ECE 445: Microphone Probe for Measurement of Specific Acoustic Impedance of Ground

Team #48
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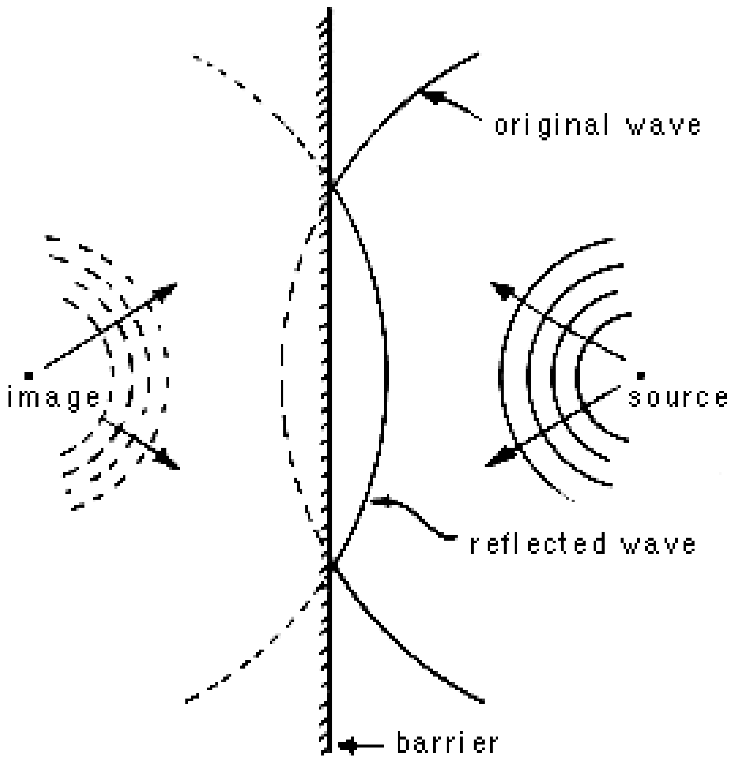
In collaboration with
Dr. George Swenson, Jr.
Dr. Michael White

Introduction

- Collaborated with Dr. George Swenson and Dr. Michael White (Construction Engineering Research Lab) to improve research hardware used in previous experiments.
- Hardware: Pressure 4-Microphone Array
- Purpose: To measure the specific acoustic impedance of surfaces.

What is Specific Acoustic Impedance?

- Specific acoustic impedance (Z) characterizes the pressure produced due to a particle velocity incident on a surface.
- Z determines the amplitude and phase of the reflected wave.
- Important for:
  - noise control
  - acoustic characterization of materials, etc.



$$\underline{Z}(\mathbf{r},\omega) = \frac{\underline{p}(\mathbf{r},\omega)}{\underline{v}(\mathbf{r},\omega)}$$

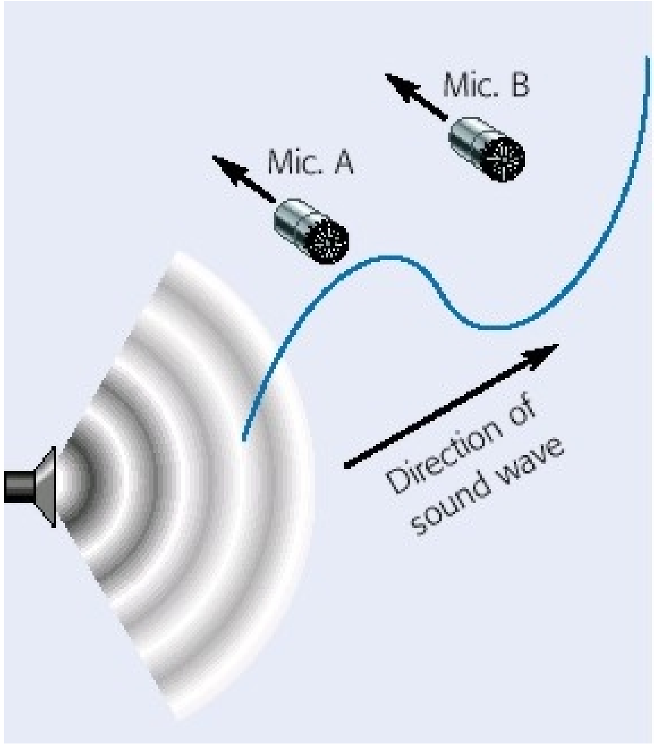
The P-P Method

Euler's Equation for Inviscid Flow

$$\frac{\partial \vec{\tilde{u}}(\vec{r},t)}{\partial t} = -\frac{1}{\rho_o}\vec{\nabla}\tilde{p}(\vec{r},t)$$

In 1-D (approximating pressure gradient)

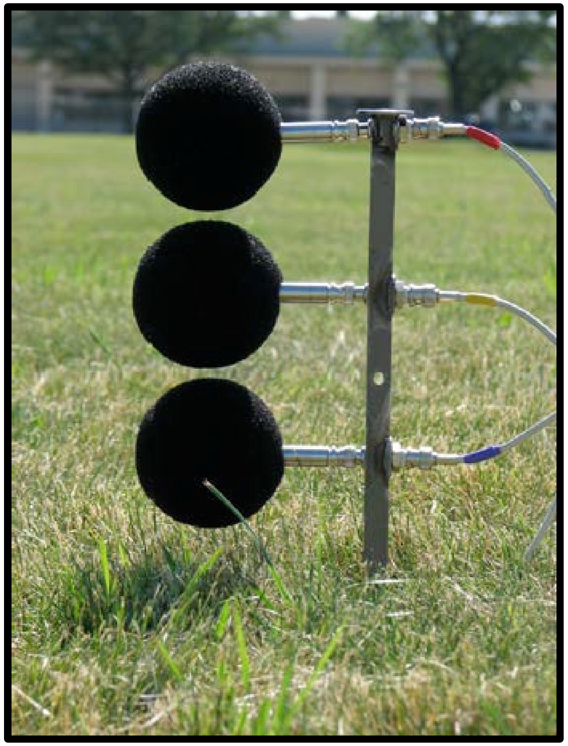
$$\frac{\partial \tilde{u}_z(\vec{r},t)}{\partial t} = -\frac{1}{\rho_o}\frac{\partial \tilde{p}(\vec{r},t)}{\partial z} \Rightarrow -\frac{1}{\rho_o}\frac{\Delta_z \tilde{p}(\vec{r},t)}{\Delta z}$$



