Microphone Probe Hardware for Measurement of Acoustic Impedance of Surfaces

Design Review

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1 Introduction

Scientists at the Construction Engineering Research Laboratory in Champaign, Illinois have had difficulties getting accurate and consistent measurements of the acoustic impedance of surfaces and materials. The setup used in the past, a two-microphone pressure probe and commercial loudspeaker sound source, produced data that required intense processing and calculations to extract information and different computational models applied on the same data produced behavior that consistently differed, making determination of which model most accurately described the acoustic impedance of that material very difficult, especially in the frequency range of interest, 50-200Hz. Our project would redesign and rebuilt the microphones, the probe, and the circuits to be more sensitive and minimize distortion of the signal due to noise or acquisition method. As well as completely new instruments, a characterization and careful measurement of the specific acoustic source loudspeaker that is used as the acoustic source during these tests will be preformed and this will improve the ability of researchers to match their experimental data with theoretical models and extract experimental parameters.

2 Design

2.1 Block Diagrams

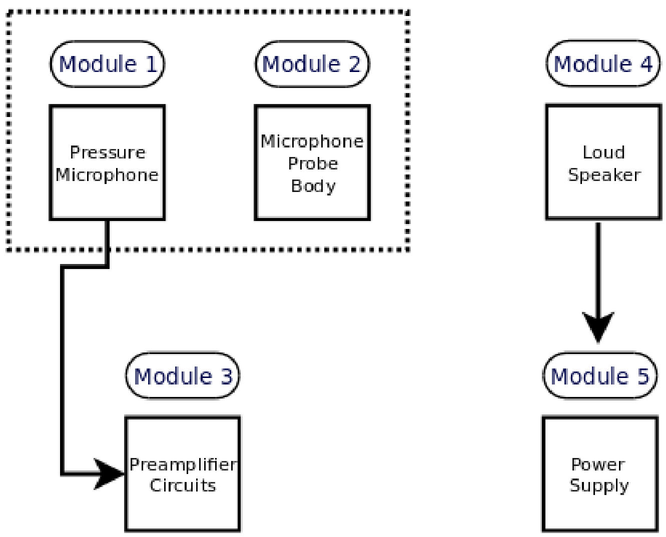

Figure 1: Block diagram of the five numbered modules with electrical connections indicated by arrows and the dotted box indicating modules are housed in the same component.

2.2 Block Descriptions

2.2.1 Pressure Microphones

The pressure microphone module will consist of four (4) electret condenser-type Knowles Electronics omnidirectional pressure microphones, model EK-23132-000. The pressure microphones will be attached to the probe body module for measurements and will each be held in a separate arm of the probe. The face of each pressure microphone should face perpendicular to the surface being measured and the membrane should be covered by a fine metal mesh attached to the rim of the microphone body by epoxy to shield it from stray electromagnetic interference. The membrane side (open side) of the microphone should point downwards towards the ground to increase sensitivity. Each microphone will record pressure data normal to the measured surface at its position and pass the analog signal to a preamplifier circuit located in the probe body. The pressure microphones will be powered by the loudspeaker power source and will be mounted to the microphone probe body. They will be removable for maintenance or repositioning purposes.

2.2.2 Microphone Probe Body

The microphone probe body will hold the four pressure microphones and be able to be secured to the ground for normal incidence measurements. The probe consist of a central stake that is driven into the ground and four separate arms attached at 10 inches from the bottom of the stake with a spacing of 10 cm between arms. The body will be machined out of aluminum for strength and a light weight. The arms of the probe body should contain minimal metal on the back side of each microphone so the symmetric directionality of the microphones is not significantly altered. The probe body itself will house the preamplifier circuits that the microphones pass their signals to but the circuits and the microphones should be removable.

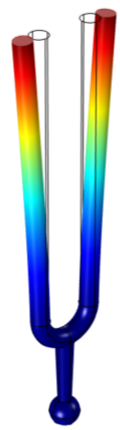

Figure 2: COMSOL Multiphysics example model of a simulation of the eigenmode of a tuning fork at an eigenfrequency of 440 Hz, showing displacement magnitudes.

2.2.3 Preamplifier Circuits

The preamplifier circuit module will be housed in the probe body during measurements. It will consist of four of the same preamplifier circuit schematic and each will take the signal from a pressure microphone and amplify it in order to send to signal to a BNC connector located 50' away from the probe body, which will also provide the power source for the microphones and the preamplifier circuits. During measurements, the preamplifier circuits will be housed inside the probe body, as close to the microphones as possible (though still in the stake rather than the arms of the probe body).

