Bar Harbor Sound Design

E122

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Max Schrader, EVE 2013
Chris Maino, PHY 2014

Project Advisor: Frederick Bianchi
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Abstract

The goal of the Bar Harbor Sound Design project was to gather acoustical data focused on the future creation of an Environmental Orchestra on Mount Desert Island. Tests were conducted at multiple locations selected to represent the multiple environments of the island. Using computer software to analyze the data, results yielded detailed information on absorption, reflection and reverberation. The testing methods developed during this project created a benchmark for future acoustical analysis on the island. The information compiled in this report advances the understanding of Mount Desert Island’s acoustics and enables future projects to design sound installations for an Environmental Orchestra.

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Executive Summary

Mount Desert Island is a stunning area, rich with natural splendor. Its beauty regularly attracts visitors, who come to explore and appreciate its sights and sounds.

Luigi Russolo was an artist with revolutionary ideas about sound, particularly about expanding the sounds used in music. Luigi created radical new instruments producing sounds not conventionally considered musical, and arranged them in orchestral performances. His ideas were rejected so heavily by concert halls full of people, that quiet music enthusiasts were turned to rioters, spewing out of concert hall doors into the streets in protest.

The idea of the Environmental Orchestra not only accepts Russolo's ideas about what sound is enjoyable, and even musical, but it expands beyond concert hall walls, and brings music and organized sound into the great outdoors, particularly beautiful and enjoyable places like Mount Desert Island. The grand picture is a listening area in one location, with the sound producing devices in locations that could be miles away. All these sound devices are synchronized and designed to work with the natural environment in which they are placed. A violin cannot be heard at great distances, but something called a sound sculpture might.

Sound Sculptures are a well-established art form that is practiced world-wide. There are wave and sea organs in San Fransisco, CA, USA, and Zadar, Croatia. The Singing Ringing Tree in England compliments the Federation Bells in Australia in this collection of pseudo-musical sound devices. Each sound sculpture produces sound in addition to being artistically structured and sculpted. The Environmental Orchestra deviates, like Russolo's ideas, from typical instruments as sound producers, to these larger scale sound sculptures. Instead of an array of violins and trumpets, the Environmental Orchestra might have instruments that harness the wind and the waves to produce sound.

In order to evaluate the idea of the Environmental Orchestra, and take the first step in accomplishing it, an acoustical analysis of the target location to establish it in had to be conducted. Frequency, reverberation, and attenuation were all factors that needed to be studied. The benchmark tests that took the first step in analyzing those factors were developed in this project, and then executed for several locations on the island. Of course, the testing was followed by a critical evaluation and recommendations for the future of the project.

Acoustical testing and analysis of the entire island at once was not a feasible option, and so it was broken down and tests were done in locations termed soundscapes. A soundscape is simply a setting for sound to travel through and interact with. Two testing methods were developed, one to analyze soundscapes as large as 100 to 600 meters, and one to analyze smaller scale soundscapes that were 100 feet long. The long distance test measured attenuation of sound, that is, the decrease in sound intensity, while the short distance test analyzed the way different frequencies, or pitches (how high or low a sound is), of sound behaved within different soundscapes. These tests did this using specialized equipment.

The equipment used in both testing methods came from four main categories, recording hardware used to record or measure acoustic signals, sound sources that produced sound waves, software used in data collection and analysis, and additional equipment needed for the testing procedures.

As far as recording hardware, the Tascam DR-40 Linear PCM recorders were used because their small size made them easy to bring on location, quick to set up and use, and because they could record in high quality in store those recordings in lossless .WAV format. Windscreens were used for recording, being that outdoor environments nearly always are accompanied by some form of wind. There was also a windscreen for the Reed ST-805 type-II sound pressure level meter used to record sound intensity.

The sound source was a crucial part of both testing methods developed. It produced the signal that was used to measure acoustic parameters of the soundscape being analyzed. The long distance and short distance testing methods both utilized different sound sources. For short distances of 100 ft, a custom built portable loudspeaker system was used. It was designed and constructed as part of the testing method development, was portable, and capable of accurately producing frequencies from 40 to 20,000Hz. The long distance testing method utilized, an air horn driven by a compressed air tank. It was capable of producing high intensity sounds that could be heard across the large distances greater than 100 m.

Three software titles were used in the collection and analysis of data, Audacity, Microsoft Excel, and Room Equalizer Wizard. Room Equalizer Wizard version 5.00 build 2142, referred to here after as REW, was a Java based software designed by John Mulcahy that simultaneously produced and recorded, by means of an attached speaker system and microphone, an audio signal. It was capable of Fast Fourier Transforms (FFT) that enabled the recorded sound wave to be analyzed on a per-frequency basis. Audacity was used to manage recordings, and to trim down the data. It was then able to export the audio recording as a data file (.txt was the file type, to be specific). Microsoft Excel was able to manipulate that data file, a necessary step for some analysis.

Additional equipment used for testing included 2 tripods that were compatible with the Tascam recorders, a GPS unit for marking locations, an anemometer equipped with a thermometer, and handheld transceivers for communication across large distances. This additional equipment was used in conjunction with the recording hardware, sound sources, and software in both the short, and long distance testing methods.

Both of the testing methods were based on a simple principle; a sound signal was produced, traveled through a soundscape, and was recorded. By comparing what was recorded to what was produced, much could be learned about the soundscape. The short distance test used the portable speaker system to generate a frequency sweep as an audio signal for testing, and the Tascam to record that signal after it traveled through the soundscape. Both the speaker and the Tascam were connected by cables to a computer running REW. REW was able to use Fast Fourier Transforms to graphically represent the frequency sweep received by microphone. This was the frequency response of the soundscape, represented by an intensity vs. frequency graph. That frequency response was compared to the frequency response of the speaker itself (measured in the same method, but with a 3ft distance between the microphone and speaker instead of 100ft), and it was that comparison that allowed for the analysis of how the soundscape changed the sound that traveled through it. Multiple frequency sweeps were generated and analyzed, to ensure accuracy of the soundscape analysis.

The long distance test used the compressed air-driven horn to produce a sound signal, and two Tascam DR-40 recorders. One Tascam was used to record the signal generated by the air horn at the source, while the other was used to record, at a distance, the signal after it had traveled through a soundscape. The air horn was set up, with a Tascam in front of it, and the second Tascam was set up by a second experimenter some distance away. Both Tascam recorders began recording, after which the air horn would be sounded. The recording of the air horn at the source could then be compared to the recording at a distance, through the use of Audacity and REW. Additionally, with the help of standard acoustics equations and Microsoft Excel, the source recording could be used to generate a mathematical prediction of what the second recording would be. That mathematical prediction was compared to what was actually recorded at the second microphone, to analyze the unique properties of the soundscape. Several soundscapes were tested with both the long and short distance testing methods.

The short distance test was done in six different soundscapes, including two grass fields, a rocky area at a mountain top, a rocky stretch of shoreline, a rocky brook, and a mossy-floored evergreen forest. After testing and analysis it was found that each of these soundscapes had a different frequency response, characterized by different qualities.

Grassy areas followed the general rule that bass frequencies, particularly below 300Hz, were inconsequentially affected, whilst higher frequencies were affected more heavily the higher the frequency. The grassy fields were also characterized by a maximum peak at 300Hz and relative dip in response between 2,000 and 3,000Hz.

The rocky mountain top area was characterized by a response that was accurate to the expected signal output up to 800Hz, and a smooth decrease in frequency response from 800 to 20,000Hz. This area had a particularly high low frequency bias.

The rocky shoreline was characterized by a response dip from 200 to 300Hz, but also by an accurate frequency response, other than that dip, from 40 to 2,500Hz. Additionally, there was a sort of sensitivity to position, essentially a randomization in frequency response above 2,500Hz.

This soundscape propagated frequencies, from 40 to 200Hz and from 300Hz to 2,500Hz effectively, and without significant attenuation. Above that, however sound was scattered and diffused randomly, creating inconsistent and variable responses.

The rocky brook had a steadily decreasing response for all frequencies above 300Hz, and there were many inconsistencies in the response. This soundscape would propagate the sound in highly inconsistent, reverberant manner, confusing the initial signal and sounding distant.

The mossy forest had an accurate response curve with unprecedented consistency between measurements. The area was full of soft materials, such as thick moss and decaying logs, which may have acted as sound absorbers, preventing reverberant reflections from skewing the response.

The long distance testing method produced data about attenuation of sound. In addition, because the air horn used produced an assortment of different frequencies, it was possible to analyze some frequency characteristics as well. Long distance tests were done in two locations, and at multiple distances at each of those locations. The first of the two locations tested using the long distance testing method was Lower Hadlock Pond, in Acadia National Park. This location characterized a quiet freshwater soundscape. The second was a forest of mostly evergreen trees, with thick moss covering the forest floor that was partially occupied by dense underbrush.

Over water, it was found that mid-range frequencies traveled very clearly without dispersion predicted by standard acoustics equations. This is because the surface of the water may reflect the sound back up at the recorder.

High frequencies (of 6000 Hz and above) were much less intense when measured at a distance than they were projected to be. This was most likely caused by reflection and absorption. High frequency waves have shorter wavelengths that can interact with the environment. When traveling through the forest the high frequencies interacted with mossy ground, numerous tree and dense branches with think needles. Over water, the high frequency waves came into contact with small ripples on the lakes surface as well as the trees surrounding the lake. All of these obstacles reduced the intensity of the signal reaching the recorder. Lower frequencies were less likely to interact with the environment because of the longer wavelengths.

Very dense brush was found to reduce the intensity of the full spectrum. This is because the sound wave cannot freely move through the brush and many reflections may destructively interact with the other sound waves.

In conclusion, many soundscapes were analyzed so that they could be understood in terms of frequency responses and attenuation. After understanding the acoustics of those soundscapes, one could predict how something would behave acoustically in a given soundscape, or additionally, one could design an instrument or sound sculpture that would perform well in said soundscape. An arrangement of these instruments, designed acoustically for the soundscape they are established in, could create an Environmental Orchestra that not only works with the acoustics of the environment, but was specifically designed for and inspired by it, representing the landscape acoustically. After understanding many of the soundscapes, the acoustic feasibility of the Environmental Orchestra is strong. In the right soundscapes, a single air horn producing intensities of 115dB or so was able to be heard at least 400 meters away, and in frequency ranges that travel well over water. A sound sculpture that utilizes many horns, not necessarily air horns, would be able to replicate and most likely surpass this acoustic benchmark.

Though the Environmental Orchestra is validated acoustically, and is hypothetically possible, there is much more work that would need to be done. As for the acoustics, the soundscapes characterized thus far do not represent the entire geography of the island. However, the testing methods developed were successful and can be carried out in many more places on the island.

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1.Introduction

This project is studying the unique acoustic qualities of Mount Desert Island. The goal of the project is to test how sound travels throughout multiple locations on the island. Specifically, pitch, intensity and reverberations have been studied during this project. This work is being done to gage the feasibility of installing musical instruments or sound sculptures on Mount Desert Island. The instruments would produce sound in unison with the sounds of the island. Acoustical analysis on the island must be conducted in order to locate areas that would be ideal for future installation and to identify issues that may be encountered in designing and building the installations. The future goal of the project is to create music and sounds on a large scale throughout the island.

Cristo and Jeanne-Claude are a visual artistic duo that was famous for wrapping objects, buildings and even natural landscapes with fabric. By wrapping these items Cristo could “reveal some of the most basic features and proportions of the object by concealing the actual item.” This project aims to do something similar only using music and soundscapes instead of fabrics and landscapes like Cristo. The project is starting by establishing where ideal locations for instruments on the island are by conducting acoustical tests at multiple locations representative of the many different landscapes of Bar Harbor.

This project also looks at the feasibility and logistics of future related projects. This includes recommendations for areas of further study. Furthermore, information gained during this project on methods of testing will prove useful to future groups.

2.Background

The first known settlers, the Abnaki, originally called Mount Desert Island, Pemetic. The Abnaki would spend their winters on the coast of the Island to catch salmon and stayed further inland during the summer. The first European expeditions of the island were in 1604, led by the Frenchman, Samuel Champlain. In 1613 French Jesuits settled on the island and built a mission. The English soon contested the land and no Europeans settled there for another 150 years. Eventually the English took the fortified land to the north of the island and in 1760, free land on the island was being given to English settlers.

Soon after, the American Revolution began and the English lost their claim on the island. The island was settled by many fishers, boat builders, lumberjacks and farmers. By 1820, the people of Mount Desert Island were linked to the sea.

In the mid-1800s artists and journalists would come to the island for its rustic lifestyle and beautiful sights. This trend made Bar Harbor a popular tourist destination internationally. By the 1880’s many wealthy families, like the Rockefellers, Morgans, and Fords, also chose to spend summers on the island. The wealthy families had large estates and made the island much more affluent.

Today Bar Harbor is still a popular summer destination and tourism is a major part of the islands economy. People enjoy going there for the rustic feel and beautiful sights of the island.

2.1 Artistic History

The Environmental Orchestra project will involve the installation of sound producing devises or sculptures into the natural environment. It is intended to be a musical and artistic piece that veers away from artificially produced, technology based sound, and focuses on natural sounds, generated by and working with the natural environment in which it is created. Looking back in time, connections with past sculptural and musical movements become visible through comparing the idea of the Environmental Orchestra project to ideas of artists through history.

Luigi Russolo had the powerful idea of incorporating "noises" in music. He questioned why it is only sounds that come from instruments were considered to be musical, and not, for example, the sound of a mechanical engine. In his book The Art of Noise(7) he emphasizes potential enjoyment from, and the beauty of, noises not typically thought of in a musical sense, saying:

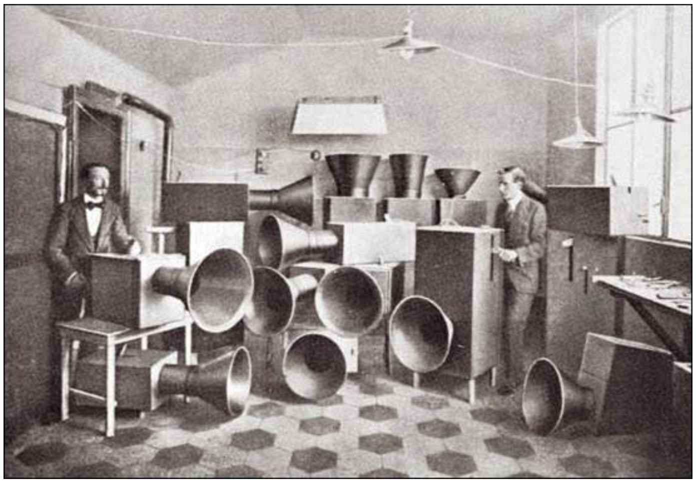


Figure 1 - Russolo with his orchestra(7)

"We will delight in distinguishing the eddying of water, of air or gas in metal pipes, the muttering of motors that breathe and pulse with an indisputable animality, the throbbing of valves, the bustle of pistons, the shrieks of mechanical saws, the starting of trams on the tracks, the cracking of whips, the flap-ping of awnings and flags. We will amuse ourselves by orchestrating together in our imagination the din of rolling shop shutters, the varied hubbub of train stations, iron works, thread mills, printing presses, electrical plants, and subways."

Russolo liked, in particular, industrial noises, and the incorporation of them into musical composition. His piece "Macchina Tipografica" is a composition of piano, unusual vocals, and background mechanized rumbling. Another notable work of his on the subject is

“Intonarumori,”(7) which was a large collection of sizable, mechanized instruments designed to mimic noises such as turbine engines and locomotives. Russolo’s ideas about commonplace noise being valuable had large influences on music that followed his time, including modern music. Russolo’s ideas about noise were radical in his time, progressing from traditionally musical sounds to those that weren’t typically considered so. In modern times it is easy to accept that, but in his time it was so controversial that rioting occurred at the presentation of some of his work. The Environmental Orchestra project is more or less the inverse of Russolo’s work, yet it retains the same spirit of exploring new musical styles. It is a regression from, rather than a progression to, modern “noise” in music, with an emphasis on working with nature, and a specific natural landscape.

In more recent history we see parallels between the Environmental Orchestra and artistic movements, which didn’t necessarily have anything to do with noise, sound or music. Land Art, or sometimes Earth Art, was at one of its peaks in the mid-1960s to early-1970s, with the involvement of Robert Smithson. Smithson’s artistic contributions were typical of the movement, creating sculpture with, and typically in, the natural environment. Eroded cliffs with lava-like flow of asphalt down them, wooden structures half buried in earth, and islands created in simple geometric shapes are all examples of Smithson’s work. Land Art focused on the use of earth like materials such as dirt, sand, stone, asphalt, and gravel, to create art that was undeniably tied to the environment. These sculptural installations were sometimes maintained, but in other cases were let to erode in natural ways, in keeping with the art itself. For example, Smithson intended his piece “Partially Buried Woodshed” be "subject to weathering, which should be considered part of the piece."(11) The Environmental Orchestra project is also intended to be a sculptural installation that is tied to the environment and nature, by means of its design, operation, and location.

Related to Land Art are the works of Cristo and Jeanne-Claude(6), who took on incredibly large scale projects in order to present things in a new way, so as to make an observer see them in a new light. These massive make-overs were of buildings, landscapes, islands, and all accomplished by wrapping the subject with fabric, uncanny amounts of it. The massive scale of these works and the change in perspective of the landscape are long-term goals of the Environmental Orchestra.

2.2 Other Installations

Sound sculpture is a visual and time based art form in which sculptures are made to produce sound or music. It can be site-specific, using the natural environment to make sound. There are many sound sculpture installations that make use of the wind or the ocean. Other sound sculpture uses its own architecture to produce music.

The architect Nikola Basic constructed the Sea Organ in Zadar, Croatia which uses a network of tubes set underneath a large set of marble steps. It uses the waves from the ocean to create harmonic sounds.

Figure 2 - Sea Organ(16)

Figure 3 - Wave Organ(13)

The Wave Organ is a similar installation made by the Exploratorium, located in the San Francisco bay. Through a series of pipes leading into the ocean, it amplifies the sounds of the water and the waves to listening stations where passersby may listen to it.

The Blackpool High Tide Organ, located in Blackpool, UK, was designed by artists Liam Curtin and John Gooding. Constructed using concrete, steel, zinc and copper sheet, it is a tidal organ, which uses the high tide to make music. It uses a series of pipes connected to the ocean, which are connected to 18 organ pipes in the sculpture. The changing of the tide pushes air up the pipes, sounding the organ pipes in a harmonic series of pitches.

Figure 4 - Blackpool High Tide Organ(14)

The Singing Ringing Tree, located in Lancashire, England, is a wind powered sound sculpture resembling a tree. It was constructed using a series of galvanized steel pipes to make a choral sound which rings in octaves.

Figure 5 - Singing Ringing Tree(8)

2.3 *Acoustics*

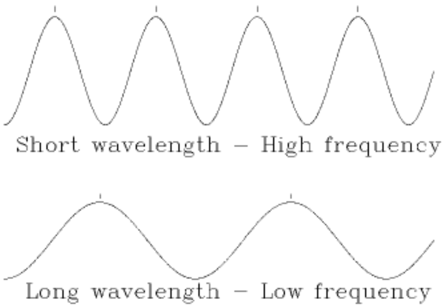
Environmental acoustics is a modern field of engineering that is concerned with sound waves outside. There is a wide range of uses for acoustical analysis. Large-scale warning systems need to be tested for effectiveness; new developments must minimize their noise pollution; large outdoor concerts use acoustical analysis to make sure the audience can hear the concert. Environmental acoustics is very difficult to evaluate because so many factors effect sound propagation. In order to simplify analysis, standardized systems of analysis must be created for practical applications.

2.3.1 Basic Principles

Acoustics, the study of sound, goes back to the ancient Greeks and Aristotle, who hypothesized that sounds waves propagate by moving air. Since then numerous scientists and engineers have added to our understanding of how sound works. Sound waves, the speed of sound, the relationship between wavelength and frequency, are a few of the many discoveries made since then. The most fundamental properties of sound are intensity and frequency. These properties determine how humans perceive them.

Pitch is determined by the frequency of a wave. Humans hear higher frequency sounds with a higher pitch and low frequency sounds as lower pitches. The frequency of a wave determines the wavelength. Short wavelengths have a higher frequency and will vibrate the inner ear at a higher frequency.

Figure 6 - Wavelength vs Frequency(15)



Sound intensity is the power per area of the sound. The more power in an area, the more intense the sound wave is. Intensity is commonly measured in decibels. Decibels are a logarithmic unit of measure that is found through a ratio between the threshold of hearing and the sound being measured. The threshold of hearing is the lowest audible intensity of sound to humans (on average) for each frequency.

2.3.2 Inverse Square Law

As sound travels outwards from its source it spreads out in a spherical shape. This means that the power of the wave per area decreases and the intensity drops. The inverse square law is used to define the intensity drop of a wave as it disperses out in a sphere.

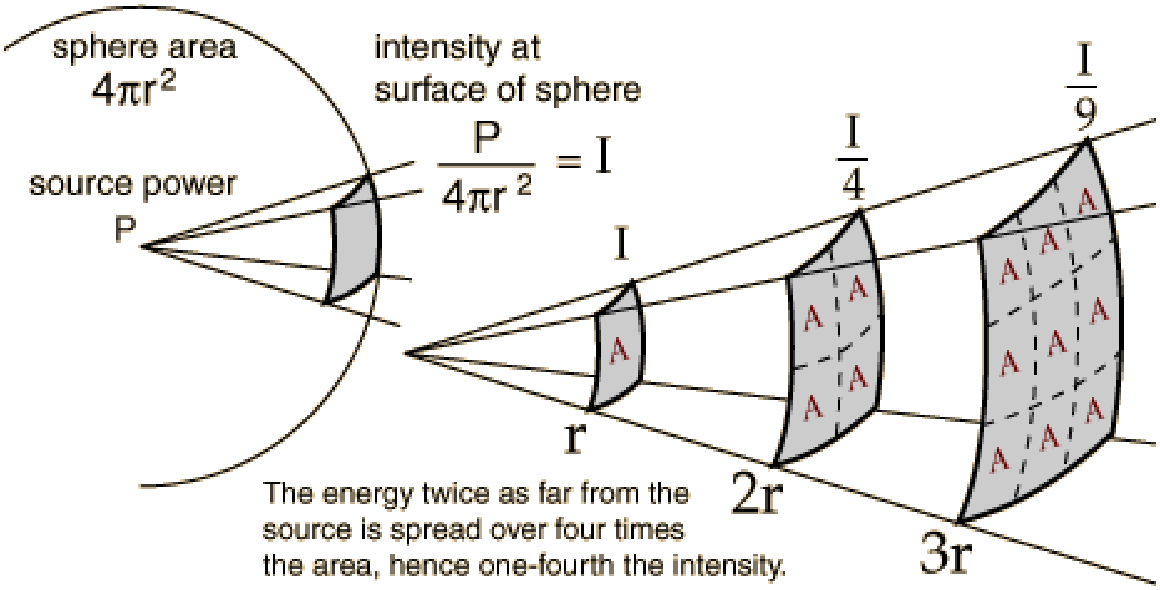


Figure 7 - Inverse Square Law(5)

As seen in the figure above, the intensity of the wave decreases exponentially. The intensity of a wave at 10 meters will be 1/100th of the intensity at 1 meter. This is a fundamental law used in acoustical analysis and has a great effect on outdoor acoustics. This law shows why a large amount of power would be needed in order to create loud noises over a long distance.

2.3.3 Reflection and Absorption

Traveling sounds often come into contact with physical barriers, such as: trees, water, rocks, soil, grass, etc. These barriers interact with the sound waves depending on the acoustic properties of the barrier and will reflect and absorb some of the sound waves. These reflected waves might be reflected back to a listener or microphone. Those waves are reverberations and commonly called echoes. Reflection also determines how wind influences sound propagation. Sounds appear to be carried by the wind when people are downwind of a noise source and the opposite is true when they are upwind of the noise source. This is not because the wind actually carries the sound but because the wind blowing away from the sound source is less likely to reflect or push the sound waves. When sound travels into the wind it is pushed up by the wind and away from listeners on the ground.

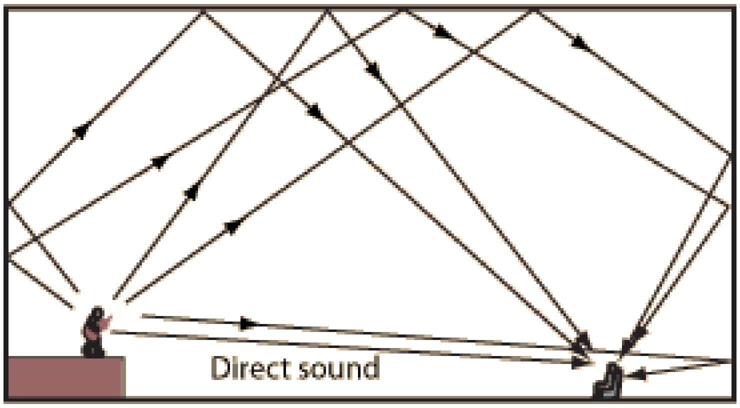


Figure 8 - Reflections and reverberation(10)

2.3.4 Sound Weighting

The loudness of a sound wave is determined by its frequency and intensity. Humans do not perceive sounds to be exactly as loud as their intensity. This is because of the way the human ear and brain have evolved to analyze sound. Because of this phenomenon, scientists have come up with weighting systems that can be applied to better approximate the loudness of sounds to the listener.

The most common system of analysis is A-weighting. This method is a weighting filter that accounts for human hearing. At lower volumes, the human ear hears pitches between 3-6kHz louder than lower and higher pitches. The filter weighs the measured loudness to better reflect the perceived loudness. B, C, and D-weighting filters also exist and are used for louder sounds. Large-scale warning systems use C-weighting. The warning systems are so loud that the perceived loudness is much closer to the measured loudness.

The weighting system is based on Fletcher-Munson curves. Harvey Fletcher and Wilden Munson developed the Fletcher- Munson's curves in 1933. The curves are a set of equal loudness contours. All the points on the contours, as seen on the graph below, have an equal perceived loudness. For example a sound wave with a frequency of 4kHz and intensity of 70 decibels is of equal loudness to the lower frequency of 100Hz at an intensity of 85 decibels.

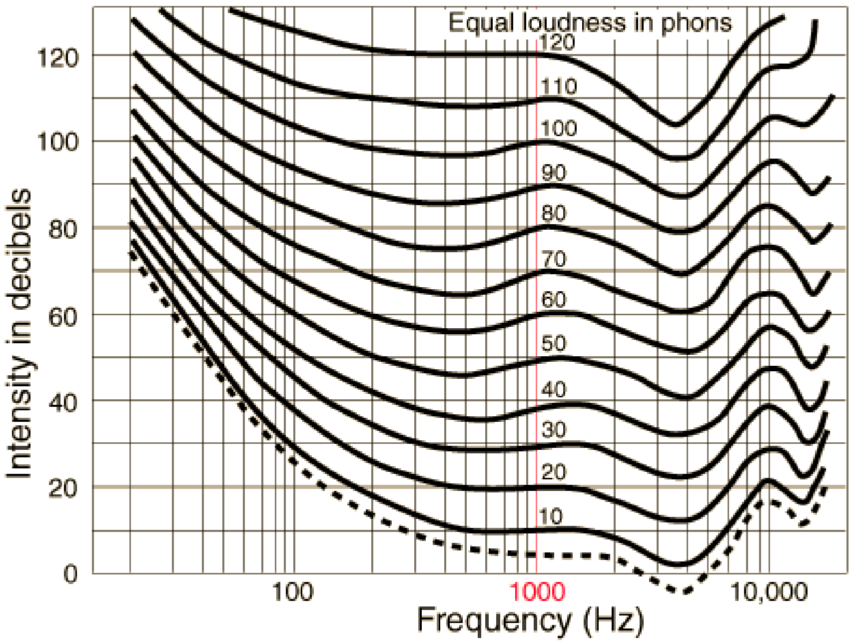


Figure 9 - Loudness(2)

At higher intensities the relative loudness contour is more flat than at lower volumes. This is why different weighting filters are used at different intensities.

The American National Standards Institute (ANSI) is an organization responsible for coordinating US national standards with international standards. ANSI had published numerous guides for analyzing sound outside using various methods for various applications. The guides that ANSI has published include detailed procedures for recording sound levels and the apparatuses required for to meet official standards. ANSI also has a certification program to show that their standards have been met for particular processes.

3.Methodology

This project studied the way sound behaves on Mount Desert Island to build a scientific foundation for the artistic concept of the Environmental Orchestra. Key locations were tested so that the unique geographical and ecological features common to the island could be acoustically understood. The testing methods used in these unique locations were designed by the team members specifically for outdoor and large environments. They used microphones, a source sound signal, and computer software to collect information about how sound interacts with its environment. Two different testing methods were developed, one for short distances no more than 100 feet, and another for longer distances no more than 600 meters. The two methods each focused on a different aspect of acoustics. The short distance test evaluated the frequency response of the soundscape being tested, whereas the long distance test generated data about dissipation of sound. The data collected using these two testing methods generated an encompassing knowledge base that could be drawn upon to help further the scientific and artistic pursuit of the Environmental Orchestra.

3.1 Equipment

The equipment used in both testing methods came from four main categories, recording hardware used to record or measure acoustic signals, sound sources that produced sound waves, software used in data collection and analysis, and additional equipment needed for the testing procedures.

3.1.1 Recording Hardware

3.1.1.1 TASCAM DR-40

Field recordings were taken using a pair of Tascam DR-40 Linear PCM recorders. These recorders were used because their small size made them easy to bring on location, quick to set up and simple to use. The Tascams use two directional microphones to record sound in stereo. These microphones are hidden in Figure 6, under the silver windscreen that was used in the field. The recordings taken with the Tascams were stored as 16bit WAV files on an SD card that were easily removed and plugged into to a computer where the data could be taken for analysis. The sample rate for each recording was 44.1 kHz. Input levels could be controlled using buttons on the side of the recorders and were adjusted to ensure the recordings were sensitive enough to pick up the sounds but low enough that the Tascams did not peak out.