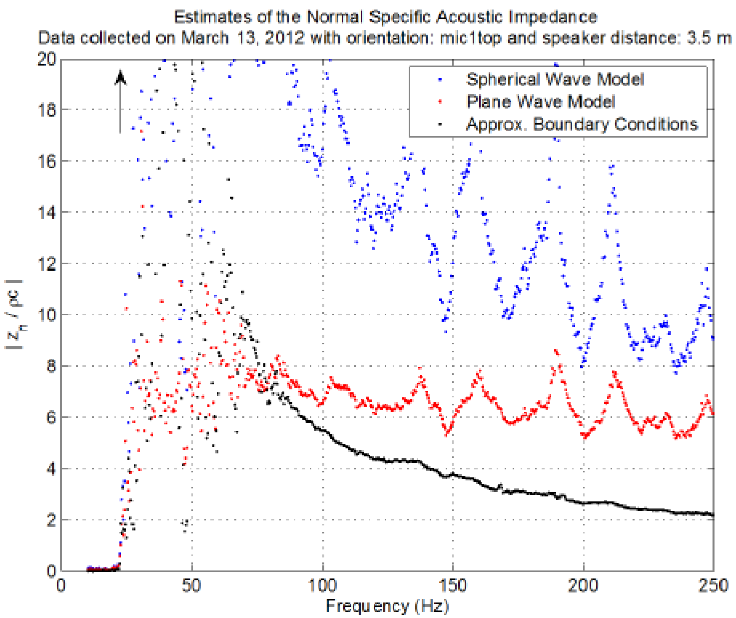
- Eliminates the need to measure *v* directly.

Failings of Previous Setup

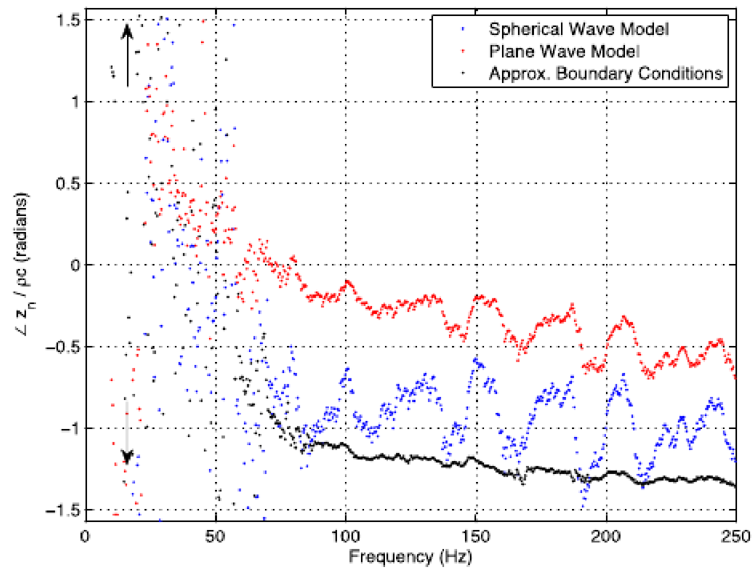
- Mechanically unstable
- Speaker output untested
- Microphone/preamp phase responses uncharacterized
- System not adaptable



Data Acquired by Previous Setup



(a)

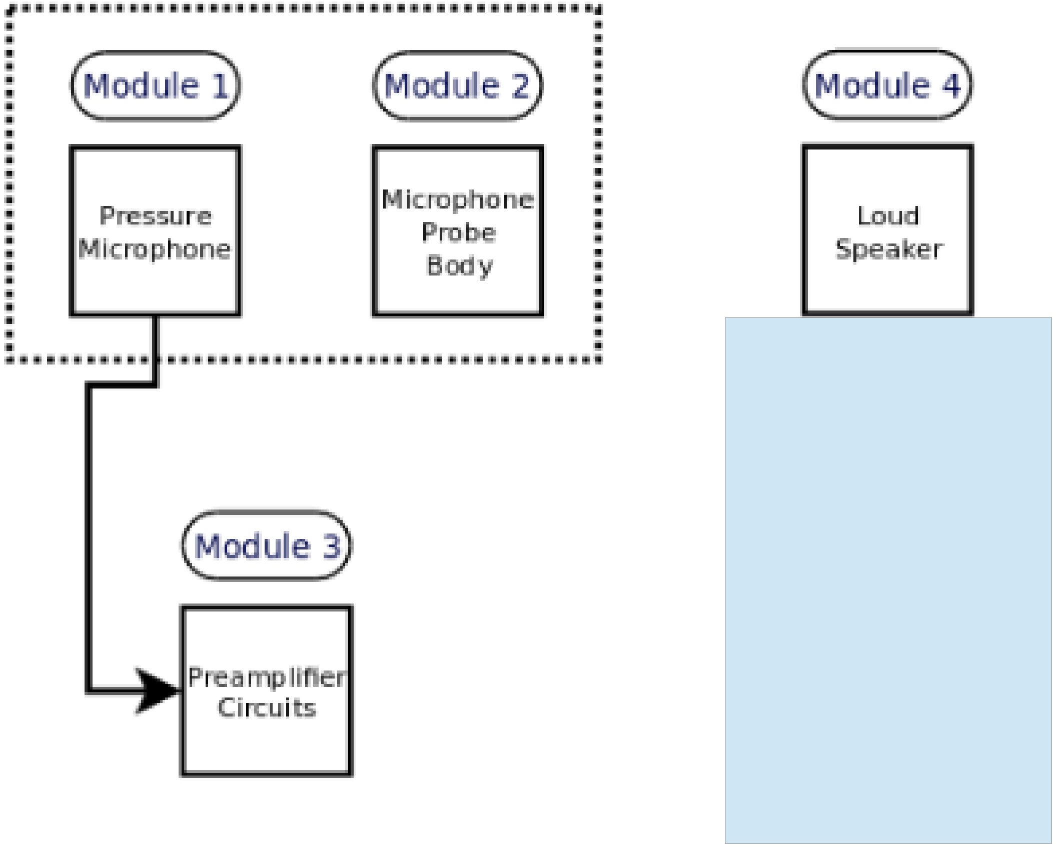


(b)

