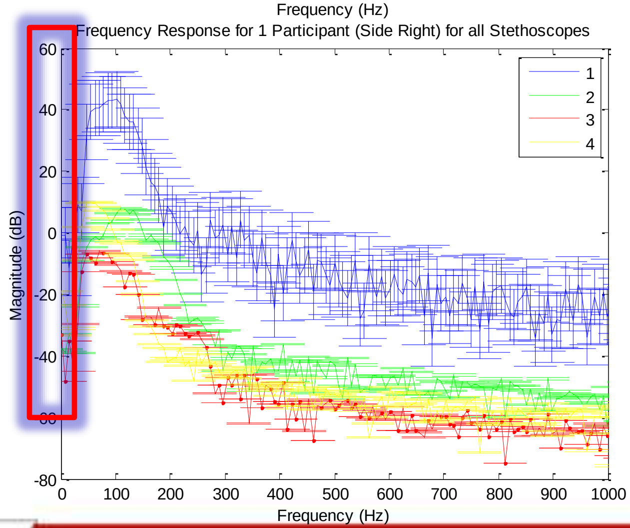


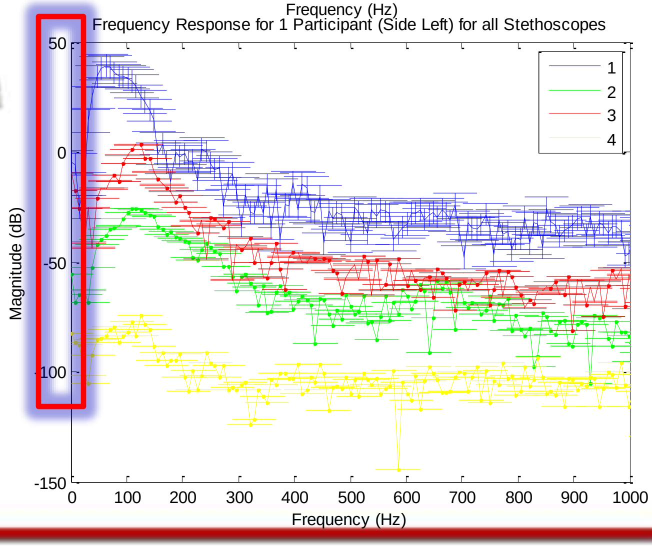
1 Participant – All Stethoscopes per Posture



