

Evaluation of the Missionary Training Center Auditorium using Room EQ Wizard

Tyler Hopkin

A capstone report submitted to the faculty of

Brigham Young University

In partial fulfillment of the requirements for the degree of

Bachelor of Science

Dr. Kent Gee, Advisor

Department of Physics and Astronomy

Brigham Young University

April 2018

Copyright © 2018 Tyler Hopkin

All Rights Reserved

ABSTRACT

Evaluation of Room EQ Wizard for Acoustical Characterization of Venues

Tyler Hopkin

Department of Physics and Astronomy

Bachelor of Science

Acoustical room characterization typically involves a lot of high end and expensive equipment for measuring, modeling, and finding solutions to problems. Recently, Room EQ Wizard (REW) was introduced to BYU as a less costly option. This paper will evaluate REW's effectiveness through the metrics of mapping sound coverage, reverberation time and clarity calculations, while providing the Missionary Training Center with acoustical consulting for their auditorium. REW proved to be efficient and effective in all metrics and helped narrow the problem down to an unforeseen interaction between the loudspeakers and podium microphone.

Keywords: Reverberation Time, Clarity, Acoustical Consulting

Acknowledgments

First, a big thanks to Dr. Kent Gee who took a chance in letting me carry out a project that was not already a part of his schedule. The time and advice he gave to me helped make my last year at Brigham Young University far more pleasant than I ever thought it would be. More than that too, thanks for teaching every acoustics related class I took and instilling in me a deeper love of physics and molding my future. I could never thank you enough.

Next, I would like to thank my spouse, Alexis Kaegi, who helped me take measurements at weird times. Thank you also for encouraging me to stay on top of the project and write-up so that graduating was a possibility. This project happened within the first few months of our marriage and while getting diagnosed with type 1 diabetes. This was not easy on you nor me, but we both made it and have some great stories because of it. I love you. So much.

Finally, a thanks to Cole Duke whose visit to the acoustics research group was too perfectly planned. I will always remember the moment you showed the sound field map of the New Zealand MTC. That's when the realization hit both Dr. Gee and me of what needed to happen to make my project happen. Thanks for making time to talk to us, point us in the right direction, and show us some hardware and software that became instrumental in carrying this project out. Also, you are a super cool dude and I love following you on Twitter. I hope that's not weird.

Here's to hoping your project, dear reader, also has success and that the information here helps you in your journey to a thesis/capstone or furthering research. Enjoy!

Table of Contents

Table of Contents	iv
List of Figures	vi
Chapter 1 Introduction	8
1.1 What is Room EQ Wizard?	8
1.2 Previously Used Methods	9
1.3 Other Equipment	10
1.4 Problem at the Missionary Training Center	10
1.5 Acoustical Characteristics of Interest	12
1.5.1 <i>Sound Coverage</i>	12
1.5.2 <i>Reverberation Time</i>	12
1.5.3 <i>Clarity</i>	13
1.6 Overview	13
Chapter 2 Methods	15
2.1 Installing Room EQ Wizard	15
2.2 Setting Up Room EQ Wizard	16
2.2.1 <i>Soundcard Calibration</i>	17
2.2.2 <i>Microphone Calibration Using the Calibration File</i>	18
2.2.3 <i>Microphone Calibration Alternative with a Sound Pressure Level Meter</i>	19
2.3 Making a Measurement.....	20
2.4 Exporting to MATLAB.....	22

2.5	Setup for the MTC.....	24
2.6	MATLAB Computations.....	26
Chapter 3 Results and Conclusions.....		27
3.1	Analysis of MTC Measurements	27
3.1.1	<i>Sound Coverage</i>	27
3.1.2	<i>Reverberation Time</i>	30
3.1.3	<i>Clarity</i>	31
3.2	Analysis of Room EQ Wizard.....	31
3.3	Conclusions	33
Appendix A		34
	MATLAB Script for Data Import and Analysis	34
Appendix B Characteristic Plots		39
	Sound Coverage Plots	39
	RT60	44
	Clarity	48
Bibliography		53
Index		54

List of Figures

Figure 1 A panoramic view of the MTC's gym, set up as an auditorium.	11
Figure 2 REW's opening window. From here you can change preference, make measurements, or open previous measurements. Other functions are available, but unnecessary for this paper's purpose.....	16
Figure 3 Preferences menu where calibration occurs for both the soundcard and microphones for setups involving REW.	18
Figure 4 Measurement window for specifying the parameters desired for a recording. The three visualizer meters on the side show (respectively from left to right) output, actual, and reference levels of a measurement.....	20
Figure 5 Example of one of the exporting menus. All options will be visually similar to this window, but with different specification options depending on the type of data being exported.	23
Figure 6 Signal flow for connecting REW to the microphones and loudspeakers at the MTC. While the interface can take two inputs, REW uses one as a reference microphone which was not needed for the purposes of this paper.	25
Figure 7 A map of the MTC auditorium and the locations (marked by red dots) where measurements were taken. North is pointing up in the picture. The podium is the located at the south end of the auditorium.	25
Figure 8 Sound coverage plots of the MTC auditorium. Plots are of relative to max sound pressure levels. Note how there are no significant differences if the left, right, or both speaker are being used.	27

Figure 9 Sound Pressure levels around the podium. Note the 15 dB fluctuation at 100 HZ and other places of large SPL changes. Each place with a large change is more likely to be the cause of feedback..... 30

Chapter 1 Introduction

Just like humans, rooms have personalities. Unlike humans, we can change the personality of rooms. In order to know what changes a room needs, we must define a set of acoustical characters which can be measured and provide a way of testing and comparing those characteristics.

1.1 What is Room EQ Wizard?

Many software options are available for acoustical evaluations. Usually calculations as to the effectiveness, cost, and ease of use for many software options must be made before an experiment can begin. This thesis will evaluate one of these software programs, Room EQ Wizard (REW)--a free application which runs using Java script on a computer to measure the acoustical characteristics of a venue. John Mulcahy created REW with consumers in mind. The software's design is meant to be easy enough for anyone with a basic understanding of loudspeakers and room acoustics to use with simple and low-cost equipment. The goal of this paper is to evaluate REW in a more professional setting and with a combination of higher-end equipment mixed with less expensive components, potentially making it a perfect fit for effective, cost efficient, and easy to use piece of software for acousticians to use moving forward.

1.2 Previously Used Methods

REW enters a field already populated by a few competitors. The acousticians at Brigham Young University (BYU) currently use Acoustic Field Recorder (AFR) for most measurement and recording processes. The developers behind AFR are BYU professor Dr. Kent Gee and graduate student Brent Reichman. The software has been developed and adapted for various recording situations. However, AFR is only a measurement system and must be paired with computational software, namely MATLAB, to study the acoustics of any given phenomenon. REW can calculate acoustical characteristics immediately following a measurement, allowing for a quicker turn around in data collection to evaluation. While unlikely to replace AFR, REW may be able to simplify some setups for BYU and provide quicker evaluations.

Another software package that has more advanced capabilities than REW is Electronic and Acoustic System Evaluation and Response Analysis (EASERA). The name says it all, but so does “advanced”. Ahnert Feistel Media Group (AFMG) created EASERA with the scientist in mind. Users are expected to be well educated in acoustics, but with the payoff of detailed results that model a room with great precision. Part of the education needed to use EASERA is a lengthy user manual and tutorial which, upon completion, still leaves users in need of a mentor to teach the application of the use of EASERA with the desired setup specifications. Cost is also a concern with this software, and so REW comes as a potential quicker, less expensive option for getting an idea of a room’s acoustical characteristics. EASERA could still be used in conjunction with REW where REW provides quick feedback to see if the room needs more detailed modeling to improve desired characteristics.

1.3 Other Equipment

REW benefits from being versatile in terms of compatibility. If a microphone can be plugged in, REW can use it to take a measurement. This allows for a wider range of options for price and quality of microphones. The question at hand is how to use microphones already owned by BYU with REW. The answer is through an intermediate interface.

The Scarlet 2i2 by Focusrite is a two input and two output, plug-and-play interface which allows the microphones owned by BYU and REW to connect with each other. All audio will flow both from and to the interface if the right connections are made. BYU owns a vast collection of GRAS microphones – mostly ¼” pressure microphones. These will not directly plug into the Scarlet 2i2 but can with the help from a phantom to integrated circuit piezoelectric – or ICP – power adapter. It is possible that a few other cables, namely 3 pin XLRs or ¼” tip ring sleeves, will be needed to connect into loudspeakers as well. The final piece of equipment needed is a sound pressure level meter for calibration of the REW’s output.

1.4 Problem at the Missionary Training Center

The Missionary Training Center (MTC) has become a place of great interest in Provo due to the addition of two new spacious buildings. Both buildings house classrooms, offices, and meeting rooms for missionaries and employees. The buildings have consolidated most of the training center’s functions but fail to give space for something else the MTC has much need for: an auditorium.



Figure 1 A panoramic view of the MTC's gym, set up as an auditorium.

One of the MTC's longstanding buildings is the gym, which is more famously known because of its use as an auditorium twice a week, as seen in Figure 1. Every Sunday and Tuesday night the Missionary Training Center invites someone to speak to the missionaries currently at the training center. If the invited person is also a member of the Quorum of the Twelve Apostles for the Church of Jesus Christ of Latter-Day Saints, then that person speaks to the missionaries in all training centers around the world by satellite transmission. This meeting, and all others requiring all the missionaries to gather together, occur inside of a gymnasium-turned-auditorium.

This architecture saves money by being multipurpose, but the dual purpose of the room results in some acoustical problems. People in the back of the auditorium find it hard to hear a speaker; meanwhile the people in the front feel that they are risking tinnitus due to the front fill loudspeakers which reside mere feet from some listeners. Simply "turning up" the main loudspeakers should help the people in the bleachers hear the speaker better, but instead everyone present gets blasted with feedback. Feedback prevents either complaint from being addressed properly, so an evaluation of the room's acoustics is in order to seek a way to satisfy both.

1.5 Acoustical Characteristics of Interest

The problem of interest here is a poor gain-before-feedback ratio. Meaning, how loud can the speaker be turned up before feedback begins? This problem could be a result of several issues, but we the three that seem most likely are sound coverage, reverberation time, and clarity.

1.5.1 Sound Coverage

Potentially the easiest and least expensive fix for the MTC is adjusting the speakers to make sure all areas of the auditorium are covered by the house main loud speakers. Because of this, sound coverage is the first characteristic we want to evaluate. By generating a sound pressure level map of the auditorium, both overall level and frequency specific, we can ensure that the loudspeakers are pointed where they should be to cover audience locations. We will know if sound coverage is the main issue if there are large sound level changes in a small area of the auditorium.

1.5.2 Reverberation Time

Another potential problem with the auditorium involves the frequency response and natural modes of the room. These can be identified by examining the reverberation time of a signal played through the loudspeakers. Reverberation time—generally denoted as RT60—is the measure of sound decay. It answers the question, “How long does it take sound to decay 60 dB?”

There are two ways of measuring RT60: T20 and T30. T20 measures the time sound takes to decay 20 decibels, and T30 30 decibels. That time is then multiplied by 3 or 2 respectively to produce the RT60 value. RT60 is frequency dependent so rather than calculating a single time

for each spot, several times for varying bandwidths of frequencies will be produced for each location where a measurement takes place.

The auditorium may have a large RT60 values which causes feedback at those frequencies with high values. This could be solved through a re-equalization of the loudspeakers or perhaps treatment of the room is necessary. The dual purpose of the room led to hard walls and floor being used during its construction which tend to keep frequencies from decaying when they should.

1.5.3 Clarity

Finally, there could be a problem with people not understanding the speaker's projected voice. Clarity, and more specifically C50 and C80, measures early sound energy to late reverberation energy which aids in understanding the distinctness of words. What counts as "late reverberant energy" is the 50 ms and 80 ms mark for C50 and C80, respectively. A more intuitive way of thinking of clarity involves distinctness. If someone is talking in the room, is each word heard individually, or does is the echo of one word clearly heard as another word is spoken? The more distinct the words are heard, the better clarity value the room has. With that said, sometimes a bit of an echo is wanted (e.g. music halls). Because of this difference, speech clarity is evaluated with C50 while music uses C80. The MTC auditorium has guests that both speak and perform music, so we will look at both metrics for clarity.

1.6 Overview

The rest of this thesis discusses the method for using REW and seeing it in action. Chapter 2 contains an explanation of how to set up and use REW and how REW was used at the MTC.

Chapter 3 reveals what REW had to say about the MTC auditorium, along with and the final evaluation of REW.

Chapter 2 Methods

This chapter covers a generic use of REW. Setting up equipment to use with REW, calibration methods, and exportation will be explained generally. After the explanation, a more specific implementation will be described to show how REW was used to measure characteristics of the MTC's auditorium. Due to this ordering, sections 2.1-2.4 will read much like an instruction or user manual. Feel free to look at REW's published help index if you feel the need for more information.

2.1 Installing Room EQ Wizard

Located inside of the black Pelican box are the Scarlet interface, phantom to ICP power converters, and a USB thumb drive. REW is on the thumb drive and can be run from the drive or transferred to the computer (which I recommend). Then click on the REW to open the application. While transferring the application, it is also recommended to move the text file named "MicCalibration.txt". This file's purpose is explained in the next section. If the thumb drive method is not working, REW can be downloaded from the creator's website: roomeqwizard.com.

REW may display a message upon start up to notify you of an available update. Feel free to do so by clicking the upgrade button. The button will take you to a website where the updated software can be found. Follow instructions there to install the updates. REW will still function without the update, so if the updating proves daunting then skip it.