Design Objectives

- More appropriate microphones
- Build and fully characterize preamplifiers
- Reduce signal noise
- Stable, fixed-spacing probes and stand
- Test and verify speaker output

Design Overview



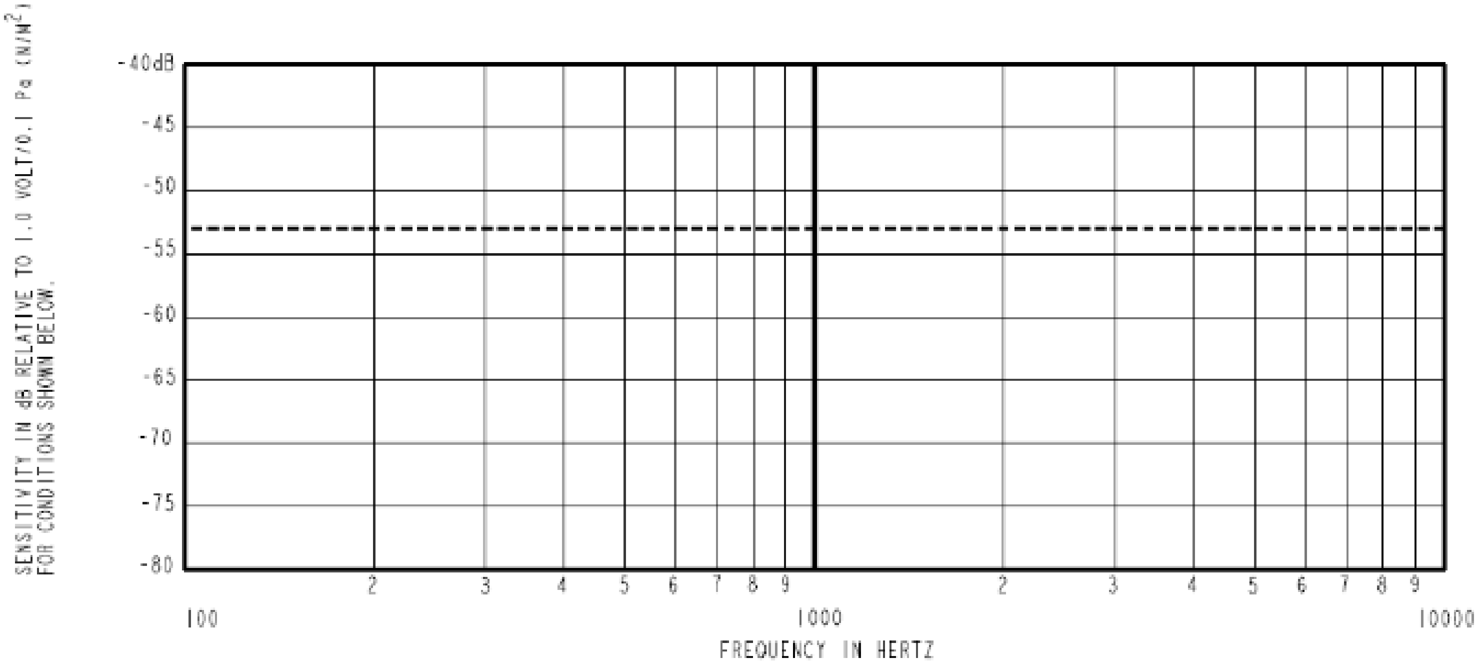
Module 1: Microphones

- Objectives:
  - Small profile
  - Good low-frequency response
  - (Relatively) flat phase response
  - High sensitivity
  - Omni-directional