Figure 10 - Tascam DR-40

3.1.1.2 REED ST-805 and REED SC-05

Sound pressure was recorded using a type-II sound pressure level meter. The Reed ST-805 allowed the max SPL to be held on the screen and recorded. The SPL meter was also capable of weighting the sound using either A or C. The Reed SC-05 was a class two sound calibrator, which fit over the microphone of

Figure 11 - ST-805 and SC-05

the Reed ST-805 tightly and was capable of producing either a 94dB or 114dB 1000Hz tone.

In order to ensure accurate readings, the Reed ST-805 was calibrated by fitting the Reed SC-05 over the microphone and adjusting a pair of screws located behind the battery so the SPL reading matched the output of the calibrator.

3.1.2 The Sound Source

Acoustical testing of reflection patterns, absorption, and loudness at a distance requires a source sound. This sound can vary between tests, for example to test frequency absorption, a specific acoustical frequency is required, while testing reflection patterns requires a burst of less specific waves. The acoustical tests done for this project required four types of sounds, and used two different sound sources, a compressed air powered horn and a loudspeaker system.

The sound source was a crucial part of both testing methods developed. It produced the signal that was used to measure acoustic parameters of the soundscape being analyzed. The two testing methods developed, one for short and one for long distances, each utilized different sound sources. For short distances, a portable loudspeaker system was used, and for long distances, an air horn was used.

3.1.2.1 Portable Loudspeaker System

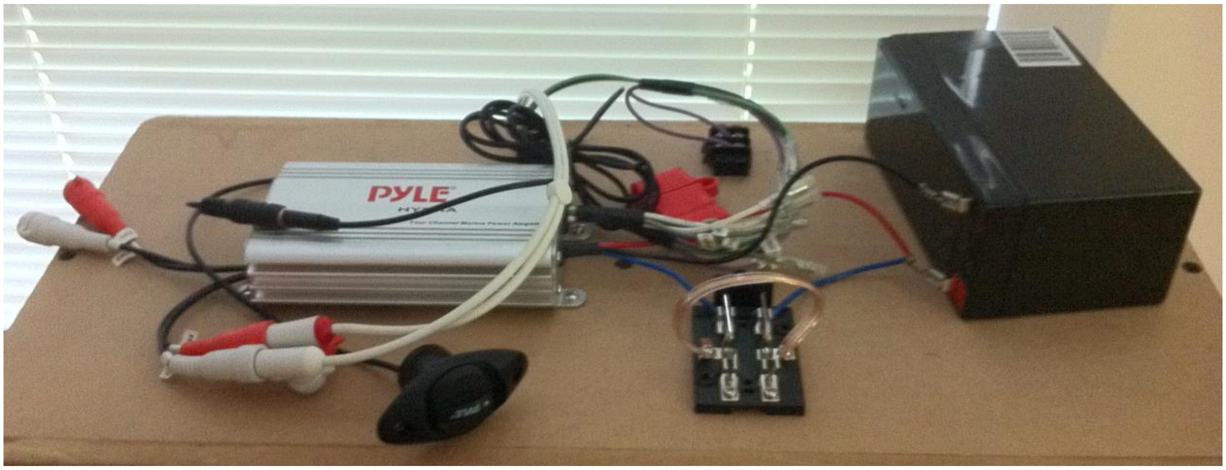


Figure 12 - Loudspeaker Top

The loudspeaker system was required to be portable, powerful, and acoustically accurate. It was custom designed and built to be battery operated, reach the necessary loudness levels, and produce frequencies from 80 to 20,000 Hz. The system was powered by a 12 volt, 8Ah sealed lead acid battery and a four channel, 400 Watt RMS amplifier. The loudspeaker portion consisted of two 6 inch paper cone drivers, two 1 inch soft dome tweeters, and two custom crossover networks (see Appendix I for technical specifications and circuit design on the portable loudspeaker system). The entire system was designed to be carried as a backpack, and easily transported via hiking trails to the various testing locations.

Figure 13 - Loudspeaker Front

3.1.2.2 Air Horn

Figure 15 - Air Compressor(4)

Figure 14 - Air Horn(9)

The air horn was powered by an 8 gallon air compressor. The air compressor was able to hold air safely at a pressure up to 120psi. The compressor was charged electrically by plugging into a standard outlet. The air compressor had two gauges. One showed the internal tank pressure and the other showed the air pressure that was being output through the hose.

3.1.3 **Software**

Room Equalizer Wizard(12) version 5.00 build 2142, referred to here after as REW, was a Java based software designed by John Mulcahy. It simultaneously produced and recorded, by means of an attached speaker system and microphone, an audio signal. It was capable of Fast Fourier Transforms (FFT) that enabled the recorded sound wave to be analyzed on a per-frequency basis. It also processed audio data with respect to time. The information collected by the software was presented to the user in graphical forms. REW was dependent upon the sound card in the computer on which it was running. All output and input signals handled by the software had to be passed through the soundcard. It was also possible to import and export files, enabling it to be used in conjunction with other programs.

Audacity(1) was used to analyze .WAV files taken from the Tascam recorders. Once imported the files could be viewed spectrally. This allowed for the important signals in the file to be located. After locating a section of interest, it could be selected in the program and analyzed by plotting spectrum. The spectral graph showed frequency and intensity and could be exported as a .txt file for further analysis in REW.

Microsoft Excel was used to create projections of the inverse square law. Projections were made by editing the .txt files outputted by Audacity. When opened in Excel there were two columns containing data for frequency and intensity. A third row could be generated using the inverse square law, which projected the intensity of the signal at various distances. The projected data could later be compared to the real data collected in the field.

3.1.4 **Additional Items**

Other gear used during the project included 2 tripods that were compatible with the Tascam recorders, a GPS unit for marking locations, an anemometer equipped with a thermometer, and handheld transceivers for communication when out on location.

3.2 Field Tests

Both of the testing methods developed were designed to analyze outdoor acoustics, and so these tests were done as experiments, out in the field. The field tests conducted use a sound source to generate a known signal. That signal travels through and interacts with a soundscape, then is recorded by a microphone. That recording is compared with the signal initially generated to analyze the acoustics of the soundscape. Additional data such as wind speed and temperature on location was recorded, along with a detailed written and photographic documentation of the landscape the field tests were being conducted in. The two testing methods shared this procedural outline, but were carried out with different equipment and in slightly different ways.

3.2.1 **Short Distance Test**

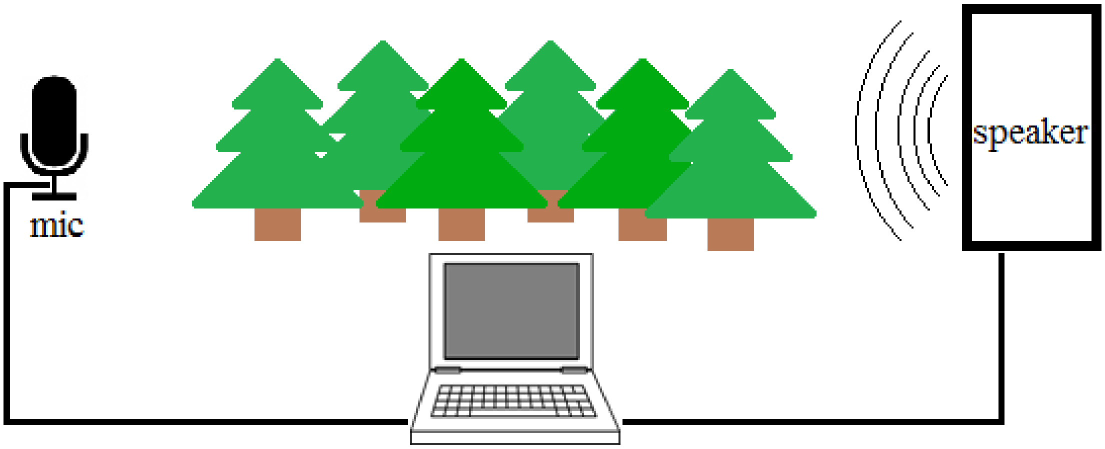


Figure 16 - Short Distance Test

Tests done at short distances were used to analyze frequency response of a soundscape, using the Tascam DR-40 recorder as a microphone, a laptop computer equipped with REW software, and the portable loudspeaker system. A tripod and an anemometer were additional equipment used in this test.

Firstly, the apparatus and software were prepared for testing. The speaker was connected to the audio output of the computer with a 100 foot 3.5 stereo male to 3.5 stereo male cable. The Tascam DR-40 recorder was connected to the microphone input of the computer with a 25 foot length 3.5 stereo male to 3.5 stereo male cable. The speaker and the Tascam were placed 100 feet apart, facing each other, in the soundscape that was to be tested. The Tascam was attached to the tripod, and the speaker was positioned in such a manner, when possible, to be elevated above the ground immediately in front of it (this included setting the speaker upon boulders with sheer faces, so that the sheer face was flush with the front of the speaker). Both the speaker and the Tascam were powered on, and the Tascam was set to record mode. The volume of the computer was set to maximum, and the gain on the amplifier was set to a level sufficient enough to accommodate output levels usable at 100 feet, without causing distortion in the amplifier (distortion in the amplifier is discussed in the Results section). The computer was powered on, and the REW software opened.

After preparing the testing apparatus, REW was used to take data. Firstly, the output level of the computer-speaker system was tested with the “check levels” feature in the “make a measurement” dialogue box. The levels were adjusted, using the “level (db FS)” feature in the “make a measurement” dialogue box, so that they were deemed usable by the REW software (level usability was indicated by the “check levels” feature). After the levels were checked, the start frequency was set to 40 hz, the end frequency to 20,000 hz, the length to 256k, and the number of sweeps to 8, using the appropriate features of the “make a measurement” dialogue box. The “start measuring” button was pressed to begin the testing. All the experimenters involved were as quiet as possible during the testing, so as not to create excess background noise as the signal generated by the speaker traveled through the soundscape to the microphone.

The final steps of the short distance test were to record additional pertinent data. The wind speed was measured with the anemometer and recorded. The soundscape was described and documented in detail, with special attention to the foliage, any buildings, boulders or rocks present, and also the positioning of the speaker with respect to the ground and the microphone (examples of these documentations are seen in the Results section of this report). Any abnormalities in the testing procedure, such as error messages or strange clicks in the signal produced by the speaker, were also recorded. The data file produced by REW was saved in an organized file system, which was regularly backed up in case of computer failure.

3.2.2 **Long Distance Test**

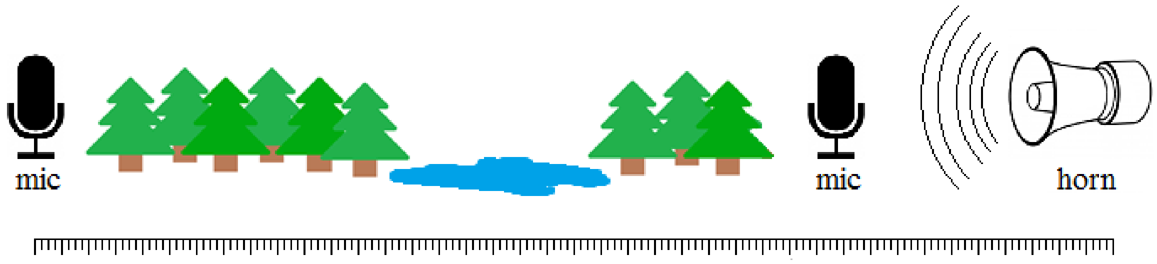


Figure 17 - Long Distance Test

Long distance tests were used show how the intensity of sound changed as it traveled, and utilized an air horn, powered by a compressed air tank, as the sound source, two Tascam DR-40 recorders, the Reed ST-805 type II SPL meter, and two tripods. One Tascam was used to record, at the source, the signal generated by the air horn, while the other was used to record, at a distance, the signal after it had traveled through a soundscape.

The equipment was setup and prepared for testing. The air horn and accompanying compressor were placed at a desired location. Half a meter away, one tripod with the Tascam and SPL meter mounted to it was placed so that both measuring instruments were pointed towards the air horn. At a desired distance away, or at distances where it was feasible, the second tripod and Tascam were set so that the Tascam was securely mounted to the tripod and pointed in the direction of the air horn. Both of the Tascams, along with the SPL meter, were equipped with wind screens. The experimenters used handheld transceivers to communicate, and both Tascams, along with the SPL meter were powered on. The Tascams were set to record in 16bit .WAV format, and the input sensitivity was set to 40. The SPL meter was set to “FAST” for sample rate, “Hi” for intensity level, “A” for weighting, and “MAX HOLD” mode.

After setting up the testing equipment, the experimenters began recording with Tascams. The air compressor was set to 30 psi and the air horn was sounded, half a meter away from, and pointed in the direction of, the recording equipment in a quick burst sound, not a sustained one. The maximum intensity held by the SPL meter was recorded as the intensity of the air horn signal at half a meter away. The SPL meter was reset to “FAST” for sample rate, “Hi” for intensity level, “A” for weighting, and “MAX HOLD” mode. The air compressor was set to 50 psi and the air horn was sounded, half a meter away from, and pointed in the direction of, the recording equipment in a quick burst sound, not a sustained one. The maximum intensity held by the SPL meter was recorded as the intensity of the air horn signal at half a meter away. Both Tascams, after recording both the 30 and 50 psi blasts, were stopped recording. The .WAV files recorded were later stored on a computer, and analyzed with software.

Additionally, the wind speed and temperature were measured, the soundscape was described and documented in detail, as were any abnormalities in, or pertinent observations of, the testing procedure.

3.3 Data Analysis

Data generated from field-testing was analyzed was using Audacity and REW. REW conducted real time analysis of sounds. These programs allowed for the measurement of absorption, reflection and reverberation. These tools allowed for the graphical representation of reverberation and attenuation. Each graph was interpreted by comparing it to control data and other data collected to understand how the sound was interacting with the environment.

3.3.1 **Short Distance Test**

For tests using the portable speaker system, the software Room Equalizer Wizard (REW) was used to generate a signal for the attached speaker system, and simultaneously record the produced sound wave with an attached microphone.

REW did real time analysis of the signal generated and produced graphs showing the intensity and pitch of the sound waves. In addition it produced waterfall graphs showing the intensity and pitch over time. These graphs were analyzed to produce qualitative and quantitative data about reverberation and frequency attenuation in the soundscape tested.

3.3.2 **Long Distance Test**

The data from the long distance field tests is analyzed making use of computers with Room EQ Wizard (REW) and Audacity. The TASCAM recorders store data as a .WAV file.

This file is uploaded to the computer and opened in Audacity. Audacity computes a spectral analysis of the recordings of the source noise. The spectral analyses are then exported as .TXT files and opened up in REQ. REQ allows 2 spectral analyses to be put on the same graph making comparisons simple and quick. The spectral analysis shows the intensity of sound vs. the frequency of the wave. Putting both graphs together allows viewers to look at frequency attenuation.

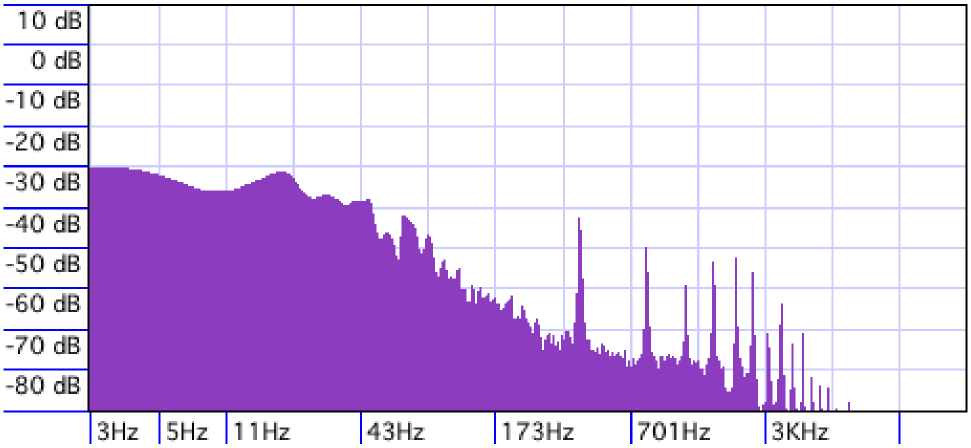


Figure 18 - Example Audacity Spectrogram

Additionally the inverse square law is applied to each test to see if the intensity attenuation was more or less than predicted. If the intensity was lower then it shows absorption took place across certain bands. If the intensity was higher than expected it means that the sound was directed towards the microphone by reverberation.

4.Results

4.1 Equipment

4.1.1 Recording Hardware

The Tascams recorders were used in both the short and long distance tests. During the first long distance testing, the levels recorded were low. This made it impossible to analyze the data. In order to improve the levels during the subsequent tests, the input levels on the Tascams were increased to an adequate level of sensitivity for the long distance test. In addition to ensuring that the data was sensitive enough, the input level could not be set too high or the Tascams would peak out during recordings and give incomplete data. The input level required for the short range tests varied from 35-40 depending on the location. It was found that a level of 40 worked the best for the long range tests.

The SPL meter and calibrator worked well for the majority of testing. During the long distance tests at the forest the SPL meter gave strange readings. During the 30 psi tests the meter giving back higher readings than during the 50 psi tests. This does not line up with the recordings, which show that the 50 psi tests were more intense signal. This could be due to the A weighting that the SPL meter applied to the signal, although this improbable. The recordings from Lower Hadlock Pond did not have this inconsistency despite using the same weighting. It is more probable that there was human error in the setup of the SPL during the testing at the forest.

4.1.2 Sound Sources

There were two sound sources used, one compressed air horn, and one portable loudspeaker system. The portable loudspeaker system was limited by the intensity level of sound it could produce, but it could produce a full spectrum of frequencies. The air horn was capable of producing much higher intensity sound, but had no spectral pitch control.

The air horn produced a much higher intensity signal that would travel over the longer distances, however the signal produced from the air horn each time was not exactly the same, therefore an additional Tascam DR-40 recorders was used recorded the signal generated by the air horn at the source each time, so as to have something to compare the distance recording to.

Distortion is the alteration of a signal inputted to a sound system, so that the output of the system is not accurate to the intended input signal. The portable loudspeaker system used as a sound source during experimentation was subject to a specific type of distortion called harmonic distortion at high volumes. Harmonic distortion is the addition of unwanted frequencies to the input signal. Those additional frequencies are integer multiples of the intended frequency, and are also known as harmonics. The Distortion in the portable speaker system made it incapable of being used as a sound source for long distance tests.

An additional limit was that the short distance test required the sound source and the microphone to simultaneously be connected to the same computer. These tests were those that utilized the REW software to measure frequency response curves. 125 feet of cable connected the speaker, computer, and microphone, enabling frequency sweep testing of areas from zero to 100 feet in length (the experimenters could not be in the line of sight between the speaker and the microphone). These tests were used to sample different environments that sound might travel through on the island. Evergreen forests, sandy areas, and rocky areas are just some examples of different environments.

4.1.3 **Software**

Software was an important part of data collection and analysis. Three software titles were used: Audacity, Microsoft Excel, and Room Equalizer Wizard (REW). It was originally intended that only Room Equalizer Wizard would be used, however the data analysis for the long distance tests was not possible using REW alone; it could only make measurements in real time based on a microphone input, not an imported recording. Two supplementary software titles, Audacity and Microsoft Excel were used to enable long distance data analysis. Audacity was used to manage recordings, trimming them to contain only data, and not superfluous material such as human voices. It was then able to export the audio recording as a data file (.txt was the file type, to be specific). Microsoft Excel was able to manipulate that data file, a necessary step for some analysis, but not for recordings. The data files of the recordings were imported to REW, so as to graphically represent the recordings for further analysis. This chain of software was the solution to the issues encountered with REW. Another solution might have been replacing this software chain with a single software title that enables the analysis of imported recordings in addition to making the real time measurements REW made.

4.1.4 **Additional Items**

The handheld GPS used for testing was highly inaccurate. The GPS gave users feedback on the accuracy of the coordinates. While in an open field the accuracy hovered around 7m. In the forest, the GPS feedback said it was accurate between 7m and 20m. Later when the coordinates were put back for use in analysis, they were found to be much less accurate than 20m. The trail where the coordinates should have been was at least 100m away from a nearby pond. The coordinates the GPS recorded were on the far side of the pond at least 150m away from the testing areas. Due to this, the distances in the long range testing at the forest are less accurate.

4.2 Short Distance Test

The short distance tests were conducted in six different locations, including two grass fields, a rocky area at a mountain top, a rocky stretch of shoreline, a rocky brook, and a mossy-floored evergreen forest. They were conducted following the methodology for the short distance tests, and the resultant data along with the analysis of the data are documented below, organized by location.

For all locations, when testing, a standard measurement was made, but additional measurements made as seen fit by the experimenters. The standard measurement was an average of 8 sine sweeps from 40Hz to 20,000Hz. REW would output eight sine sweeps, and automatically average them, outputting only one graph. This intensity vs. frequency graphs showed the frequency response of the soundscape being tested, expressing the reflective and absorbent, in addition to the reverberant properties of the soundscape. In addition to the standard 8 sine sweeps, additional measurements included recording strictly the background noise and measuring with only a single, un-averaged sine sweep. Other data collected about each soundscape, such as photographs and decay graphs can be found in the Appendix.

Additionally, during the analysis of all locations, a comparison was made to the expected signal output of the speaker, which was an approximation based off the measured frequency response of the speaker. It was made by using REW to add an offset to the measured frequency response of the speaker so that the intensity of the soundscape frequency response generated by a test and the frequency response curve of the speaker graphically match in intensity as closely as possible. Generally, low frequencies were less affected by an environment, so this approximation was made by graphically aligning the lower end of the speaker frequency response curve and the measured response of a soundscape.

4.2.1 Grass Field One

Two grass fields were tested. Both were at the address 105 Eden Street, Bar Harbor, Maine, on the campus of the College of the Atlantic. The figure below shows satellite images of Field One, with approximate positions of the portable speaker system and microphone marked by icons.

Figure 19 - Grass Field One

Field One was an open, level grassy field, with well cut grass. It was bordered by a row of trees and a busy road on one side, scattered trees and a six foot grass banking on the opposite, with buildings on the side behind the speaker, and behind the microphone. The road was a source of background noise however it was not so great so as to prevent testing. Multiple repetitions of the short distance were done at Field One. The first, here after referred to as Test One, was an average of 8 sine sweeps, using REW, which produced data that exhibited a peculiar linear periodicity in frequency response. This periodicity was unusual, and the testing was repeated a second time, here after referred to as Test Two, to either confirm or deny the suspicion that the periodicity was an anomaly.

4.2.1.1 Field One, Test One

There was a strange anomaly in the intensity vs. frequency plot generated. There was a periodic repetition of dips in the response. Starting at 350±5Hz, there were 10±5dB drops in the response, that occurred every 100±5Hz. There were also sharp phase shifts that seem to correlate to these drops.

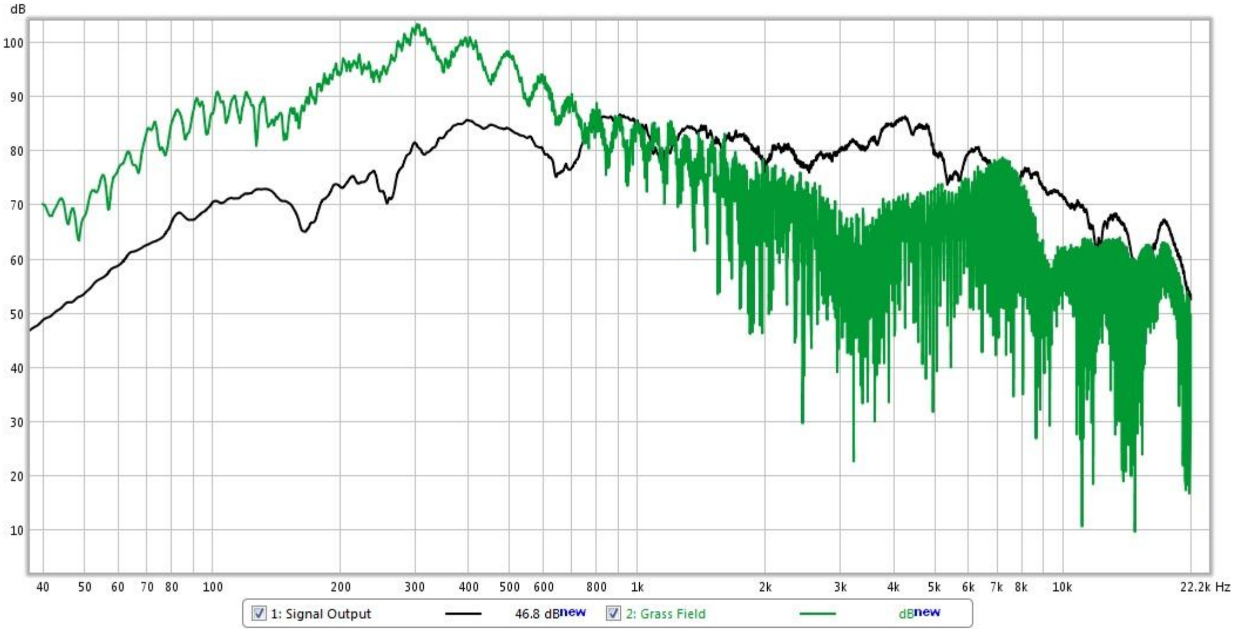


Figure 20 - The signal outputted compared to the average of 8 signals received after traveling through a grassy field

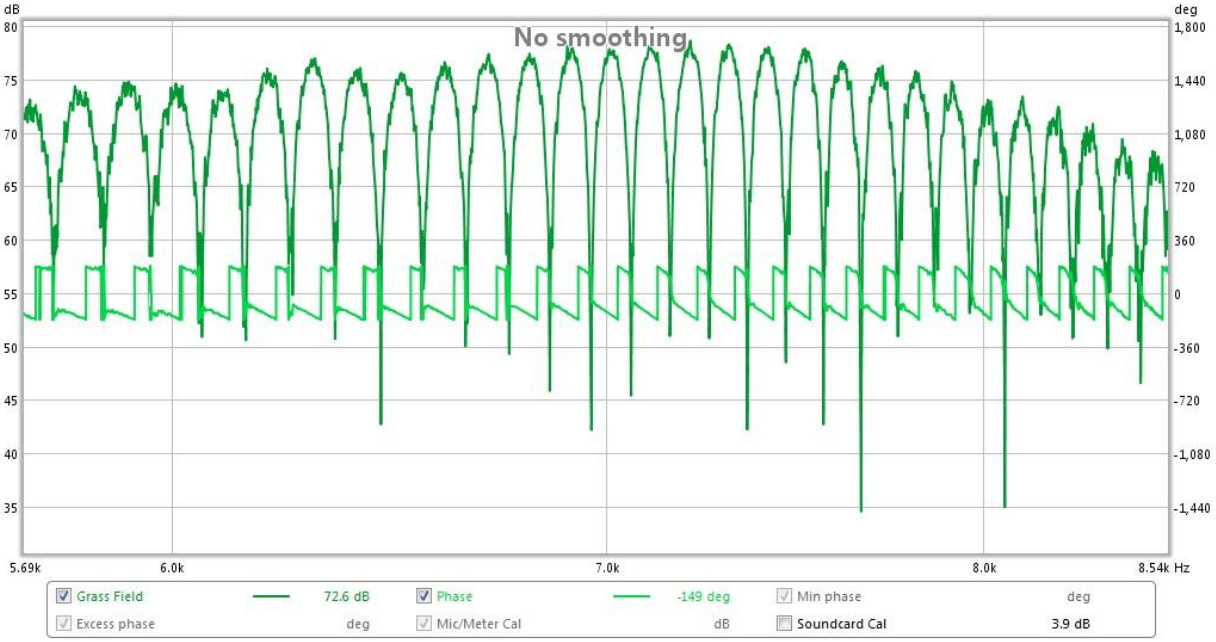


Figure 21 - An example of the periodicity in frequency response and phase observed

The decay graph in Appendix III shows that a frequency range of 1600 to 4000Hz decayed more slowly than the rest of the graph, especially the 2700 to 3700Hz range. This frequency range also had less consistent repetition of the periodic signal dips, and a phase curve that was less pattern-like.

Besides the periodicity, there were still general trends in frequency response visible. Specifically, there was a maximum peak of 103±1dB at 300±5Hz, which matched the expected signal output (the term expected signal output was discussed at the beginning of the Short Distance Test section) within ±8dB, as did frequencies below 300±5Hz. There was a relative minimum of 56±10dB at 3,290±5Hz, which was a 44±8dB drop from the expected signal output of the speaker. There was a relative peak of 79±1dB at 7240±5Hz, which was 17±8dB below the expected signal output. There was a relative minimum of 55±5dB at 9480±5Hz, which was 35±8dB below the expected signal output. These dips and peaks characterized the response, and exposed that the frequencies below 300Hz were unaffected by the soundscape, and that there were significant signal losses in the mid to high ranges, particularly in the 3,000Hz to 4,000Hz range, and to a lesser extent in the 6,000Hz to 8,000Hz range.

An intriguing observation made was that human hearing is more sensitive in the 3,000Hz to 4,000Hz across many intensities, in such a manner that seemed to counter-act the dip observed in the frequency response of the grassy field. It was also observed that during the testing there were many reflections in the form of audible, distinguishable echoes, presumably off the buildings at the far end of the field.