Updating may add new feature, change appearance of the application, or remove other features mentioned in this paper. In fact, an update came out just before MTC measurements were recorded and I had to relearn how to navigate the application again due to some added new features and appearance. This paper reflects everything up to REW V5.19 Beta 8, the most current software as of 30 March 2018. The Scarlet 2i2 interface will also have to install a driver if it is being used with your computer for the first time. Since the interface is plug-and-play, everything should happen automatically once the interface is connected to the USB port. If this does not happen, then it is left to the user to find out how to install the driver for the interface.

2.2 Setting Up Room EQ Wizard

With REW up and running, we turn our attention to calibrating. Two different calibrations are needed: one for the sound card and one for the microphone.

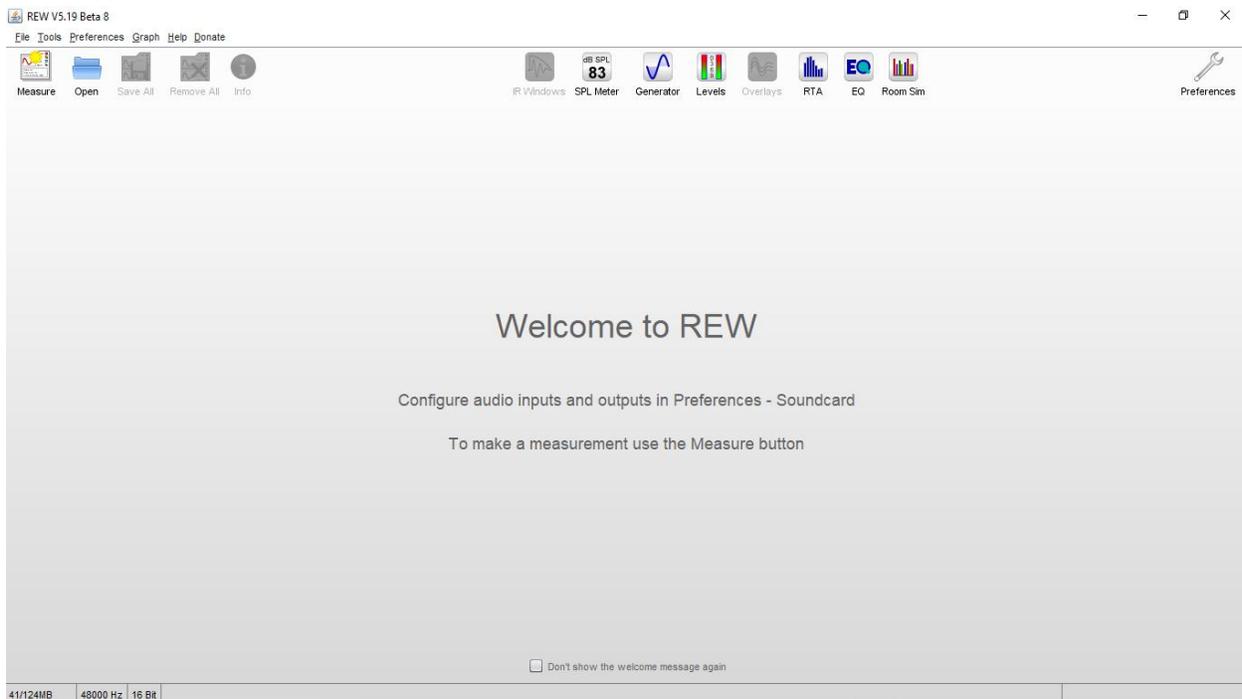


Figure 2 REW's opening window. From here you can change preference, make measurements, or open previous measurements. Other functions are available, but unnecessary for this paper's purpose.

2.2.1 Soundcard Calibration

For the soundcard calibration, we will create a closed loop system using REW and the Scarlet 2i2 interface. The purpose of this calibration is to find the electrical noise floor of both the computer and interface combined, which REW will then remove from measurements. With REW running and the interface connected to the computer, connect the input of the interface to the its own output. This can be done with two cables with ¼” tip ring sleeve (TRS) ends, or two XLR to TRS cables. Make sure phantom power button is on for channel 2 of the interface, but not for channel 1 (measurements will only be taken through channel 2). On the REW main page (Figure 2), look for the wrench in the top right corner labeled “Preferences” and click on it. The preferences window should now be open to the default “Soundcard” tab (Figure 3). The only option to change here is under “Level”; in the dropdown menu, select “Use main speaker test signal to check/set levels”. Now hit “Make Cal...” in the “Calibration” section. Leave any notes you wish, hit “Ok”, and name the file. The name now appears in the “Calibration section”. Press the “Calibrate...” button now. At the bottom of the window a “Next” button should become available. The text above the button will tell you what is going on, but in short REW is about to calibrate the soundcard through the closed loop system. After two “Next” presses you should see levels appear in the meters on the right side of the window. If you hear the 1 kHz tone press cancel, then you need check your interface connection, or change the device output/input options to select the interface and repeat the last couple of steps, starting with the “Calibrate...” button. After hitting “Next” again, a measurement will be taken and then the “Preferences” window will appear again. At this point, the calibration should be done, but these next steps are a good

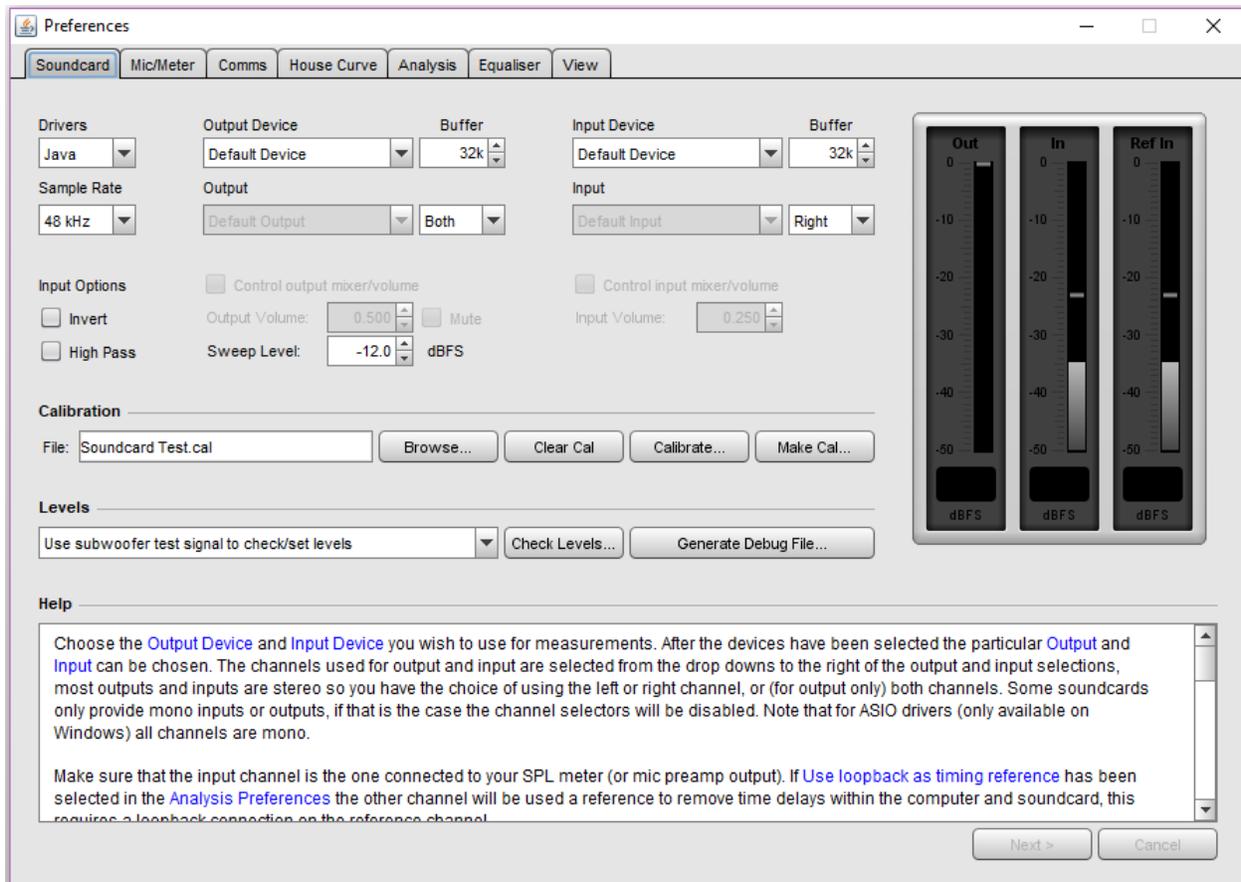


Figure 3 Preferences menu where calibration occurs for both the soundcard and microphones for setups involving REW.

precaution. Save the measurement outside of the “Preferences” window by clicking on the floppy drive (hovering will display “Save Measurement As”). Be sure to save it as a “Calibration Data” file type. This will be nice to have later in case measurements don’t record with the soundcard calibration just made. REW can recalculate measurements after the fact if the calibration data is saved. This can be done by selecting “Change Cal...” at the bottom of the measurement thumbnail, then choosing the corresponding soundcard calibration data.

2.2.2 Microphone Calibration Using the Calibration File

With that calibration complete, we are now ready to move on to microphone calibration. This one will be much simpler. First undo the closed loop and connect everything as needed (e.g.

output of interface to speakers, microphones into the input). Now, remember the other file on the thumb drive, “MicCalibration.txt”? It is a text file containing data that represents the GRAS ½” pressure microphone’s frequency response (spoiler: the response is basically flat). In the “Preferences” window, select the “Mic/Meter” tab. Click on the “Browse...” button and then select the “MicCalibration.txt”. All recordings will now take this calibration file into account. If you notice post-recording that the calibration did not get used, follow the same method from the soundcard calibration method to add it in after the fact.

2.2.3 Microphone Calibration Alternative with a Sound Pressure Level Meter

If the text file method doesn’t fit your needs, there is another way of calibrating the microphone through use of a sound pressure level meter (SPL meter). In “Preferences” under the “Mic/Meter” tab click on the circle next to “C weighted SPL meter” and close out of the window. Now click the SPL Meter button in REW which will open up a new window. Match the settings on the new window with the setting being used on your sound pressure meter, then click “Calibrate”. A window will appear asking for you to choose a signal source. Select “Use REW speaker cal signal” from the dropdown and press “OK”. White noise will play through your system’s output speakers. If you have not set your speakers to your desired level yet, be sure to do that now. With white noise playing, run your SPL meter and look at the reading. Input the meter’s reading into the “SPL Reading Calibration” window and then press “Finished”. A final window will be displayed showing the maximum SPL supported with your calibration. Press “OK” and the calibration is complete. This method does not have the ability to calculate calibration data after recordings are made, so it is recommended that you keep REW’s “SPL Meter” window open and your SPL meter on to compare that they are getting the same results as you make measurements.

2.3 Making a Measurement

At last, we are ready to make a recording. From the REW main page, select the “Measure” button to open a new window (Figure 4). From this window we will specify the type of signal to send into a room. Procedure will follow from the top of the new window to the bottom. After all the calibrating, the SPL option will be our best measurement method and provide the information we desire. From the dropdown below the SPL/Impedance option, select “No timing reference”. This means that no external trigger will start an REW recording. In the next box down, we will

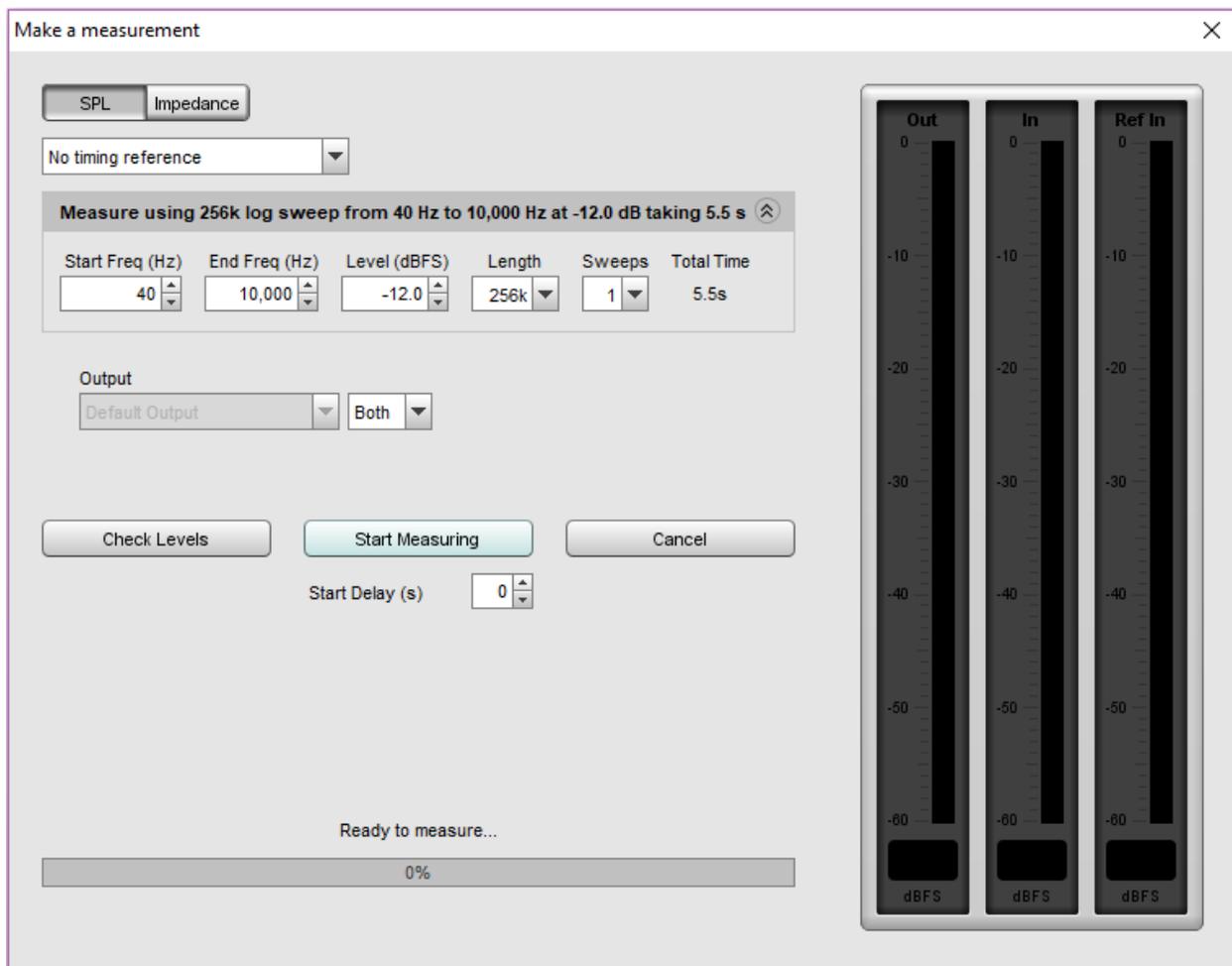


Figure 4 Measurement window for specifying the parameters desired for a recording. The three visualizer meters on the side show (respectively from left to right) output, actual, and reference levels of a measurement.