Previous: GRAS 40AE 0.5" Mic

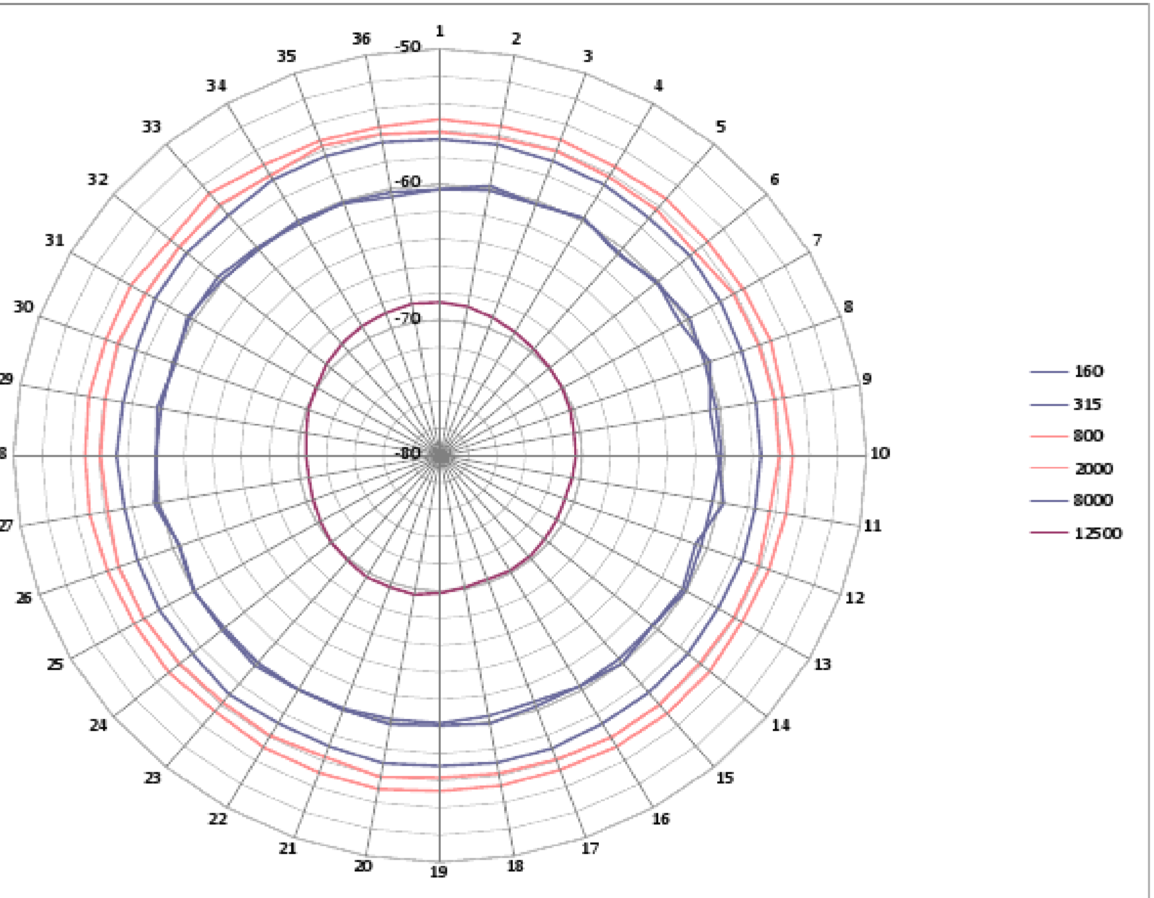
Current: Knowles Electronics WP-23502

Microphones: Sensitivity and Frequency Response



~ -53dB Sensitivity (relative to 1.0V/0.1Pa)

Microphones: Omnidirectionality



- Lacked the anechoic chamber necessary to perform test.
- Instead, tested by William Ballad at Knowles for WP-23502 upon request.

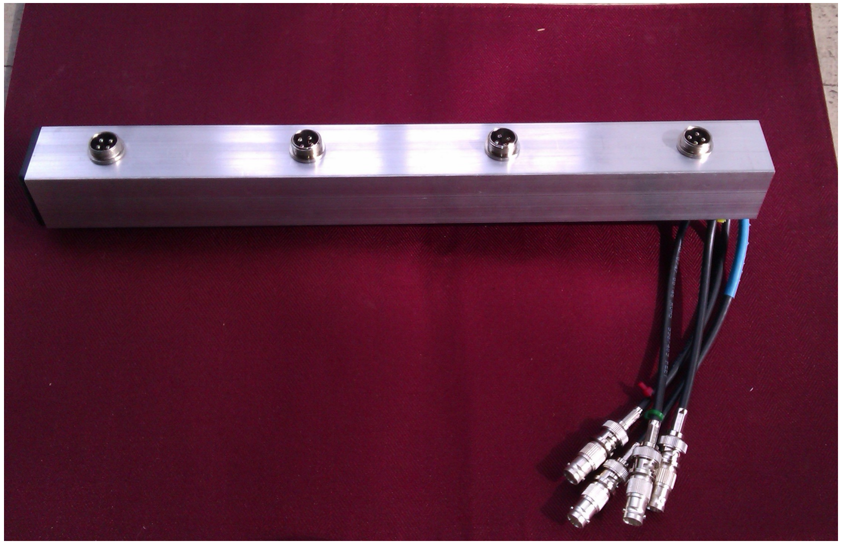
Module 1: Requirements and Verifications

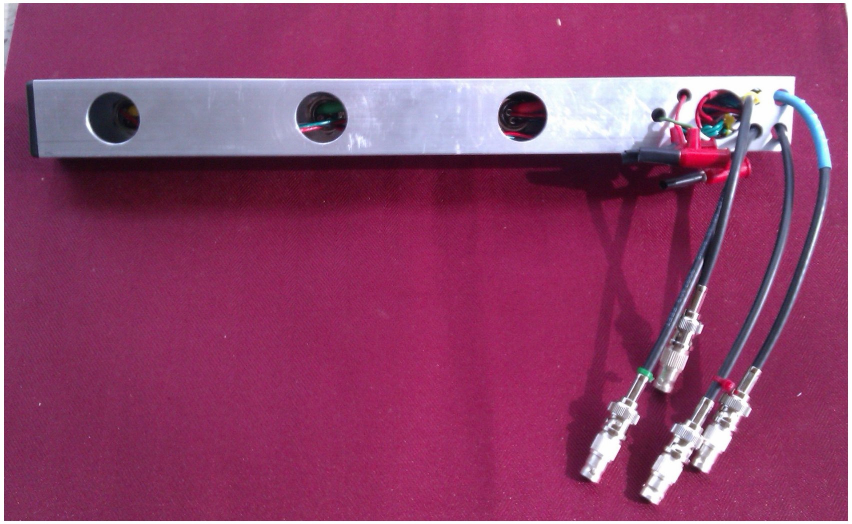
Requirement	Verification	Passed/Failed?	Explanation
Microphones have a nominal sensitivity of -50 dB(±3dB) at 94dB SPL (relative to V-out at 74dB SPL).	Measure voltage outputs at: 0.1 Pa (74 dB SPL) and 1.0 Pa (94 dB SPL).	Passed	-

Module 2: Probe Body

- Objectives:
  - Stable against vibrations
  - Modular
  - Minimal profile
  - Able to be dissembled for storage/repairs

