Microphone Probe Hardware for Measurement of Acoustic Impedance of Surfaces

Project Proposal

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1 Introduction

1.1 Statement of Purpose

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. Their current setup, a two-microphone probe, produces data that requires intense processing and calculations to extract information and different computational methods on the same data produce values that do not agree as expected (especially in the range of interest, 50-200Hz). We have chosen to redesign the microphone probe and possibly the sound source to a more sensitive, more portable, and more flexible set up.

1.2 Objectives

1.2.1 Goals

- Design a microphone probe that is sufficiently sensitive to record acoustic impedance frequency sweeps down to the 50 Hz range.
- Design a microphone probe and sound source set up that is portable enough to be brought into the field by two or three engineers.
- Devise a solution that would shield the probe and source from ambient wind noise that could contaminate measurements of pressure differences and particle velocities but either does not significantly reduce the sensitivity or frequency range of data taken or is removable for measurements in controlled laboratory conditions.
- Ensure that the microphones are able to be places in very close proximity if not on the surface being measured (under 20 cm) to decrease the calculations needed to extract data.

1.2.2 Functions

- Microphone probe includes both instruments to measure acoustic particle velocity and instruments to measure sound pressure differences.
- The probe design allows for the microphones to be places in close proximity to the surface, reducing the need for calculations to extrapolate acoustic impedance at a surface from a measurement significantly above the surface.

1.2.3 Features

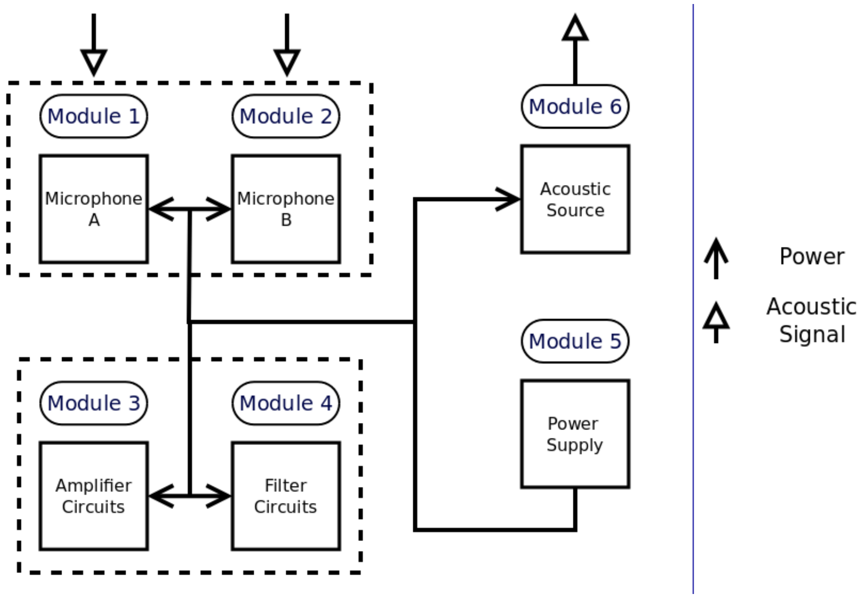
- Portable probe, minimal set up in the field
- Attached to a laptop, probe allows for *in situ* estimates of acoustic impedance
- Calibrated and documented probe frequency response
- Probe contains both a particle velocity microphone and pressure amplitude microphone
- Compact probe geometry

1.2.4 Benefits

- Portable probe allows easy measurement of multiple sites in the area to check for anomalous readings
- *In situ* estimates using the data allows for additional measurements to be if needed, eliminating multiple trips to sites
- Carefully tested frequency response aids in interpretation of data and calculations
- Dual velocity and pressure measurements allows for complex acoustic impedance to be calculated
- A compact probe reduces interference from waves reflecting off of probe body

2 Design

2.1 Block Diagram



This project consists of six separate modules that can be worked on independently of each other. In this manner, modifications that need to be made to one module (such as adding additional filters for one microphone or a changing the acoustic source) do not impact the functioning of the others. The modules 1 and 2 (the pressure amplitude and particle velocity microphones) will both be housed in the probe body, which will be rigid and specially machined for the probe set up. Modules 3 and 4 (the amplifier circuits and the signal filters) will be housed away from the probe body in a separate, shielded box. Module 5 (the power supply) will consist of a rechargeable, pre-made battery unit that provides power to all the modules. Module 6 (the acoustic source) is a separate, preexisting instrument and will not be redesigned by our group expect to make the power supply common to the probe and the source.