specify the type of signal being recorded. Input the frequency range you are most interested in obtaining information from and keep the level at -12 dBFS. The last two drop down options in this portion of the window determine the length of the recording. Length is measured in bite size and multiplies with the number of sweeps to obtain a recording length which is visible under “Total time”. Choose options that fit your situation and analytical method. Proceeding further down, under the “Output” option be sure to select the device relevant to your set up. Now press “Check Levels” and make sure you hear white noise through your setups speakers. The meters on the side of the window will activate to show output level and input levels of your devices. If you do not receive a “Level OK” message, then adjust your speaker’s output levels until REW outputs the message. Without adjusting any levels for input or output, you can hit “Start Measuring”. A sweep will play through your system and be recorded by REW with a little delay before and after the button press. Once complete, your measurement will appear on the left side of REW’s main window. Take this time to rename your measurement—should you so desire—and then press the “Measure” button on the main window again to make another recording. Settings between recordings are preserved.

After recording, REW calculates various metrics which you can now look through. If a plot looks empty you may need to scroll up and down to find data or click a “Generate” button in the bottom left corner of the plot area.

Measurements can be saved either individually or as a group. To save individual measurements, click on the measurement on the left side of REW’s main window, then press the floppy drive icon. A window will appear where you can choose where to save the measurement. To save a group of measurements select the “Save All” button above the measurements. A window will appear asking for any comments you want to add (optional), then after selecting

“OK” you will be asked to choose a destination and name for the file being saved. Either of these options save in a format only useable by REW. By clicking on the file in the destination folder, or selecting it from the “Open” button, the measurement(s) will be added to the list of active measurements.

2.4 Exporting to MATLAB

While REW does supply users with a lot of useful information, it may not provide all the information you are looking for. Exporting data is an option! You will most likely want to take your data and do some analysis in MATLAB. Three options are available for exporting. Two of the options export data one recording at a time, the other does an entire set of measurements.

Under “File” on the main page of REW, scroll down to the “Export” option. The move over to “Export all measurements as text”. The option saves all active measurements as individual text files, with the catch being the data includes just the SPL information. This information includes SPL and phase data for various frequencies. I recommend using the “No smoothing” and “REW export number format” options, but the others are up to your preference. Remember your file path for when we switch to MATLAB. These settings, and an example of what the window looks like, can be seen in Figure 5.

The “Export measurement as text” option follows the exact same process, but only saves the data for the selected measurement. The other set of information you will likely be interested in is reverberation time and clarity. By selecting the “Export RT60 data as text” you again will only save one measurement at a time, but this time get various RT60 and clarity criteria data as a function of frequency.

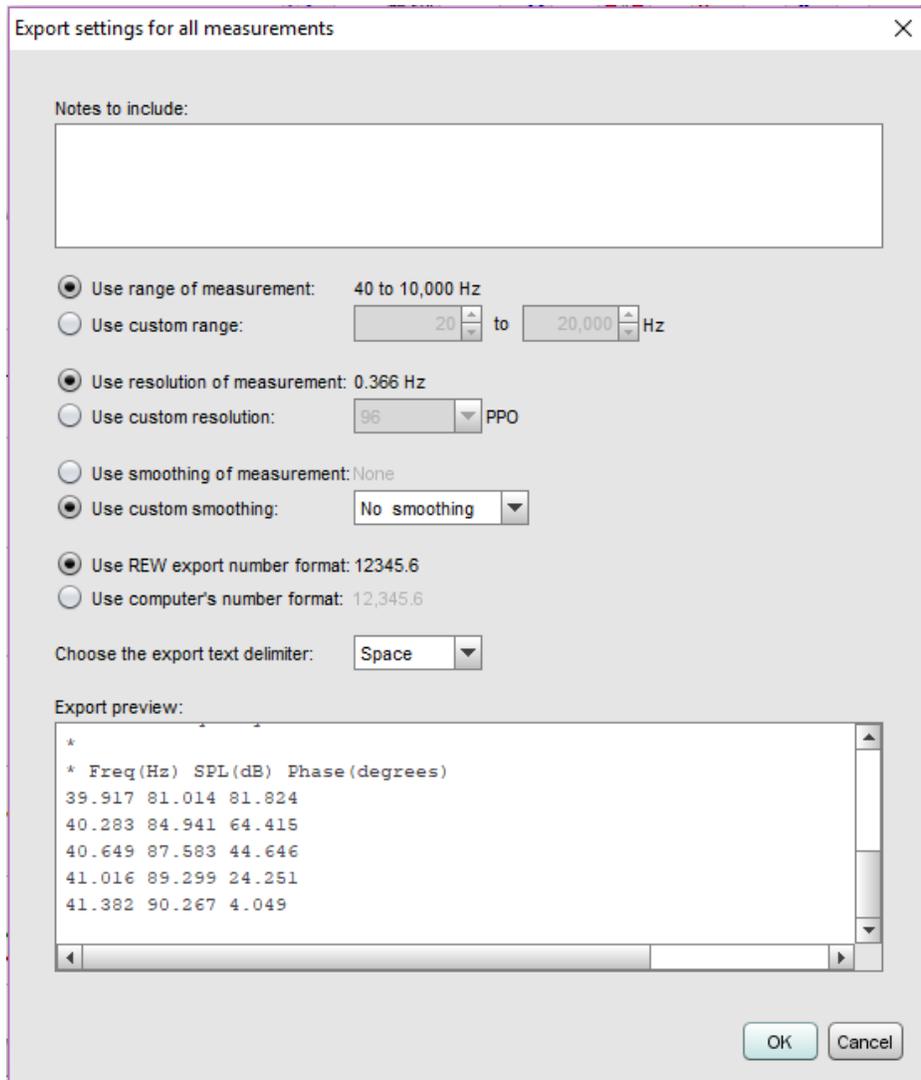


Figure 5 Example of one of the exporting menus. All options will be visually similar to this window, but with different specification options depending on the type of data being exported.

With your data now exported, launch MATLAB. The *importdata()* function will be your new friend for retrieving REW measurements. You will use three arguments in *importdata()*. The first will be the entire file name (with path include if not in the same folder as the script you are running) and file extension of `‘.txt’`. Second will be whatever delimiter option you selected (i.e. “ ” for space or “,” for commas). Third is the number of non-data lines at the start the file. If you did not add comments to your data, that number is 14. Choose a variable name for *importdata()* to save to, then run your script. Your variable is stored as a struct where the first

item in the struct is the data and the second item is the header information. To access and use your data put “.data(:,n)” after your variable name. Different values of n access different parts of the data. The data stored goes as follows: $n=1$ for frequency, $n=2$ for SPL, $n=3$ for phase. Now you should have all the tools necessary to analyze your data.

2.5 Setup for the MTC

Your setup will likely be different than the one used at the MTC but this should show a way of integrating REW with other pieces of equipment. The setup at the MTC needed to mimic the conditions of the gym when set up as an auditorium as closely as possible. Because of this, REW had to be connected into the main loudspeakers (house mains) through the in-house mixer. The output of the Scarlet 2i2 interface easily connected to the mixer’s omni inputs by using a TRS to XLR cable. The mixer typically equalizes inputs before sending the output signal, so the equalizer was turned off to ensure unmodified characteristics of the room were measured. The MTC’s podium microphone was not used for taking measurements. The two reasons for that decision reside in the overall purpose of this paper: 1) the microphone is prone to producing feedback which is not desired in the measurements and 2) an evaluation of how BYU’s current supply of microphones interact with REW. The microphone used for the recording connected into the interface’s second input by means of the phantom to ICP power adapter and associated cables. The signal flow for the setup can be found as a block diagram, Figure 7.

The microphone was placed in 64 locations around the auditorium, most of which followed a grid. A map of the auditorium with the locations can be found in Figure 6. Locations were chosen so a plot of sound coverage could be made with a fine enough resolution to locate places of higher or lower sound levels, but not so fine as to require a lot of time and recordings.

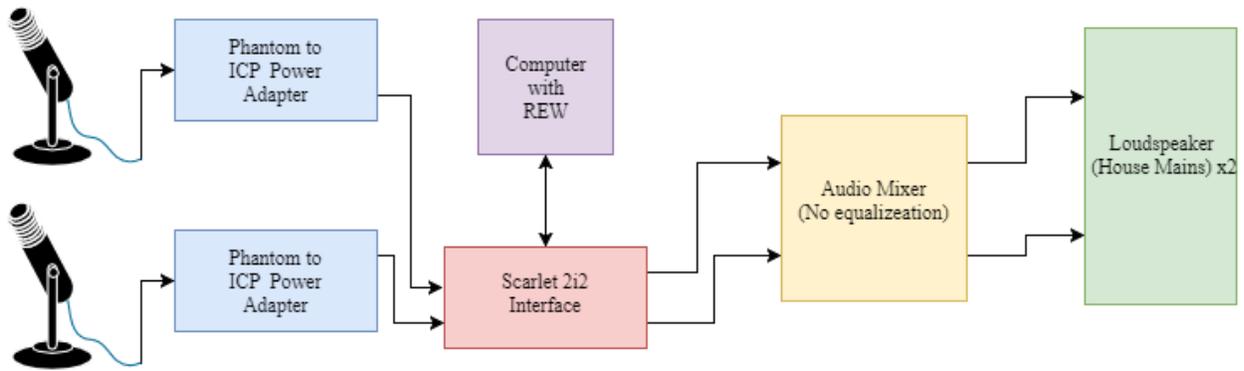


Figure 7 Signal flow for connecting REW to the microphones and loudspeakers at the MTC. While the interface can take two inputs, REW uses one as a reference microphone which was not needed for the purposes of this paper.

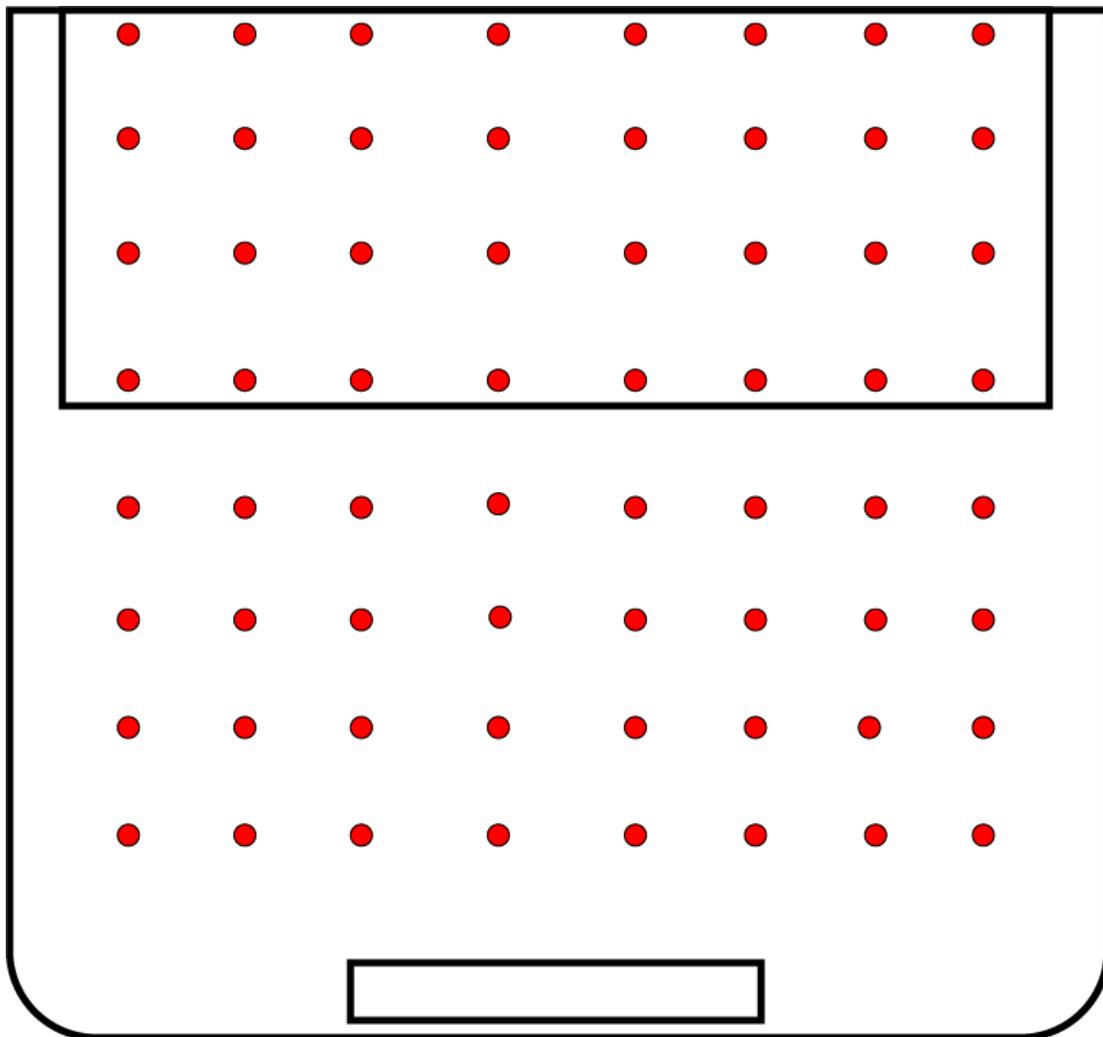


Figure 6 A map of the MTC auditorium and the locations (marked by red dots) where measurements were taken. North is pointing up in the picture. The podium is the located at the south end of the auditorium.