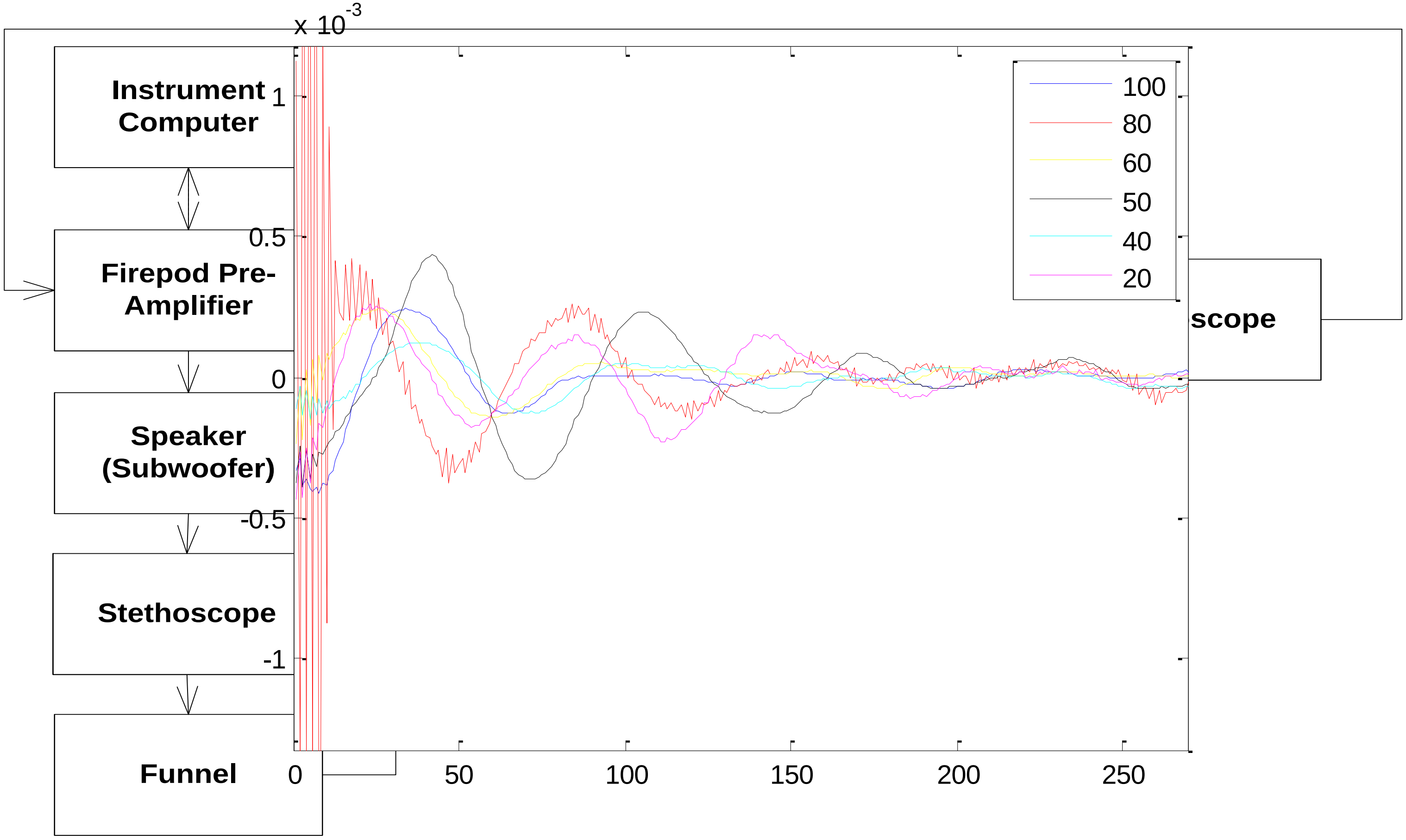




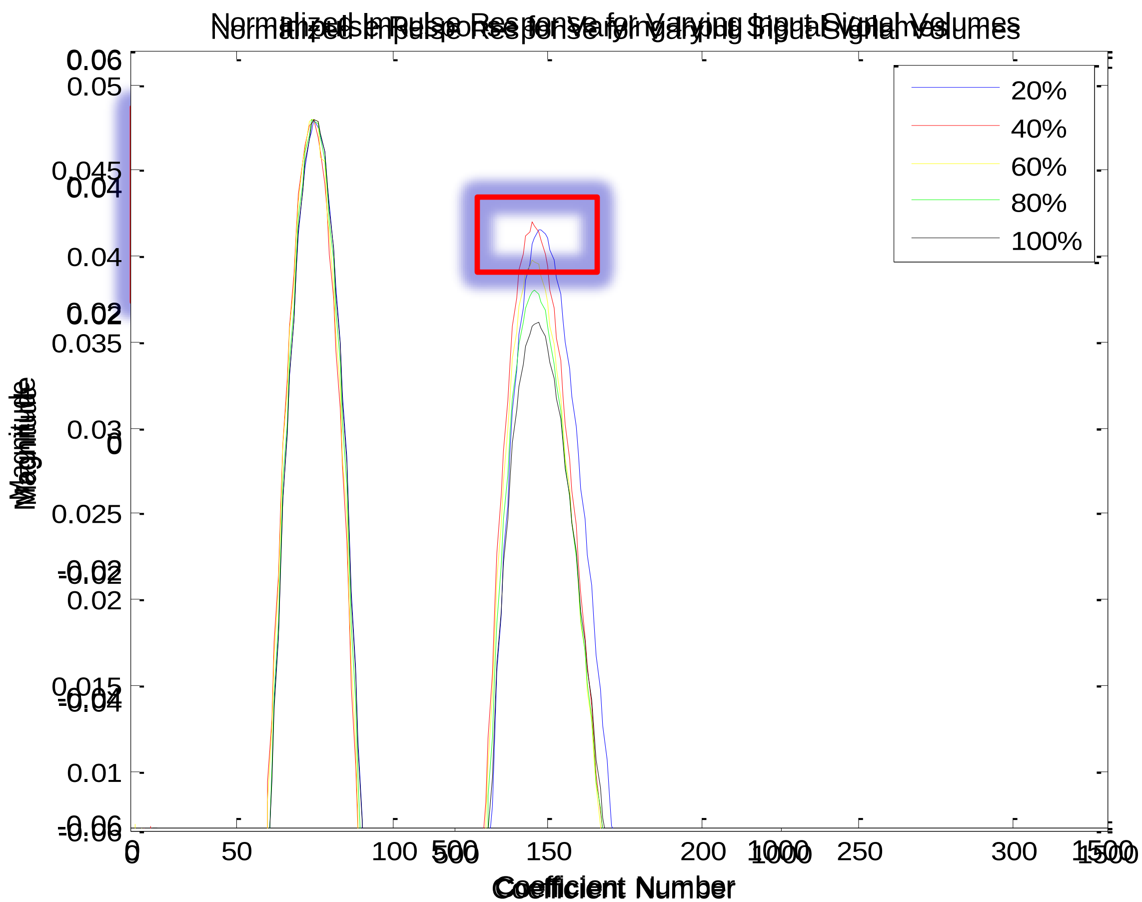




Non – Linearity Experiment



Non – Linear Experimental Results



Conclusion and Future Work

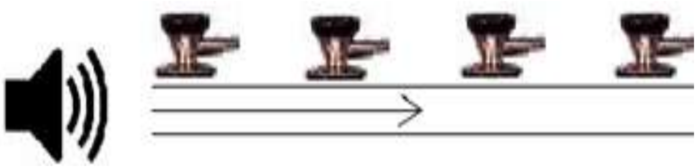
- A novel instrument has been developed to measure changes in propagation delay as the density of water increases within a chest phantom model
- The instrument is capable of monitoring changes in the location of fluid within the chest phantom model
- Preliminary human trials correlate nicely with chest phantom model results
- Fine changes can be detected with posture movements

THANK YOU!

QUESTIONS?

Open Air Column Model

- Hollow cylindrical tube with each stethoscope attached to the surface
- Use v = d/t, NLMS, Cross-Correlation to verify propagation delay of pulsed WGN input



	Theoretical Delay t = d/v (ms)	NLMS Delay (ms)	Cross-Correlation Delay (ms)
1 - 2	0.6	1 0.2041	1 0.2041
1 – 3	1.34	1.25 0.4849	1.25 0.4849
1 – 4	1.808	2.875 0.7868	2.875 0.7868

Plastic Bucket Model

Instrument Calibration

- Sound propagation delay must account for delays of the instruments emitting and acquisition devices.