2.2 Block Descriptions

2.2.1 Particle Velocity Microphone (Microphone A)

The particle velocity microphone will measure the acoustic particle velocity incident on the probe. The typical particle velocity of ambient air without wind or acoustic waves is $5.0 * 10^{-8}$ m/s. This means that our particle velocity microphone would have to be sensitive to at least that level. The sensitivity of the microphone will depend on the intensity of the sound wave produced by the acoustic source. A candidate for a particle velocity microphone is a MEMS (micro electro-mechanical system) device manufactured by Microflown AVISA.

2.2.2 Pressure Amplitude Microphone (Microphone B)

The pressure amplitude microphone is actually two microphones held a fixed distance from each other. Their function measure the difference in pressures by using a vibrating membrane condensed microphone to produce electrical voltage changes in response to an incident pressure. Either a pair of recording-quality matched dipole microphones must be purchased or a condenser microphone must be modified. The sensitivity of this module is determined by the intensity of the wave produced by the acoustic source but should not be so sensitive that it produces excess noise.

2.2.3 Amplifier Circuits

To reduce the size of the probe and avoid interference, as well as allowing modifications to be made without deconstructing the entire probe, the amplifier circuit and the filter circuit will be housed in a separate, shielded box from the probe body containing modules 1 and 2. The amplifier circuit will amplify the signals received from the probes and pass the signal to the filters for processing. The amplifier circuit goes ahead of the filter circuit because amplifiers are a potential source of noise in the data. The exact design of the amplifier circuit will be finalized after the microphones are purchased and tested.

2.2.4 Filter Circuits

The filter circuit will take data from the amplifier circuit and reduce unwanted signal components from the microphones, the amplifier, and general electrical noise. The filters must be designed so as not to add distortion to the signal or to filter out actual data. The filter circuit will be continuously checked throughout the project duration so as to work correctly with the amplifier circuits and the microphones. The filter circuit will be developed with the amplifier circuit and after the microphones have been purchased and tested.

2.2.5 Acoustic Source

The acoustic source is a preexisting instrument that will be modified to run off the same power supply as the microphones and the amplifier and filter circuits. No other redesigns or modifications need to be made to this module.

2.2.6 Power Supply

The power supply module will run three sources of power to the microphone probe body, the amplifier and filter circuits box, and the acoustic source. The battery needs to last 5+ hours and be rechargeable. Ideally the power supply would not weigh more than 20 lbs, preferably under 10 lbs. The exact power supply used will be determined by estimating the power consumed by the rest of the modules over a period of 4 hours. The power supply will ideally be bought pre-assembled and will need minimal modifications to fit this project.

2.3 Performance Requirements

1. Module 1 (the particle velocity microphone) must be sensitive to intake and record real-time particle velocities on the order of $5.0 * 10^{-8}$m/s. It will pass this information to the amplifier and filter circuits (modules 3 and 4).

2. Module 2 (the pressure amplitude microphone) must intake and record real-time pressure differences on the order of $1.0 * 10^{-3}$ Pascal. It will pass this information to the amplifier and filter circuits (modules 3 and 4).

3. Module 3 (the amplifier circuit) will take signals from modules 1 and 2 and amplify the signal so that it is easily processed by the filter circuits (module 4). It must do so without distorting the data or adding enough noise so that parts of the signal are lost. It will pass the signal to the filter circuit (module 4).

4. Module 4 (the filter circuit) will take the signal from module 3 and filter out known noise from the microphones, the amplifier, and general electrical noise. It must not destroy information contained in the signal or introduce false readings into the signal. It will pass the signal out to a yet unspecified connector that interfaces with a laptop that preforms the data analysis.

5. Module 5 (the acoustic source) will provide the source of the acoustic waves used to measure the acoustic impedance of a surface. It is preexisting and will only be modified to run off the common set up power supply.

6. Module 6 (the power supply) will be purchased pre-made as much as possible. It will provide a common power supply to the rest of the modules via three cords and must be able to supply enough power to run the entire set up for at least 4 hours. It must also be rechargeable and not required to be connected to an outlet to function.

3 Verification

3.1 Testing Procedures

- Testing Checkpoint #1: Microphone Calibration

Once received, the microphones must be tested and calibrated. Calibration will be performed using precision acoustic calibrators, which have been made available by the project sponsors.

- Testing Checkpoint #2: Amplifiers

After construction, the amplifier circuitry will be tested for proper performance. The noise floor of the amplifiers must be very low, and the signal should be magnified for easy manipulation and interpretation (millivolt-to-volt range). Test signals will be used to excite the microphones, and the amplifier response will be monitored in LabVIEW in order to verify proper gain and overall performance.