A few extra points were chosen to better map how the sound is received around the podium. The microphone was gaffed to a stand roughly one meter up (approximately where a listener's head would be located while seated in the auditorium). Each location had three recordings taken: one with just the left speaker outputting sound, one with just the right speaker, and the final one with both speakers. The three recordings allowed for an examination of each speaker's sound coverage as well as any potential interference nodes or antinodes.

REW was configured to produce a 40 Hz to 10 kHz sweep of length 256k samples (a 5.5 second recording). The mixer was adjusted during calibration to produce a sound level through the house mains that matched the "MicCalibration.txt" file. The associated faders and gain for the house mains were not disturbed for the remainder of the process. After three recordings were made at one location, the microphone was positioned to the next nearest spot on the grid which had not been used before. The process continued until all points had three recordings taken.

2.6 MATLAB Computations

For exporting purposes, names of the measurements were selected with first a letter to designate which speakers were being used (B-both, L-left, R-right) followed by two digits. The first digit signified the east/west position in the auditorium with the second digit representing the north/south position. Both SPL and RT60 data for each measurement was exported and analyzed in MATLAB. Loops and cells were implemented to automate the importing process. A detailed description of the script can be found in Appendix A.

Chapter 3 Results and Conclusions

With calibration, measurements, and computations completed, our attention now turns to the analysis of all the work. What follows is an explanation of the acoustical properties of the MTC’s auditorium and some recommendations for counteracting negative attributes found therein. Then, an evaluation of REW is given regarding its use for research.

3.1 Analysis of MTC Measurements

The acoustical properties of the MTC’s auditorium are evaluated in this section. Specifically, sound coverage, reverberation time, and clarity over the grid of points mentioned in Section 2.5.

3.1.1 Sound Coverage

We begin with an examination of the sound coverage. Figure 8 Sound coverage plots of the MTC auditorium. Plots are of relative to max sound pressure levels. Note how there are no significant differences if the left, right, or both speaker are being used. three plots of the sound

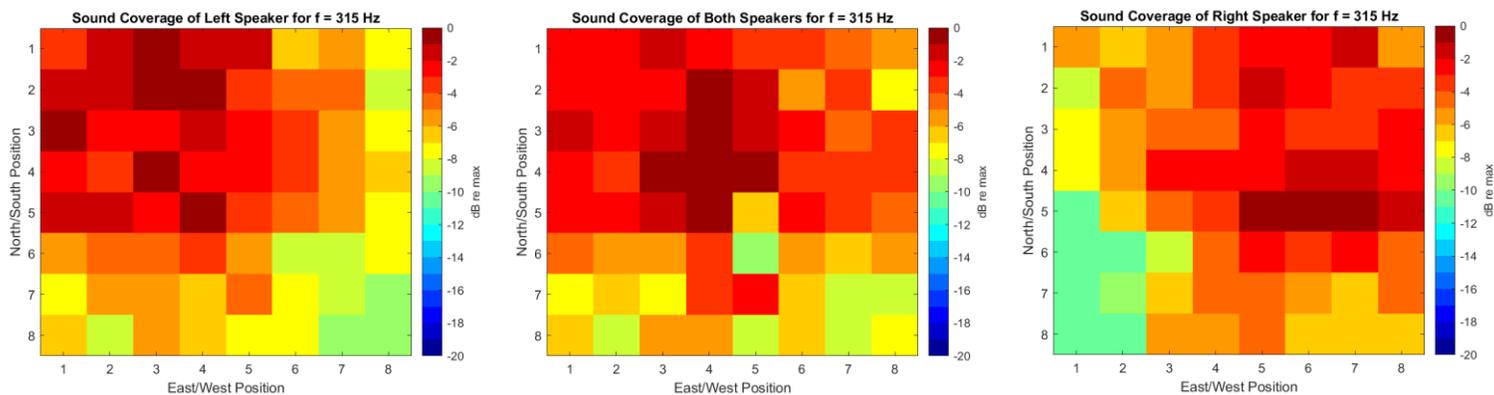


Figure 8 Sound coverage plots of the MTC auditorium. Plots are of relative to max sound pressure levels. Note how there are no significant differences if the left, right, or both speaker are being used.

coverage at the same frequency but with different speaker configurations—left speaker only, both speakers, right speaker only. The differences between the plots are a couple decibels at most. This is true for all frequencies related to sound coverage, RT60, and clarity, so we will only consider plots showing both speakers being used from this point on.

The sound field in the audience contains up to a 15 dB difference from location to location. This is best observed at lower frequencies, specifically those below 200 Hz. For higher frequencies, the sound field evens out. Plots showing SPL as a function of frequency and position can be found in

Appendix B. An examination of the plots leads to the conclusion that the speakers adequately fill the auditorium with sound. Human speech has a fundamental frequency range of 200-400 Hz. Any sound lower than 200 Hz could contribute to feedback but will not hinder a listener's ability to hear speech through the loudspeakers. We conclude that no significant problems are found in the sound coverage of the auditorium.

A piece of passed-down knowledge for new employees at the MTC involves the problematic frequencies of the auditorium. Those frequencies include frequency bands of 125, 200, 5 k, and 8 kHz. Each of those frequency bands contain a local maximum, meaning they are most likely to cause feedback where the podium microphone resides. Because of this, several recordings were taken around the podium in addition to the grid points mentioned previously. Ideally, the sound pressure level should be lowest at the podium so that a high gain before feedback ratio can be achieved.

The extent of this problem can be investigated by examining other points near the podium microphone location (Figure 9 Sound Pressure levels around the podium. Note the 15 dB fluctuation at 100 HZ and other places of large SPL changes. Each place with a large change is more likely to be the cause of feedback.). A 10 dB fluctuation is observed across a distance of about two meters. The highest sound level occurs at the podium microphone location, and all other points surrounding the microphone are significantly lower. This leads to the conclusion that the speakers are interacting with the podium in such a way that resonances form around the microphone. This explains why the frequencies listed before generate feedback.

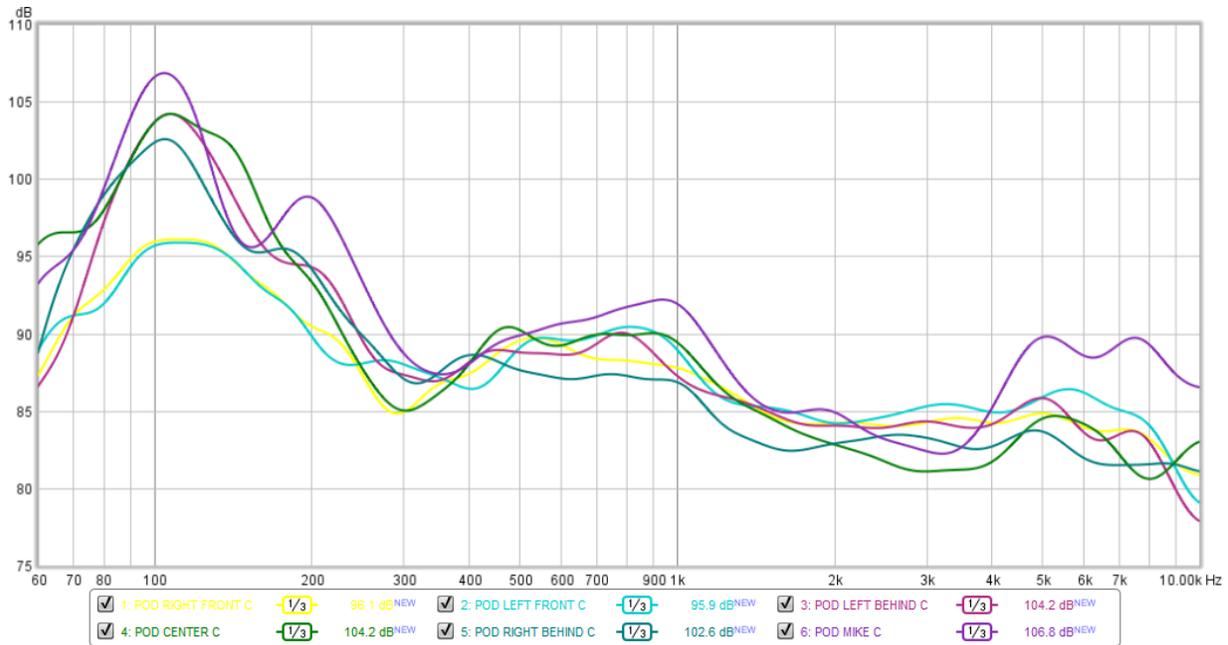


Figure 9 Sound Pressure levels around the podium. Note the 15 dB fluctuation at 100 HZ and other places of large SPL changes. Each place with a large change is more likely to be the cause of feedback.

The podium-speaker interaction was an unexpected outcome of the measurements. None of the initial guesses in terms of feedback and sound coverage involved the podium being a problem. Because of this result, it is recommended that further investigation of the sound field around the podium microphone be examined to better understand the podium-speaker interaction.

3.1.2 Reverberation Time

The general trend for reverberation time in the auditorium can be found in Appendix B. It should be noted that the RT60 for frequencies lower than 500 Hz have a slightly higher time. REW calculates several different versions of RT60, the ones of most interest being T20, T30 (T20 and T30 are defined in Chapter 1). An ideal value for reverberation time is around 1.5 to 2.0 seconds for speech and music. The auditorium fits this criterion for all frequencies tested. We note here that some extrapolation is necessary when reading the plots. REW, for some unknown

reason, did not calculate the RT60 for some frequencies and speaker combinations. Instead, zeros were put in their place and are obvious to see in the plots. They mainly appear at the lowest of frequencies and more frequently in T30 calculations. For frequencies where REW produced all—or nearly all—values for each location, there is little difference between the reverberation at each spot. Half a second difference at most for some frequencies. While it is disappointing that incomplete plots were produced, there is enough evidence to claim that the reverberation time is consistent around the auditorium, and at a value which is perfect for both speech and music.

3.1.3 Clarity

Plots for clarity, also found in Appendix B, provide some similar results as sound coverage and RT60. The ideal C50 and C80 values are between -1 to +4 dB, but this is just a baseline value. A higher value simply means that the clarity is even better. The maximum value for clarity—both for C50 and C80—is 5 db. From there, the value goes as far down as -8 dB for some locations around the auditorium. Appendix B contains the plots for clarity, showing relative max values of clarity.

The large difference and low values of clarity are not of great concern due to the frequencies at which they occur. The lowest values fall below 250 Hz; well below the normal range of speech. From 250 Hz up, the values even out and give values in range for ideal clarity.

3.2 Analysis of Room EQ Wizard

REW performed well for measuring the characteristics at the MTC, but now an overall evaluation is in order. The most beneficial aspects of REW are cost, versatility, and ease of computation. REW being free is a huge cost reduction where most software requires a

subscription or large price tags for their use, and the lower cost does not lower quality as much as one would expect. In fact, the drop of quality is better attributed to the equipment being used or user error.

With the right adapters and cables available, REW can be used with any microphone and speaker system. Because of its versatility, the quality of the measurements more depends on the equipment connected to REW. Even then, a low-quality microphone can be calibrated in REW to try improving data acquisition. The trick here is having a calibration file or knowing the response of the microphone being used to build your own calibration file.

Once a set up is finalized and calibration is accounted for, results are immediate. REW allows for a quick measurement quality check right after recording, as opposed to after taking down and importing the results to carry out an analysis. The only concern here is users having a correct understanding of how REW computes results. For example, REW computes a one-third octave band smoothing differently than same value of smoothing carried out in MATLAB. The difference being that REW smooths with small bin widths while the MATLAB script runs with much larger bin widths.

Exporting data from REW to another computational program can be cumbersome, but with many exporting options from REW, users just need some time to be able to use, compute, or analyze data however they please. It is upsetting that it was only during importing that incorrect values for RT60 were found, but now that problem can be looked for ahead of exporting.

Overall, that is REW in a nutshell: a pleasing program. The program can be used to not only with a variety of equipment, but also with countless users and their preferences in data analysis.