Module 2: Probe Holder

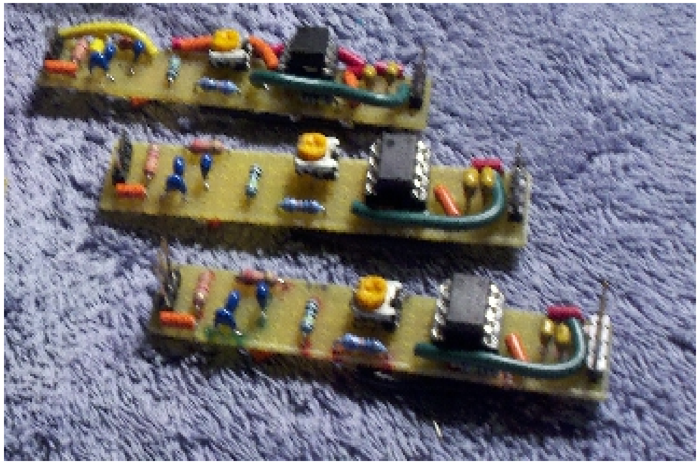




Module 2: Requirements and Verifications

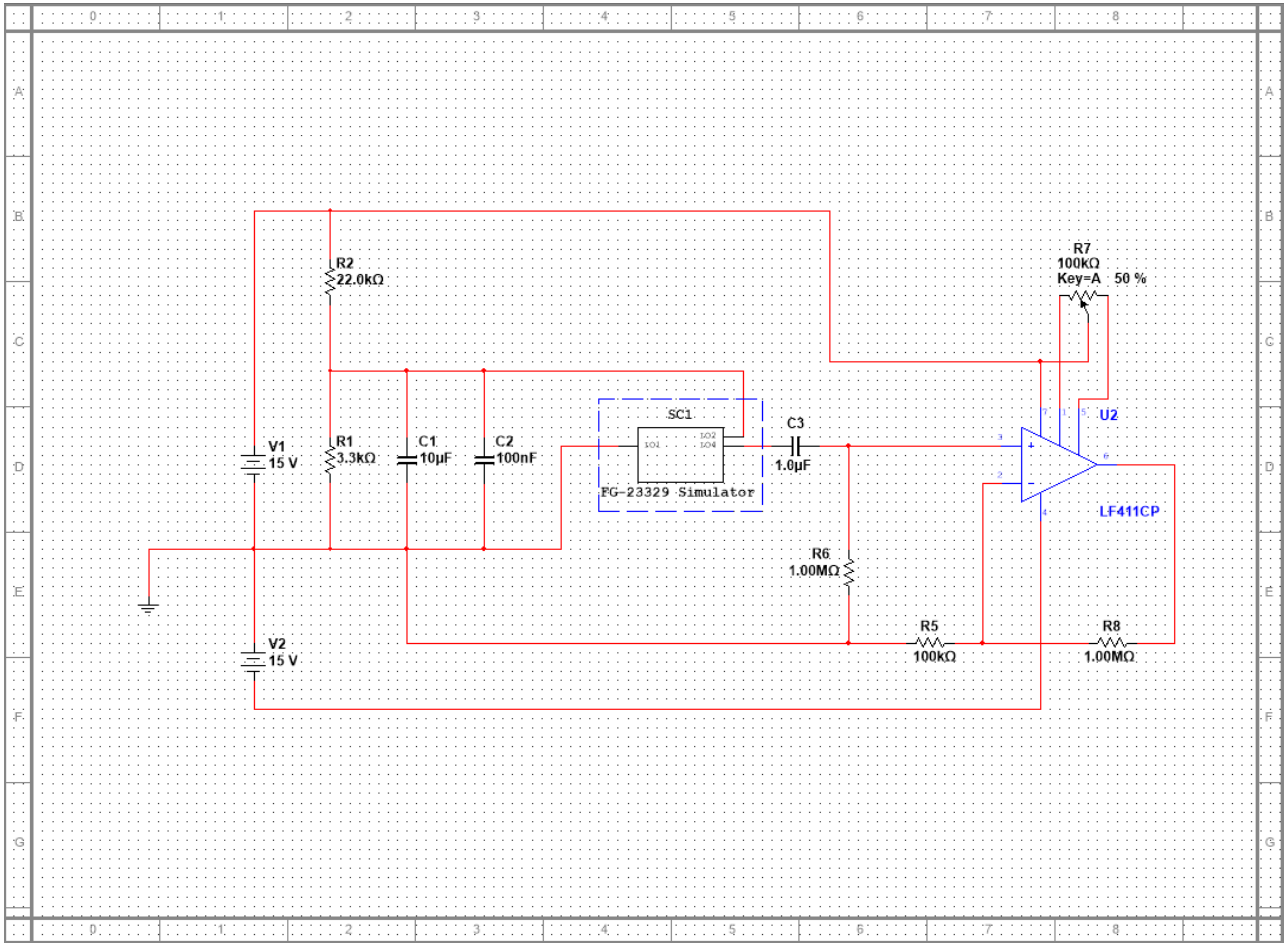
Requirement	Verification	Passed/Failed?	Explanation
Probe body acoustic interference is minimal (local differences in pressure field simulation with and without microphone do not exceed 10%±5%).	Import CAD files of probe body into COMSOL. Run two simulations for pressure incident on probe and flat surface. Extract pressure at 200 equally spaced points and analyze in MATLAB.	Inconclusive- Test not preformed.	Simulations could not be preformed reliably in COMSOL. Results were not reproducible and did not pass basic sanity checks (strange local pressures, available acoustic sources simulation methods not physical).
The probe body should be stable against vibrations induced by incident sound waves (lowest eigenfrequeny at no less than 500Hz±100Hz).	Import CAD files of probe body into COMSOL. Run eigenfrequency simulation and export results.	Inconclusive- Test not preformed.	Simulations could not be preformed reliably in COMSOL. Lowest eigenmode found corresponded to a wavelength much greater than L/2 (lowest expected mode for simple beam of length L).