The overall trend of the response curve suggests that the higher frequencies were interacting with the soundscape in reflective or absorptive ways, as the response of the soundscape varied greatly from the expected speaker output signal. The response curve of the field became very unstable above 1,000Hz, which was observed as high spikes and dips in intensity between neighboring frequencies. This was partially observed as the periodicity issue, but there were clear instabilities in the response in addition to that. Greater variances from the expected speaker signal not only suggested sound waves were interacting with the soundscape, but they also correlated to increased instability in the response curve of the soundscape. This could have suggested that instability in the response curve was due to the soundscape interacting with the sound signal, affecting specific frequencies more drastically than the rest. Alternatively, it could have suggested that the background noise, which was inherently more unstable, was being confused with the sound signal output by the speaker as the overall intensity of the sound dropped. A manner to test which of these two options could have explained the instabilities would have been to run tests at multiple source volumes, and then to have observed the difference in instabilities compared to the difference in intensity of the signal and background noise.

4.2.1.2 Field One, Test Two

Test Two was conducted because the abnormal periodicity in the Test One data warranted further investigation. Test two took procedural variable into more careful consideration. The laptop wireless card was known to cause occasional difficulties with the soundcard, in the laptop computer being used for the testing, and so it was disabled during Test Two. Additionally the cables were arranged in straight lines, with no coils or kinks, and all programs other than REW were closed whilst testing. While arranging the cable in a straight line avoids coils and kinks, it might also act as an antenna for radio frequencies; however there were no observed signs of that in our testing. Additionally, a measurement was made in REW of only one sine sweep, in addition to a measurement of 8 averaged sine sweeps, to check if the periodicity was caused by REW's averaging process.

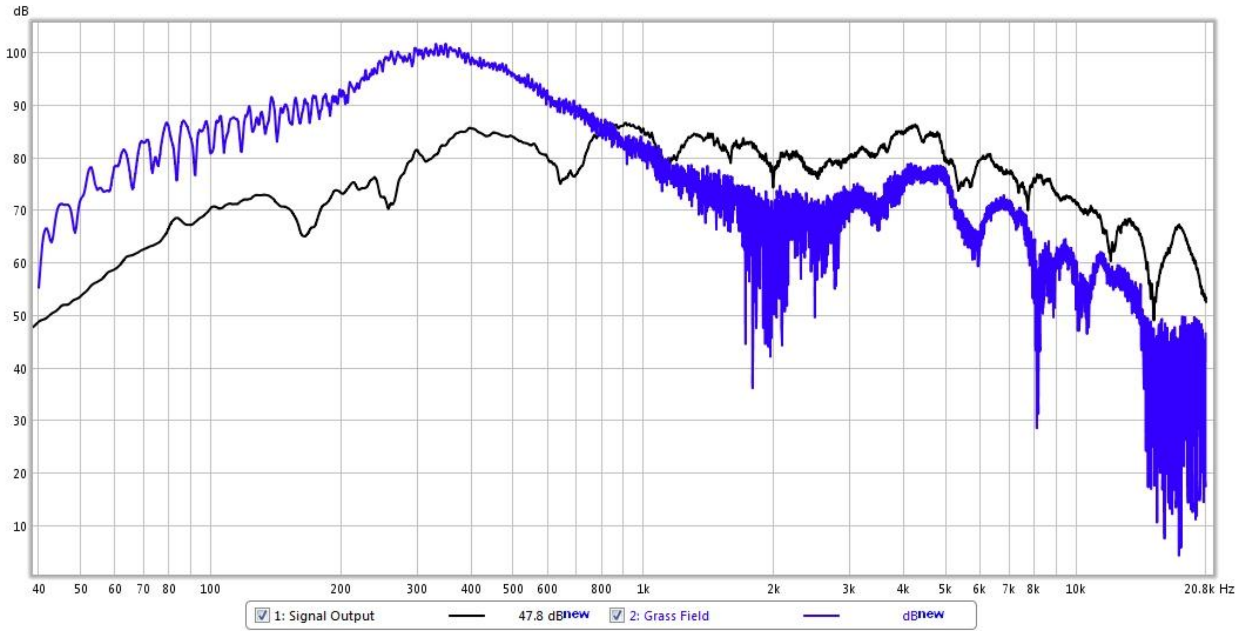


Figure 22: The signal outputed compared to an average of 8 signals recieved after traveling through a grassy field

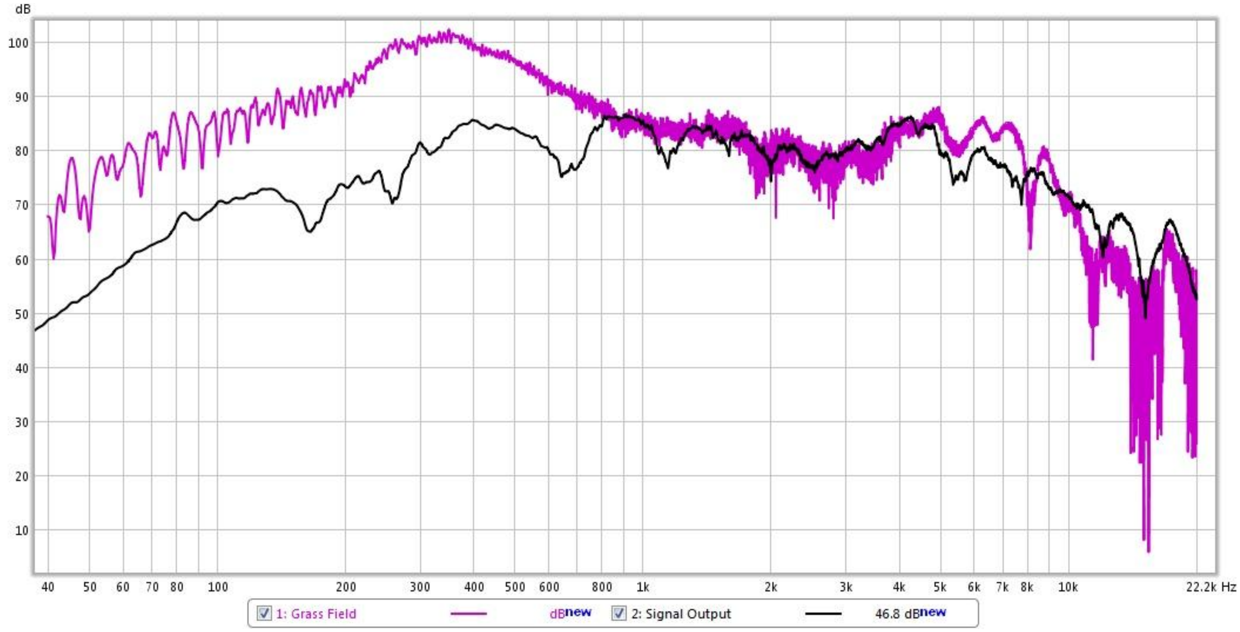


Figure 23: The signal outputed compared to a single signal recieved after traveling through a grassy field

General trends in the frequency in Test Two were very similar to that of the Test One. The main difference was that the dip between 3000 and 4000Hz was less prominent. Test Two and Test One exhibited a similar peak in the 300 to 400Hz range, which is more visible in Test Two, due to the elimination of the periodic frequency dips. In addition the frequency response starting at 3000Hz more closely resembles that of the signal output, suggesting that those signals are attenuated evenly. The dip between 3000 and 4000Hz that was so prominent in Test One seems to have leveled out. The average of the frequencies between 40 and 350Hz had approximately the same slope as the source signal; however it does not follow the source signal as closely as Test One. Because Test Two data was taken on a different day than Test One, it is possible that changing atmospheric conditions affect the frequency response noticeably. There was still a steady drop in frequencies from 350 to 2,000Hz.

4.2.1.3 *Field One, Summary*

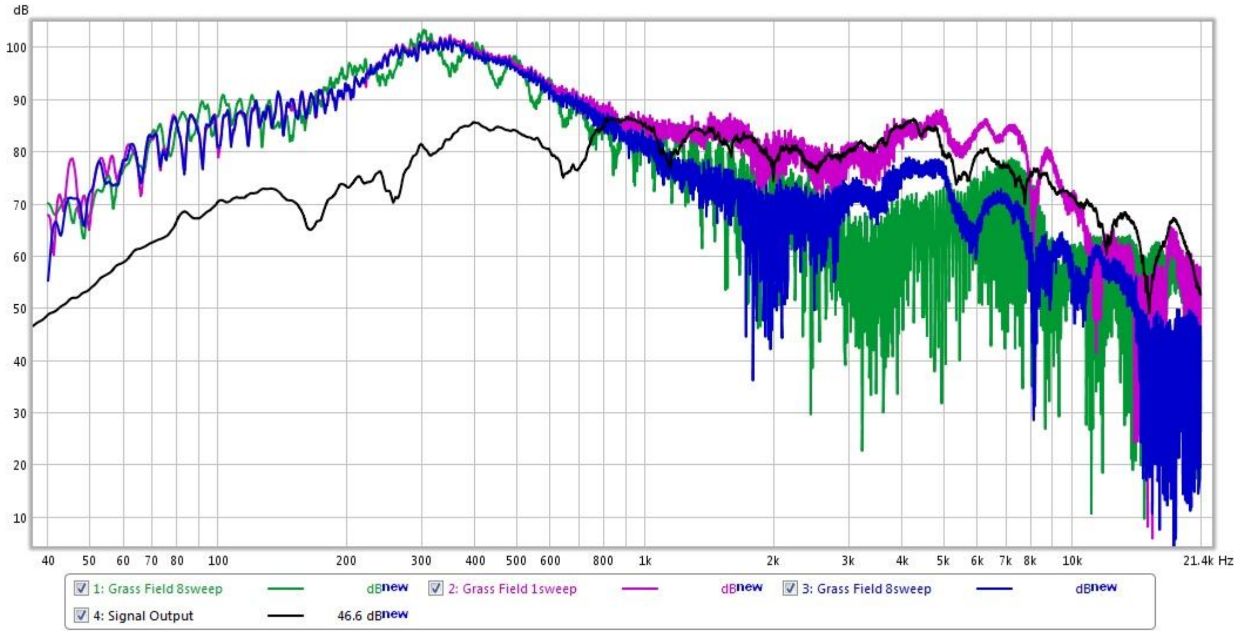


Figure 24: This is the signal output compared to the three different measurements discussed

All the frequency response data collected at Field One was compared. The responses of the lower frequencies, particularly 500Hz and below, were consistent with each other much more than the higher frequency responses. The higher frequencies followed similar response curves, however differed dynamically by substantial amounts. Within the higher frequencies, there was more difference in intensity between the response curves in the 4,000Hz to 10,000Hz range than in frequencies above or below that. The difference in frequency response between test of the same grass field could have been because, in the Field One soundscape, higher frequencies behave in inconsistent, less predictable ways. Additionally, it could have also been because of varying and inconsistent background noise affecting the measurement. Additional tests done at times of low traffic might have shown less inconsistency between measurements.

Despite inconsistencies between measurements, and instabilities in responses, it is visible that the higher frequencies were attenuated more so than the low frequencies. There were noticeable peaks in frequency response between 5,000Hz and 7,000Hz, and the frequency response of the high frequencies was inconsistent and unpredictable in comparison to the lower frequencies.

4.2.2 Grass Field Two

Two grass fields were tested. Both were at the address 105 Eden Street, Bar Harbor, Maine, on the campus of the College of the Atlantic. The figure below shows satellite images of Field Two, with approximate positions of the portable speaker system and microphone marked by icons. Seven measurements were made here, one without wireless and with wavy cable layout, one without wireless and with straight cable layout, one with wireless and wavy cable layout, two background noise measurements, and two single sweep measurements to help further characterize the frequency response.

Figure 25 - Grass Field Two

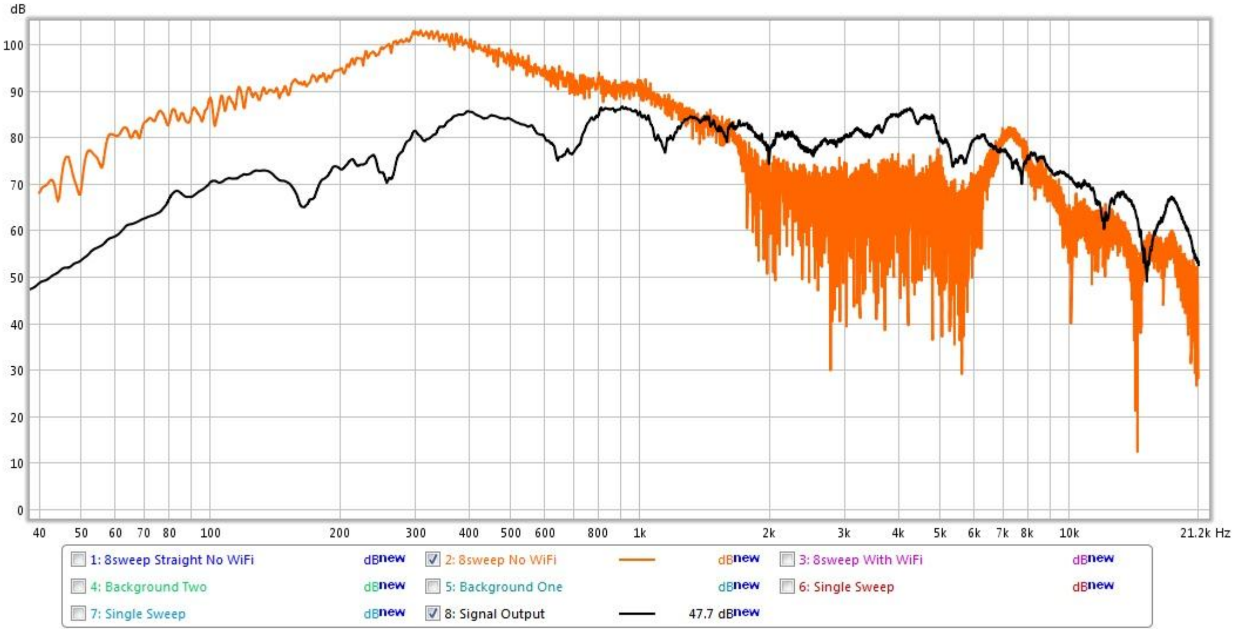


Figure 26 - Measurement without wireless

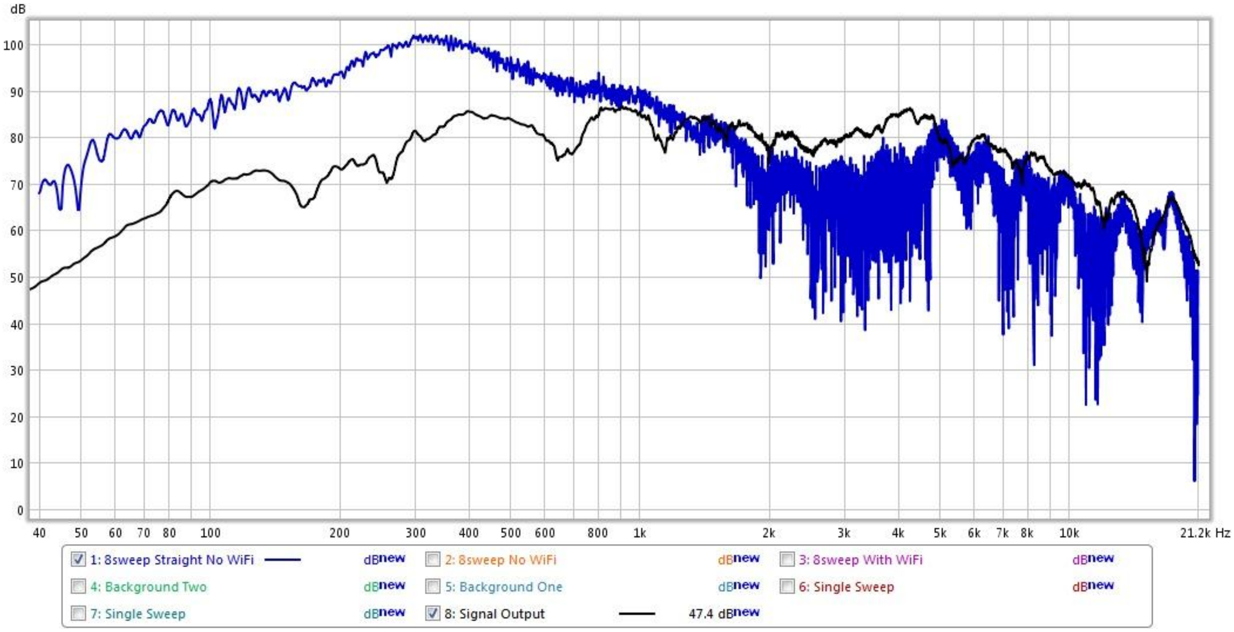


Figure 27 - Measurement with all cables straightened and no wireless

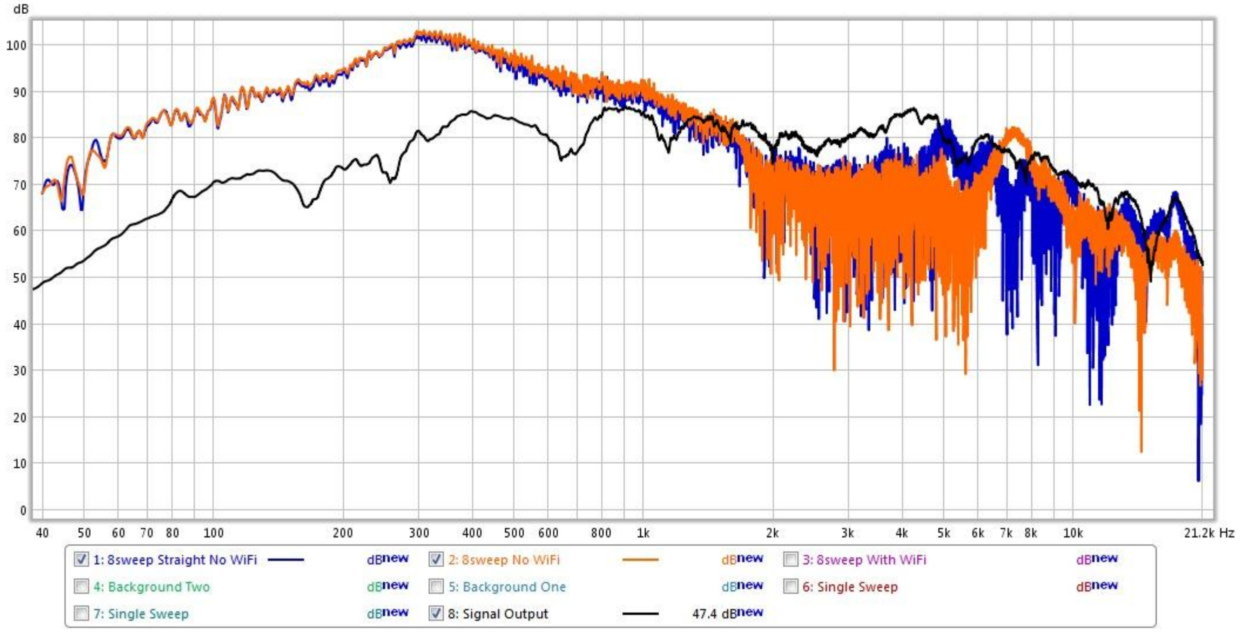


Figure 28 - Measurements both without wireless, but one with wavy microphone cable arrangement and one with straight speaker cable arrangement

There were differences between the tests with different cable arrangements, mostly at lower intensities, where the primary differences were in the response inconsistencies. There was a noticeable difference in the position of a relative peak, which occurred around 7,300Hz for the wavy cable arrangement, and did not occur in the measurement done with a straight cable arrangement. The measurement with straight cable arrangement exhibited two peaks, one at 5,000Hz that was comparatively high, and one at 6,300Hz that did not appear in the measurement it was compared to, but did in other measurements made in the field. The straightness of the cables may have caused the change in frequency response, however the change was relatively small. More controlled tests with repetition in measurements might have shown more conclusively the effect of cable arrangement.

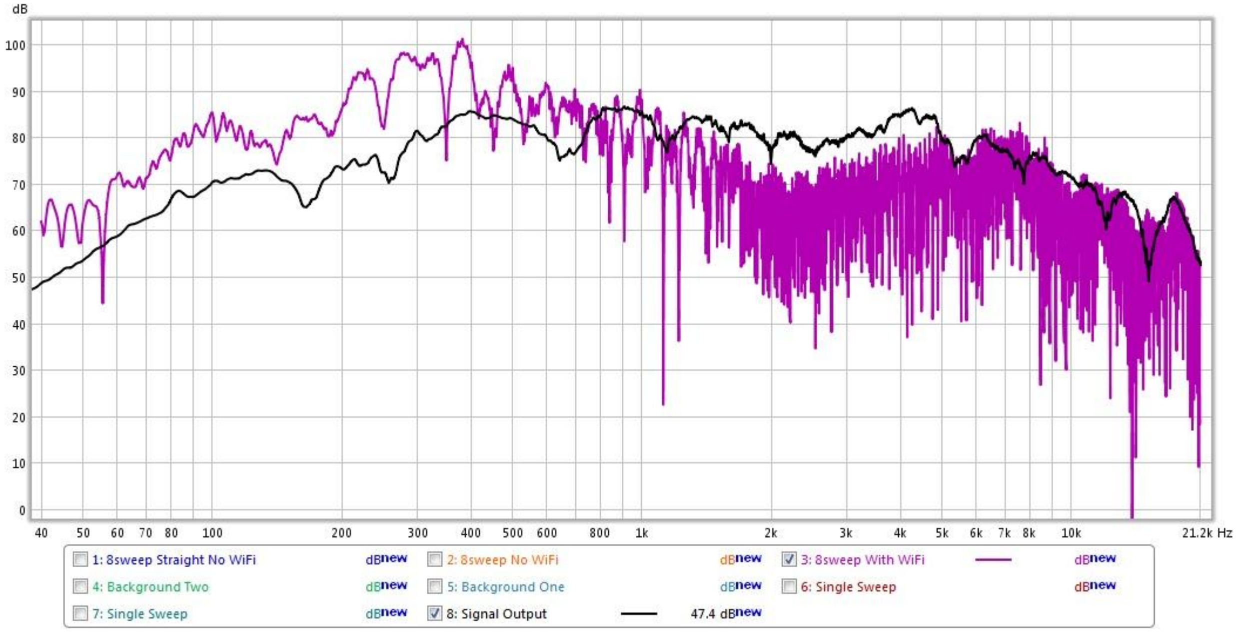


Figure 29 - Measurement with wireless internet active

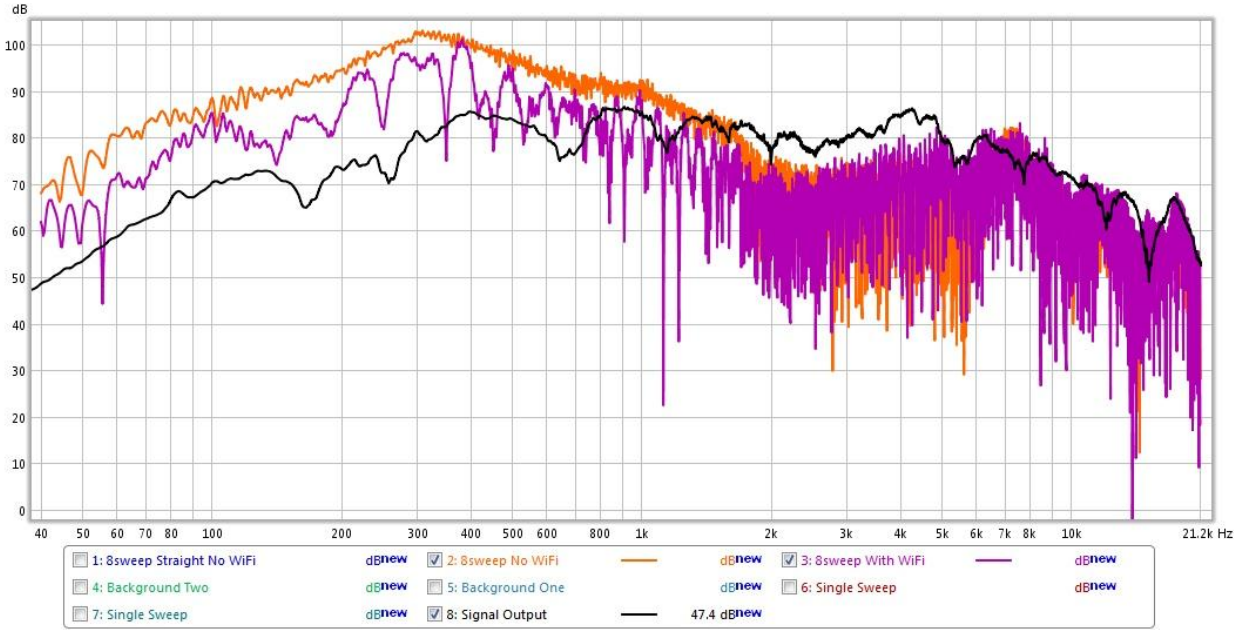


Figure 30 - Measurement with wifi compared to measurement without

The wireless card on the laptop running REW had been known to influence the soundcard, and because REW relied on the soundcard so heavily, accessing wireless internet whilst conducting REW measurements affected those measurements significantly. Measurements made whilst using wireless exhibited sudden drops in the response curve, generating especially inconsistent results. It can be seen in the measurements made in Field Two that having the wireless on can, though it doesn't do it consistently, have a consistent effect on the data collected.