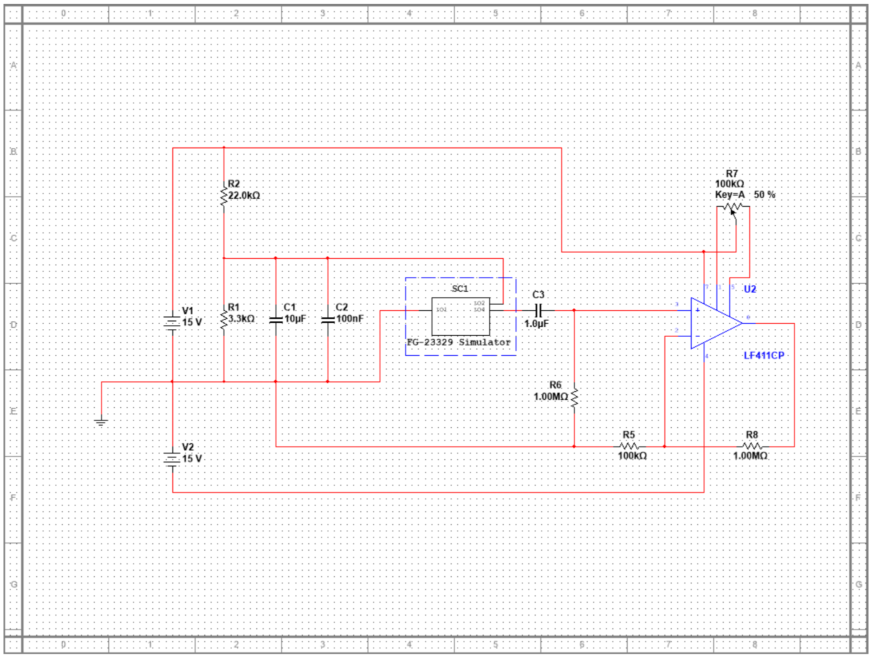

Figure 3: Simulated preamplifier circuit schematic. See Figure X+1 for pressure microphone schematic used in simulation. Simulation done in National Instruments Multisim.

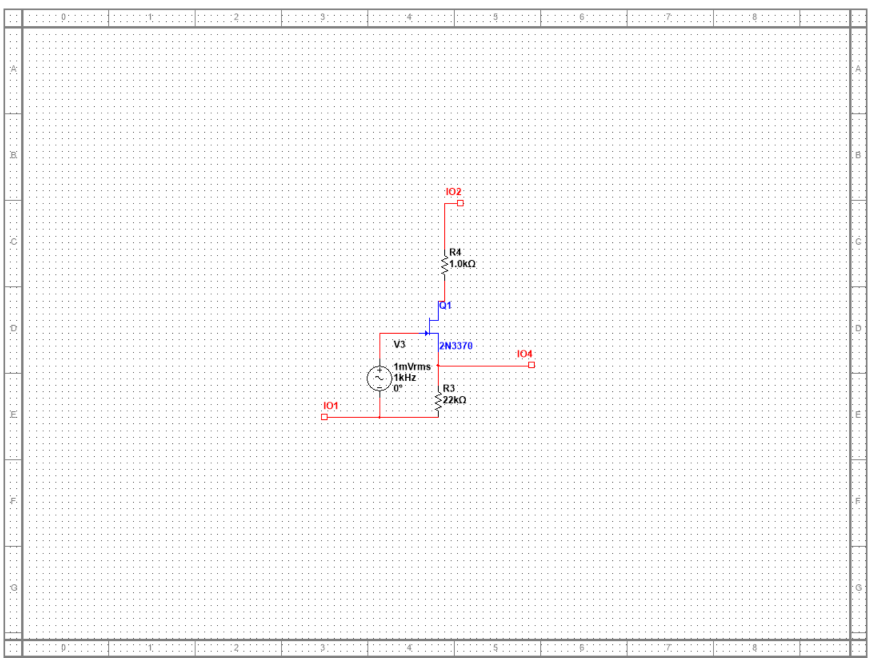

Figure 4: FG-23329 pressure microphone schematic used in preamplifier circuit simulations.