- Testing Checkpoint #3: Filtering

The filters will be tested by similarly to the amplifiers. Test signals of varying frequency content will be used to excite the microphones, and the output of the filter components will be monitored in LabVIEW. The signal responses will be checked for correct attenuation in frequency ranges of known noise sources and ranges outside those necessary for acoustic impedance testing

- Testing Checkpoint #4: Prototype

Before fully assembled into the final device housing, testing will be performed to verify that the device is performing properly as a whole. Extra testing will be performed in order to make adjustment to microphone placement and other aspects of device geometry in order to optimize performance.

- Testing Checkpoint #5: Final Product Verification Testing

Once all components have been deemed functional and the device has been fully assembled into its housing, there will be a final battery of testing in order to ensure that all components continue to function after the final assembly.

3.2 Tolerance Analysis

The most critical parts of this project are the particle velocity and pressure microphones. The exact sensitivity and mechanism used by each to measure what they are intended to do will vary based on if we choose to construct them ourselves or purchase them but these are the two most important factors that must be checked and tested. The pressure amplitude will be tested using a piston calibration chamber and the output will be analyzed to see if it varies from the expected value. The pressure amplitude measurement will be swept over a wide range (to be determined) to test that it functions correctly at all conceivable pressure amplitudes that acoustic impedance will be measured at. The particle velocity microphone will be much harder to test and calibrate and more research must be done on how this will be preformed but it will also be tested over the range of particle velocities expected in the acoustic impedance measurement range.

4 Costs and Schedule

4.1 Cost Analysis

(See last page)

4.2 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/Kevin
	Meet with collaborators to get information on acoustic source	Anna/Kevin
	Get familiar with COMSOL	Anna
2/17	Work on finalizing design review	Anna/Kevin
	Determine which parts will be purchased and which will be constructed	Anna/Kevin
	Find examples or model circuits for parts that need to be built	Anna/Kevin
2/24	**Design review**	Anna/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 amplifier and filter circuits	Kevin
3/10	Make sample measurements using microphones	Anna
	Determine specific requirements and modifications on the amplifier and filter 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 amplifier and filter circuits	Kevin
3/24	Finalize mock-up demo	Anna/Kevin
	Continue samples measurements using the prototype microphone probe	Anna
	Calibrate the microphone probe and test the frequency response	Anna
	Connect the filters to the microphone probe and examine the signal output	Kevin
	Order power supply	Kevin
3/31	**Mock -up Demos**	Anna/Kevin
	Modify the filter and amplifier circuits	Kevin
	Finalize the microphone body and make more sample measurements	Anna
4/7	Finalize the amplifier and filter circuits	Kevin
	Take the project to a field and make measurements	Anna/Kevin
4/14	Finalize presentation	Anna/Kevin
	Modify circuits or microphone setup based on field measurements	Anna/Kevin
4/21	**Demo/Presentation**	Anna/Kevin
4/28	Write documentation for the microphone probe set up	Anna/Kevin
	Finalize calibrations on the microphone probe	Anna/Kevin
5/5	Turn in project to collaborators	Anna/Kevin

Labor

Name	Hourly Wage	Total Hours	Salary $(\textbf{Hourly Wage} \times \mathbf{2.5} \times \textbf{Total Hours})$
Kevin Looby	\$35.00	180	\$15,750.00
Anna Czerepak	\$35.00	180	\$15,750.00

Parts

Device Module	Part	Part Number	Quantity	Individual Price	Subtotal
Amplifiers	47k Resistor	ERG-1SJ473A	4	\$0.036	\$0.144
	22k Resistor	ERG-1SJ223A	2	\$0.036	\$0.072
	1k Resistor	ERG-1SJ102A	2	\$0.036	\$0.072
	100 μF Capacitor	C3225Y5V0J107Z	2	\$0.341	\$0.682
	10 μF Capacitor	C2012Y5V1A106Z	6	\$0.025	\$0.150
	Op-amp	TL071CDR	2	\$0.125	\$0.250
Microphones	*		2	\$0.00-200.00	\$0.00-\$400.00
Filters	*		-	\$5.00	\$10.00
Power Supply	*		1	\$40.00	\$40.00
-	Wiring/Cabling		-	\$10.00	\$10.00
Total					\$71.37-\$471.37
*Part to be determined based on design requirements (est. pricing)					

Machining Cost: \$100

Simulation Cost: \$0.00 - \$50.00

$$\begin{aligned}\textbf{Grand Total} &= \textbf{Salaries} + \textbf{Parts} + \textbf{Machining Cost}\\ &= \$\mathbf{31,500.00} + (\$\mathbf{71.37} - \$\mathbf{471.37}) + \$\mathbf{100.00} + (\$\mathbf{0.00} - \$\mathbf{50.00})\\ &= \$\mathbf{31,671.37} - \$\mathbf{32,121.37}\end{aligned}$$