3.3 Conclusions

Room EQ Wizard was not created with physicists in mind, but an acoustician can utilize it as the great tool it is to evaluate the characteristics of a room. This work has shown how REW is easy to use, compatible with a variety of equipment, quickly gives data for analysis, and costs nothing. Of particular use are the explanations of how to set-up and use REW and in a setting where room characteristics were measured.

The Missionary Training Center's auditorium served as wonderful proving grounds for REW and resulted in a better understanding of what is not the issue. The three hypotheses made at the beginning were all disproved. However, the start of a new hypothesis is born from the results. Sound interacts in an unknown way with the podium, and so to get to the root of the problem more research will need to be conducted. A closer look at the podium should prove more useful in helping the MTC achieve a higher gain-before-feedback ratio.

It is possible to donate to the John Mulcahy to show appreciation for this wonderful software he has designed. The software's homepage at roomeqwizard.com has a link for donations.

Appendix A

MATLAB Script for Data Import and Analysis

```
%%RESEARCH CALCULATIONS
clear; close all;
%Load in Data
Bspeakers=cell(8,8);
Rspeaker=cell(8,8);
Lspeaker=cell(8,8);
BspeakersRT=cell(8,8);
RspeakerRT=cell(8,8);
LspeakerRT=cell(8,8);
for i=1:8
    for j=1:8
        %SPL Loading
        Bstr=strcat('B',num2str(i),num2str(j),'.txt');
        BstrRT=strcat('B',num2str(i),num2str(j),'RT.txt');
        Btemp=importdata(Bstr,' ',14);
        Bspeakers{i,j}=Btemp.data(:,2);

        Rstr=strcat('R',num2str(i),num2str(j),'.txt');
        RstrRT=strcat('R',num2str(i),num2str(j),'RT.txt');
        Rtemp=importdata(Rstr,' ',14);
        Rspeaker{i,j}=Rtemp.data(:,2);

        Lstr=strcat('L',num2str(i),num2str(j),'.txt');
        LstrRT=strcat('L',num2str(i),num2str(j),'RT.txt');
        Ltemp=importdata(Lstr,' ',14);
        Lspeaker{i,j}=Ltemp.data(:,2);

        %RT60 and C50/80
        fid=fopen(BstrRT);
        BtempRT=textscan(fid,'%f%s%f%f%f%f%f%f%f%f%f%f%f%f%f', 'Delimiter', ' ',
        'Headerlines', 14);
        fclose(fid);
        % BspeakersRT{i,j}=cell2mat(BtempRT(1),BtempRT(5),BtempRT(7));
        % New Method with 1-frequency 5-RT20 7-RT30 14-C50 15-C80
        BspeakersRT{i,j}=cell2mat(BtempRT(1,[1,5,7,14,15]));
        fid=fopen(LstrRT);
        LtempRT=textscan(fid,'%f%s%f%f%f%f%f%f%f%f%f%f%f%f%f', 'Delimiter', ' ',
        'Headerlines', 14);
        fclose(fid);
        LspeakerRT{i,j}=cell2mat(LtempRT(1,[1,5,7,14,15]));
        fid=fopen(RstrRT);
```

```

RtempRT=textscan(fid, '%f%s%f%f%f%f%f%f%f%f%f%f%f%f', 'Delimiter', ' ',
'Headerlines', 14);
fclose(fid);
RspeakerRT{i,j}=cell2mat(RtempRT(1,[1,5,7,14,15]));
    end
end

%%
%Check import
semilogx(Btemp.data(:,1),Btemp.data(:,2))
grid on
title('Imported SPL')
xlabel('Frequency (Hz)')
ylabel('SPL (dB)')
figure
semilogx(BtempRT{1},BtempRT{5},BtempRT{1},BtempRT{7})
grid on
title('Imported RT20 and RT30')
xlabel('Frequency (Hz)')
ylabel('Time (s)')
figure
semilogx(BtempRT{1},BtempRT{14},BtempRT{1},BtempRT{15})
grid on
title('Imported C50 and C80')
xlabel('Frequency (Hz)')
ylabel('Value (dB)')

%%
x=1:8;
y=1:8;
%Covert back to autospec
ref=20e-6;fs=48000;ns=2^9;N=length(Btemp.data(:,2));
%Turn into OTO Band
f = Btemp.data(:,1);
BOTO=cell(8,8);
ROTO=cell(8,8);
LOTO=cell(8,8);
fprintf('Starting OTO\n')
for i=1:8
    for j=1:8
[fc,BOTO{i,j}]=FDOT0spec(f,ref^2*10.^(Bspeakers{i,j}/10),[40 10000],'rect');
[~,ROTO{i,j}]=FDOT0spec(f,ref^2*10.^(Rspeaker{i,j}/10),[40 10000],'rect');
[~,LOTO{i,j}]=FDOT0spec(f,ref^2*10.^(Lspeaker{i,j}/10),[40 10000],'rect');
    end
end
end
fprintf('Finished with OTO\n')
figure
semilogx(fc,10*log10(BOTO{1,1}/ref^2))
grid on
title('OTO Band SPL Plot')

```

```

xlabel('Frequency (Hz)')
ylabel('SPL (dB)')

%Convert to dB
fprintf('Starting SPL Conversion\n')
for i=1:8
    for j=1:8
        BOTO{i,j}=10*log10(BOTO{i,j}/ref^2);
        ROTO{i,j}=10*log10(ROTO{i,j}/ref^2);
        LOTO{i,j}=10*log10(LOTO{i,j}/ref^2);
    end
end
fprintf('Finished with SPL Conversion\n')

%%
Bmat=cell2mat(BOTO);
Lmat=cell2mat(LOTO);
Rmat=cell2mat(ROTO);
%For GIF
h = figure;
filename = 'BSoundCoverage.gif';
i=2; %For selecting a specific frequency
% for i=1:25 %Iterates through all frequencies
    Bplot=Bmat(:,i:25:200);
    Bplot=Bplot-max(Bplot);
    imagesc(x,y,Bplot)
    str = sprintf('Sound Coverage of Both Speakers for f = %d Hz',fc(i));
    title(str)
xlabel('East/West Position')
ylabel('North/South Position')
colorbar
caxis([-20 0])
    pause(1)
    drawnow
% Bstr=strcat('SC',num2str(fc(i)),'B'); %These 2 lines are for saving figures
% print(Bstr,'-dpng')

%L Speaker Only
figure
% i=1;
% for i=1:25
Lplot=Lmat(:,i:25:200);
Lplot=Lplot-max(Lplot);
    imagesc(x,y,Lplot)
    str = sprintf('Sound Coverage of Left Speaker for f = %d Hz',fc(i));
    title(str)
xlabel('East/West Position')
ylabel('North/South Position')
colorbar
caxis([-20 0])

```

```

    pause(1)
    drawnow
%   Lstr=strcat('SC',num2str(fc(i)),'L');
%   print(Lstr,'-dpng')

    %Right Speaker Only
    figure
%   for i=1:25
Rplot=Rmat(:,i:25:200);
Rplot=Rplot-max(Rplot);
    imagesc(x,y,Rplot)
    str = sprintf('Sound Coverage of Right Speaker for f = %d Hz',fc(i));
    title(str)
xlabel('East/West Position')
ylabel('North/South Position')
colorbar
caxis([-20 0])
    pause(1)
    drawnow
%   Rstr=strcat('SC',num2str(fc(i)),'R');
%   print(Rstr,'-dpng')

%% RT60 and Clarity Figures
for i=1:7
RTmatB=cell2mat(BspeakersRT);
RT20B=RTmatB(:,5:5:40);% Switch between T20(2) T30(3) C50(4) C80(5) by replacing
% X in X:5:40
RT20Bi=RT20B(i:7:56,:);
RT20Bi=RT20Bi-max(max(RT20Bi));
RTfreq=RTmatB(1:7,1);
% figure
imagesc(x,y,RT20Bi)
str = sprintf('C80 of Both Speakers for f = %d Hz',RTfreq(i));
title(str)
xlabel('East/West Position')
ylabel('North/South Position')
colorbar
caxis([-15 0])
pause(1)
drawnow
    Bstr=strcat('C80f',num2str(RTfreq(i)),'B');
    print(Bstr,'-dpng')

RTmatL=cell2mat(LspeakerRT);
RT20L=RTmatL(:,5:5:40);
RT20Li=RT20L(i:7:56,:);
RT20Li=RT20Li-max(max(RT20Li));
% figure
imagesc(x,y,RT20Li)
str = sprintf('C80 of Left Speaker for f = %d Hz',RTfreq(i));

```

```

title(str)
xlabel('East/West Position')
ylabel('North/South Position')
colorbar
caxis([-15 0])
pause(1)
drawnow
Lstr=strcat('C80f',num2str(RTfreq(i)),'L');
    print(Lstr,'-dpng')

RTmatR=cell2mat(RspeakerRT);
RT20R=RTmatR(:,5:5:40);
RT20Ri=RT20R(i:7:56,:);
RT20Ri=RT20Ri-max(max(RT20Ri));
% figure
imagesc(x,y,RT20Ri)
str = sprintf('C80 of Right Speaker for f = %d Hz',RTfreq(i));
title(str)
xlabel('East/West Position')
ylabel('North/South Position')
colorbar
caxis([-15 0])
pause(1)
drawnow
Rstr=strcat('C80f',num2str(RTfreq(i)),'R');
    print(Rstr,'-dpng')
end

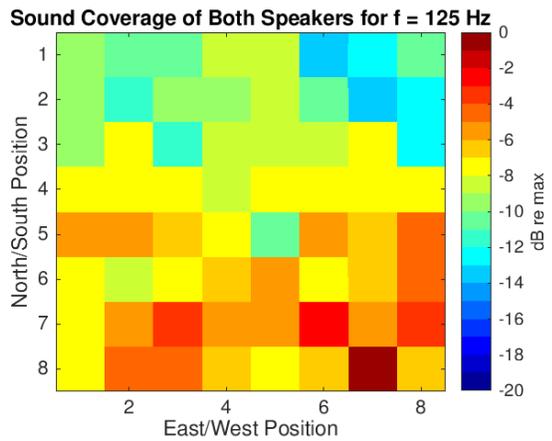
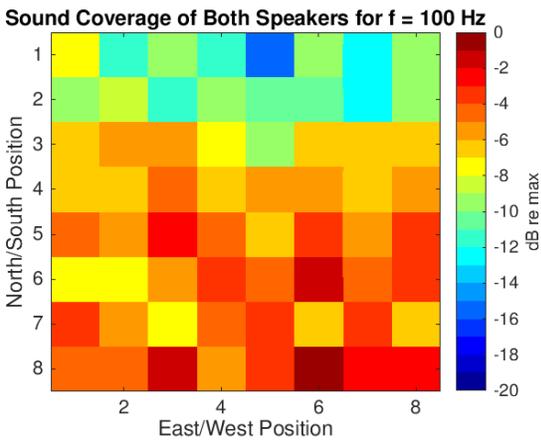
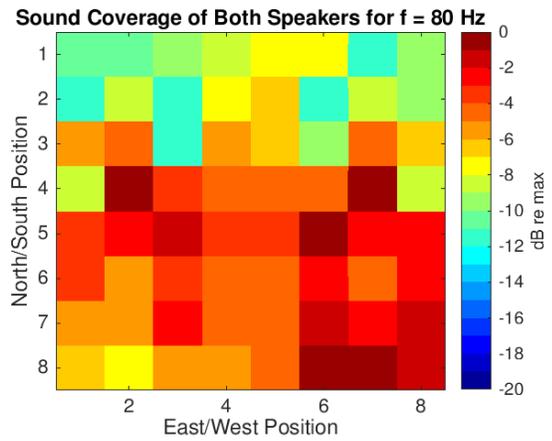
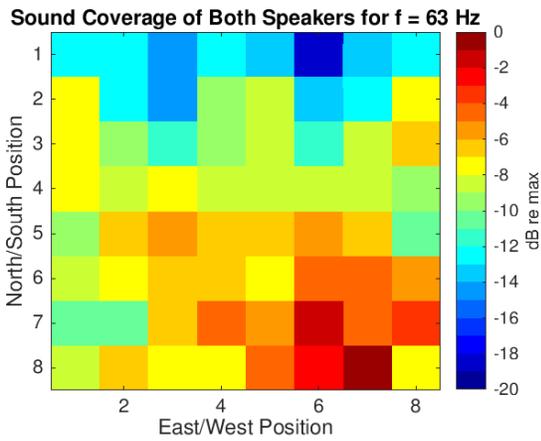
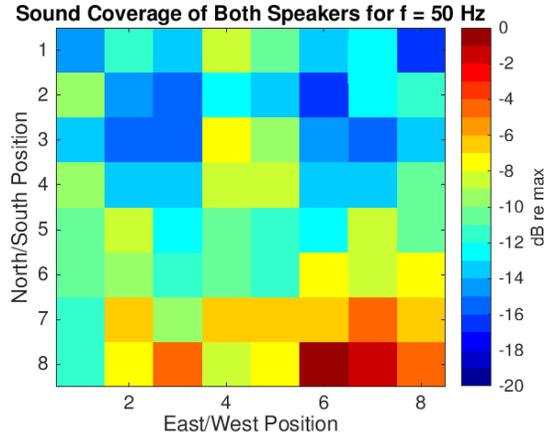
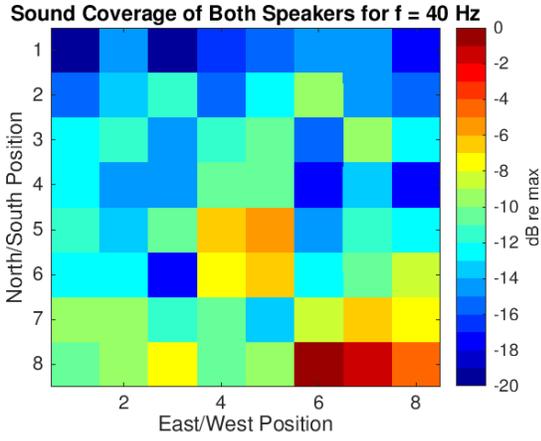
```

Appendix B Characteristic Plots

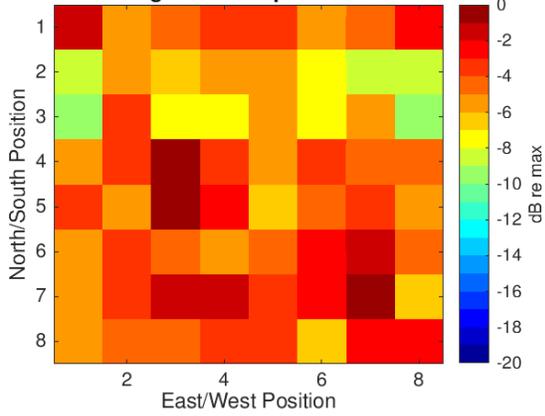
Many plots were generated and compared for this thesis. What follows is a description of what can be determined from the plots alone. For better context, refer to Section 3.1.