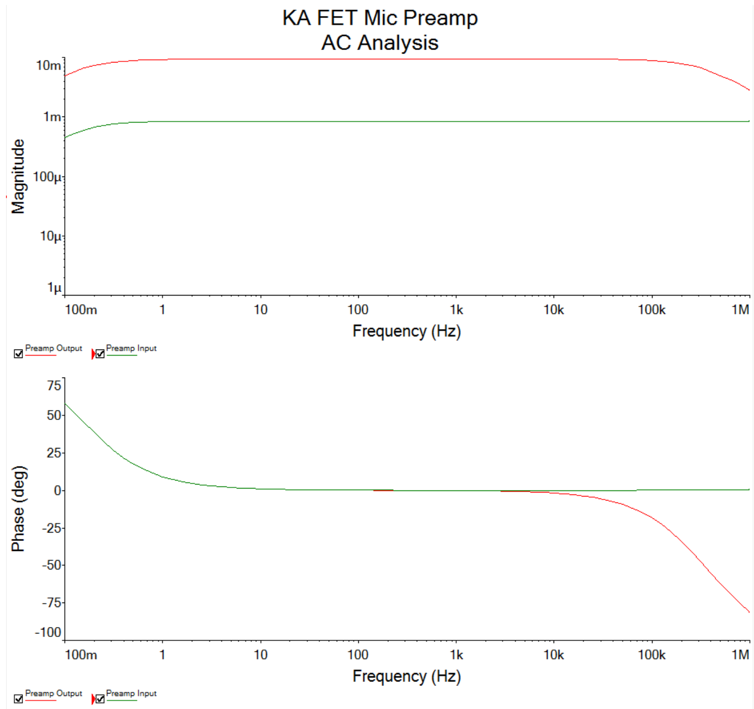

Figure 5: The simulated microphone preamplifier magnitude and phase responses as functions of frequency.

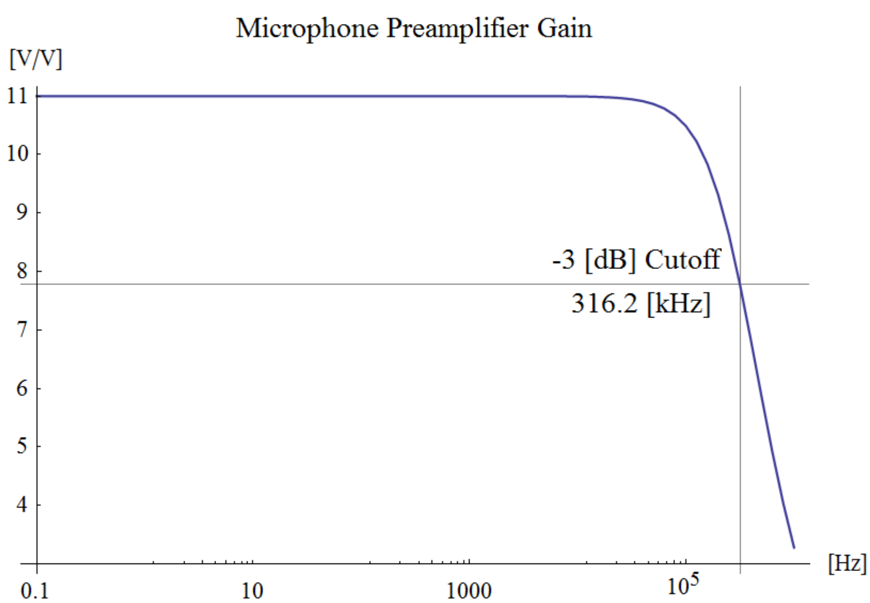

Figure 6: Simulated microphone preamplifier circuit gain as a function of frequency.

2.2.4 Loudspeaker

The loudspeaker module consists of a commercial-grade SuperCube II model bass-type loudspeaker manufactured by Definitive Technologies. It is powered by a 110V generator and, for normal acoustic impedance measurements, suspended 22 cm off the ground by a braided metal wire strung between two supports and used as the acoustic sound source for the measurements. The loudspeaker is premade and may need not be constructed or modified but due to its importance in the impedance measurement experiment, it must be characterized. This particular model has a quoted frequency response of 10 Hz - 200 Hz but the actual frequency response and also the acoustic field shape produced by the loudspeaker are unknown. Because the accuracy of various models for the measurement of acoustic impedances depends heavily on the shape of the source acoustic field and its intensity at various distances, characterizing and testing the loudspeaker is an important part of the impedance microphone probe project.