Module 3: Preamplifers

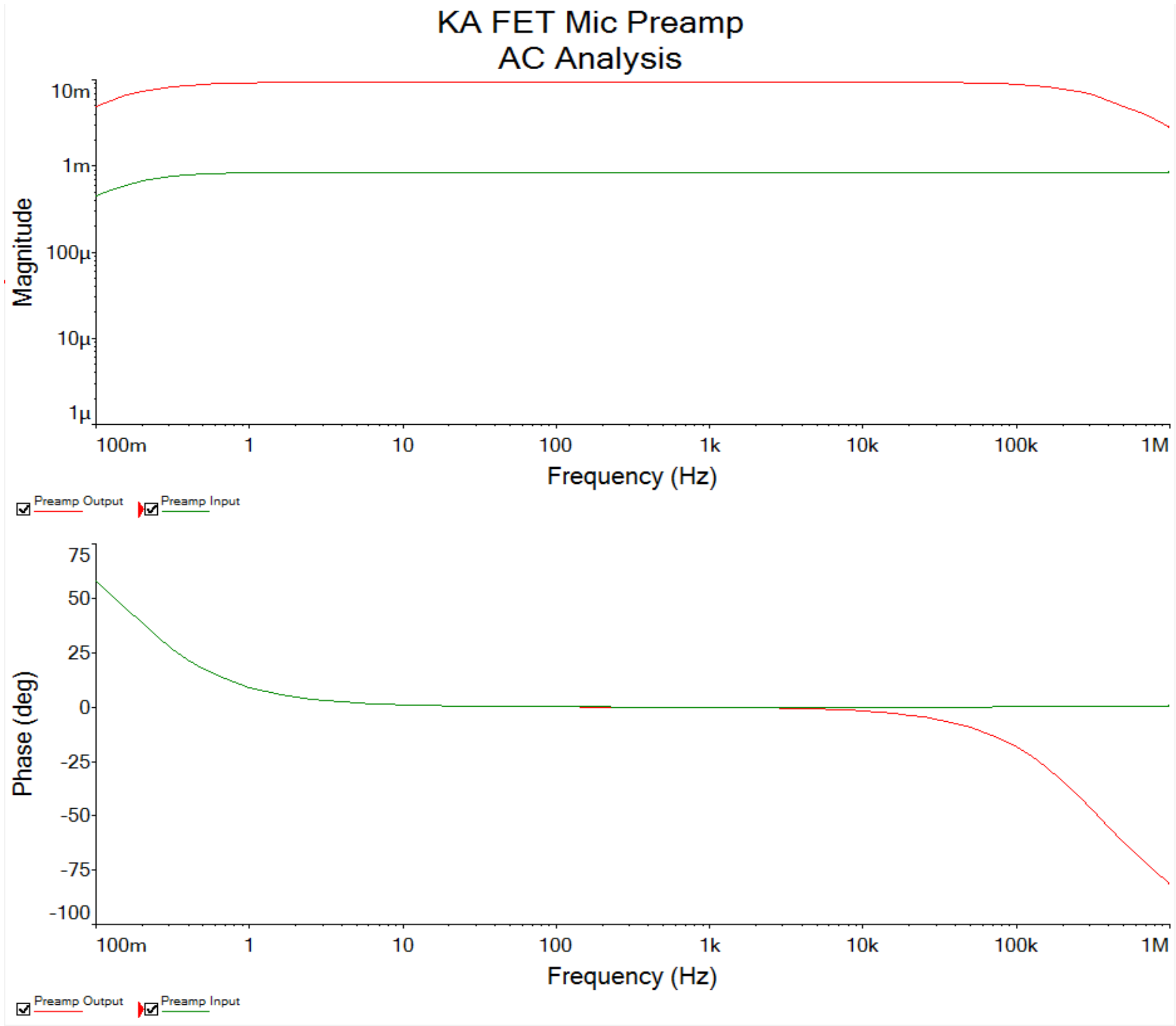


- Dedicated preamplifier for each microphone
- Simulated in National Instruments Multisim
- Tested with NI myDAQ