Sound Coverage Plots

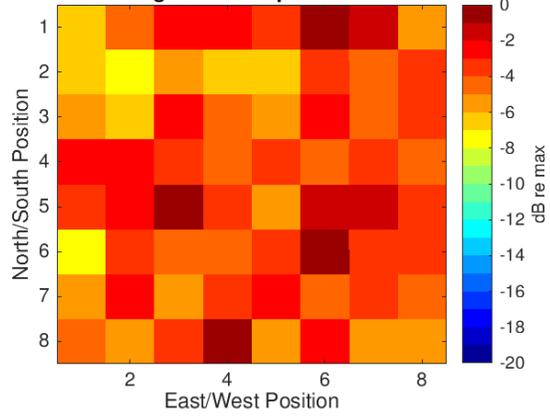
75 Plots were generated to examine the sound field as a function of frequency and position. There were 25 frequency bandwidths examined for three different cases: left speaker only, both speakers, right speaker only. What follows are sound pressure level plots at various locations around the auditorium compared to the maximum sound pressure level for a given frequency. Not all plots are printed here, but enough for readers to understand the conclusion that sound coverage was not the main issue of the auditorium's acoustics. The podium is located at the East/West position of 5 but not actually in these grids. It would be further below each graph.



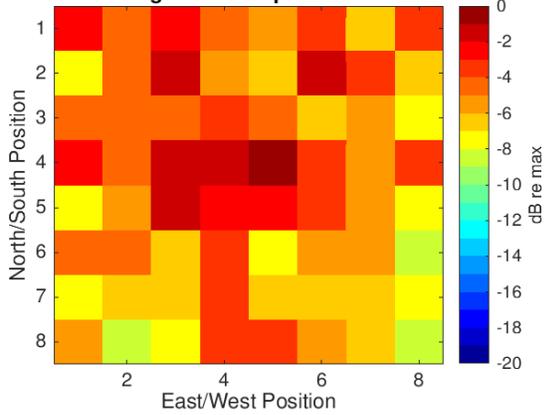
Sound Coverage of Both Speakers for $f = 160$ Hz



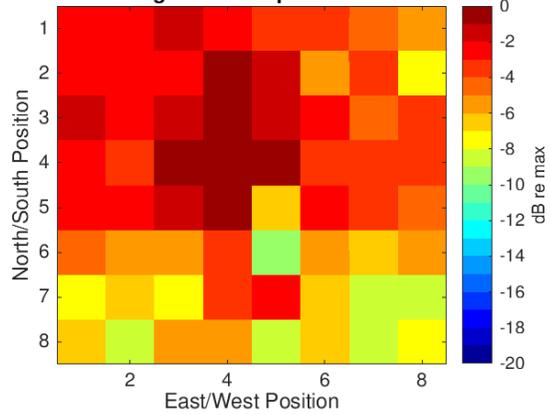
Sound Coverage of Both Speakers for $f = 200$ Hz



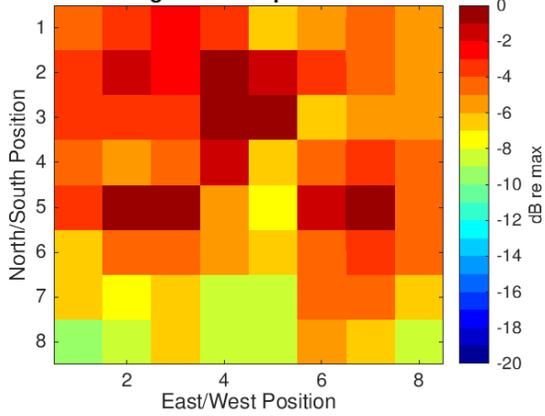
Sound Coverage of Both Speakers for $f = 250$ Hz



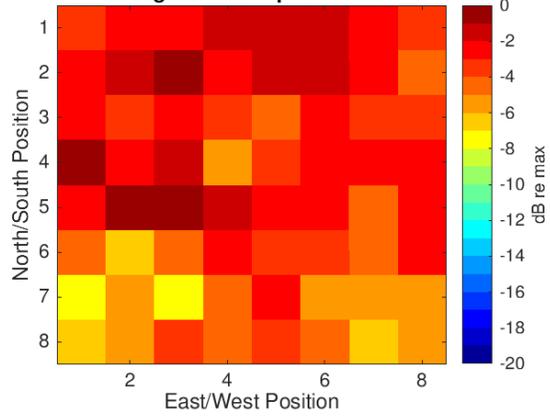
Sound Coverage of Both Speakers for $f = 315$ Hz



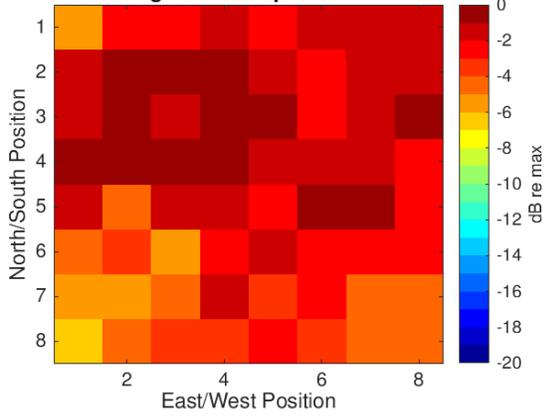
Sound Coverage of Both Speakers for $f = 400$ Hz



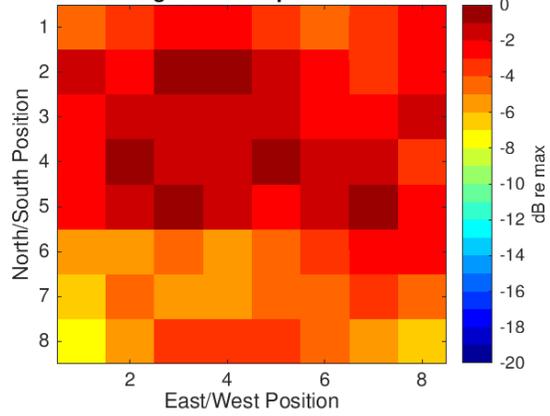
Sound Coverage of Both Speakers for $f = 500$ Hz



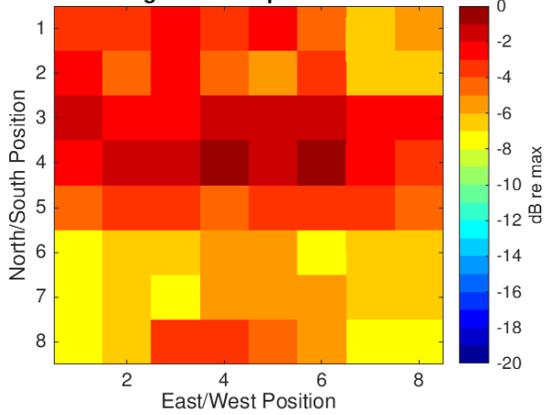
Sound Coverage of Both Speakers for $f = 630$ Hz



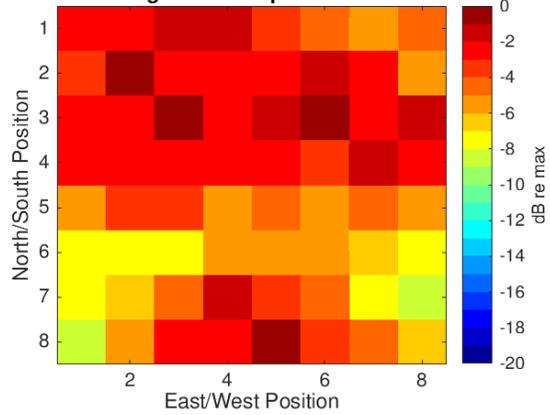
Sound Coverage of Both Speakers for $f = 800$ Hz



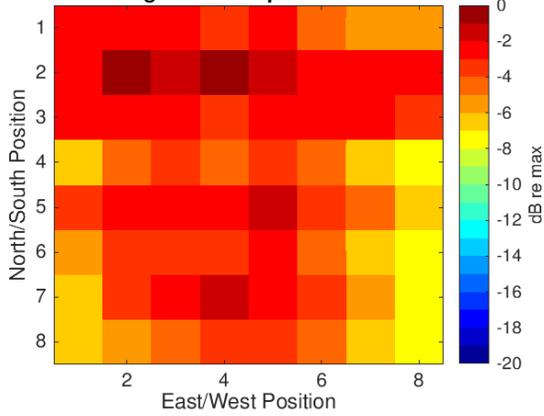
Sound Coverage of Both Speakers for $f = 1000$ Hz



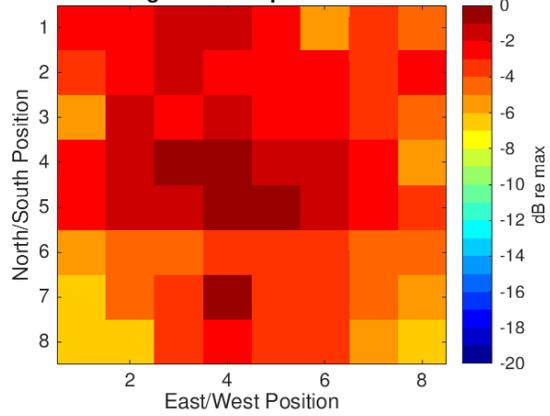
Sound Coverage of Both Speakers for $f = 1250$ Hz



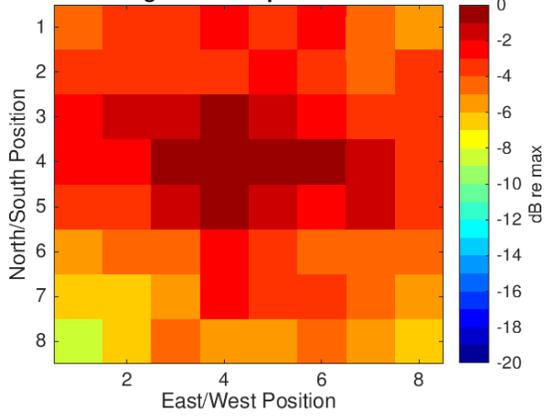
Sound Coverage of Both Speakers for $f = 1600$ Hz



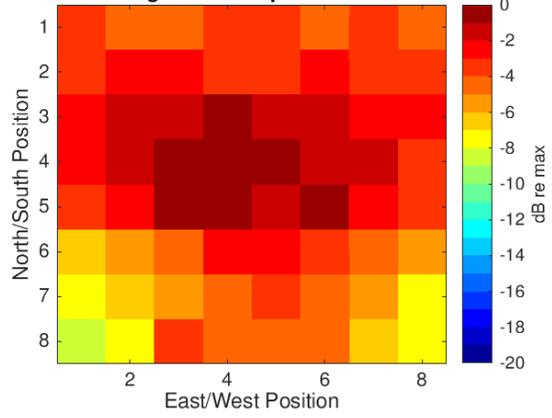
Sound Coverage of Both Speakers for $f = 2000$ Hz



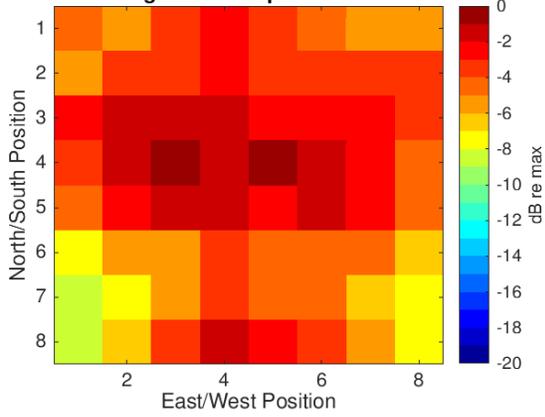
Sound Coverage of Both Speakers for $f = 2500$ Hz



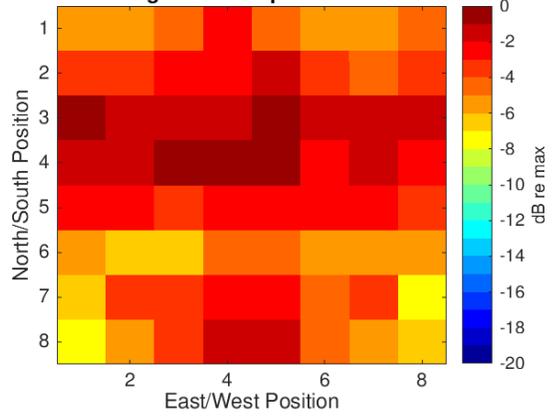
Sound Coverage of Both Speakers for $f = 3150$ Hz