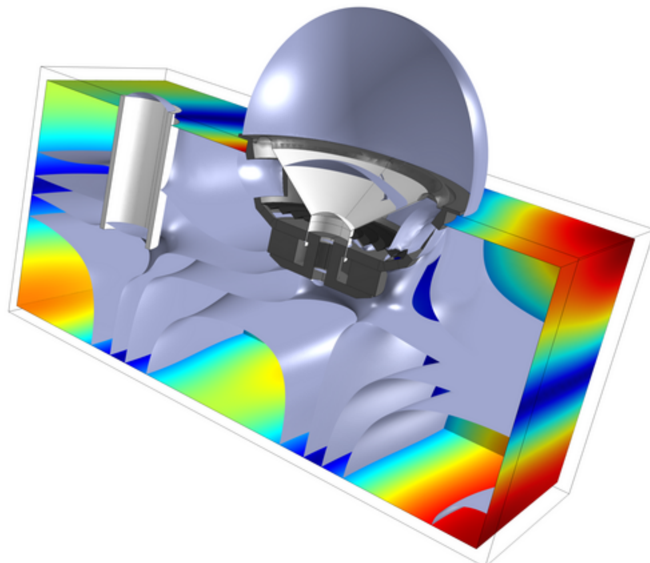

Figure 7: COMSOL Multiphysics example model of a simulation of a loudspeaker driver, including total electrical impedance and calculation of the on-axis pressure field output.

2.2.5 Power Source

The power source module will consist of a 110V generator that provides the power source for the loudspeaker. The power source is pre-built and already purchased but it must be tested to ensure the generator is working and outputting the specified voltage and a clean power signal so that the loudspeaker functions correctly.

3 Tolerance Analysis

3.1 Tolerance Analysis

The most critical parts of this project are the pressure microphones. Because the microphones are being purchased, they are expected to function as advertised. However, due to imperfections in manufacturing, variations is sensitivity and phase response are expected. Without proper calibration and thorough characterization of these properties of the microphones, the system as a whole will not provide usable output.

4 Requirements and Verification

4.1 Pressure Microphones

Requirements	Verifications
The pressure microphones should have a nominal sensitivity of $-50dB \pm 3dB$ at 74dB SPL (sound pressure level).	• The microphones will be fixed in a support arm at a fixed distance from a test speaker. The sound pressure field produced will be measured with a hand-held sound pressure meter. The output of the microphones will be hooked up to a frequency spectrum analyzer and the response to various frequencies will be measured. • If the sensitivity of the microphones have a sensitivity lower than the specified range, they will be sent back to the manufacturer and a new microphone will be ordered.

4.2 Microphone Probe Body

Requirements	Verifications
The probe body profile should be minimal so as not to interfere with the incident and reflected acoustic waves. The spatial variation in pressure fields between the simulation with a microphone body and without should be $10\% \pm 5\%$.	• A CAD model of the microphone probe body will be made. COMSOL Multiphysics Acoustic Module will be used to simulate acoustic waves incident on the probe body near a rigid plane. The diffraction of the incident acoustic pressure waves due to the probe will be examined and a spatial overpressure field will be simulated. The overpressure value at each region of space will be subtracted from and divided by the values at the same region in the simulation without the microphone probe body. From this, a percentage difference field will be obtained. • If the geometry of the probe is such that diffraction by the probe generates a difference of over 15% between the probe and free space models, especially on the axis normal to the ground surface, the design will be modified to minimize diffraction further.
The probe body should be stable against vibrations due to the incident acoustic waves and hold the microphones rigid during testing. This means that the lowest eigenfrequency of the probe body structure should be above $500Hz \pm 100Hz$.	• A CAD model of the microphone probe body will be made. COMSOL Multiphysics Structural Mechanics module will be used to simulate the 10 lowest eigenmodes of the probe body. • If any of the eigenfrequencies are less than 500 Hz, the geometry must be modified to provide stability and resimulated to raise the lowest eigenfrequencies. To accomplish this, the vibrational eigenmodes for frequencies less than 500 Hz will be images and examined to provide guidance on how and where to reinforce the probe body against vibrations.

4.3 Preamplifier Circuits

Requirements	Verifications
Each preamplifier circuit has a uniform gain (to a tolerance of ±10% variation) of at least 7 V/V over the frequency range of interest (1 Hz - 11 kHz)	• The circuit will be connected to a frequency analyzer, and a 1 V sinusoidal test signal will be applied to the circuit and swept over the specified frequency. The gain of the circuit will be measured on the frequency analyzer.