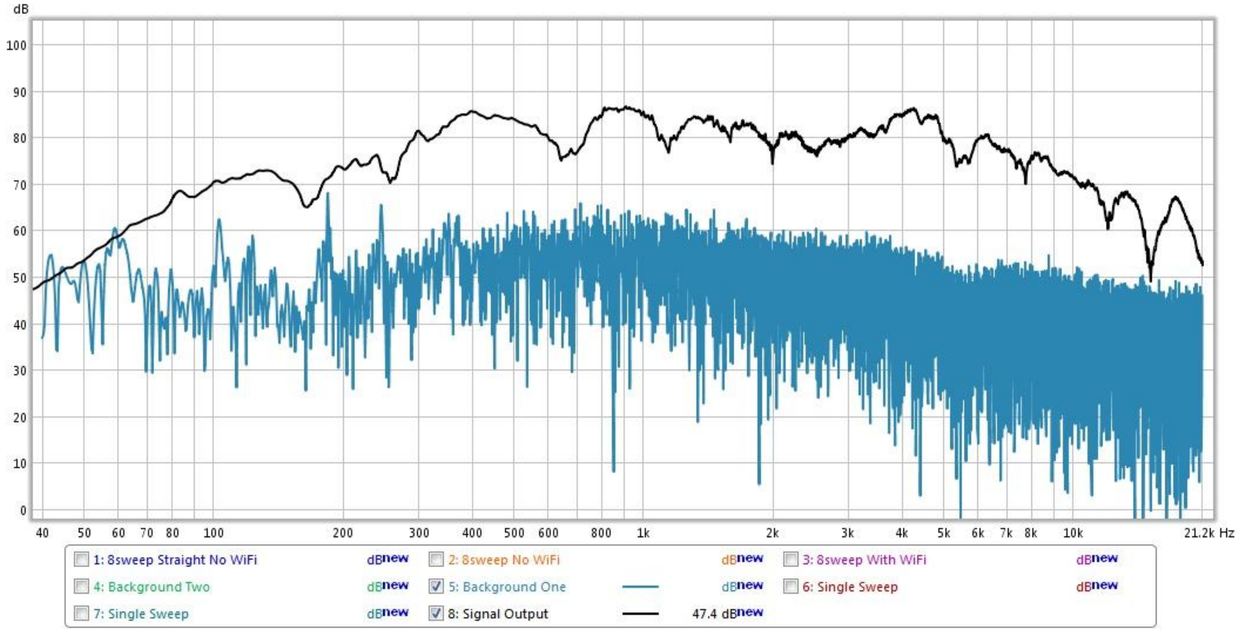


Figure 31 - Background noise measurement one

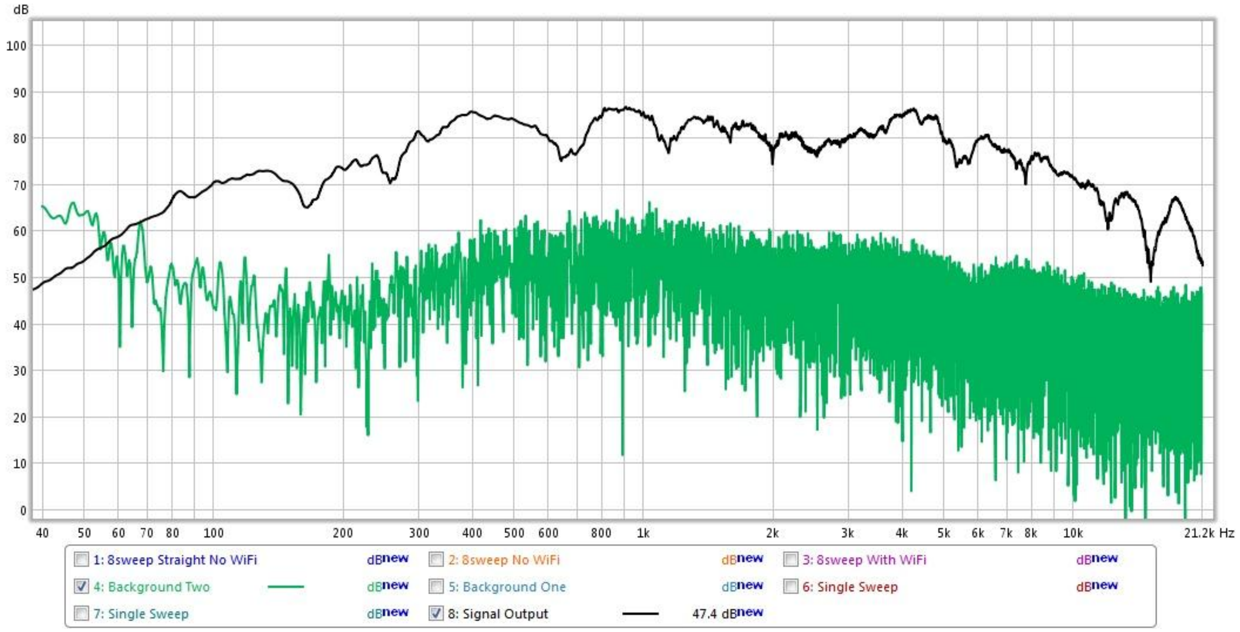


Figure 32 - Background noise measurement two

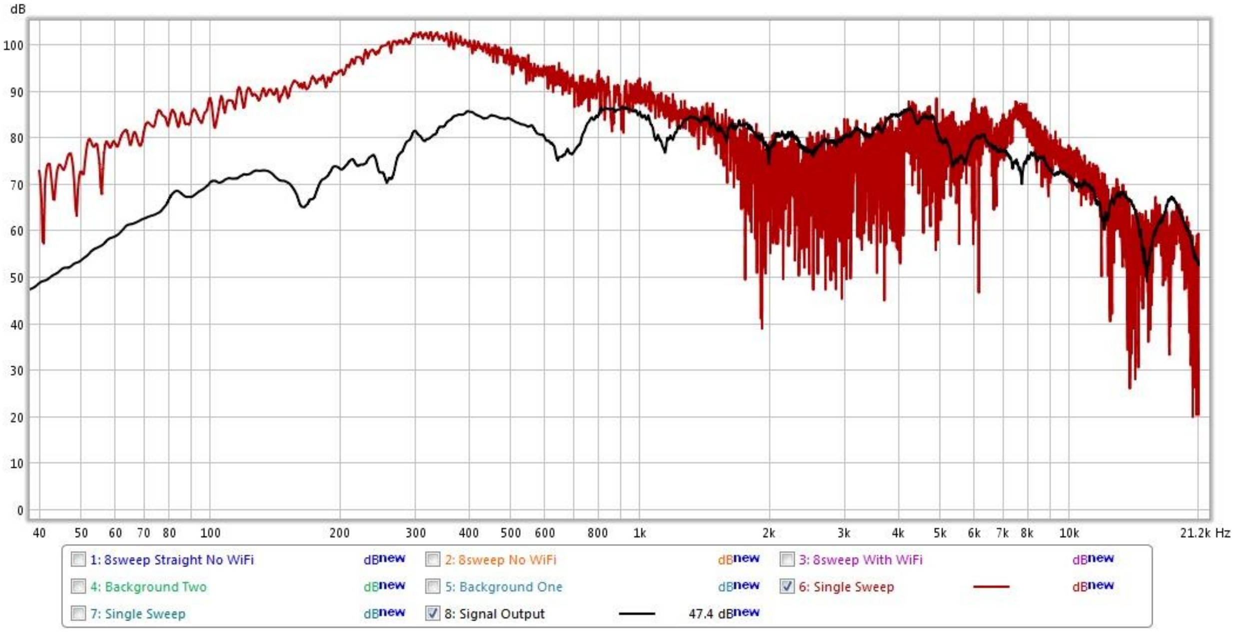


Figure 33 – First single sweep measurement

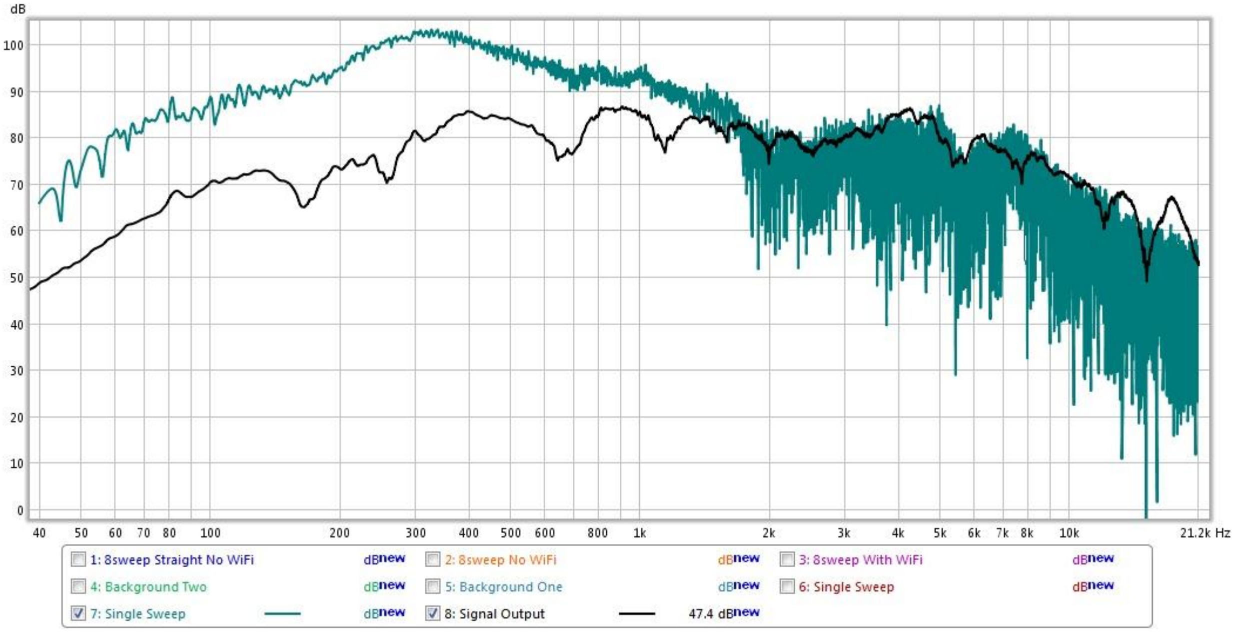


Figure 34 - Second single sweep measurement

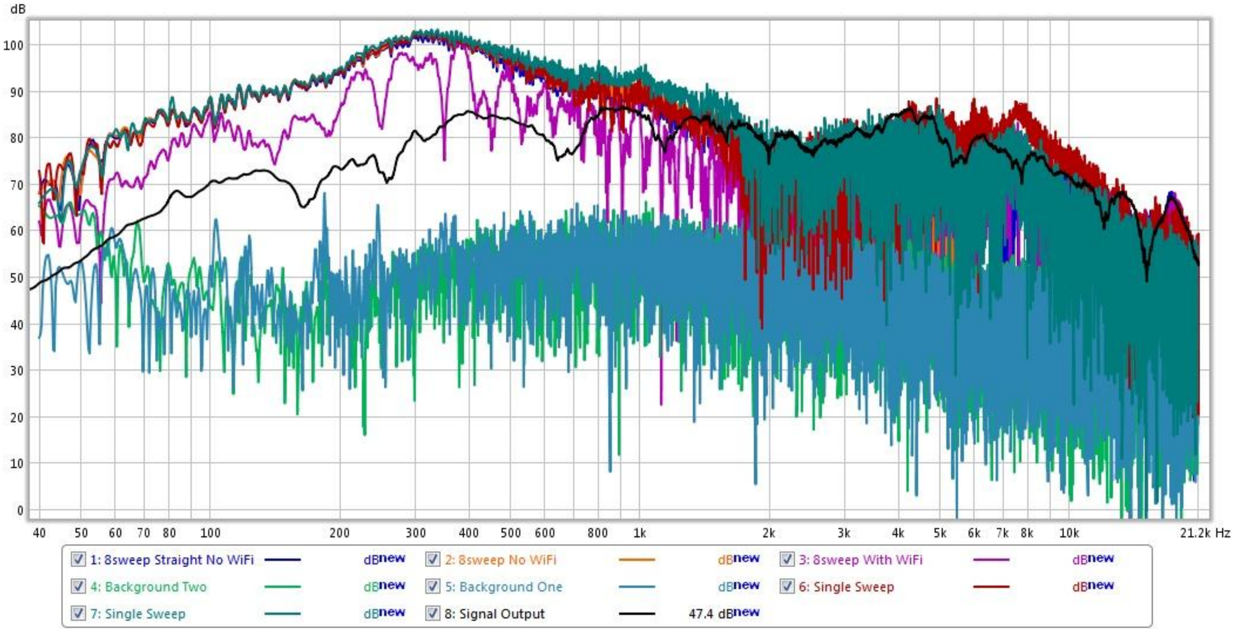


Figure 35 - Overlay of all measurements

With the addition of the single sweep and background data, the characterization of the frequency response becomes more visible. There is a relative dip between 2,000 and 3,000Hz that is visible in all the measurements. Additionally there is an absolute maximum around 300Hz. These two features are common across both grass fields tested, and can be attributed to that soundscape.

4.2.3 Rocky Mountaintop

The rocky mountain top, in particular the one belonging to Norumbega Mountain in Acadia National park, was a unique soundscape that possessed large flat areas of solid rock. These areas of exposed rock gave larger wavelength (lower frequency) sound waves the opportunity to reflect off a surface with an area comparable to its wavelength. This generated initial expectations that the low frequencies would be reverberated and reinforced.

This soundscape was characterized by a rocky area with an elevation change of approximately 20 feet between speaker and the microphone. The open rocky area was surrounded by various evergreen, small and large, narrow and wide needles. Also, some lichen and grass patches were present on the flat rock floor, along with loose rocks approximately a half to two feet in diameter. As in all other short distance tests, there was a 100 foot distance between speaker and microphone, plus two or minus five feet. Two measurements were taken, each an average of 8 sine sweeps from 40 to 20,000Hz.

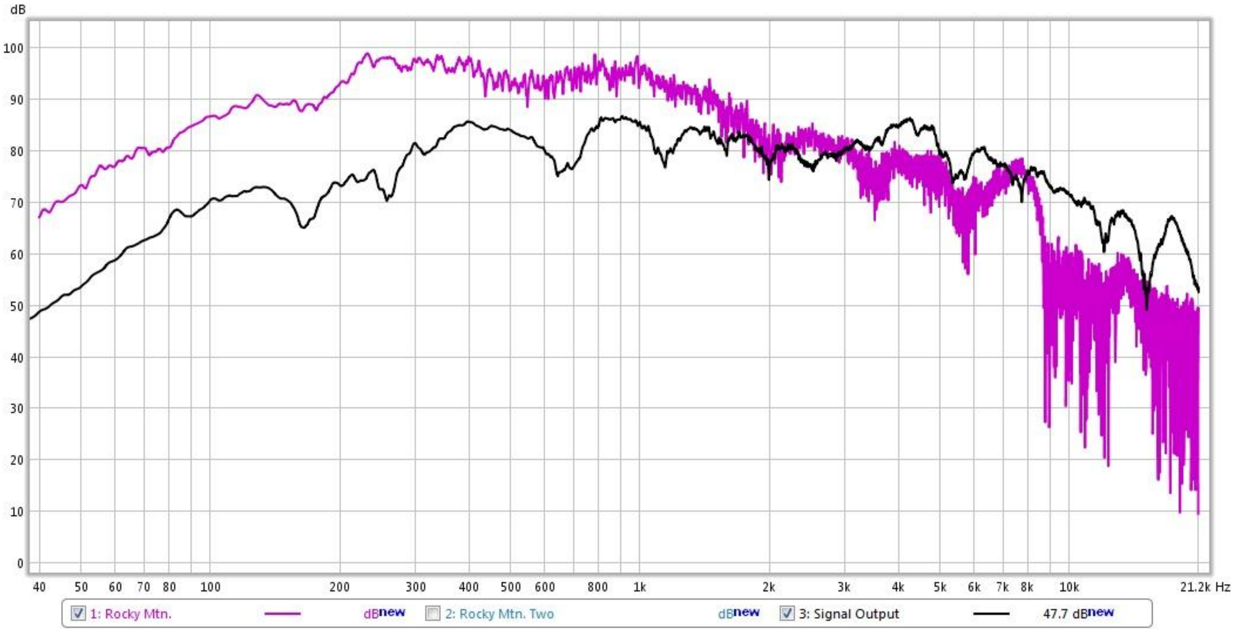


Figure 36 - First measurements made in a rocky mountain area

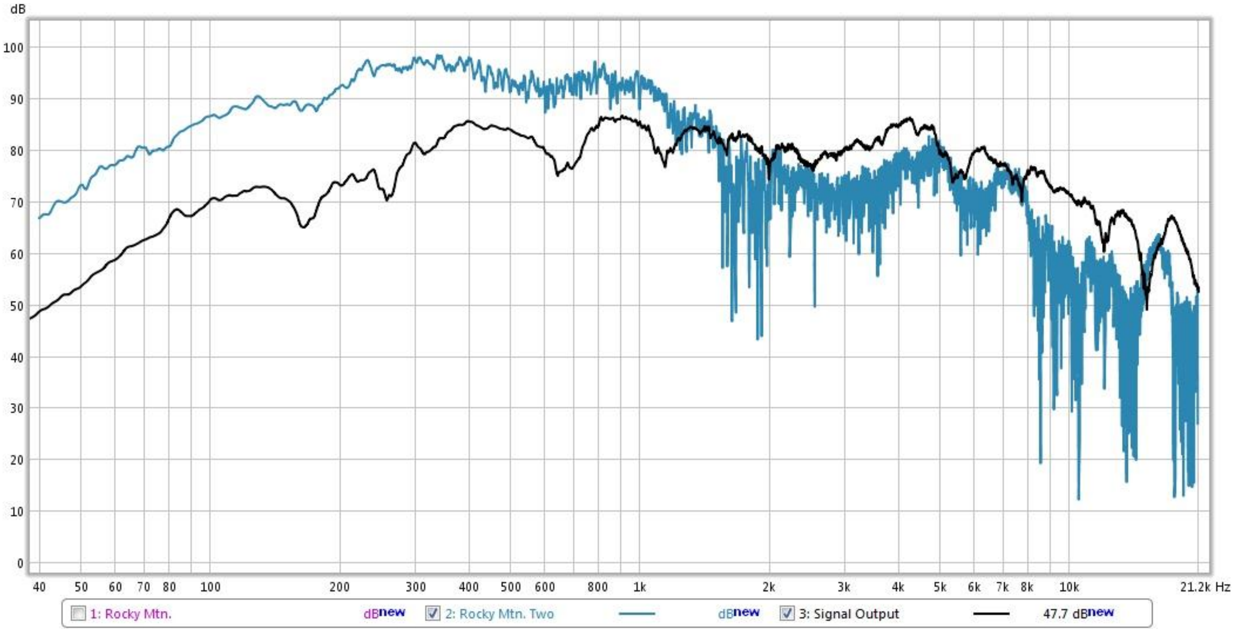


Figure 37 - Second measurements made in a rocky mountain area

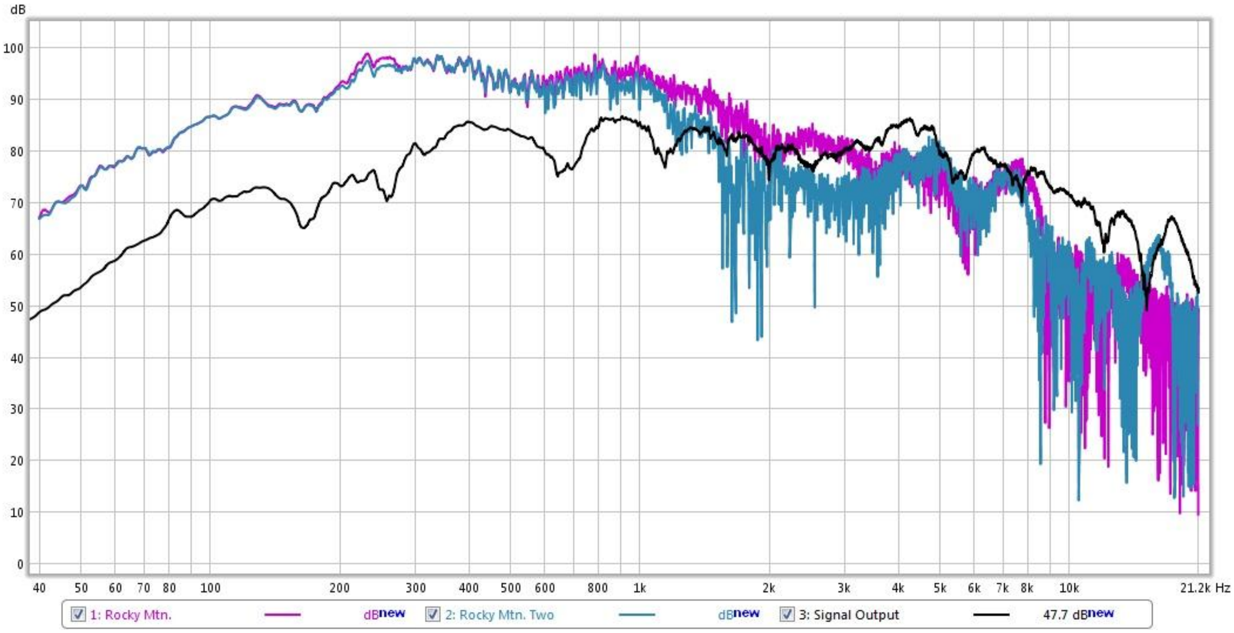


Figure 38 - Overlay of both measurements made in the rocky mountain area

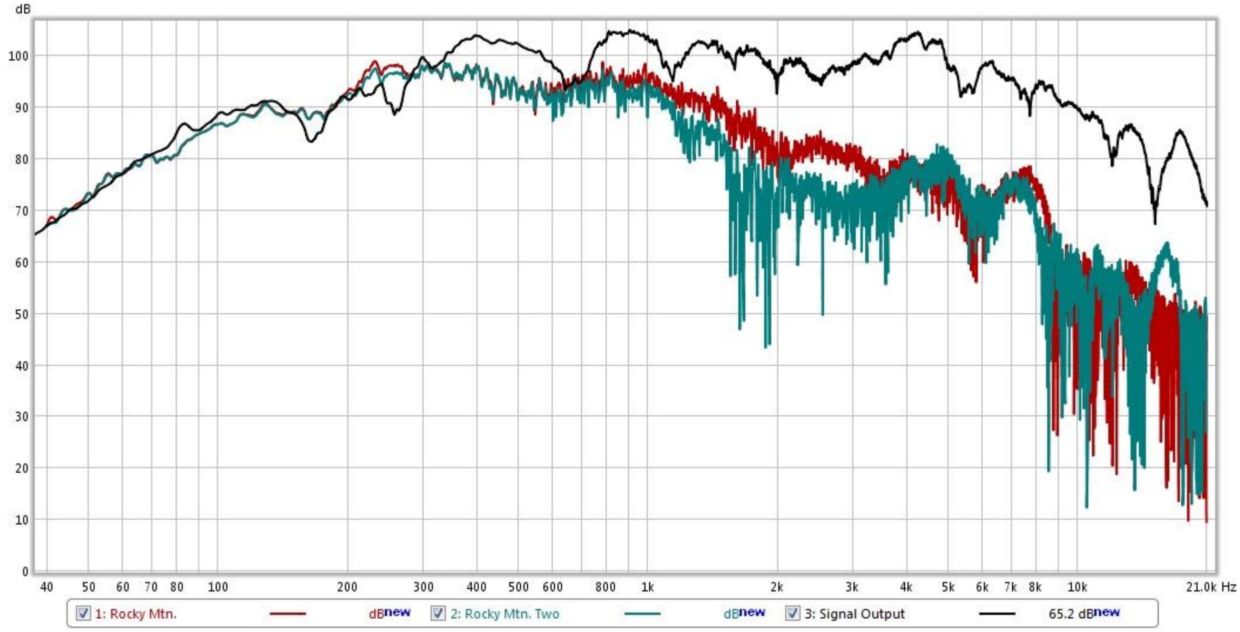


Figure 39 - Expected signal output of rocky mountain area

The rocky area offered a frequency response characterized by a relatively smooth decrease in response that spanned from 800Hz to 20,000Hz. In addition, the response was accurate to the expected signal output within a tolerance of ±8dB up to 800±5Hz. The instabilities in the response were relatively few, and were more or less inconsistent between tests, suggesting they were due to intent background noise, especially at lower intensity levels.

In addition to the sine sweeps, a less scientific, subjective test was conducted. Music familiar to the experimenters was played through the speaker system, so that the sound of the environment could be established. Wandering around the soundscape as the music played, higher frequencies were much more audible close to the speaker, and at 100 feet there was clear bass reinforcement in the sound, suggesting that the low frequencies were reverberated, and not that the high frequencies were highly absorbed, though there could have been (and most likely was) a combination of low frequency reinforcement and high frequency attenuation.

The listening of music familiar to the experimenters was an effective tool for establishing the proportions of reverberation of low frequencies to absorption of high frequencies, however it was not quantitative or scientific. If decibel levels of sustained test tones were recorded at different distances from the source, a scientific and quantitative (after an analysis using the inverse square law) method of determining reflection/absorption ratios might be achieved.

4.2.4 **Rocky Shoreline**

The rocky shoreline measurements were made in a soundscape characterized mainly by rocks of all sizes, mostly boulders and rocks of one to two foot diameter. About half the rocks were covered in a two inch blanket of seaweed (more seaweed in measurement 1.0). There were barnacles on the lower half of most rocks, mild ocean waves, and a breeze off the coast. The rocks terminated in the water on one side and in thick underbrush and 15 to 40 feet tall trees including beech, birch, ash and maple on the other. Wind was inconsistent, between 2 and 5 mph. The speaker placement with respect to the rock it was sitting on, the placement with respect to the angle between the speaker and the microphone, and the amount of seaweed between in the soundscape tested varied between different measurements. To differentiate, the measurements were labeled 1.0 (more seaweed), 2.0 (speaker on a flat surface), 2.1 (speaker off axis), and 2.2 (speaker on axis).

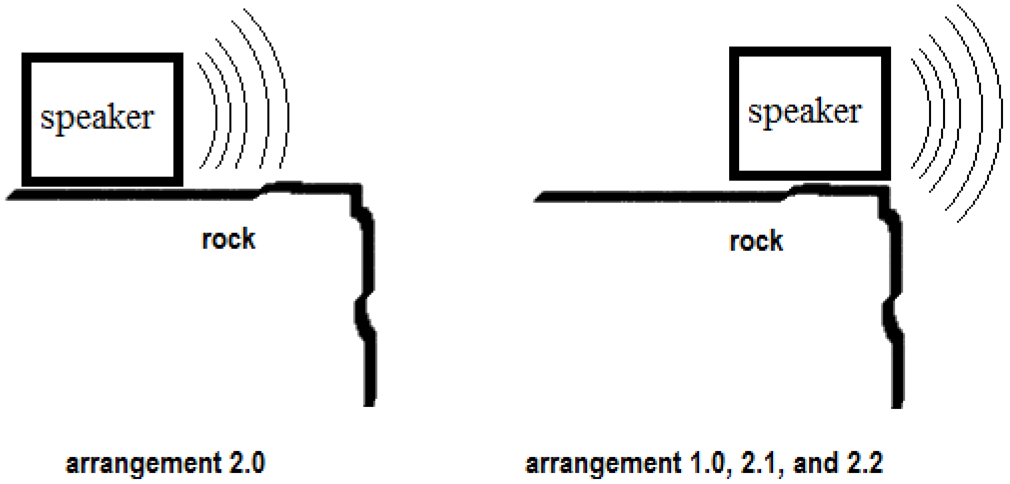


Figure 40 - The arrangements of the speaker with respect to the rock it was sitting on

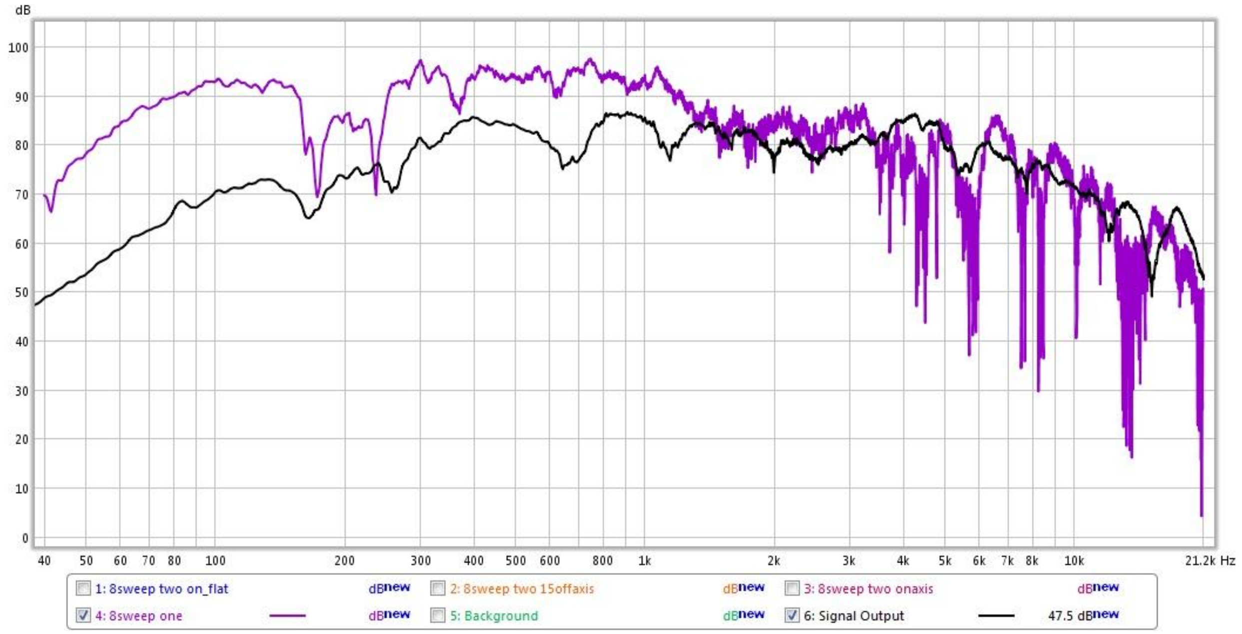


Figure 41 - Rocky shore response for measurement 1.0 (more seaweed)

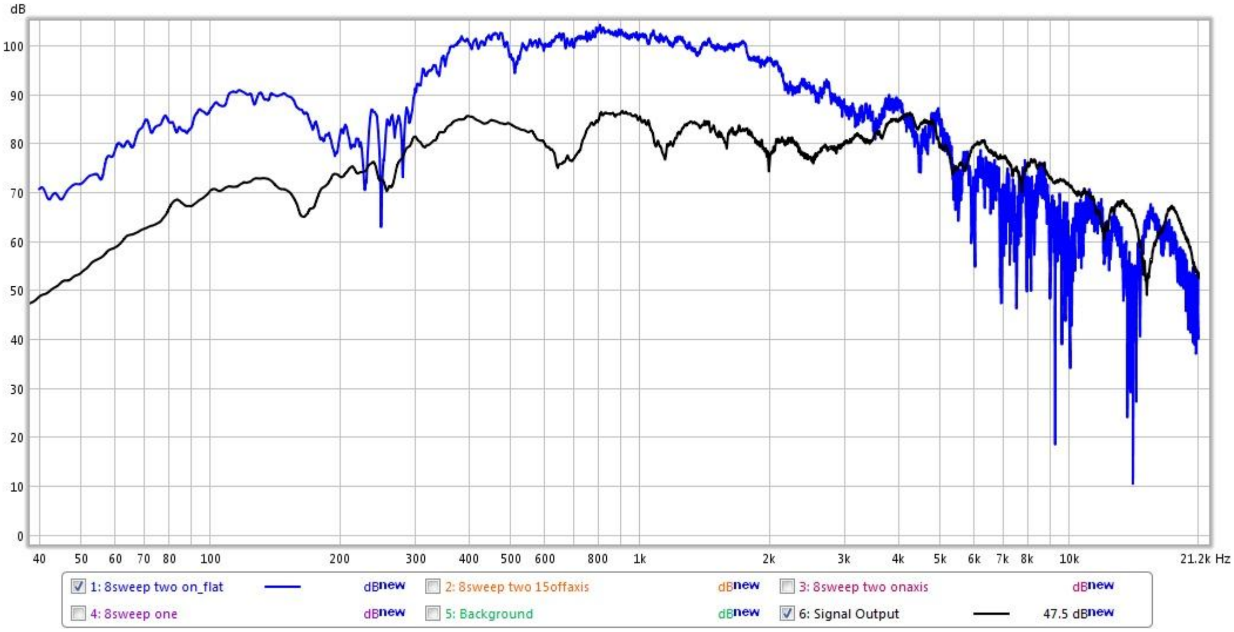


Figure 42 - Rocky shore response for measurement 2.0 (speaker on a flat surface)

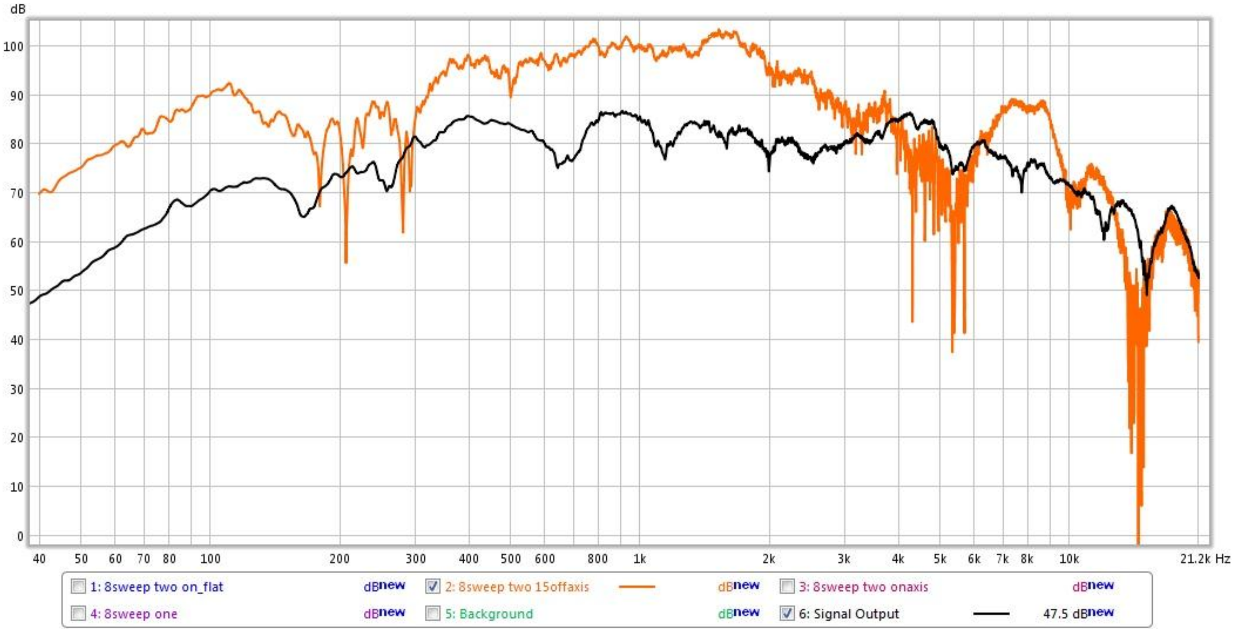


Figure 43 - Rocky shore response for measurement 2.1 (15 degrees off axis)

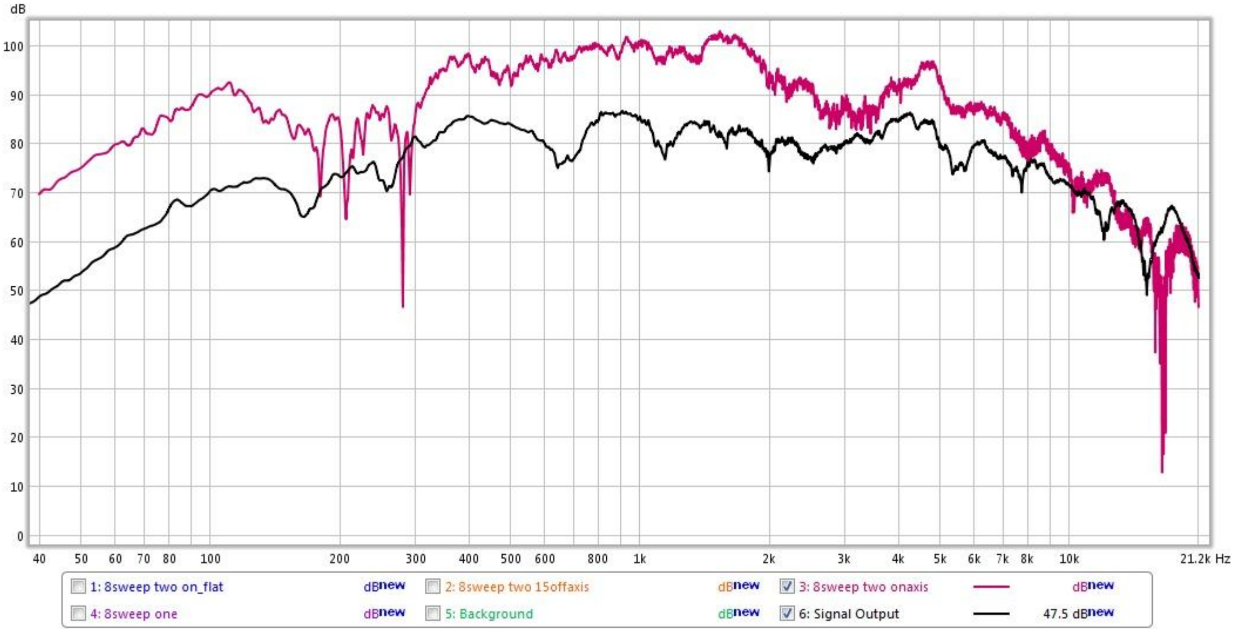


Figure 44 - Rocky shore response for measurement 2.2

The rocky shoreline tests included two measurements (measurement 2.0 and 2.2) to test the difference in placement of the speaker. In one of those measurements (measurement 2.0), the speaker was placed on a flat surface, so that the surface it sat on was perpendicular to the face of the box, and then other of the measurements (measurement 2.2) was shifted by a few feet so that the face of the speaker box was flush with the sheer face of a rock. The idea was that in the measurement where the speaker sat on a flat surface, not at the edge of a cliff-like sheer face, the sound would interact with the rock surface it was sitting on, and have interesting reflection patterns.