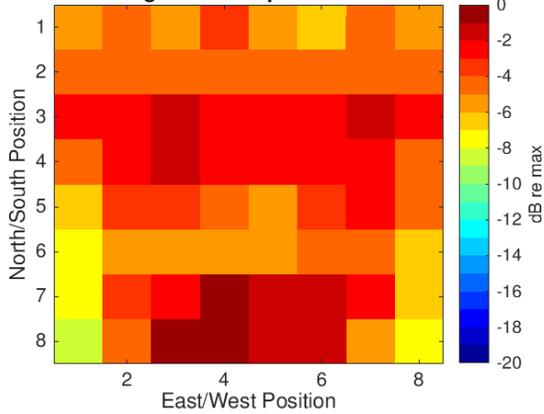
Sound Coverage of Both Speakers for $f = 4000$ Hz



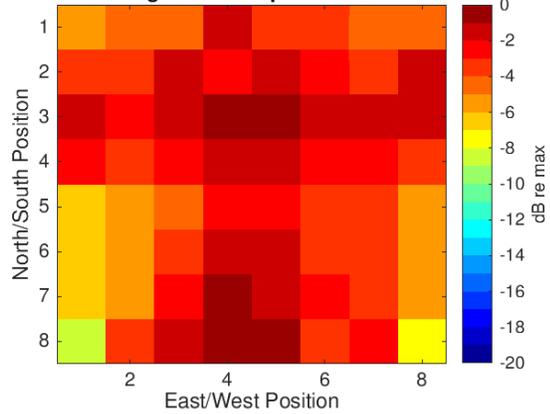
Sound Coverage of Both Speakers for $f = 5000$ Hz



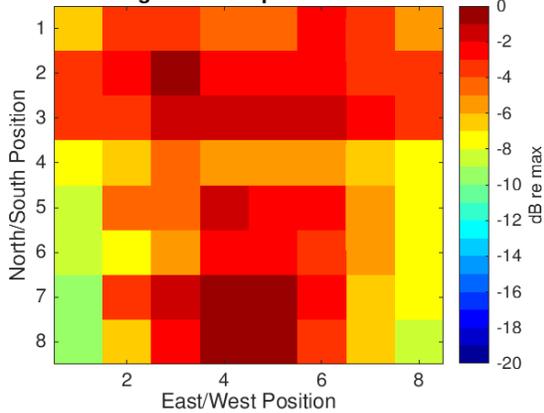
Sound Coverage of Both Speakers for $f = 6300$ Hz



Sound Coverage of Both Speakers for $f = 8000$ Hz

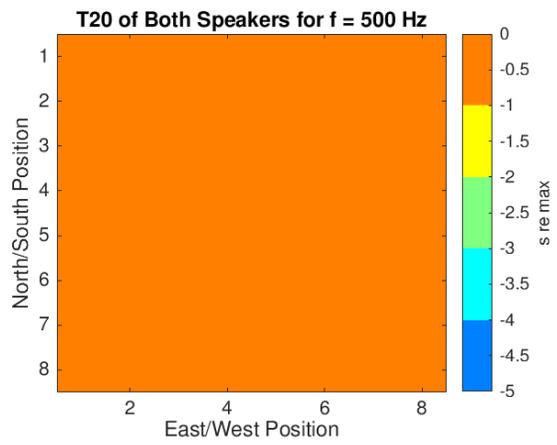
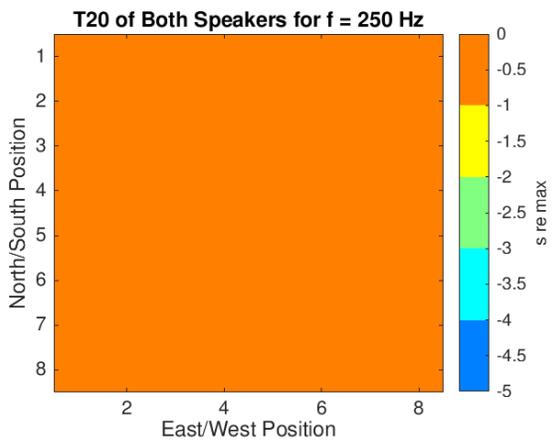
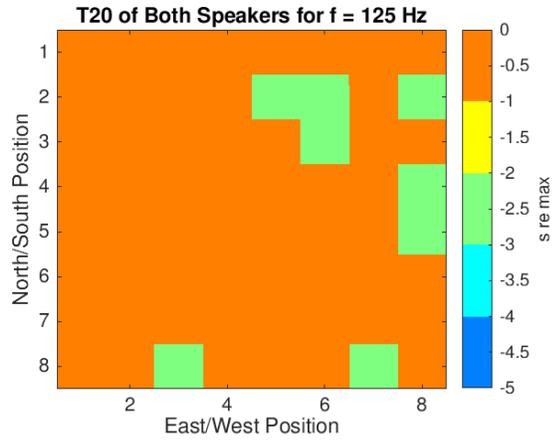
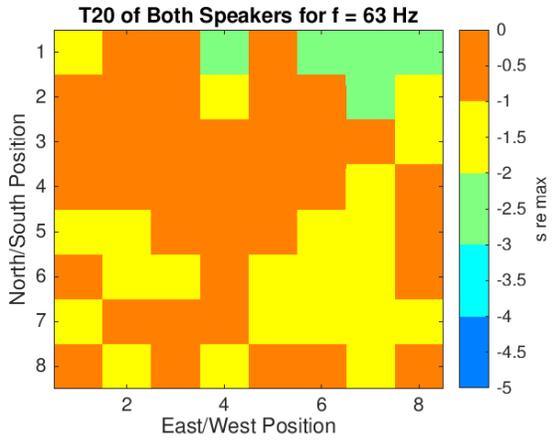


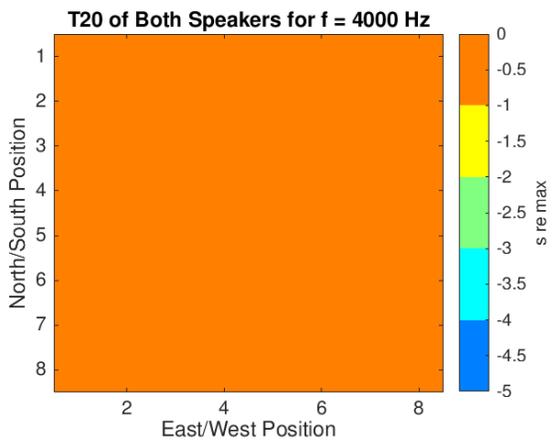
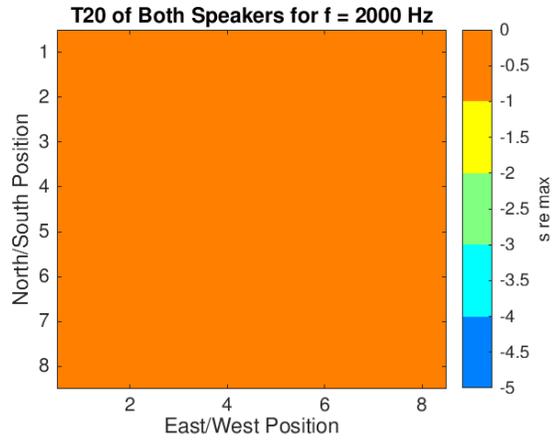
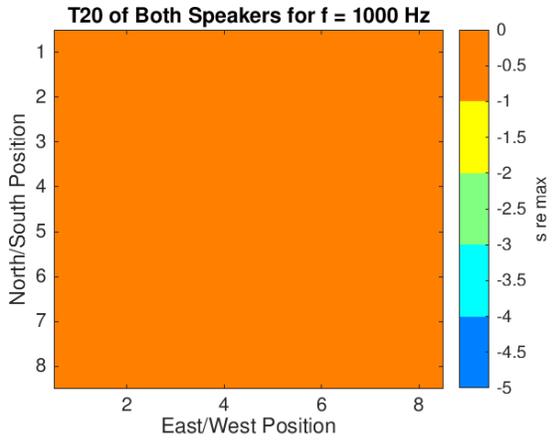
Sound Coverage of Both Speakers for $f = 10000$ Hz

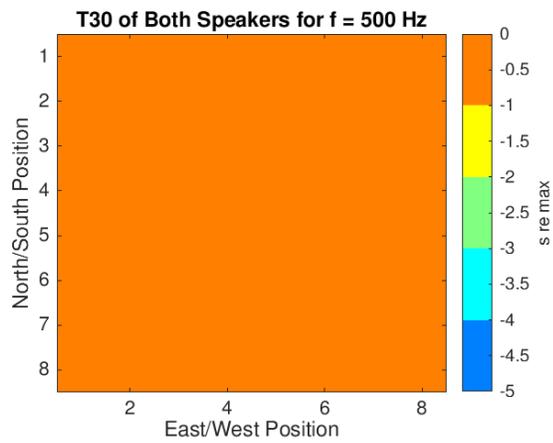
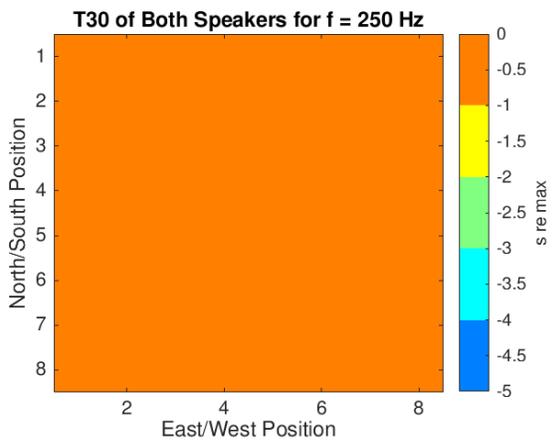
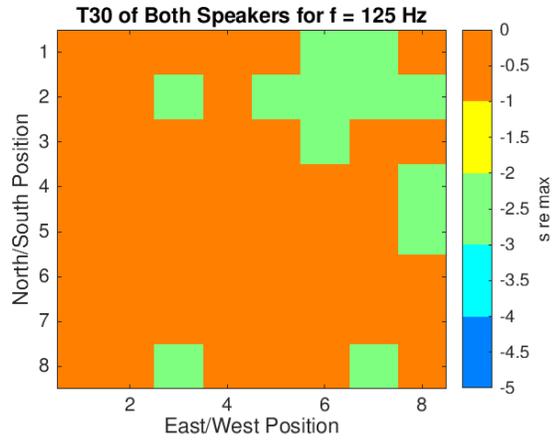
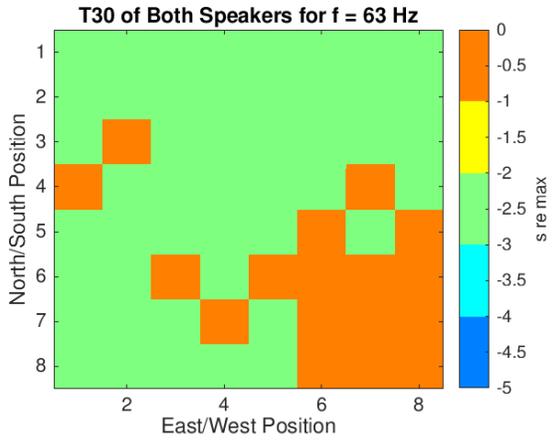


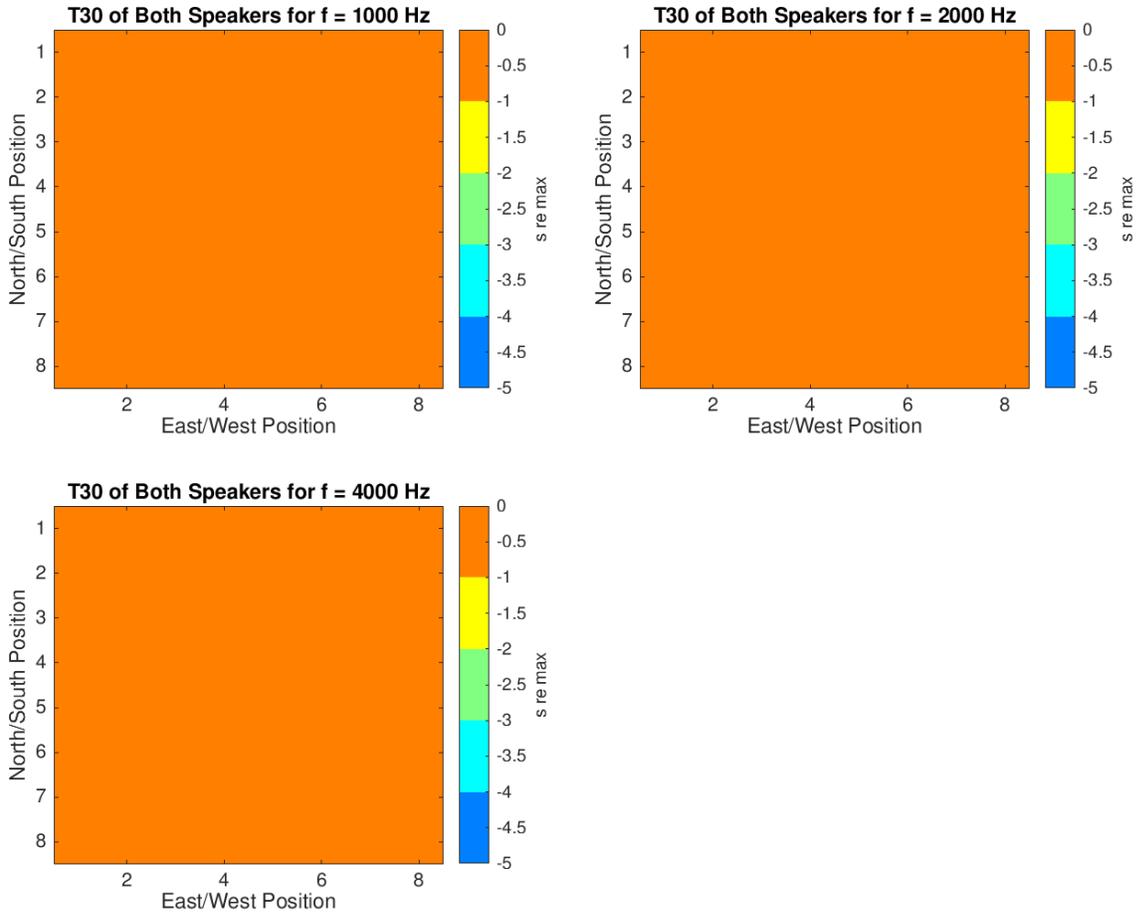
RT60

These plots, like the sound coverage ones, have values compared to the maximum value at each frequency. The T20 plots will be shown first, then the T30. We again mention that there are gaps of data in lower frequency plots, with a greater number appearing in T30 plots. Many of the plots have a solid color because the reverberation time for that frequency across all points was within half of a second from the maximum.