4.4 Loudspeaker

Requirements	Verifications
The loudspeaker acoustic output pressure field shape should be known to determine which model will provide the best prediction of impedance. The fit of the simulated pressure field shape to either a spherical, plane wave, or beam shape should have an R^2 value of 0.7 ± 0.2.	• The loudspeaker will be disassembled partially and dimensions and components measured. A CAD model of the loudspeaker cone, driver, and enclosure will be made. COMSOL Multiphysics Acoustics and AC/DC Module will be used to simulate the electromagnetics of the coil transducer and the structural mechanics of the driver to simulate the shape of pressure wave fronts enemating from the loudspeaker. The steady-state solution (time-independent solution) will be analyzed to find surfaces of equal pressure and create a partial contour mapping. From this simulation, the pressure values and spatial location (x,y,z) of the loudspeaker acoustic field at the distance used during measurements will be taken. The values will be input into Origin for statistical analysis and interpolated to generate an approximate function for the pressure field shape. This interpolated function will be fit to the function for spherical, planar, or beam fields to see which shape fit gives the highest R^2 value (with $R^2 = 0$ indicating no correlation between the data and the fit and $R^2 = 1.0$ indicating perfect correlation). • If the R^2 values for all three ideal field shape fits are below 0.5, then a new approximate function must be defined from the simulation data and no easy idealizations can be made in the processing of data from the microphones during measurements.

4.5 Power Source

Requirements	Verifications
Voltage outputted by the generator is 110V±10V and has a sinusoidal waveform.	• The generator will be powered on and hooked up to an oscilloscope in the power laboratory in Everitt using special high voltage probes. The output voltage and waveform will be examined to ensure it is within the acceptable limits. • If the output voltage is under 100V or over 120V or the waveform is not acceptably sinusoidal (clipped peaks, linear segments, etc), the power generator will be swapped out for another generator.

5 Schedule and Cost Analysis

5.1 Schedule

Week	Task	Responsibility
2/10	Research microphones (pressure and particle velocity)	Anna
	Research amplifier and filter circuits	Kevin
	Research acoustic impedance measurement methods	Anna
	Meet with collaborators to get information on acoustic source	Kevin
	Get familiar with COMSOL	Anna
2/17	Work on finalizing design review	Kevin
	Determine which parts will be purchased and which will be constructed	Anna
	Find examples or model circuits for parts that need to be built	Anna
2/24	**Design review**	Kevin
	Order microphones	Anna
	Order circuit components	Kevin
	Research power supplies	Kevin
	Research methods used to computer acoustic impedance from given data	Anna
3/3	Begin testing microphones	Anna
	Begin constructing preamplifier circuits	Kevin
3/10	Make sample measurements using microphones	Anna
	Determine specific requirements and modifications on the preamplifier circuits	Kevin
3/17	Begin designing the microphone probe body (CAD)	Anna
	Simulate microphone probe body and acoustic reflections in COMSOL	Anna
	Continue to work on preamplifier circuits	Kevin
3/24	Finalize mock-up demo	Kevin
	Continue samples measurements using the prototype microphone probe	Anna
	Calibrate the microphone probe and test the frequency response	Anna
	Connect the preamplifiers to the microphone probe and examine the signal output	Kevin
	Test power supply generator	Kevin
3/31	**Mock -up Demos**	Anna
	Modify the preamplifier circuits	Kevin
	Finalize the microphone body and make more sample measurements	Anna
4/7	Finalize the preamplifier circuits	Kevin
	Take the project to a field and make measurements	Anna
4/14	Finalize presentation	Anna
	Modify circuits or microphone setup based on field measurements	Kevin
4/21	**Demo/Presentation**	Anna
4/28	Write documentation for the microphone probe set up	Kevin
	Finalize calibrations on the microphone probe	Anna
5/5	Turn in project to collaborators	Kevin

5.2 Cost Analysis

5.2.1 Labor

Name	**Rate**	**Hours**	**Total**
Kevin Looby	\$55/hr	180	\$24750
Anna Czerepak	\$55/hr	180	\$24750
		Labor Total:	\$49500