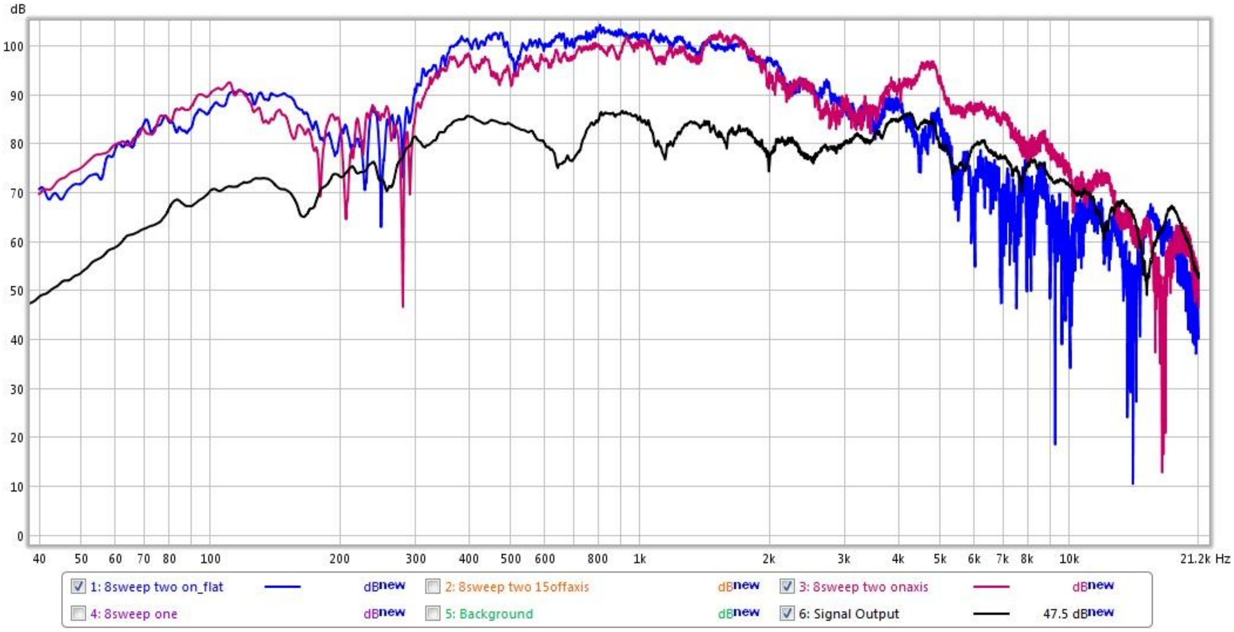


Figure 45 - Overlay of measurements 2.0 and 2.2

The difference between speaker placements (measurements 2.0 and 2.2) was that the frequency band of 4,000Hz to 10,000Hz exhibited increased levels when the speaker was on a the edge of a sheer face. This suggested that placing the speaker on a flat surface diminished a certain frequency band, and not all frequencies above a certain point. This frequency band could have been related to the length of the flat surface in front of the speaker, only affecting frequencies with comparable to that length. Additional tests could have been conducted that tested the frequency response as the length of flat surface was varied.

The second set of measurements tested on and 15 degrees off axis response. This meant that the microphone and speaker were not pointed directly at each other, but were off by 15 degrees. There was one test done off axis, and one done on axis. Measurement 2.1 was off axis and measurement 2.2 was on axis.

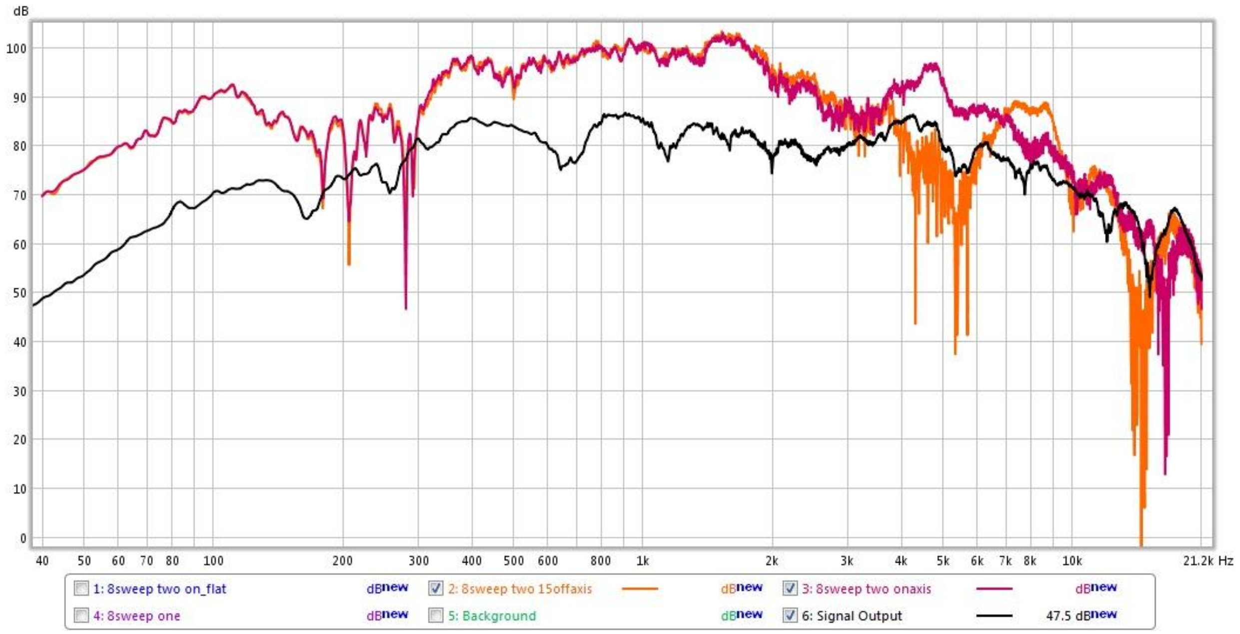


Figure 46 - Overlay of measurements 2.1 and 2.2

The on and off axis response was very close for frequencies below 3,800Hz, replicating itself nearly exactly below 2,000Hz. The variations in response were sudden and only applied for a certain band of frequencies, which was not typical of off axis responses. Off axis response is affected by the property of high frequency waves to bend more slowly than low frequency waves, causing consistently increasing differences in high frequency between on and off axis response. What was seen in the off axis test done on the rocky shore, is that frequencies 15 degrees off axis exhibited sudden sharp dips (example: 4,000 to 6,000Hz) and even some peaks (example: 7,000 to 9,000Hz) in response. This suggested that the rotation of the speaker by 15 degrees affected the reflective and absorptive properties of the soundscape more so than the change in on-off axis. Additional tests could have been done in different locations, at angles greater than 15 degrees, and at angles to both the left and right of axis to explore this issue further.

Measurements 1.0 and 2.2 were arranged in the same manner, save that for measurement 1.0 both the microphone and speaker placement was shifted ten feet towards the shore to include more seaweed in the soundscape tested.

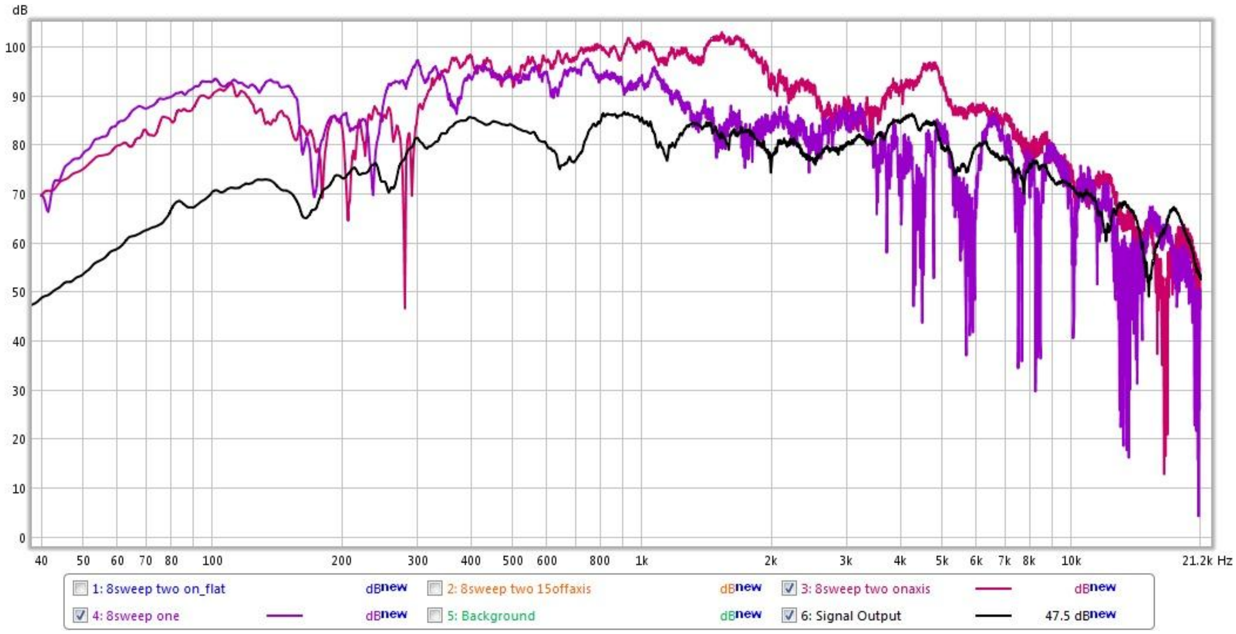


Figure 47 - Overlay of measurements 1.0 and 2.2

The added seaweed seemed to decrease response in the wide band of frequencies 500Hz to 2,800Hz and also between 3,500Hz and 6,500Hz. These decreases could be attributed to seaweed having absorptive properties in those frequency ranges, but also could have been attributed to the ten foot shift of the speaker and microphone. As seen in the off-angle response test, it was possible that small changes in speaker placement had drastic effects on frequency response. Tests where the soundscape was manipulated to include more seaweed without changing the position of the speaker and microphone might have brought more definitive results, as the variable of shifting the microphone would have been eliminated from the equation.

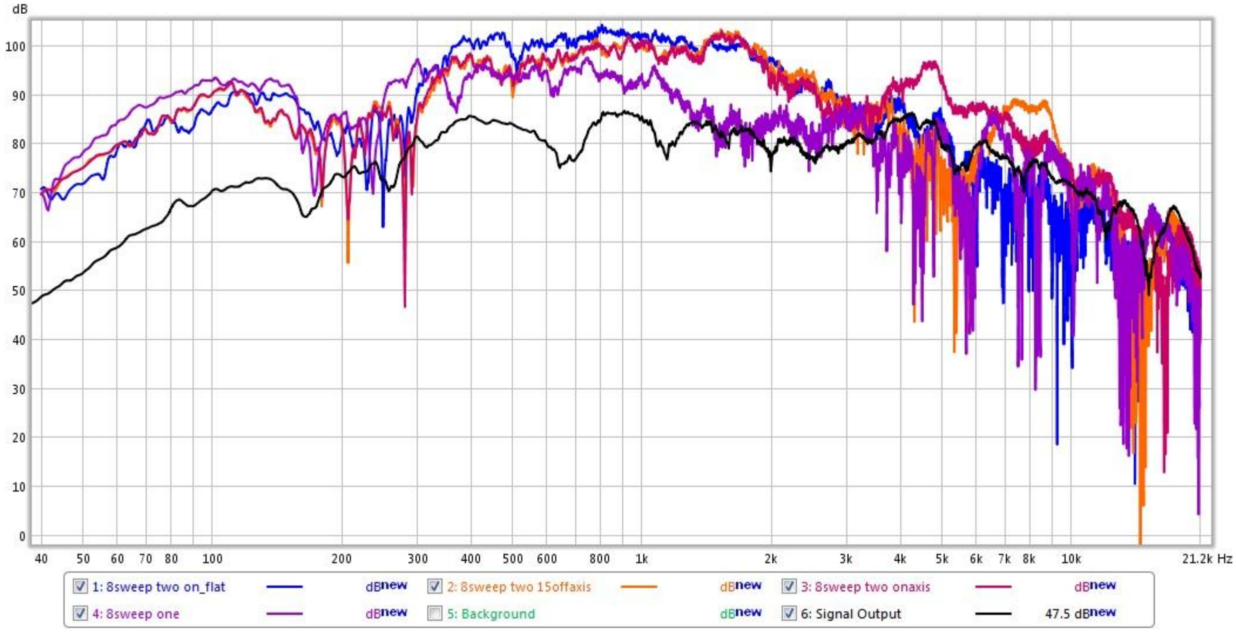


Figure 48 - Overlay of all response measurements

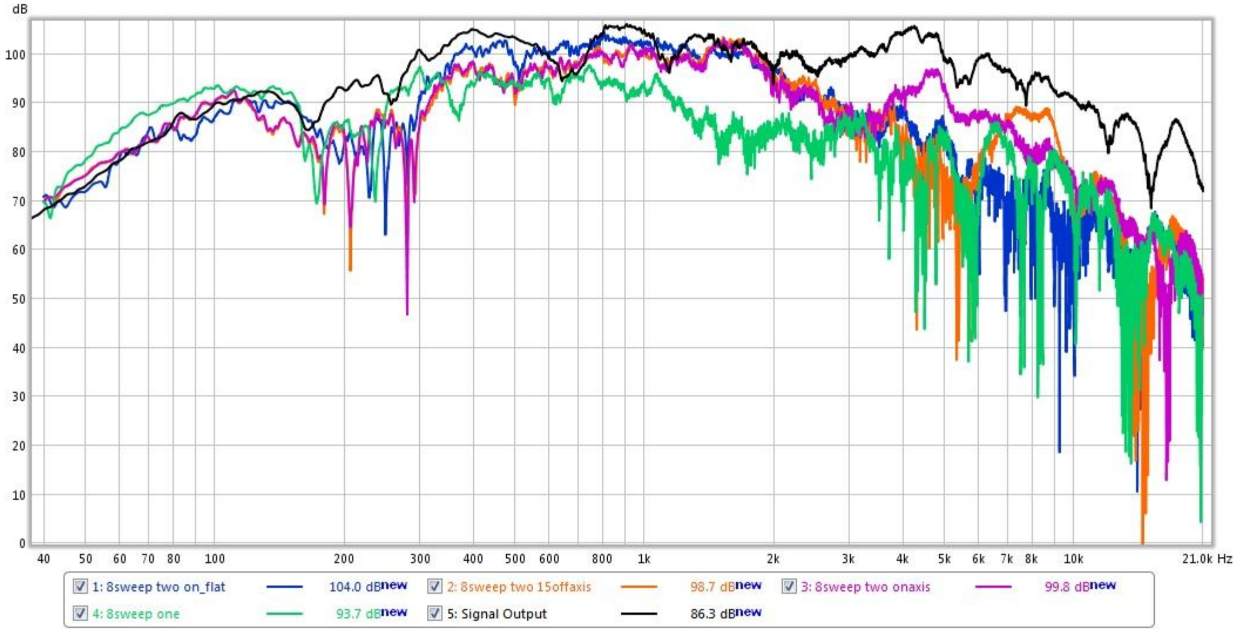


Figure 49 - Expected signal output of rocky shore

The rocky shoreline interacted with the low frequency range of 200 to 300Hz, and caused a dip in the frequency response in that range. After that dip, the measured signals met the expected signal output all the way up to 2,500Hz. After 2,500Hz many inconsistencies in the response were visible, and different measurements disagreed with one another in that higher frequency range. That suggested that small changes in the positioning of the speaker had more drastic changes in response above 2,5000Hz than below it.

Issues with small changes in the arrangement of the speaker in the soundscape became clear in the rocky shore tests. It was demonstrated by the on and off axis tests especially, where a mere 15 degree rotation of the speaker caused drastic spikes and dips in frequency response, that small changes in placement in the soundscape changes its response significantly. While this makes the response of a soundscape such as the rocky shore difficult to characterize, it shows that soundscape interacts drastically with sound traveling in it. What could be said was that the rocky shore soundscape had a response that was difficult to predict on a 100 foot scale, and had high degrees of change in reflective and absorptive properties. Tests of rocky shoreline on a larger scale may have had a more predictable response, and this soundscape could have been a good candidate for long distance tests.

4.2.5 **Rocky Brook**

Approximately ten feet wide and located on Hadlock Pond Trail in Acadia National Park, this trickling Brook was populated by over-hanging beech branches while evergreen trees stood along shore. The water quietly trickles over mildly mossy, mostly flat rocks comparable to the width of the stream in this shady, cool area.

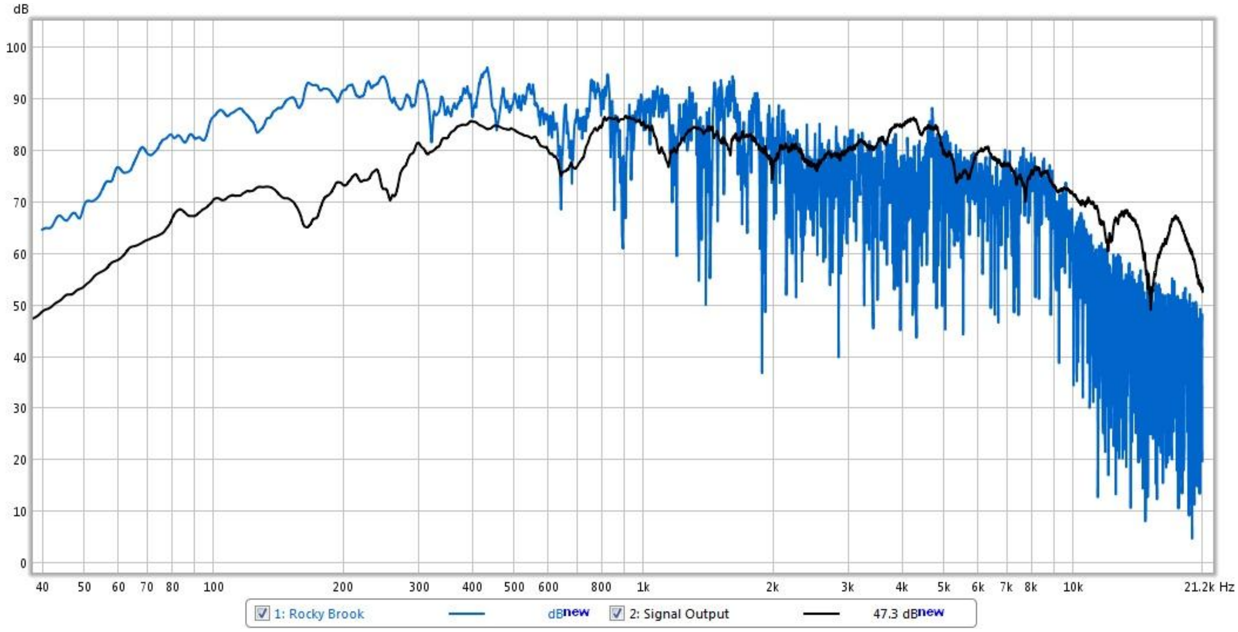


Figure 50 - Frequency response of the rocky brook

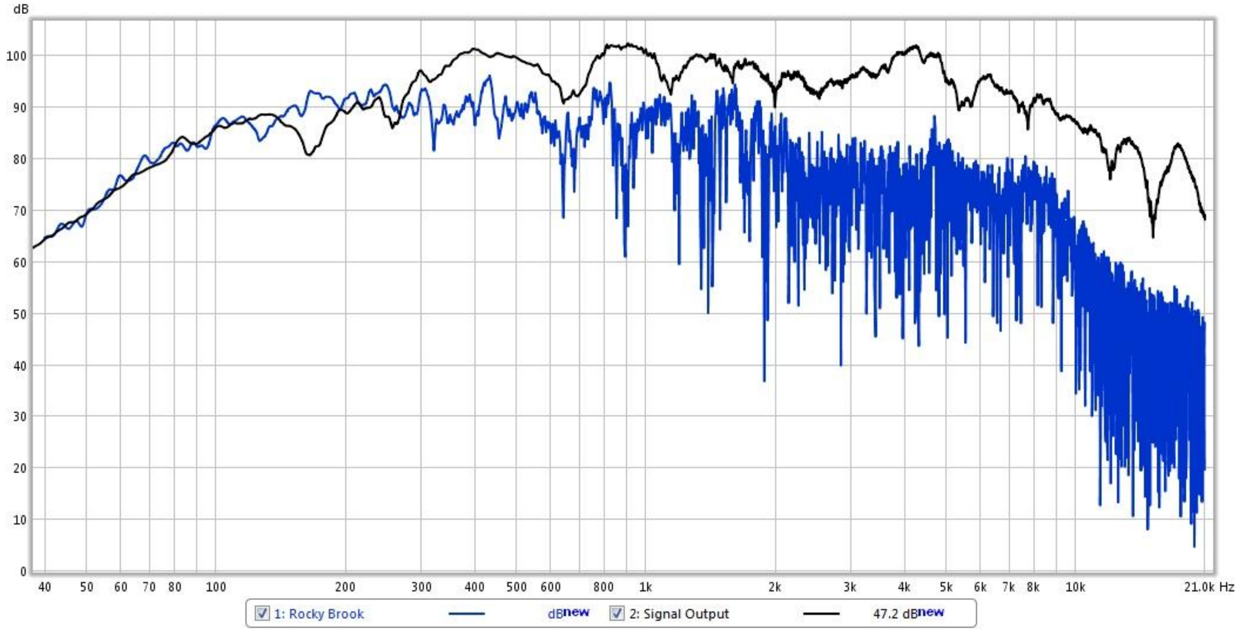


Figure 51 - Expected frequency output of the rocky brook

The rocky brook exhibited a unique frequency response characterized by copious amounts of instabilities, a smoothly decreasing response from 300Hz to 8,000Hz, after which the steady decrease becomes more rapid, and the instabilities become more prominent. The response of the rocky brook does not follow the expected signal output very closely, deviating from it by greater than ±8dB at 165±5Hz and for the majority of frequencies above 340±5Hz. There were many spikes in frequency response that do fall within the expected frequency range, though neighboring frequencies didn't. These peaks, such as at 4,720±5Hz, might be attributed to signals that were either not absorbed, or were absorbed by some parts of the soundscape, and reverberated by others.

The general shape of the brook was that of a tunnel, with open air above the water (for the most part) and sudden walls of forest on either side, along with a treetop roof high above the water. This shape could have fostered reverberation, such that sound would reflect of the trees and water and be directed back to the microphone, rather than being diffused into background noise. Additional, though subjective, support for the rocky brook's reverberant tendencies were the observations of the experimenters, who reported that the speaker sounded surprisingly distant, and the signal it produced seemed full of echoes.

4.2.6 Mossy Forest

The mossy forest offered the most consistent data out of all the short distance tests. Additionally, its response was very close to the expected signal output. With that in mind, it should be noted that there was very little background noise present. The soundscape was characterized by a lack of wind in an evergreen forest with a very mossy floor. There were many downed and decaying branches and trees.

One thing to note is that during every sine sweep, there were two strange clicks audible, one in the lower frequencies, and one in the very high frequencies. REW was closed and re-opened, and four additional tests were run to further investigate the source of the clicks, but it could not be determined. The data was processed and analyzed as usual, regardless of the clicks.