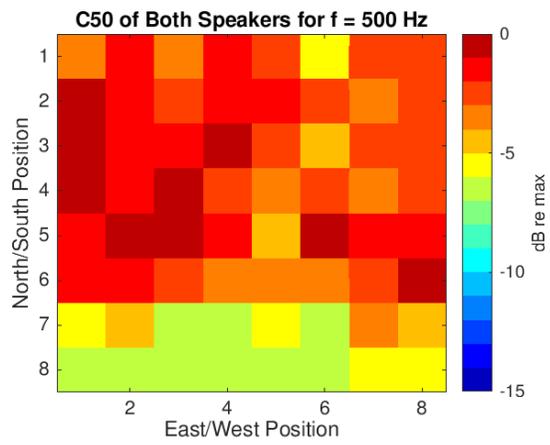
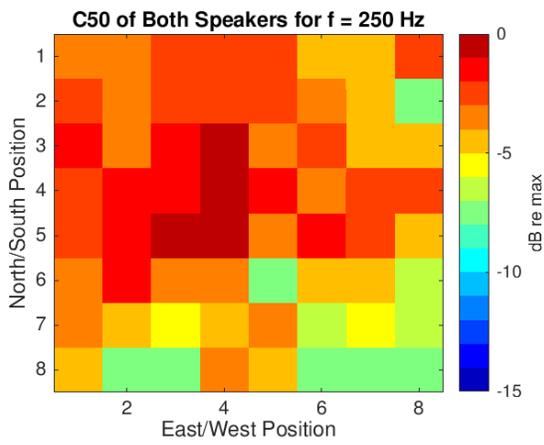
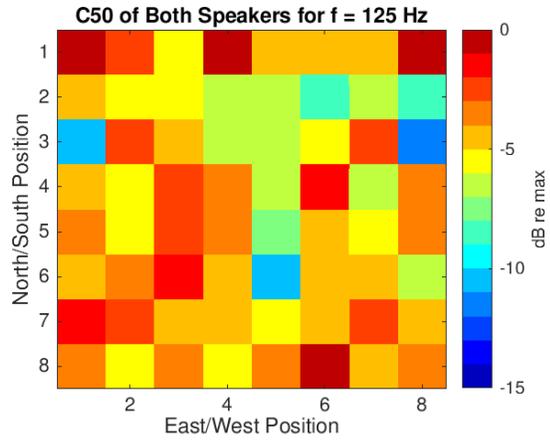
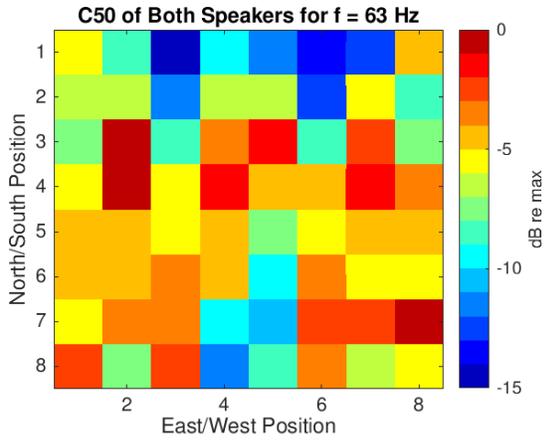


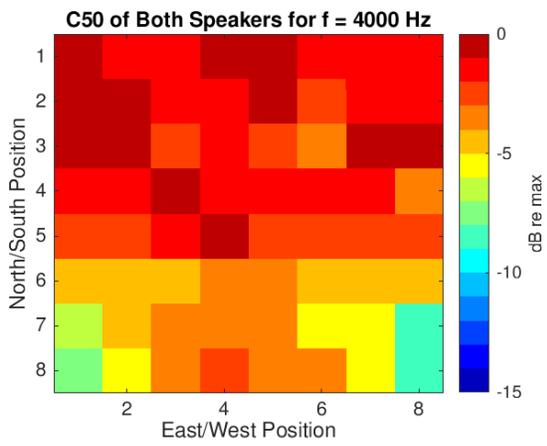
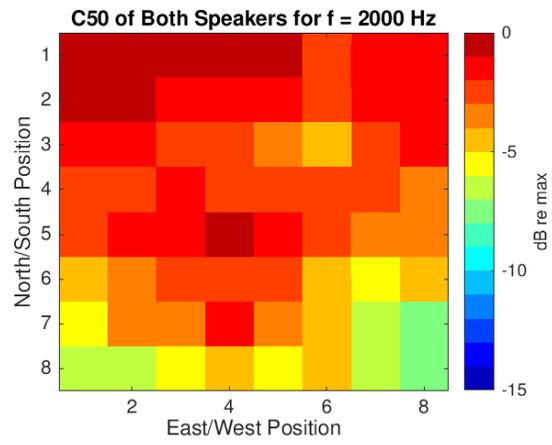
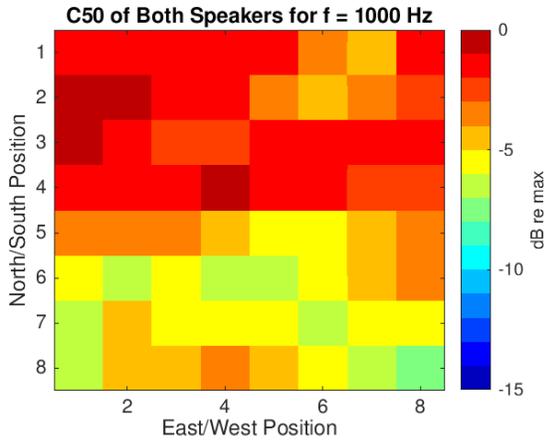


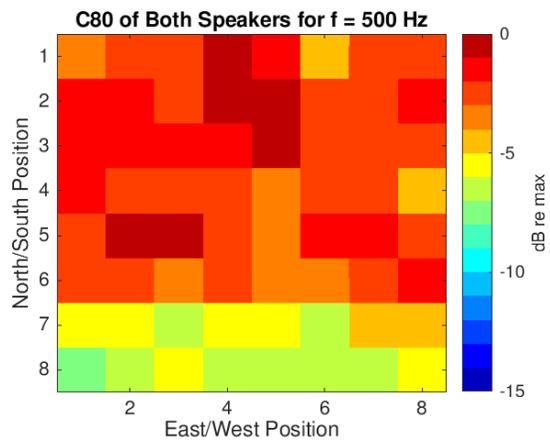
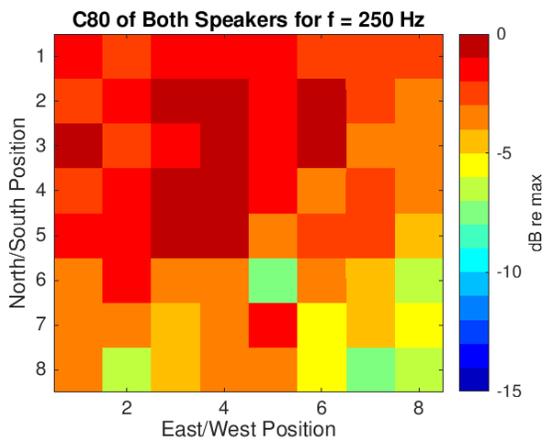
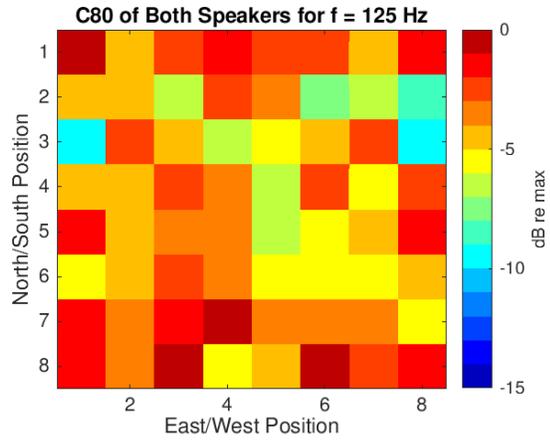
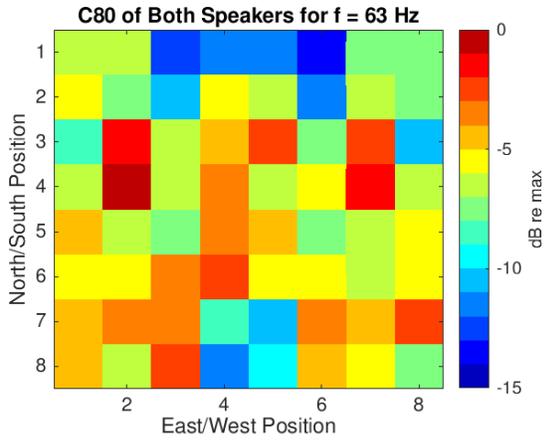


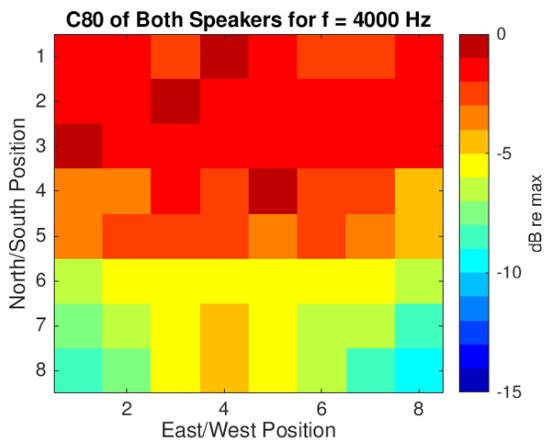
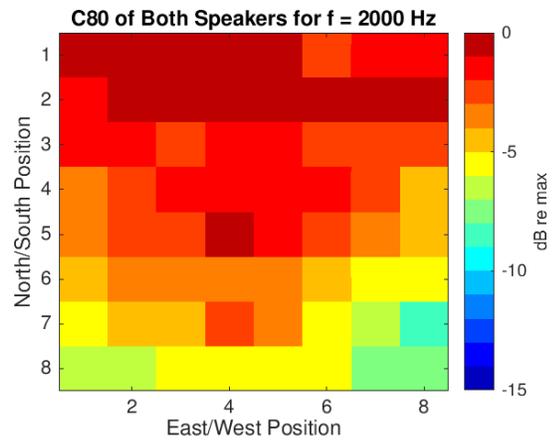
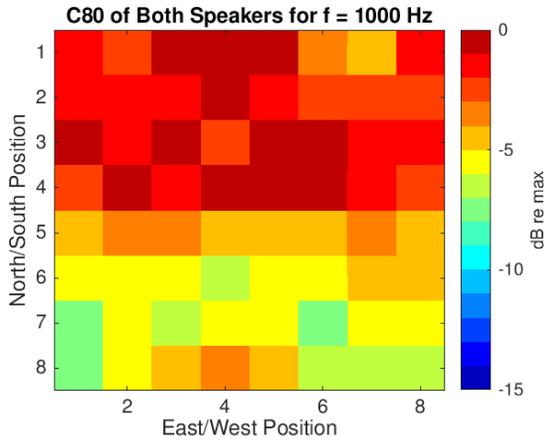
Clarity

Plots corresponding to C50 are given first, followed by C80. Like before, these plots are all plotted with values adjusted relative to the maximum value at each frequency. Unlike the other plots, that value could have been positive or negative. The most positive value achieved for any clarity measurement was around 5 dB which puts all plots in ideal clarity range, except the low frequency plots.









Bibliography

Index

Acoustic Field Recorder (AFR), 10

clarity

Exporting data of, 23

Clarity, 14, 31

Electronic and Acoustic System Evaluation and Response Analysis (EASERA), 10

MATLAB, 23, 27

Missionary Training Center (MTC)

characteristics of interest, 13

equipment setup, 25

map of, 25

problem defined, 11

Room EQ Wizard (REW)

explanation of, 9

version used, 17

RT60, 13, 23, 30

Scarlet 2i2, 11, 18, 25

Sound Coverage, 13, 25

Analysis of, 28