5.2.2 Parts

Part Name	Part Number	Vendor	Quantity	Unit Price	Subtotal
JFET Op Amp	LF411CP	Digi-Key	4	\$1.71	\$6.84
Metal Film Resistor 3.3 kΩ	EMP100JR-52-3K3	Digi-Key	4	\$0.14	\$0.56
Metal Film Resistor 22 kΩ	HHV-25JR-52-22K	Digi-Key	4	\$0.31	\$1.24
Metal Film Resistor 100 kΩ	1622796-1	Digi-Key	4	\$0.41	\$1.64
Metal Film Resistor 1.00 MΩ	RNF14FTD1M00	Digi-Key	8	\$0.15	\$1.20
Potentiometer 100 kΩ 50%	EVN-DJAA03B15	Digi-Key	4	\$0.86	\$3.44
Capacitor 0.1 μF	FK28X7R1H104K	Digi-Key	4	\$0.29	\$1.16
Capacitor 1.0 μF	FK28X5R0J105K	Digi-Key	4	\$0.29	\$1.16
Capacitor 10 μF	FK18X5R0J106M	Digi-Key	4	\$0.48	\$1.92
Condenser Pressure Mic.	FG-23329	Knowles Electronics	4	\$25.00	\$100.00
				Parts Total:	\$119.16

5.2.3 Machining

$$\text{Machining Cost} \approx \$100$$

5.2.4 Total Cost

$$\begin{aligned}\text{Total Cost} &= \text{Labor} + \text{Parts} + \text{Machining}\\ &= \$49500 + \$119.16 + \$100\\ &= \$49719.16\end{aligned}$$

6 Safety Statement and Ethics

6.1 Safety Statement

The chief safety considerations in this project will be the testing of high voltages in the power supply module and the machining of the microphone probe body.

The high voltages associated with the power supply module (over 100 Volts) require care when testing the module. The testing will all be done under the supervision of a power lab manager and in a dedicated power lab. Care will be taken when selecting probes to hook up the signal generated by the power supply to an oscilloscope for testing and the power generator will not be handled directly when the module is on. This will minimize the chance for electric shocks and the destruction of sensitive lab instruments.

The machining of the probe body will be done by one member of the design team and care must be taken to ensure that all safety rules in the machine shop are followed. No machining will be done without another member in the machine shop to minimize the chance for accidents. Long hair and loose clothing will be held back and safety goggles will be worn to prevent injuries when working with the mills and lathes.

Following these considerations will ensure that the project is completed in a safe and timely manner.

6.2 Ethical Issues

1. The goal of this project is to produce a device to be used to measure the specific acoustic impedances of materials and surfaces. The primary impetus for these measurements is for use in reducing the

noise pollution produced by United States Army research bases. As such, our device helps to improve conditions for those living within close proximity to U.S. Army bases, consistent with the first policy in the IEEE Code of Ethics:

   (a) 1. *to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;*

2. Having been contracted by a party external to the University, the potential for conflicts of interest to arise exists. With this in mind, we will do our best to ensure that, should any such conflict of interest become apparent, it will be dealt with quickly and appropriately, as outlined in the second policy of the IEEE Code of Ethics:

   (a) 2. *to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;*

3. As our work has been contracted by an outside source, it is of utmost importance that we provide reliable and accurate data regarding the product we are producing.

   (a) 3. *to be honest and realistic in stating claims or estimates based on available data;*

4. Upon completing this project, we will have greatly improved our own understandings of acoustics, especially in regards to the functionalities of acoustic transducers and material responses to acoustic waves. Additionally, we hope that our device will allow for further research into the acoustic properties of materials.

   (a) 5. *to improve the understanding of technology; its appropriate application, and potential consequences;*

   (b) 6. *to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;*

5. The basis for our work was laid out in a previously completed master's thesis. Because we are building off of the work of others, it is important that we be sure to keep distinct the work that we have completed ourselves and the work contributed by others.

   (a) 7. *to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;*

6. Our work has led us to collaboration with many professionals working in related research fields. As such, we hope that our interactions with these professionals remains consistent with the tenth principle in the IEEE Code of Ethics.

   (a) 10. *to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.*

7 References

[1] J. Borth and G. Swenson, "Survey of Free-Field Methods to Measure the Normal Specific Acoustic Impedance of Ground Surfaces In-Situ At Low Frequencies," Master's Thesis, University of Illinois at Urbana-Champaign, 2012.

[2] American National Standards Institute, "Method for Determining the Acoustic Impedance of Ground Surfaces," ANSI S1. 18-2010, 2010.

[3] P. J. Dickinson and P. E. Doak, "Measurements of the normal acoustic impedance of ground surfaces," J. Sound Vibrat., vol. 13, pp. 309-322, 1970.

[4] M. A. Nobile and S. I. Hayek, "Acoustic propagation over an impedance plane," J. Acoust. Soc. Am., vol. 78, pp. 1325-1336, 1985.