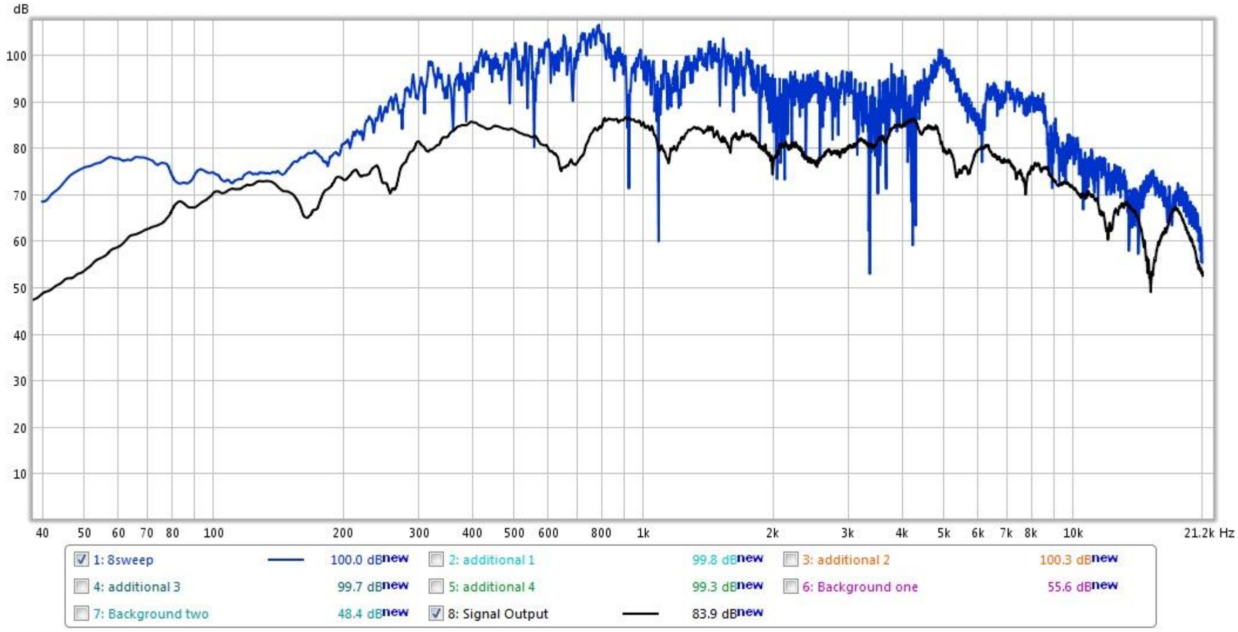


Figure 52 – Frequency response of the mossy forest

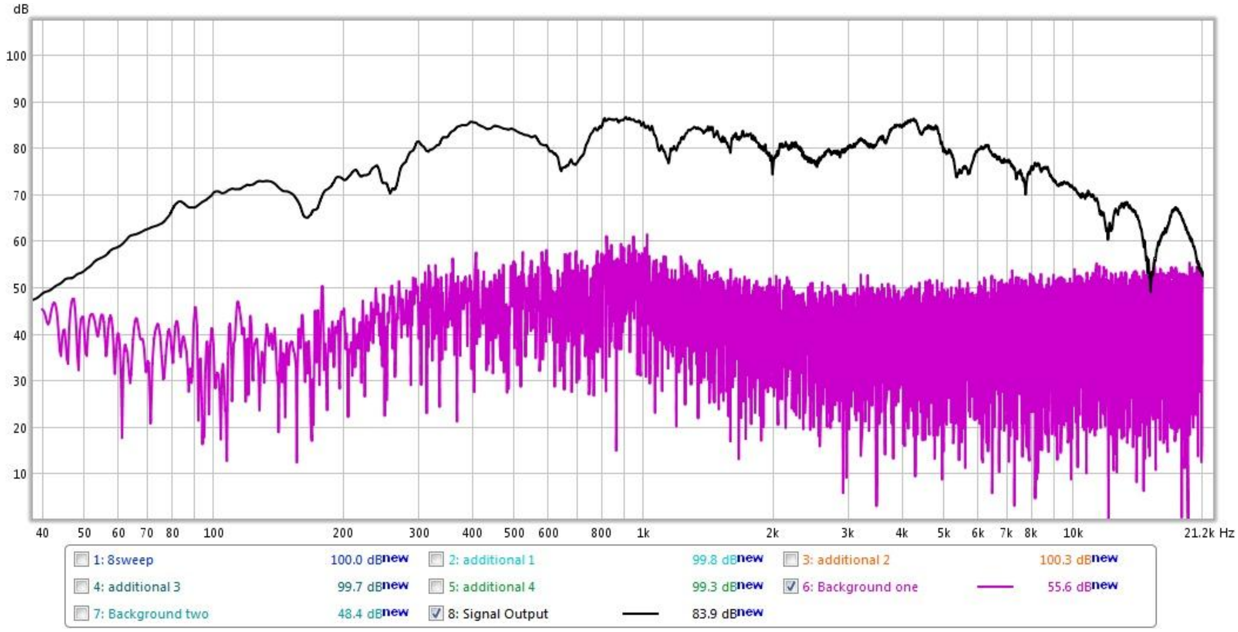


Figure 53 - Background noise measurement one

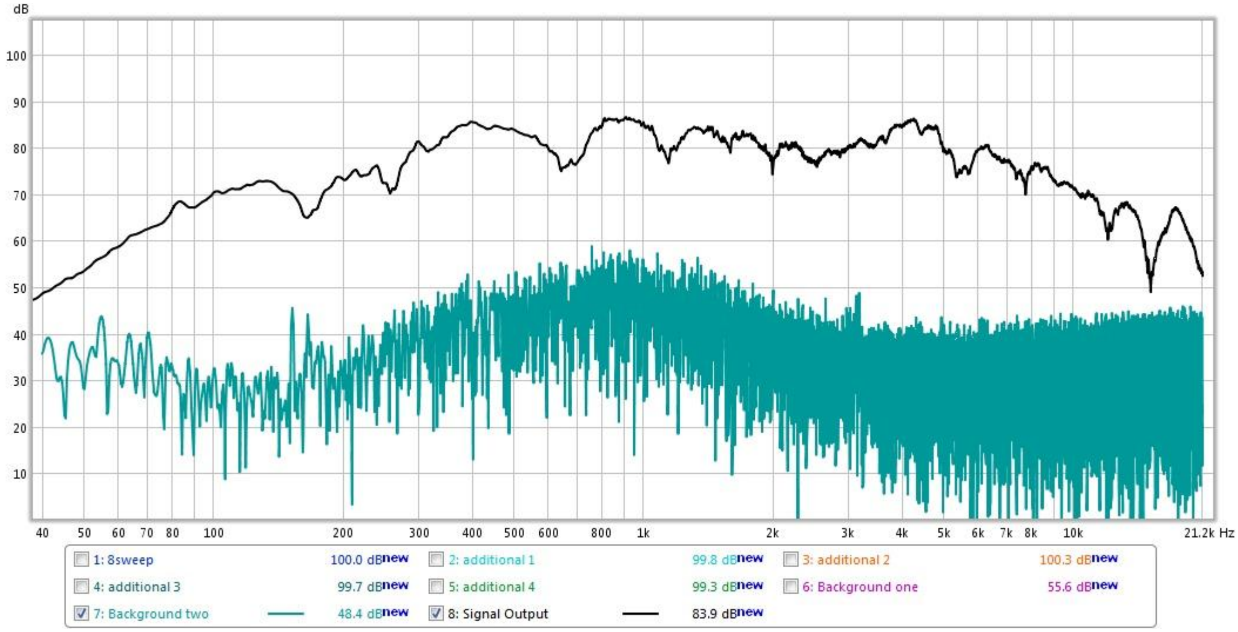


Figure 54 - Background measurement two

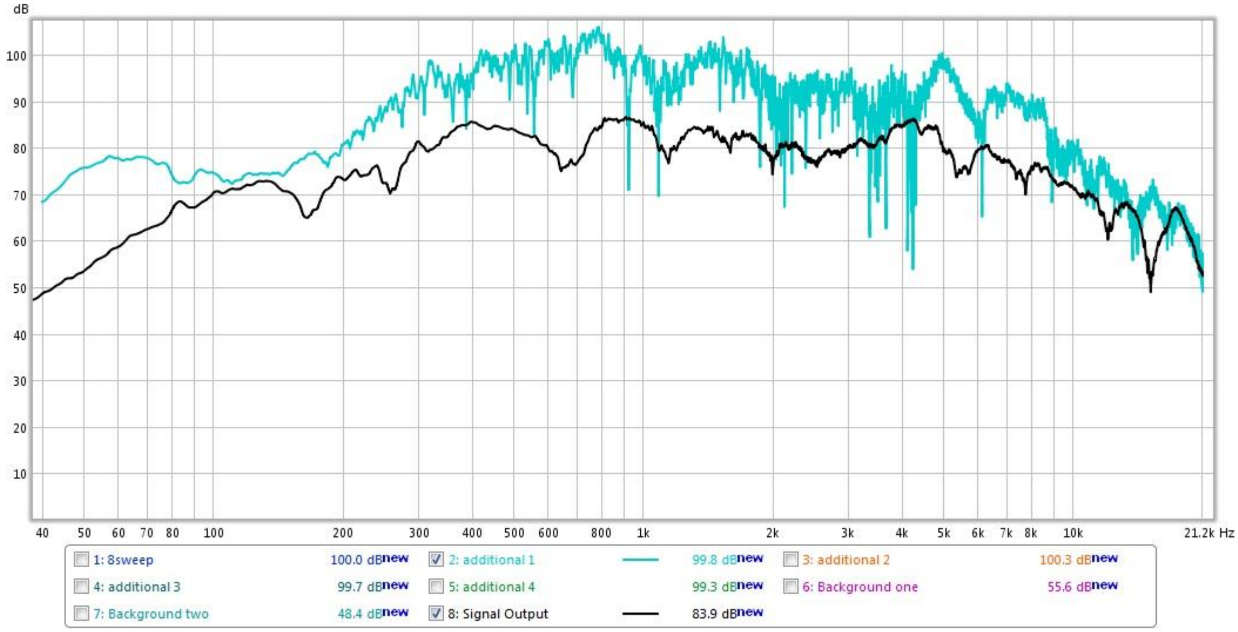


Figure 55 - Additional measurement 1

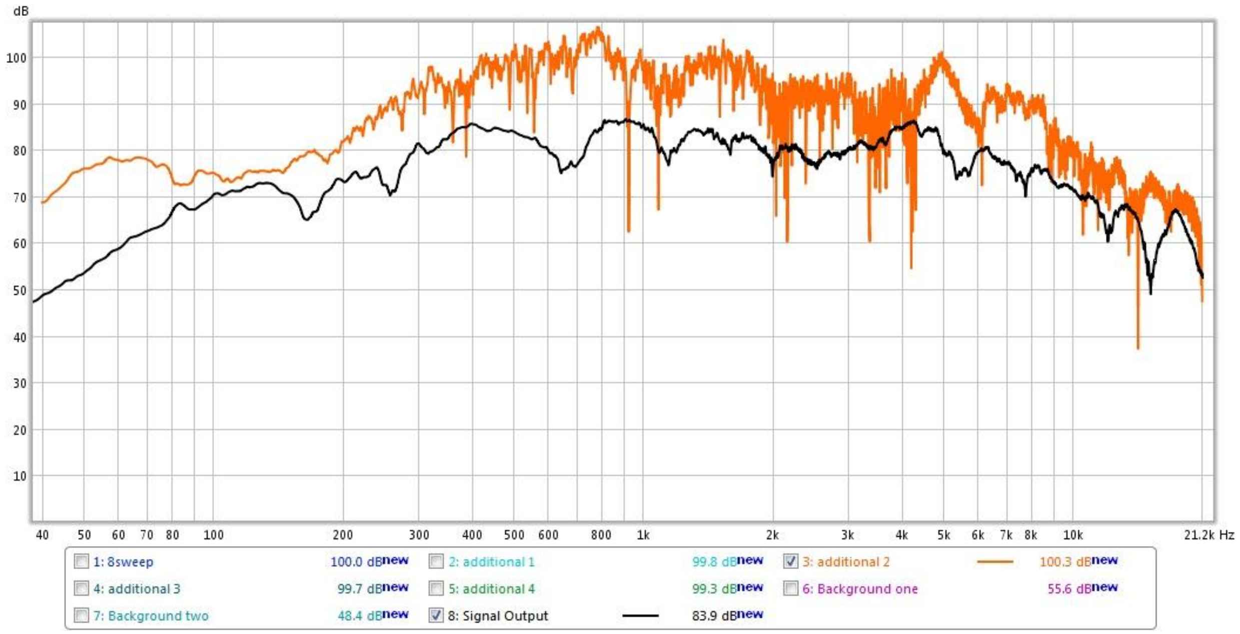


Figure 56 - Additional measurement 2

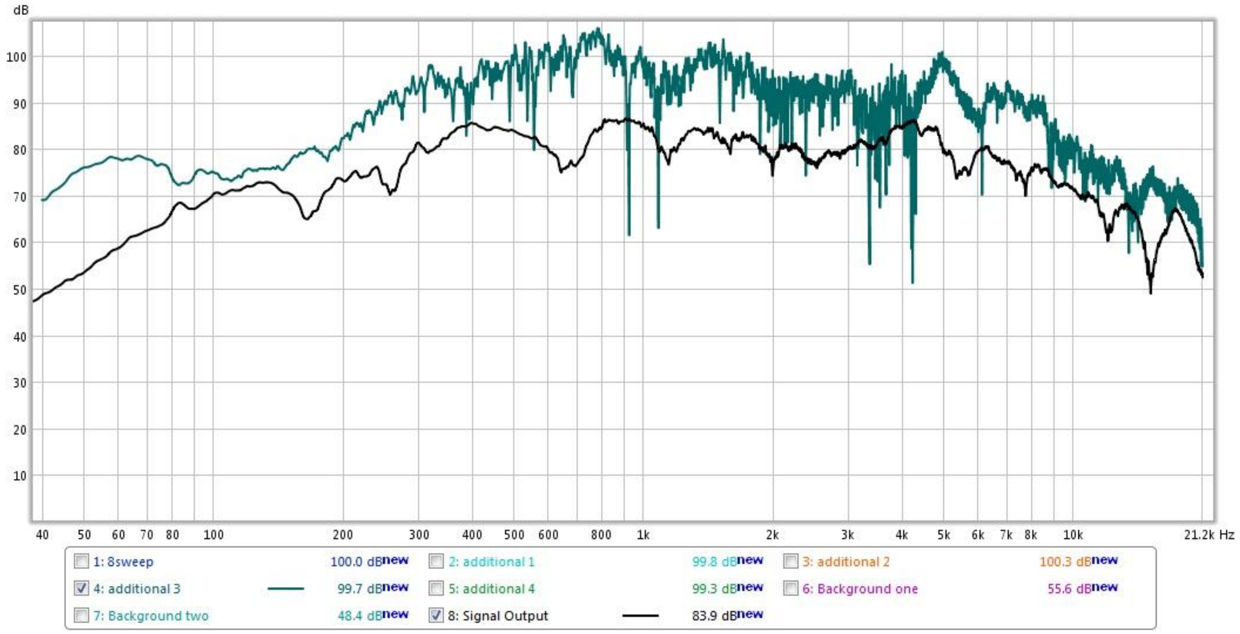


Figure 57 - Additional measurement 3

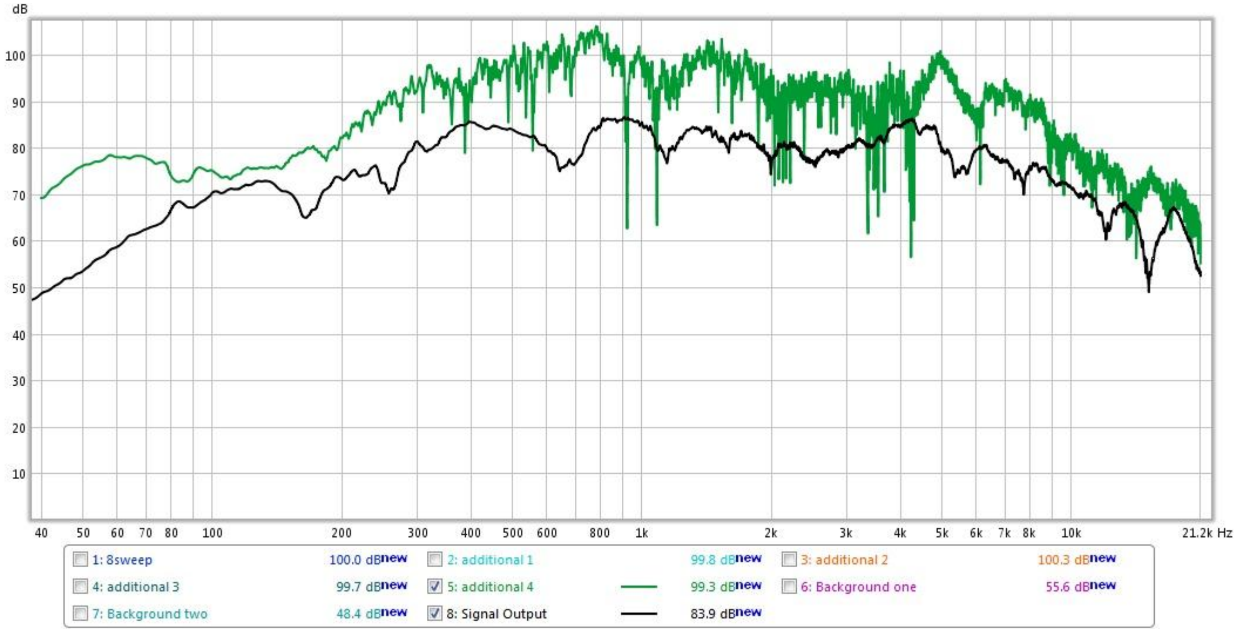


Figure 58 - Additional measurement 4

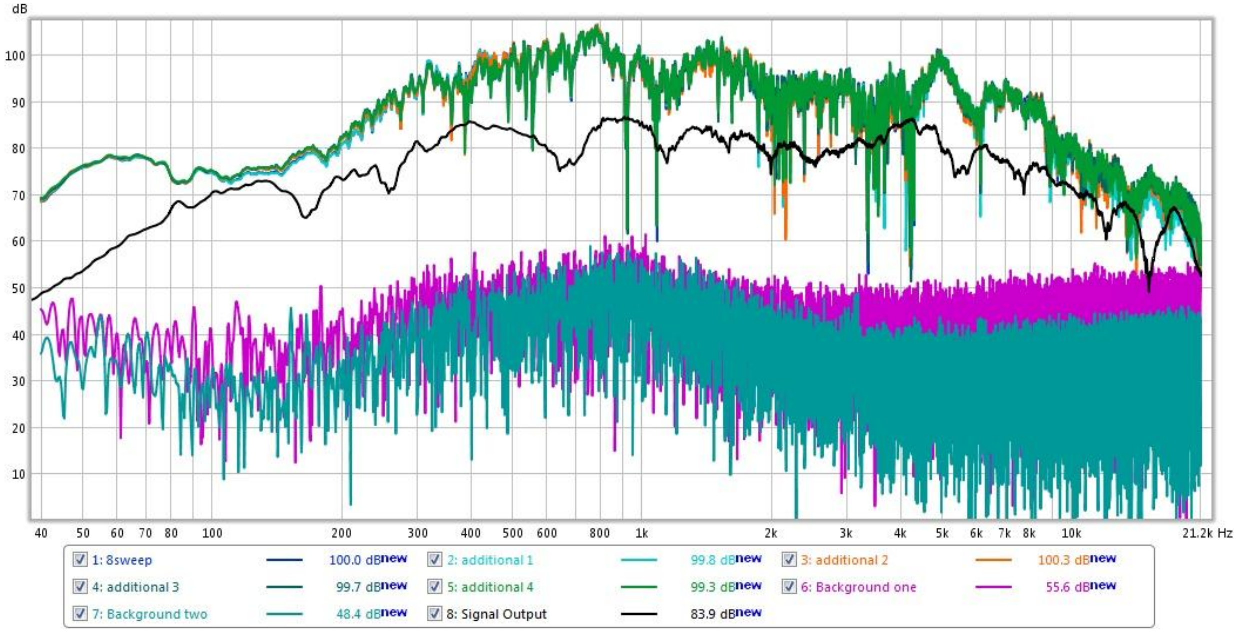


Figure 59 - Overlay of all measurements made in the mossy forest

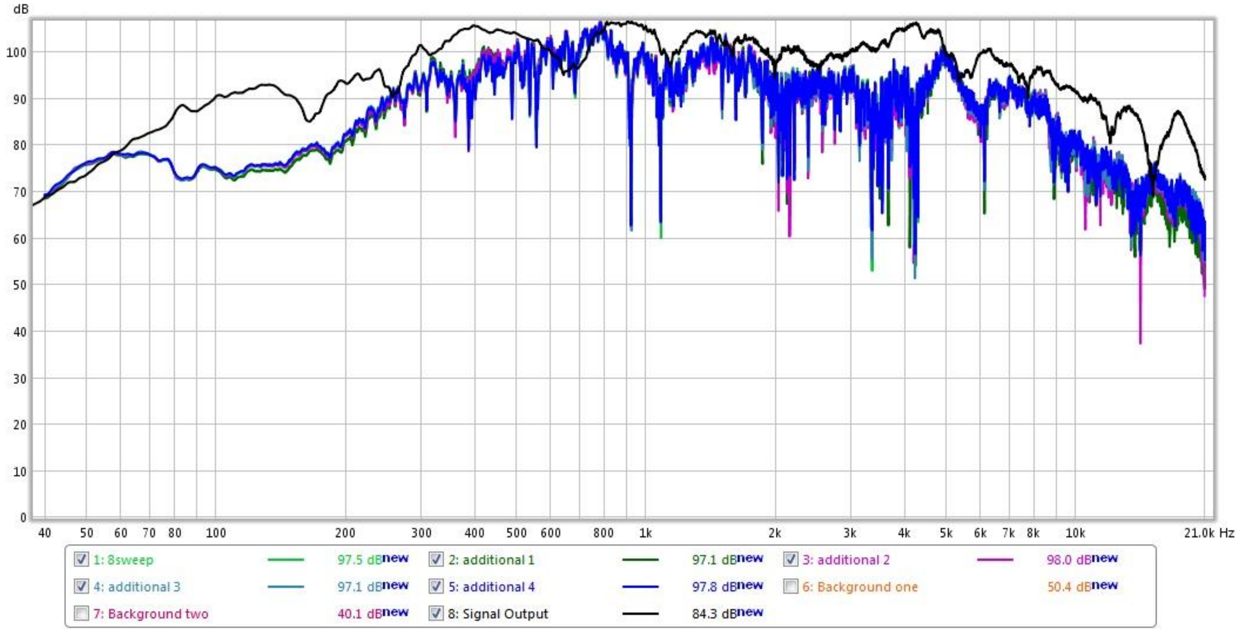


Figure 60 - Expected signal output of the mossy forest

The distinguishing feature about this soundscape was that all measurements made matched up very closely. There were some differences in the inconsistencies of the response, mainly that they were of different intensities, but even the inconsistencies in response were located at the same frequencies. This repetition of inconsistencies in every measurement suggests that they were due to absorption rather than confusion with background noise.

The expected signal output of the speaker was difficult to determine for this test, as the low frequency response did not match up as it did for most tests. However, it was shifted up by around 20dB, as it was for the rest of the measurements. This was a feasible option because all the measurements were conducted at very close to the same intensity level, and required about the same amount of shifting.

After establishing the signal output as accurately as possible, it could be seen that the frequency response of the mossy forest followed the expected signal response very closely for the entire spectrum of 40 to 20,000Hz tested. That characterizes the response as accurate to the source, and audible as a clean, unaltered signal.

These measurements were also made at a later time of the day than the rest of the measurements made for the Short Distance Tests. It was noticeably, and measurable in the background recordings made, quieter in this soundscape. That could have been because of the time of day the measurements were made at (which was quieter), or because the mossy forest was quiet in its own right. The thick moss that covered the floor of the forest was soft and spongy. It could have been that the moss acted to absorb much of the background noise. Additional testing of the moss in particular could have shown its absorptive properties.

4.2.7 **Short Distance Tests Summary**

Grassy areas followed the general rule that bass frequencies, particularly below 300Hz, were inconsequentially affected, whilst higher frequencies were affected more heavily the higher the frequency. The grassy fields were also characterized by a maximum peak at 300Hz and relative dip in response between 2,000 and 3,000Hz.

The rocky mountain top area was characterized by a response that was accurate to the expected signal output up to 800Hz, and a smooth decrease in frequency response from 800 to 20,000Hz. This area had a particularly high low frequency bias.

The rocky shoreline was characterized by a response dip from 200 to 300Hz, but also by an accurate frequency response, other than that dip, from 40 to 2,500Hz. Additionally, there was a sort of sensitivity to position, essentially a randomization in frequency response above 2,500Hz. This soundscape propagated frequencies, from 40 to 200Hz and from 300Hz to 2,500Hz effectively, and without significant attenuation. Above that, however sound was scattered and diffused randomly, creating inconsistent and variable responses.

The rocky brook had a steadily decreasing response for all frequencies above 300Hz, and there were many inconsistencies in the response. This soundscape would propagate the sound in highly inconsistent, reverberant manner, confusing the initial signal and sounding distant.

The mossy forest had an accurate response curve with unprecedented consistency between measurements. The area was full of soft materials, such as thick moss and decaying logs, which may have acted as sound absorbers, preventing reverberant reflections from skewing the response.

4.3 Long Distance Test

4.3.1 **Forest near Route 3**

Figure 61 - Forest near Route 3

Testing was done in a forested region near Upper Hadlock Pond. Parking alongside Route 3 gave easy access to trails that cut into the forest. This allowed the air horn and compressor to remain by the road and testing to be done from the road into the forest. The area where the air horn was set up is marked S on the map for source. Distances were measured with GPS and also approximated during testing. The GPS data received for this test was highly inaccurate, the coordinates for each location were on top of Upper Hadlock Pond, which were 200m away from the trail used for testing. As a result the locations on the map above (excluding the source) may be inaccurate.

4.3.1.1 Point A

The closest location to the source is Point A. This location was approximately 200m (±50m) away from the source. Point A was surrounded primarily by evergreen trees with moss growth. The ground was covered in thick moss and dotted by exposed sections of rock and soil. There were numerous fallen trees and branches scattered around the area. The path leading up to Point A also has extensive root growth that was exposed by the soil. The ground was not firm and felt spongy. Additional details and pictures of the location can be found in Appendix IV.

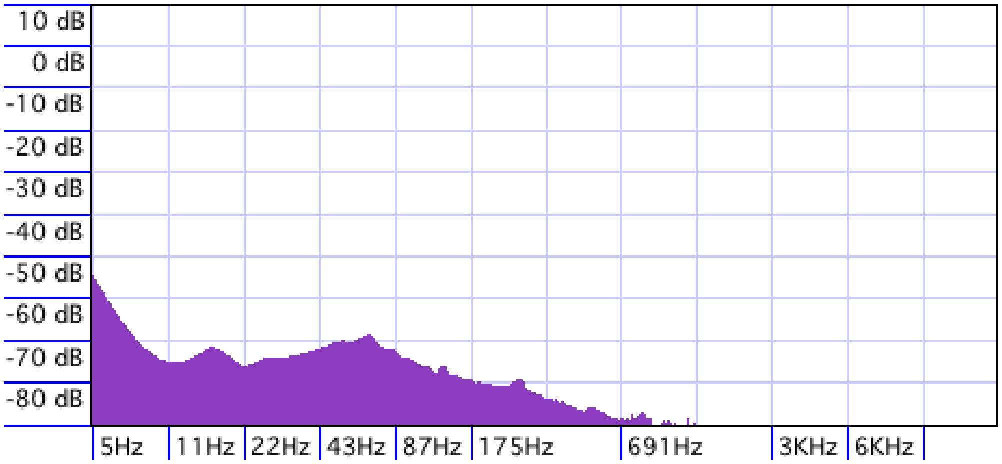


Figure 62 - Point A Background Noise

The background levels at Point A were in the lower range. The background levels peak around 70Hz with dips in levels around 10 Hz and 20 Hz. Noise picked up above 700 Hz is negligible.

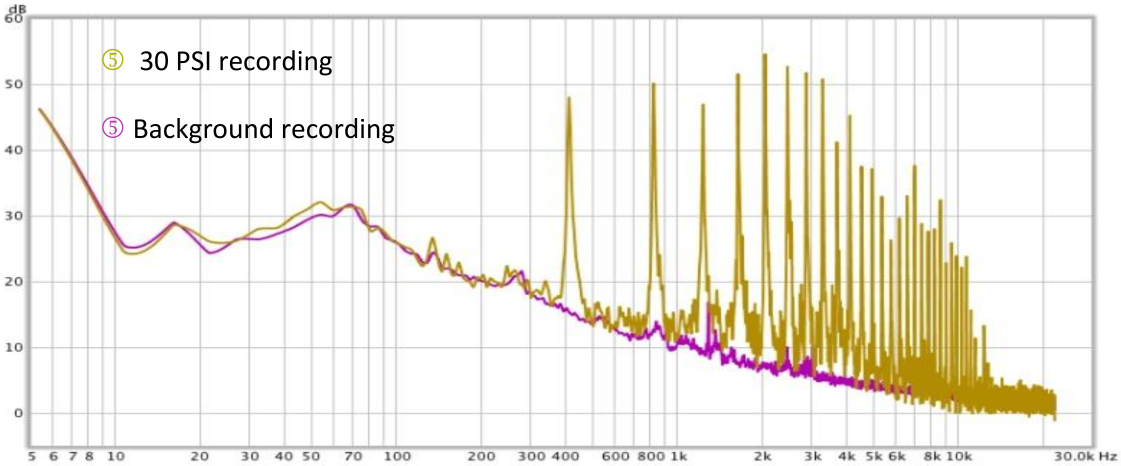
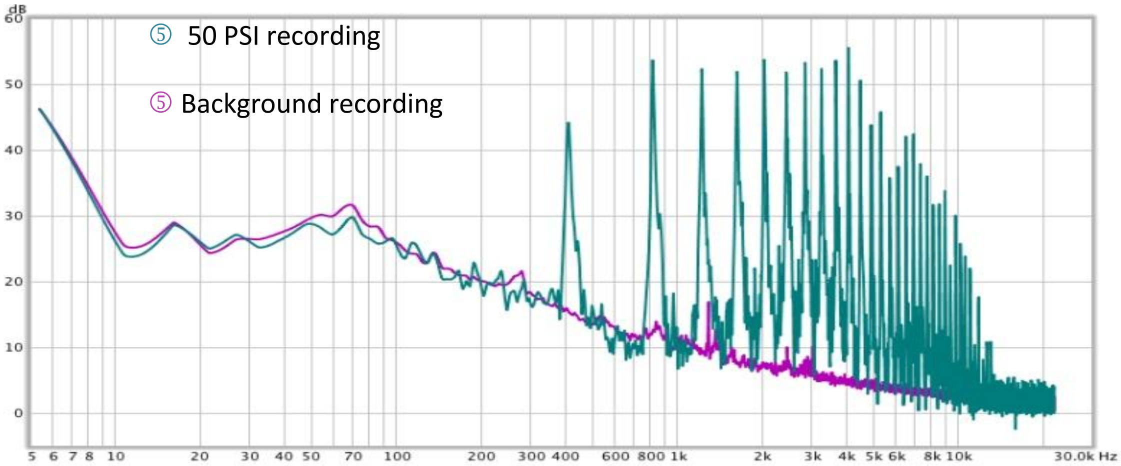


Figure 63 - 30 psi recording at Point A with background noise

Figure 64 - 50 psi recording at Point A with background noise



At 30 and 50 PSI the horn is clearly audible in the higher range. Peaks are visible in the graph starting at 400 Hz and continuing every 400 Hz up until 10 kHz. Below 400 Hz the graphs follow the shape of the background noise. This shows that the signal from the horn reaching the recorder was primarily in the 400-10000 Hz range. Although frequencies that were lower may have traveled to the recorder, they were not intense enough to be picked up over the background noise of the forest. Because all the frequencies picked up below 400 Hz were background noise, some of the lower frequencies were excluded from the analysis.