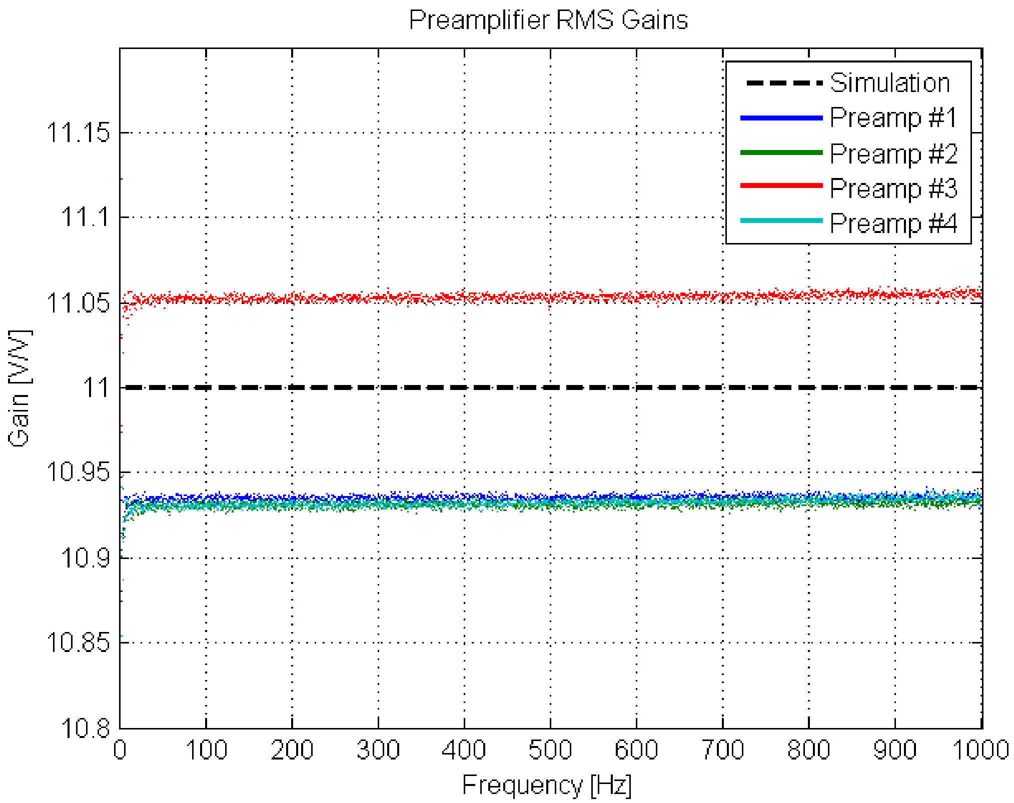
Preamplifiers: Circuit



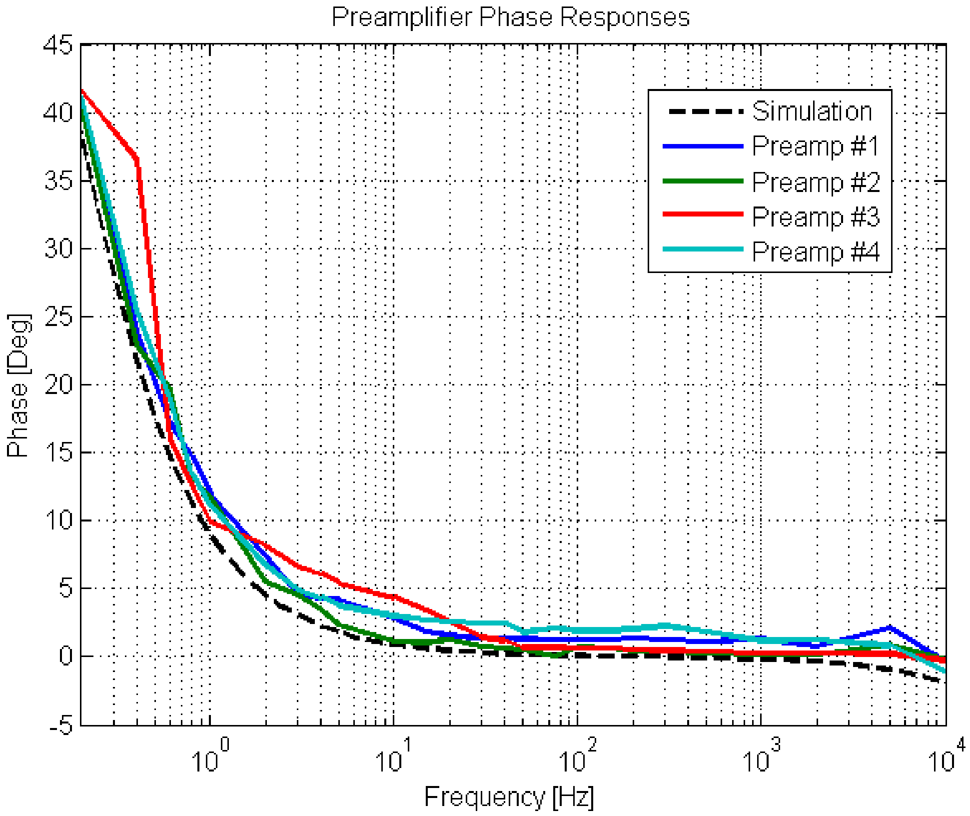
Preamplifiers: AC Simulation



Preamplifiers: Calculated Gain



Preamplifiers: Measured Phase Response



Module 3: Requirements and Verifications

Requirement	Verification	Passed/Failed?	Explanation
Voltage across microphone power supply terminals must be between 1.0 [V] and 2.5 [V].	Measure voltage across a resistor with resistance equivalent to the microphone (~22 kOhm) If within range, repeat with microphone	Pass	-
Mean gain of preamplifer circuit should be 11 [V/V] with a tolerance of 3%	Simultaneously measure input and output of each preamp and calculate gain	Pass	-

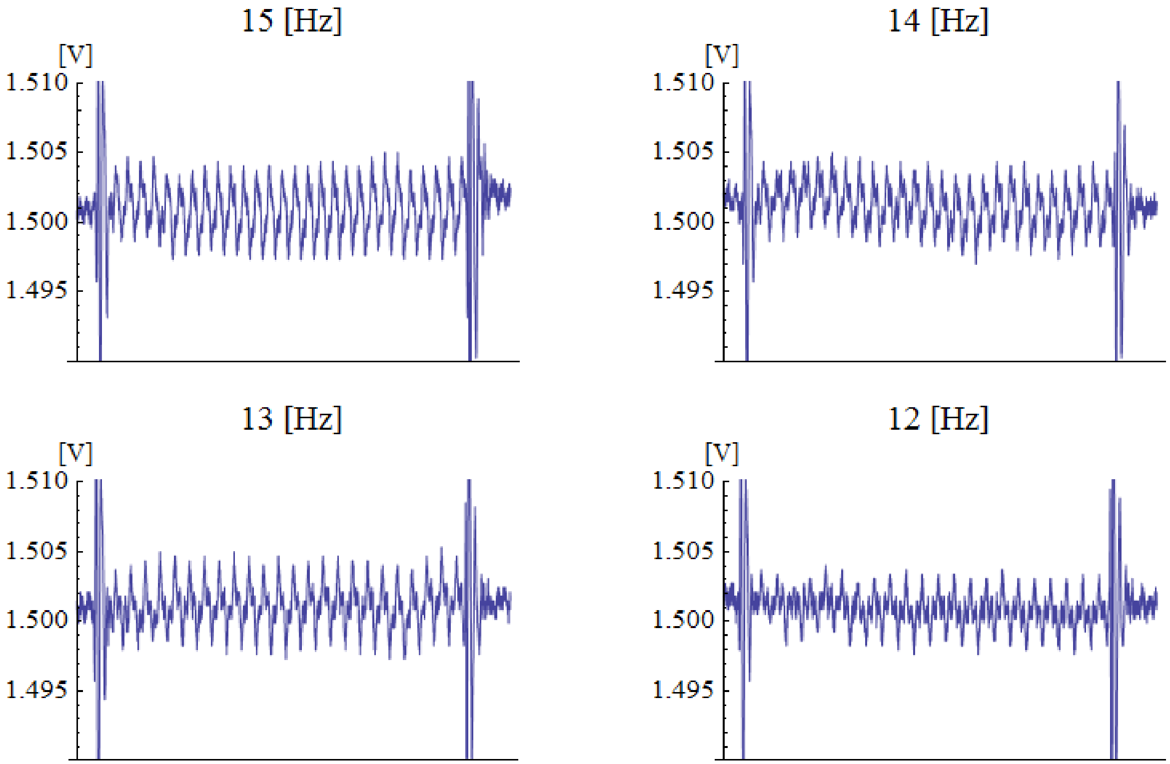
Module 3: Requirements and Verifications