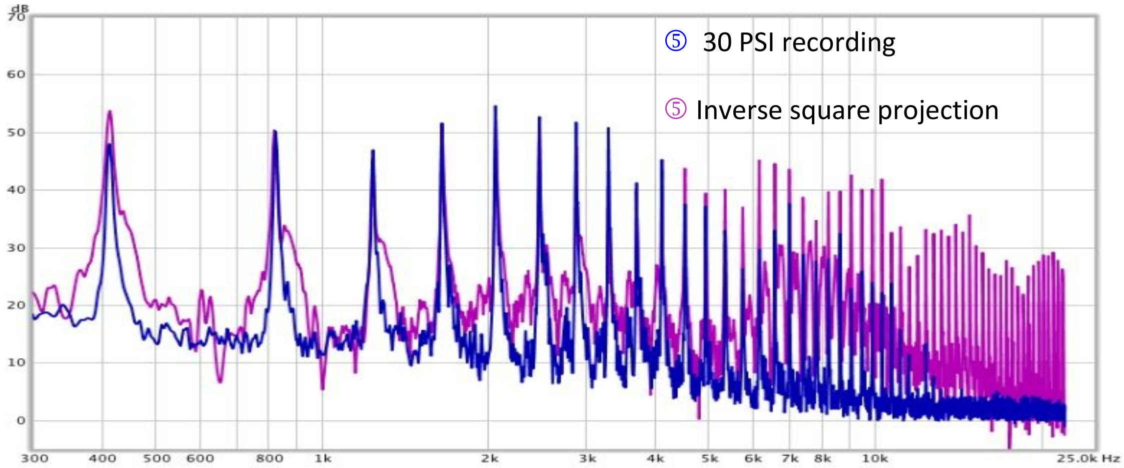
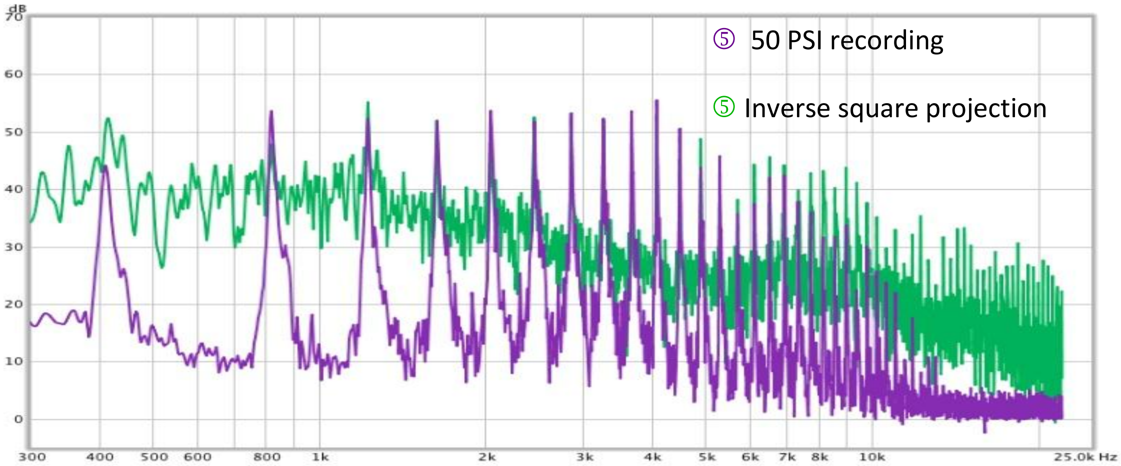


Figure 65 - 30 psi recording at Point A with Inverse square law projection

Figure 66 - 50 psi recording at Point A with Inverse square law projection



In the 30 and 50 psi tests, the intensity of the sound dropped off more than predicted at frequencies of 4600 Hz and higher. The inverse square law is an ideal situation and does not account for the physical barriers of a forest. The higher frequencies were the most effected by the environment. The mossy ground and numerous trees aided in absorbing and reflecting the signal away from the Tascam recorder. In both recordings the intensity of the frequencies between 3000-5000 Hz was higher than projected by the inverse square law. This meant that those frequencies were being reverberated towards the recorder and not expanding outwards as the inverse square law predicted.

4.3.1.2 Point B

The second location from the source is Point B. This location was approximately 300m (±50m) away from the source. Point B was surrounded primarily by evergreen trees with moss growth. The evergreens were smaller than the trees located at Point A and had more branches with needles. The needles and branches of the trees made a thick brush. The ground was covered in thick moss and dotted by exposed sections of rock and mud. The path leading up to Point B had a small wooden bridge passing over a muddy pit. The ground was not firm but muddy. Additional details and pictures of the location can be found in Appendix IV.

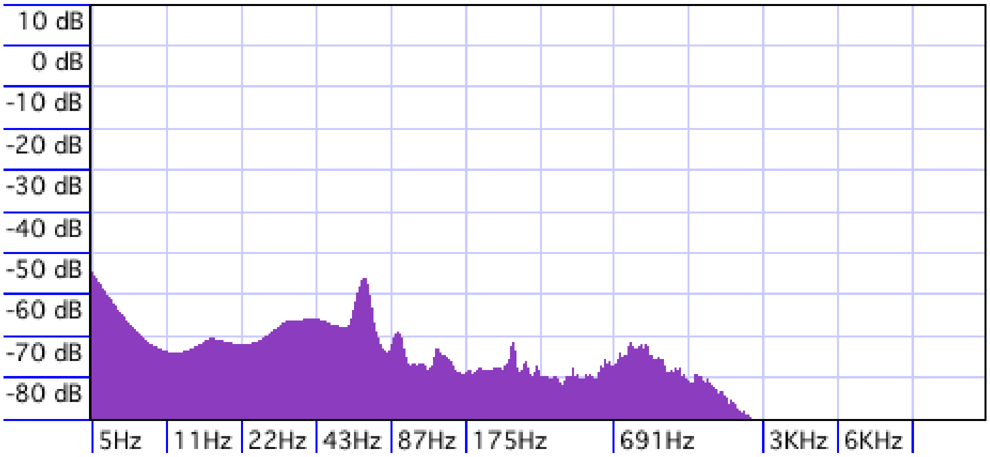


Figure 67 - Point B Background Noise

The background levels at Point B were primarily in the lower range. The background levels peak around 60 Hz with dips in levels around 10 Hz and 20 Hz. Noise picked up above 3000 Hz is negligible.

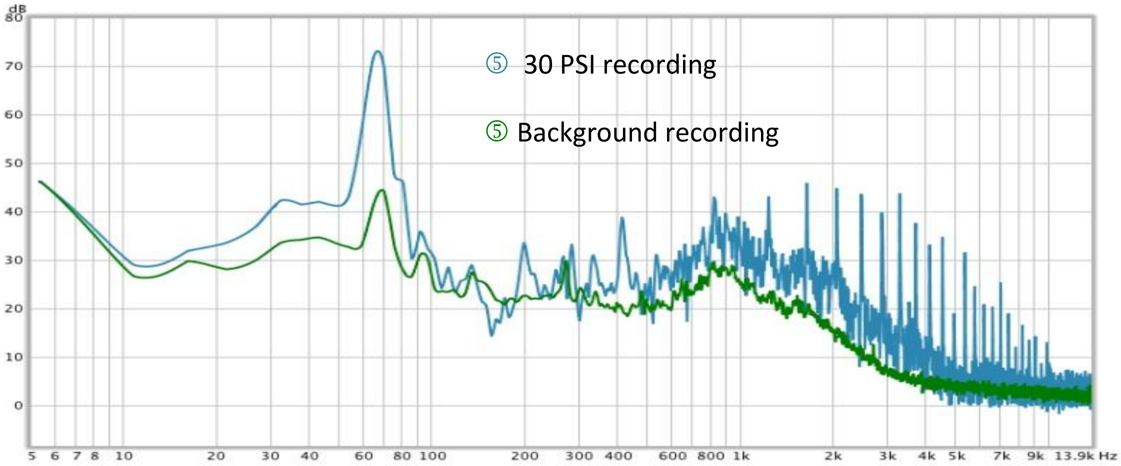
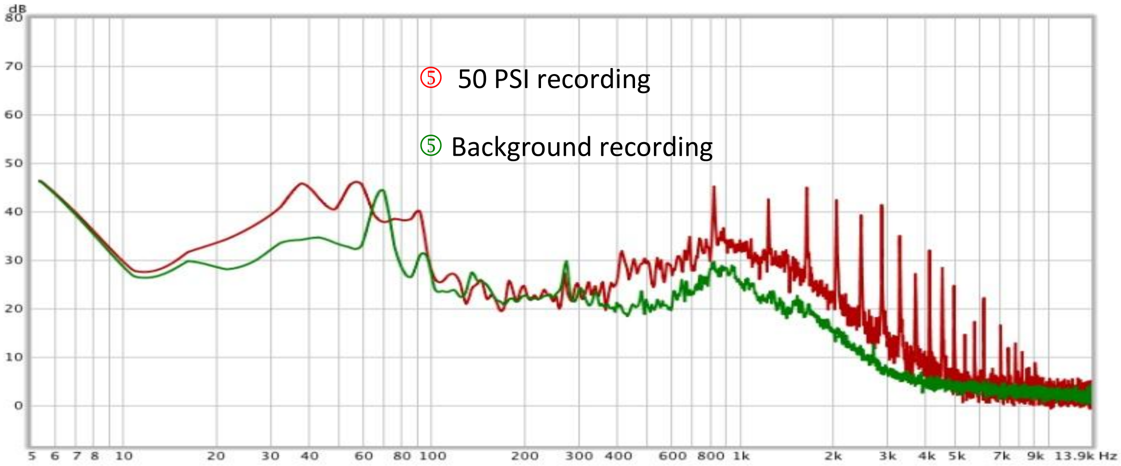


Figure 68 - 30 psi recording at Point B with background noise

Figure 69 - 50 psi recording at Point B with background noise



At 30 and 50 PSI the horn is clearly audible in the higher range. Peaks are visible in the 30 psi graph starting at 400 Hz and continuing every 400 Hz up until 10 kHz. There is also a large peak at 70 Hz, which seems to be related to background noise. There is a similar peak in the background noise at 70 Hz although it is a lower intensity. This suggests the two are related and the peak is not from the air horn but background noise fluctuations. In the 50 psi graph the first visible peak is at 800 Hz. Below 400 Hz, both graphs follow the shape of the background noise (excluding the peak at 70 Hz). This shows that the signal from the horn reaching the recorder was primarily in the 400-9000 Hz range. Although frequencies that were lower may have traveled to the recorder, they were not intense enough to be picked up over the background noise of the forest. Because all the frequencies picked up below 400 Hz were background noise, some of the lower frequencies were excluded from the analysis.

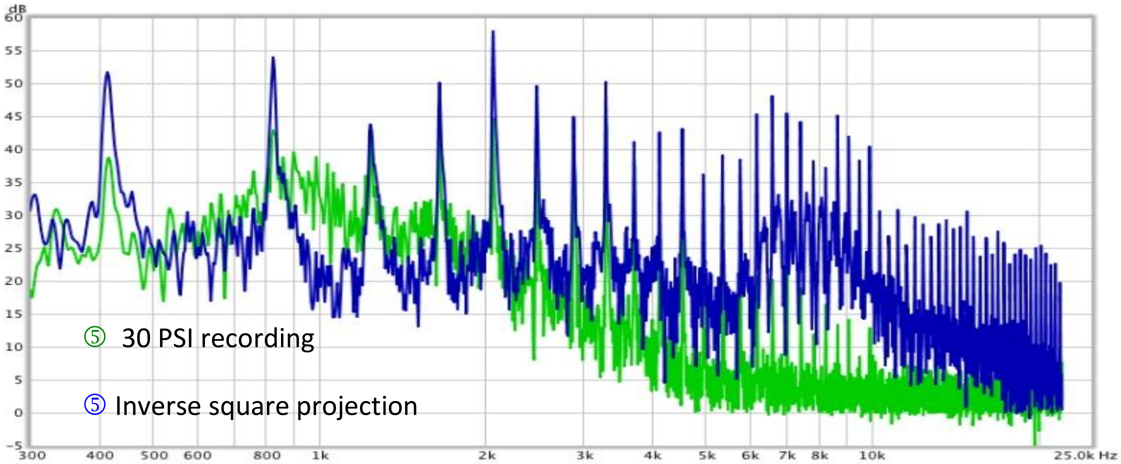
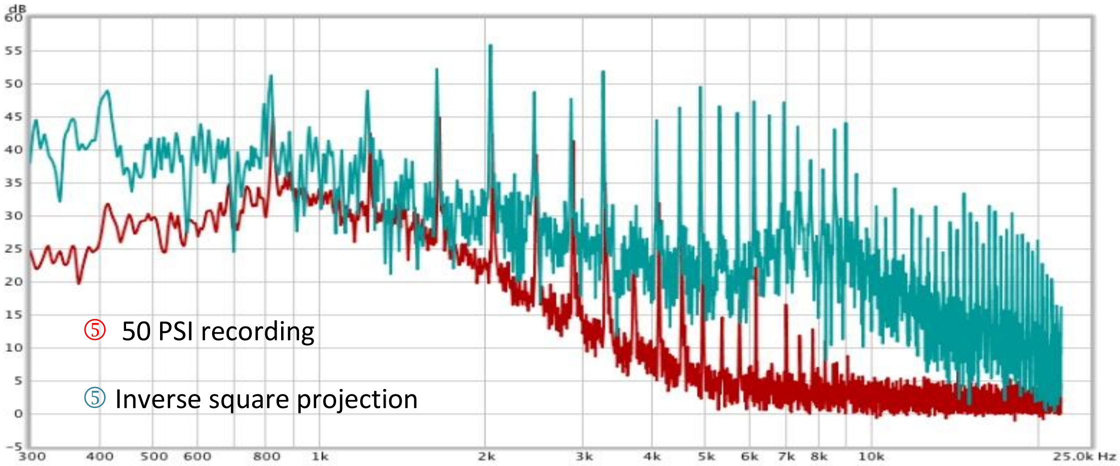


Figure 70 - 30 psi recording at Point B with Inverse square law projection

Figure 71 - 50 psi recording at Point B with Inverse square law projection



In the 30 and 50 psi tests, the intensity of the sound dropped off more than predicted over the full bandwidth. The inverse square law is an ideal situation and does not account for the physical barriers of a forest. The higher frequencies were the most effected by the environment. The increased distance and foliage compared to Point A has made the inverse square law less effective at predicting the intensity. The dense small trees between the recorder and the air horn reflected more sound away from the recorder decreasing the intensity across all frequencies.

4.3.1.3 Point C

The furthest location from the source is Point C. This location was approximately 400m (±50m) away from the source. Point C was surrounded primarily by evergreen trees with moss growth. The evergreens had more branches with needles than the trees by Point A. The ground was covered in thick moss and dotted by exposed sections of rock and mud. The path leading to Point C was similar to Point A although the path was declining. This meant the sound from the air horn had to travel over an incline to get to the recorder. The ground was not firm and felt spongy. Additional details and pictures of the location can be found in Appendix IV.

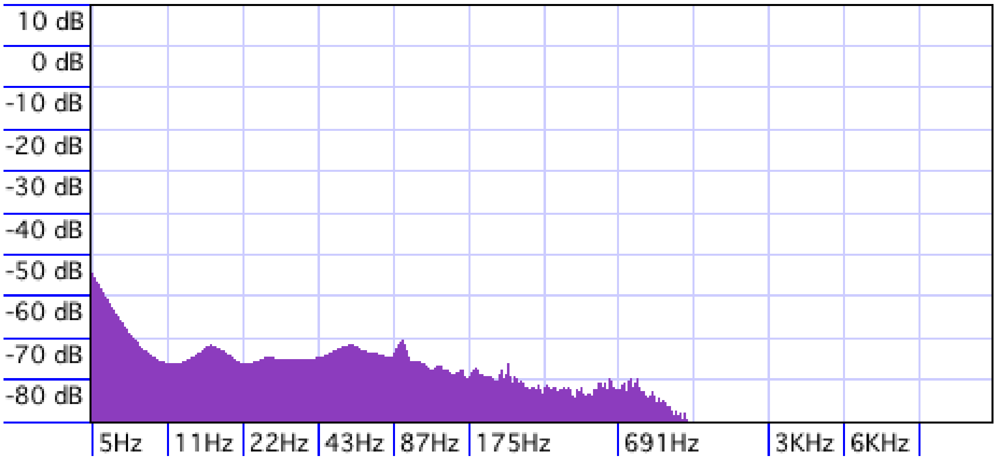


Figure 72 - Point C Background Noise

The background levels at Point C were in the lower range. The background levels peak around 50 Hz and 12 Hz. Noise picked up above 700 Hz is negligible. This was the quietest of the three recording points.

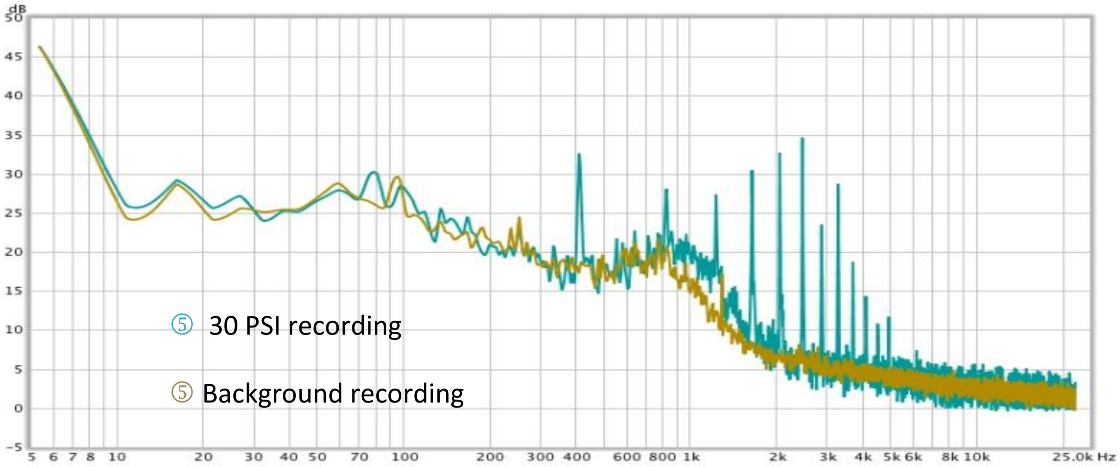
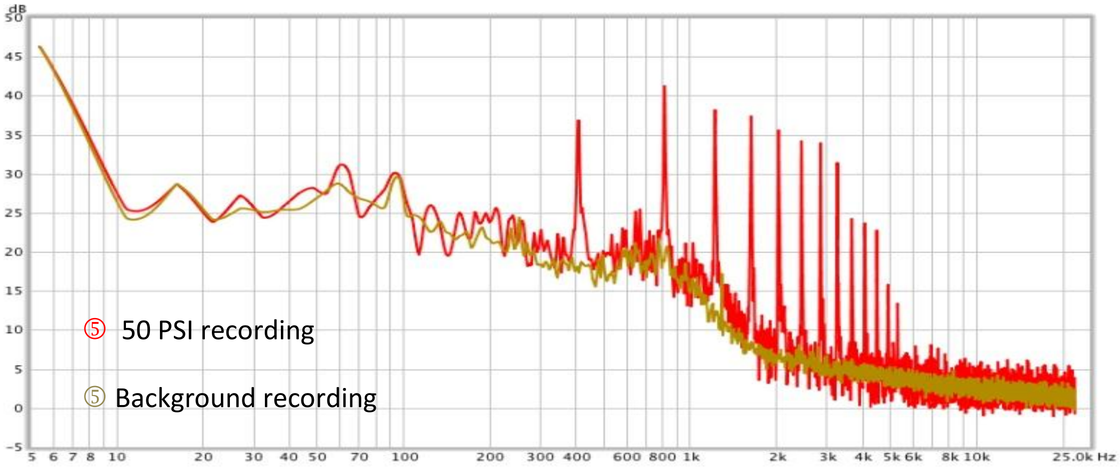


Figure 73 - 30 psi recording at Point C with background noise

Figure 74 - 50 psi recording at Point C with background noise



At 30 and 50 PSI the horn is audible in the higher range. Peaks are visible in the graph starting at 400 Hz and continuing every 400 Hz up until 5.5 kHz. Below 400 Hz the graphs follow the shape of the background noise. This shows that the signal from the horn reaching the recorder was primarily in the 400-5500 Hz range. Although frequencies that were lower may have traveled to the recorder, they were not intense enough to be picked up over the background noise of the forest. Because all the frequencies picked up below 400 Hz were background noise, some of the lower frequencies were excluded from the analysis.

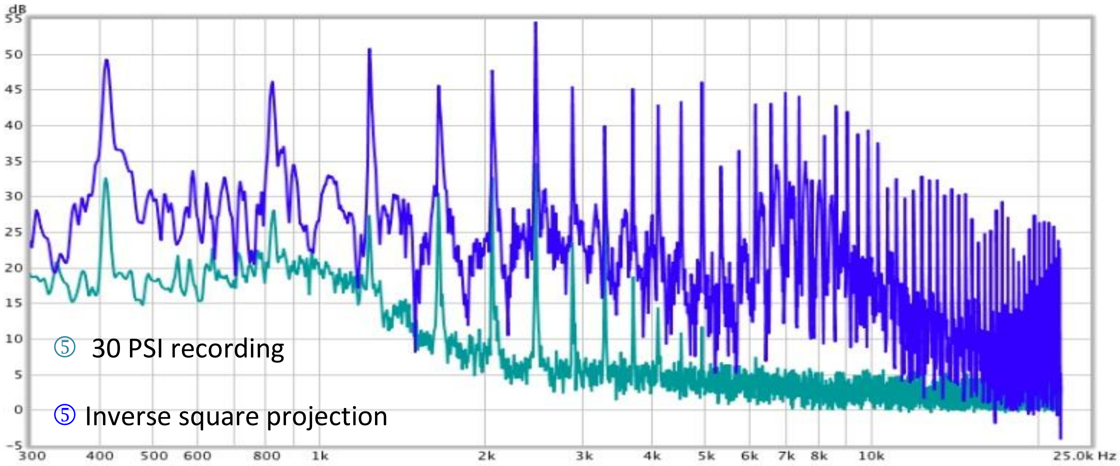
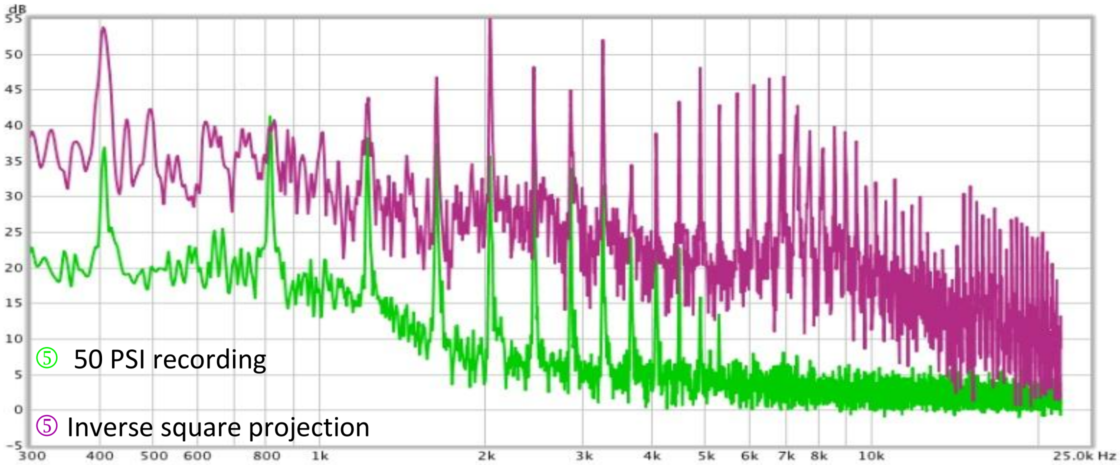


Figure 75 - 30 psi recording at Point C with Inverse square law projection

Figure 76 - 50 psi recording at Point C with Inverse square law projection



In the 30 and 50 psi tests, the intensity of the sound dropped off more than predicted over the full bandwidth. The inverse square law is an ideal situation and does not account for the physical barriers of a forest. The higher frequencies were the most effected by the environment. The increased distance has made the inverse square law less effective at predicting the intensity.

The dense small trees and elevation change between the recorder and the air horn reflected more sound away from the recorder decreasing the intensity across all frequencies.

4.3.2 **Lower Hadlock Pond**

Figure 77 - Lower Hadlock Pond

The second long distance test was conducted over water. Lower Hadlock Pond was the testing area. The air horn was set up on a rock marked S for source on the map above. The rock was accessible by a dirt road which allowed access with the air compressor. Recordings were taken from three points labeled A, B, and C. The distance between each point was measured using Google Maps. This test aimed to find how the air horn signal traveled over water to see if reflections off the surface helped transmit the signal.

4.3.2.1 Point A

The closest location to the source was Point A. This location was approximately 330m (±10m) away from the source. Point A was located on top of a cement dam. The ground was mostly hard dirt with short grass lining the path. There were numerous small trees and bushes located on the right side of the trail when facing the air horn. Additional details and pictures of the location can be found in Appendix IV.

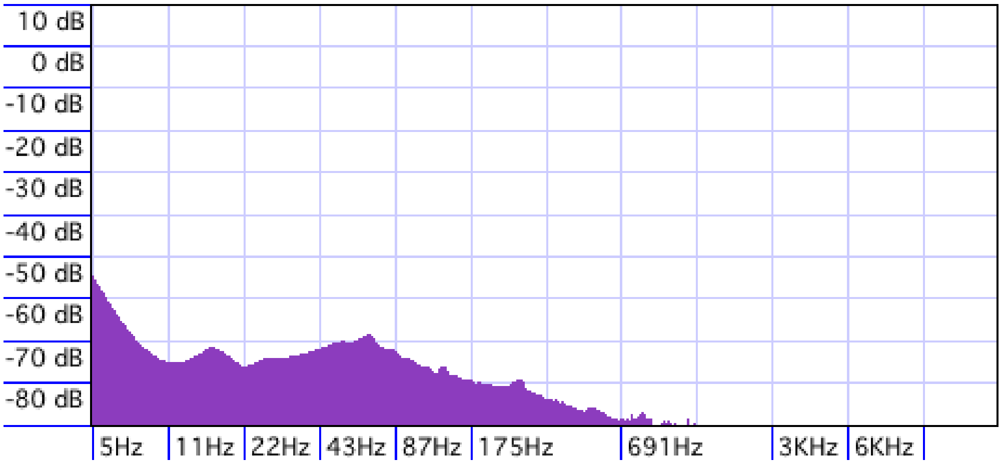


Figure 78 - Point A Background Noise

The background levels at Point A were in the lower range. The background levels peak around 70Hz with dips in levels around 8 Hz and 20 Hz. Noise picked up above 700 Hz is negligible.

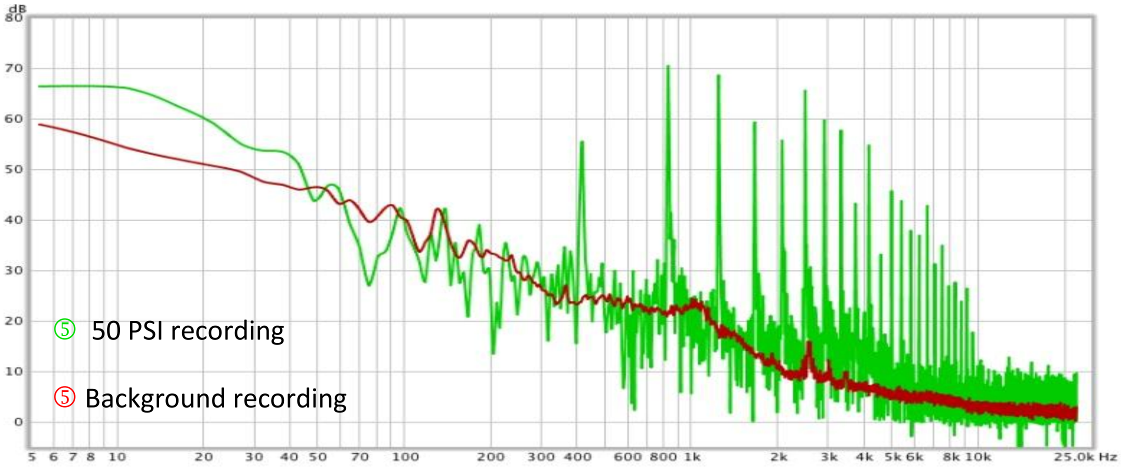
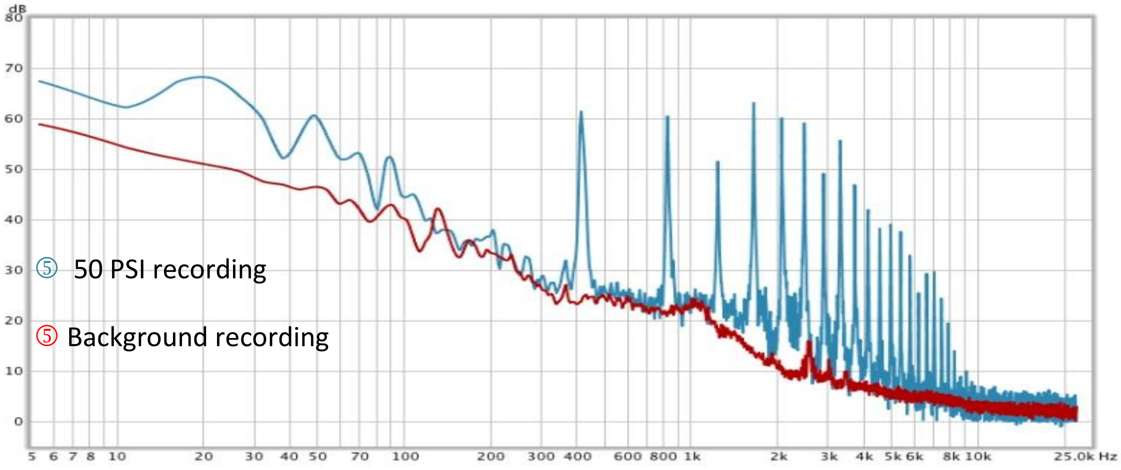


Figure 79 - 30 psi recording at Point A with background noise

Figure 80 - 50 psi recording at Point A with background noise



At 30 and 50 PSI the horn is clearly audible in the higher range. Peaks are visible in the graph starting at 400 Hz and continuing every 400 Hz up until 10 kHz. Between 100-400 Hz the graphs follow the shape of the background noise. Below 100 Hz both graphs show a signal being picked up. It is unclear if the noise below 100 Hz is produced by the air horn. The peaks starting at 400 Hz and higher have been established as noise from the horn. Although it is possible that the low frequencies are from the horn, it is unlikely because the characteristics of the graph are different. A likely cause of these differences is background noise from traffic on Route 3.