Requirement	Verification	Passed/Failed?	Explanation
Phase response follows model and is well-characterized at low frequencies	Use an oscilloscope to calculate relative phase between input and output signals	Pass	-

Module 4: Loudspeaker

- Commercial-grade Definitive Technologies 'SuperCube II' subwoofer
- 8″ woofer pressure-coupled to two 8″ radiators

Loudspeaker: Measured Lower Limit



Future Work

- Calibration: of microphones, of frequency response of probe.
- Modify microphones to lower low-frequency cut-off.
- Re-run simulations of probe body
- Characterize loudspeaker directivity and field

Acknowledgments

- Dr. George Swenson Jr. and Dr. Michael White (CERL)
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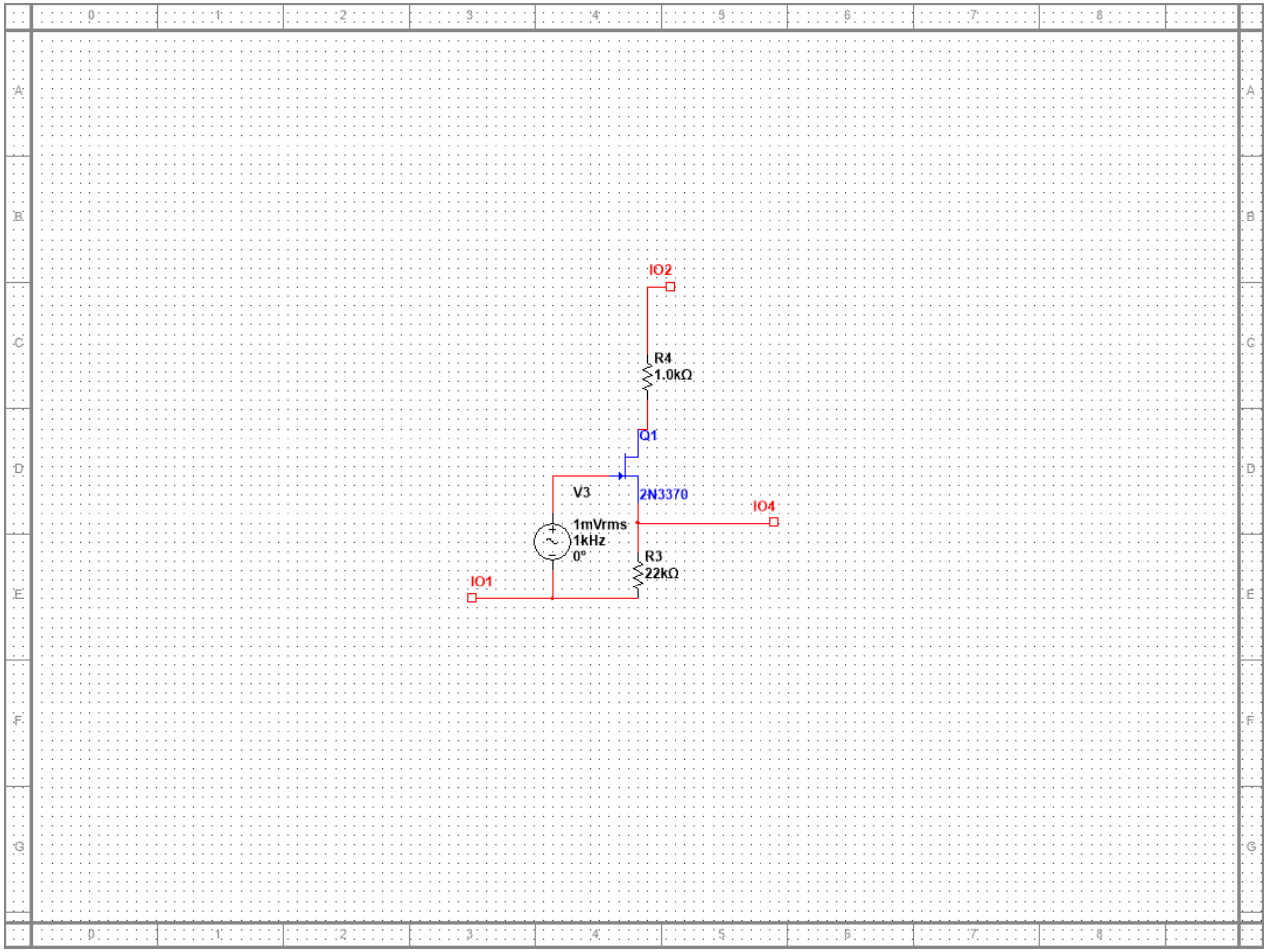
- Dr. Jont Allen (ECE) and Dr. Steven Errede (Physics)

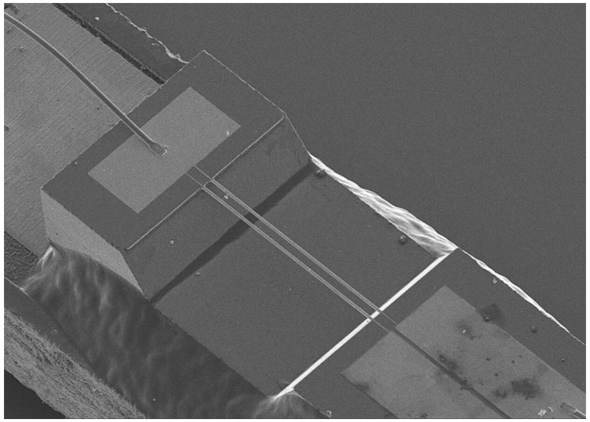
Supplemental Slides

Preamplifiers: Microphone Simulation Subcircuit



How is Z Measured?

- Two values: complex pressure and particle velocity.
- Problem: particle velocity is *terribly unfeasible* to measure.
  - Microflown MEMS device? Awful, expensive.



- For this reason, need a method that avoids direct measurement of *v*.