Because all the frequencies picked up below 400 Hz were background noise or not produced by the air horn, some of the lower frequencies were excluded from the analysis.

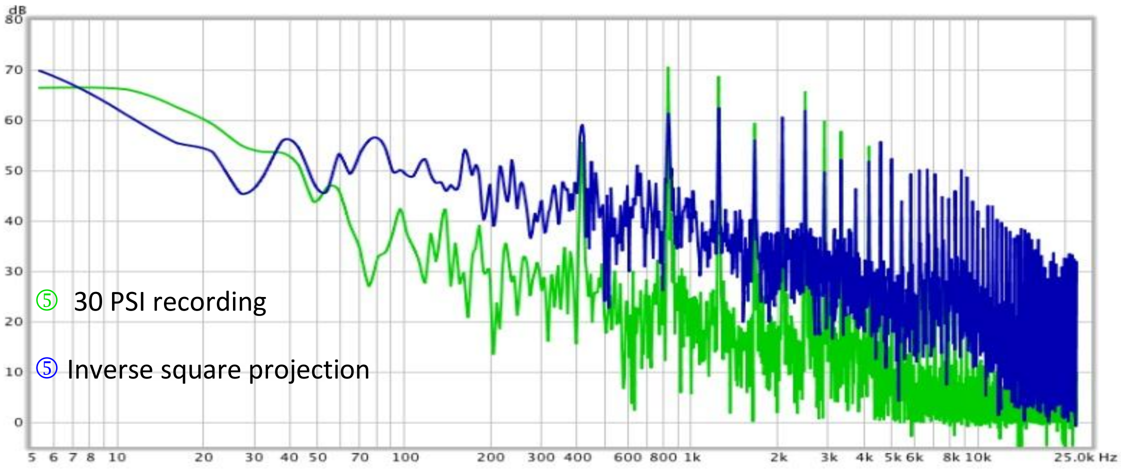
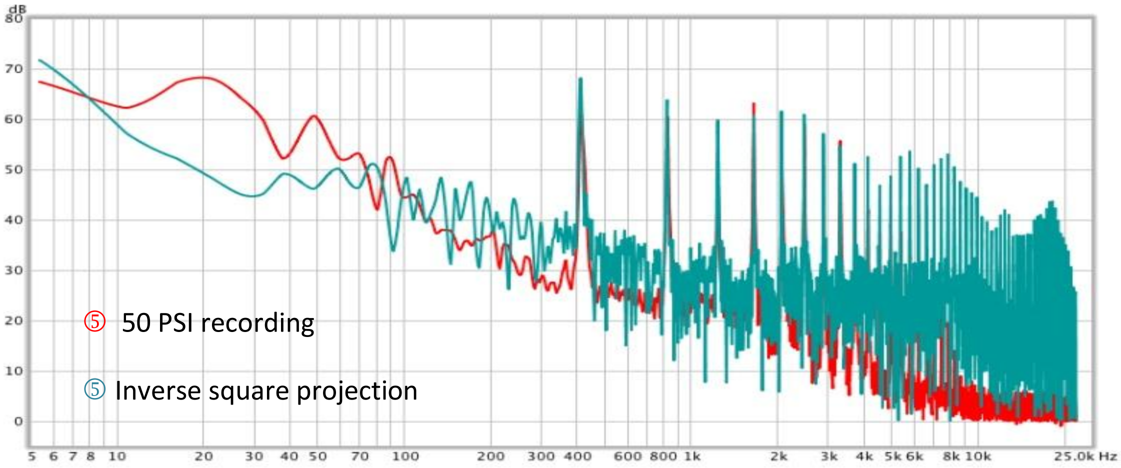


Figure 81 - 30 psi recording at Point A with Inverse square law projection

Figure 82 - 50 psi recording at Point A with Inverse square law projection



In the 30 psi test, the intensity of the sound dropped off less than predicted at frequencies between 600 and 4000 Hz. The inverse square law is an ideal situation and does not account for the physical barriers the water. The frequencies that were received with higher intensities were most likely reflected off of the water. This was not accounted for with the inverse square law which predicted the sound intensity if the waves had not had any reverberation. In both recordings the intensity of the frequencies higher than 4000 Hz were lower than projected by the inverse square law. This meant that the water and trees nearby were absorbing those frequencies.

4.3.2.2 Point B

The second closest location to the source was Point B. This location was approximately 350m (±10m) away from the source. Point B was located on top of an exposed rock that was a foot above the water. The ground behind the rock was mostly hard dirt and covered with small bushes and trees. Additional details and pictures of the location can be found in Appendix IV.

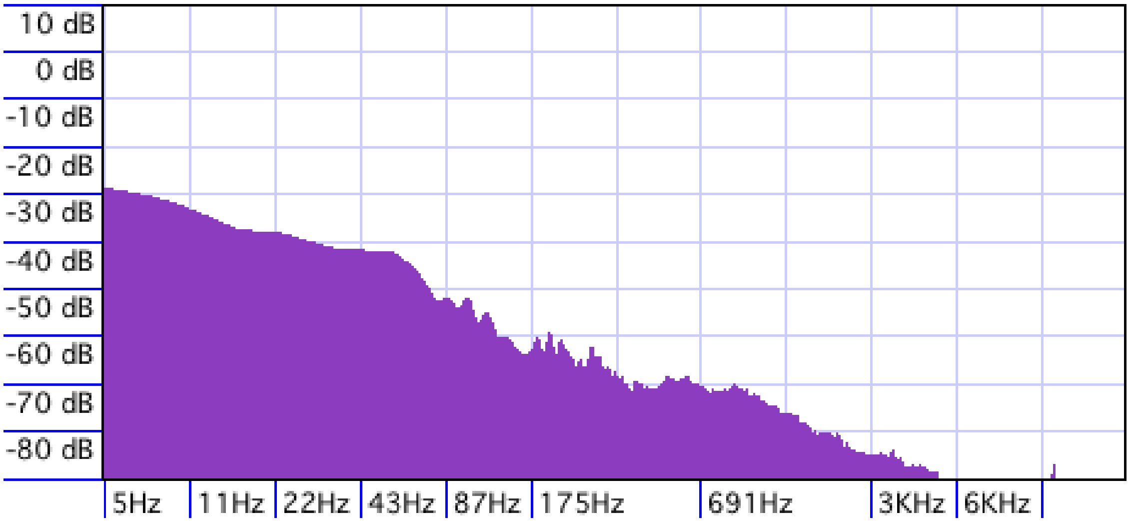


Figure 83 - Point B Background Noise

The background levels at Point B were in the primarily in the lower range. There were high background levels during this test. Because of the proximity to water, the microphone was picking up noise from water splashing against the rock. The highest level was at 5 Hz. The background noise is negligible over 5000 Hz.

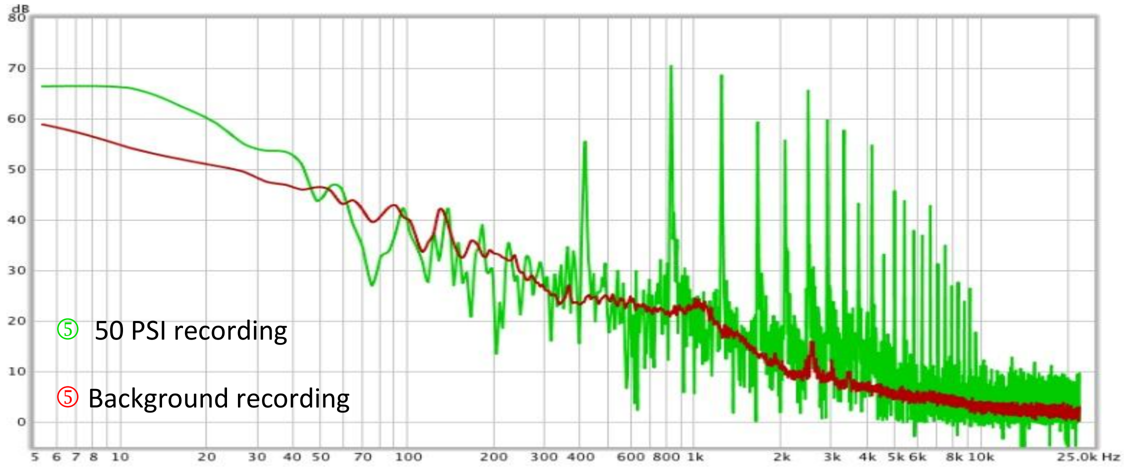
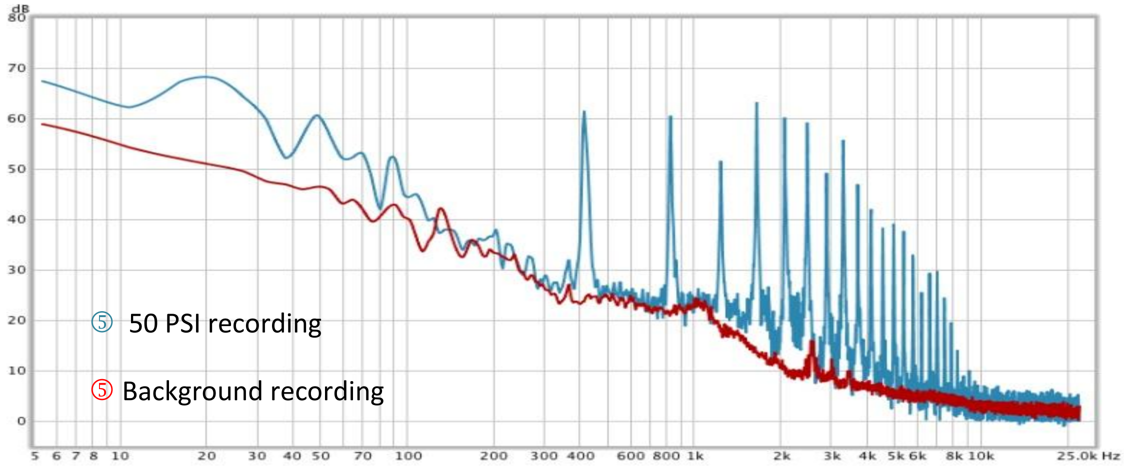


Figure 84 - 30 psi recording at Point B with background noise

Figure 85 - 50 psi recording at Point B with background noise



At 30 and 50 PSI the horn is clearly audible in the higher range. Peaks are visible in the graph starting at 400 Hz and continuing every 400 Hz up until 10 kHz. Between 100-400 Hz the graphs follow the shape of the background noise. Below 100 Hz both graphs show a signal being picked up. It is unclear if the noise below 100 Hz is produced by the air horn. The peaks starting at 400 Hz and higher have been established as noise from the horn. Although it is possible that the low frequencies are from the horn, it is unlikely because the characteristics of the graph are different. A likely cause of these differences is background noise from traffic on Route 3.

Because all the frequencies picked up below 400 Hz were background noise or not produced by the air horn, some of the lower frequencies were excluded from the analysis.

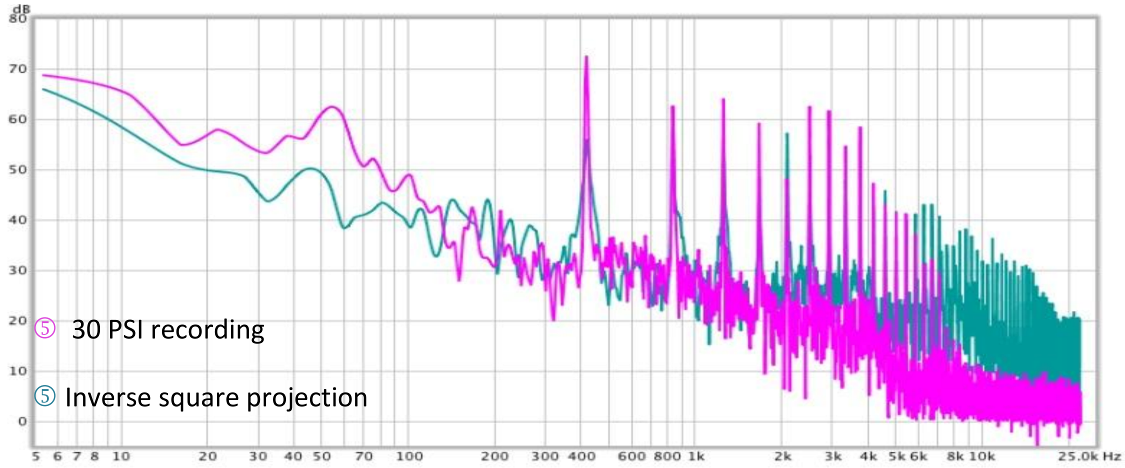
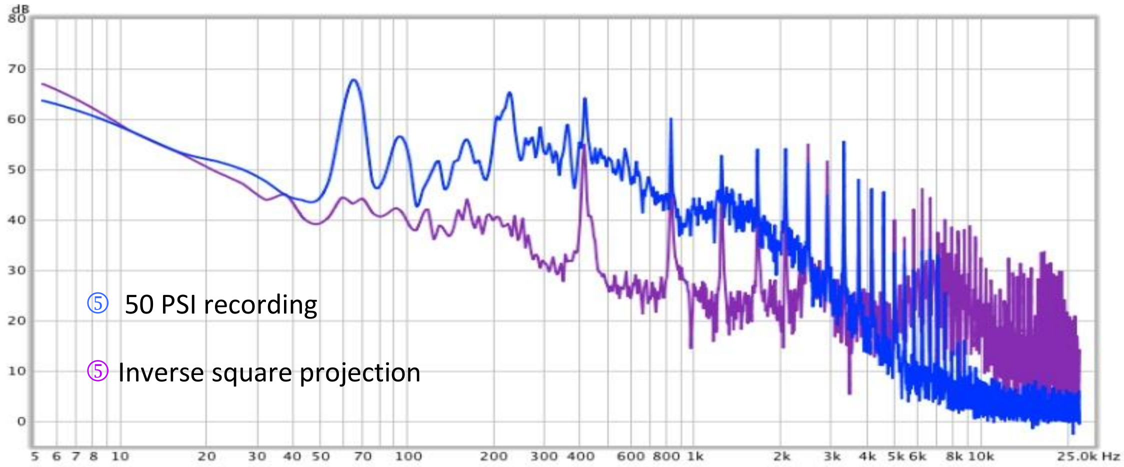


Figure 86 - 30 psi recording at Point B with Inverse square law projection

Figure 87 - 50 psi recording at Point B with Inverse square law projection



In both the 30 and 50 psi tests, the intensity of the sound dropped off less than predicted at frequencies between 400 and 6000 Hz. The inverse square law is an ideal situation and does not account for the physical barriers the water. The frequencies that were received with higher intensities were most likely reflected off of the water. The 50 psi recording also picked up additional noise between the peaks. This was not accounted for with the inverse square law which predicted the sound intensity if the waves had not had any reverberation. In both recordings the intensity of the frequencies higher than 6000 Hz were lower than projected by the inverse square law. This meant that the water was absorbing those frequencies.

4.3.2.3 Point C

The furthest location from the source was Point C. This location was approximately 420m (±10m) away from the source. Point C was on a small sandy shore on the far side of the pond. The area behind the shore was mostly hard dirt and covered with small bushes and trees. The trees and bushes were widely spread out. Additional details and pictures of the location can be found in Appendix IV.

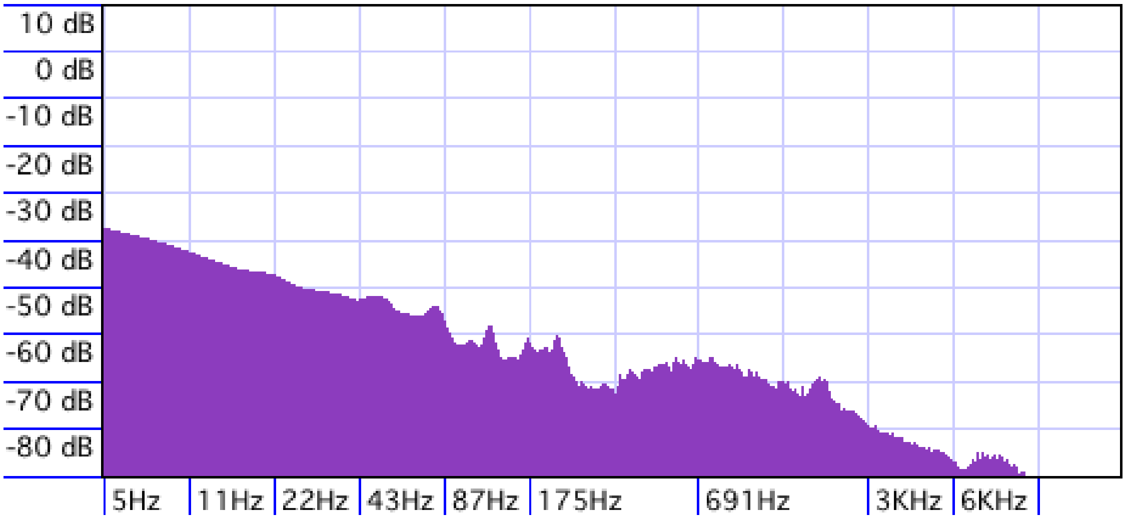


Figure 88 - Point C Background Noise

The background levels at Point C were in the primarily in the lower range. There were high background levels during this test due to the proximity to the water; the microphone was picking up noise from water splashing against the rock. The highest level was at 5 Hz. The background noise is negligible over 6000 Hz. The background noise is very similar to the background noise at Point B.

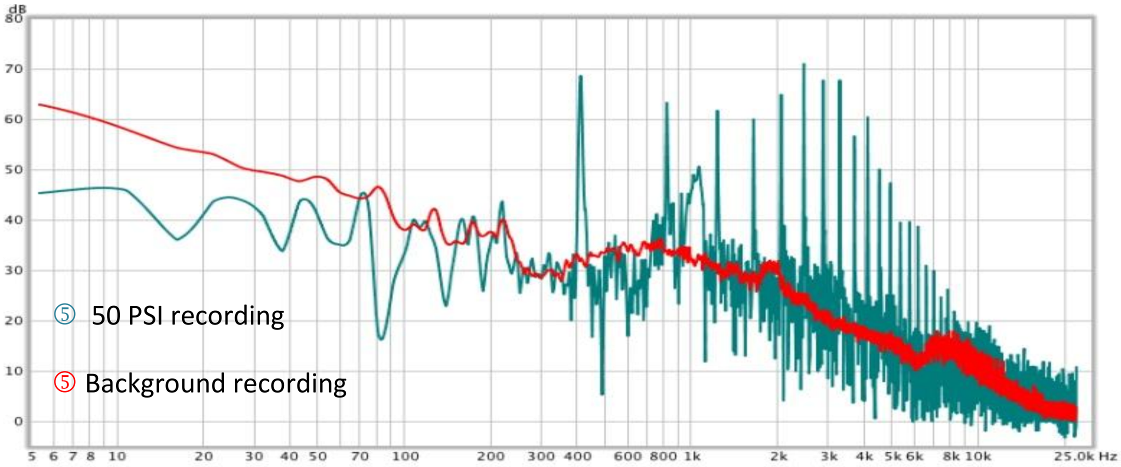
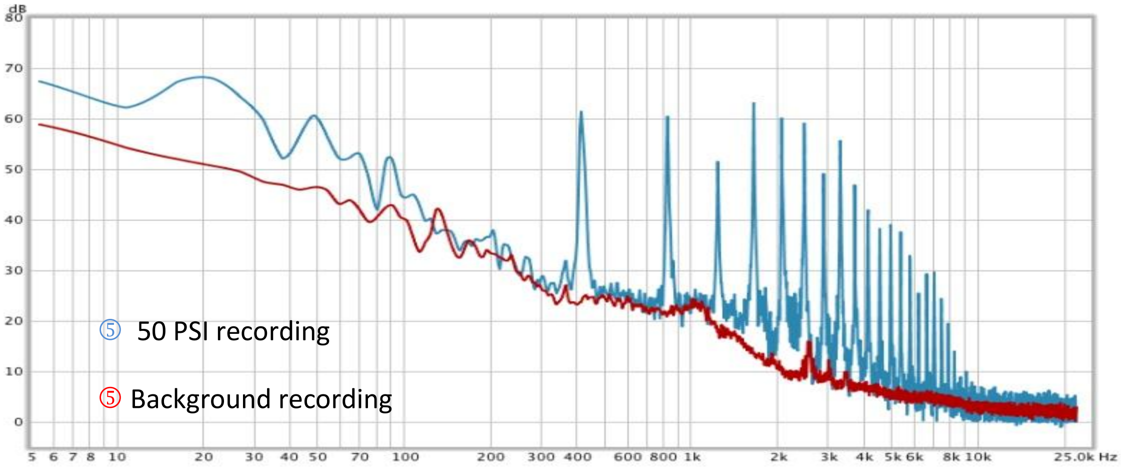


Figure 89 - 30 psi recording at Point C with background noise

Figure 90 - 50 psi recording at Point C with background noise



At 30 and 50 PSI the horn is clearly audible in the higher range. Peaks are visible in the graph starting at 400 Hz and continuing every 400 Hz up until 10 kHz. Below 400 Hz the graphs follow the shape of the background noise. Because all the frequencies picked up below 400 Hz were background noise or not produced by the air horn, some of the lower frequencies were excluded from the analysis

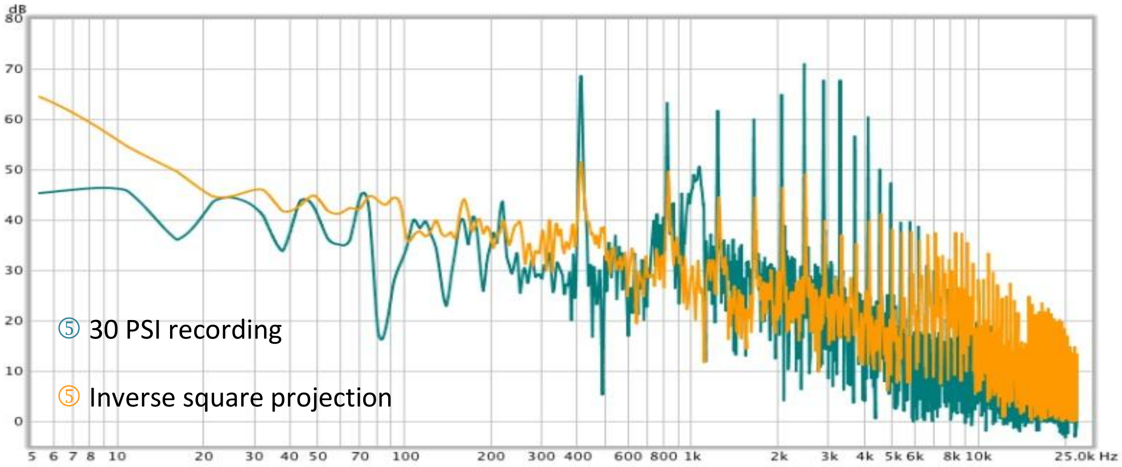
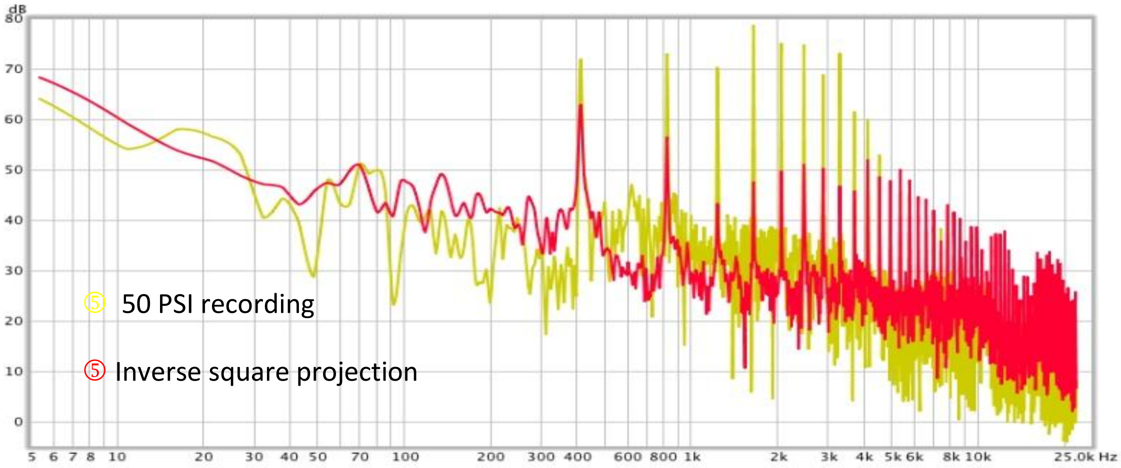


Figure 91 - 30 psi recording at Point C with Inverse square law projection

Figure 92 - 50 psi recording at Point C with Inverse square law projection



In both the 30 and 50 psi tests, the intensity of the sound dropped off much less than predicted at frequencies between 400 and 6000 Hz. The inverse square law is an ideal situation and does not account for the physical barriers the water. The frequencies that were received with higher intensities were most likely reflected off of the water. The 50 psi recording also picked up additional noise between the peaks. This was not accounted for with the inverse square law which predicted the sound intensity if the waves had not had any reverberation. In both recordings the intensity of the frequencies higher than 6000 Hz were lower than projected by the inverse square law. This meant that the water was absorbing those frequencies.

4.3.3 Long Distance Tests Summary

Point	PSI	Temp (°F)	Wind speed (mph)	Max SPL (db)	% Error
	Forest by Route 3				
A	30	72.5	0	93.1	10.03%
A	50	72.5	0	91.6	15.59%
B	30	73.0	0	114.0	14.50%
B	50	73.0	0	106.1	16.79%
C	30	72.7	0	107.3	16.50%
C	50	72.7	0	102.1	17.88%
	Lower Hadlock Pond				
A	30	80.6	0-3	101.5	19.95%
A	50	80.6	0-3	119.0	18.23%
B	30	78.1	1-4	99.2	12.73%
B	50	78.1	1-4	107.8	14.33%
C	30	79.2	1-3	98.3	10.63%
C	50	79.2	1-3	108.3	9.78%

Figure 93 – Table of Long Distance Data

The table above shows a compilation of the data collected from the two long distance test sites. Trends found in this data include, the retention of mid-range frequencies over water, the loss of high frequencies, and the influence of trees/brush on the intensity of the signal.

There was a strange trend in the Forest data. The SPL meter detected higher sound pressures during the 30 psi tests than the 50 psi tests. This did not match up with the recordings taken from those tests where the 50 psi test is clearly more audible. The A weighting on the meter is also not the cause because the weighting was the same as the Lower Hadlock Pond test showed the 50 psi test was more intense. The most likely cause of the strange data is human error. The SPL meter may not have been set up properly for the 30 or 50 psi tests.

Over water, it was found that mid-range frequencies traveled very clearly without dispersion predicted by the inverse square law. This is because the surface of the water reflects the sound back up at the recorder.

High frequencies (of 6000 Hz and above) were much less intense when measured at a distance than they were projected to be. This was most likely caused by reflection and absorption. High frequency waves have shorter wavelengths that can interact with the environment. When traveling through the forest the high frequencies interacted with mossy ground, numerous tree and dense branches with think needles. Over water, the high frequency waves came into contact with small ripples on the lakes surface as well as the trees surrounding the lake. All of these obstacles reduced the intensity of the signal reaching the recorder. Lower frequencies were less likely to interact with the environment because of the longer wavelengths.

Very dense brush was found to reduce the intensity of the full spectrum. This is because the sound wave cannot freely move through the brush and many reflections maybe destructively interact with the other sound waves.

4.4 Conclusions

The results of the Short Distance Tests were characterizations of soundscapes based on observation and frequency analyses. They were directly applicable to the Environmental Orchestra, but had scientific value of their own as well. The characterizations of soundscapes would be helpful, for example, in establishing the best locations for outdoor musical performances, or understanding what impact traffic noise will have on the surrounding areas. Noise from a road would have traveled intact for a long distance in a mossy forest, whereas road noise would have been scattered and diffused into ambient noise more quickly in a rocky mountain area.

The applications of the soundscape characterizations in the construction of the Environmental Orchestra were less hypothetical. Understanding how sound interacts with a rocky shoreline would be critical if a sound sculpture was put on an island across from a listening environment. Bar Harbor, in particular, has many different islands surrounding it, all with rocky shorelines. The data and frequency characterization from the rocky shore measurements would suggest, for example, that frequencies between 300 and 2,500Hz would travel well, and also that frequencies above 2,500Hz would have a more unpredictable behavior. If a sound sculpture was placed on a rocky mountaintop, the frequencies below 800Hz would travel well, but frequencies above that would be attenuated through reflection and dissipation, creating a natural bass equalizer, emphasizing the low frequencies.

Long range testing characterized sound traveling through a forest and over water. It was found that the frequencies put out by the horn traveled more easily over water than in the forest. Reverberations off the waters surface made intensity levels higher than predicted by the inverse square law. Absorption and reflections in the forest reduced the intensity below what was expected from the inverse square law.

This data characterized several different soundscapes so that they could be understood in terms of frequency responses. Additionally, taking into consideration the decay data found in

Appendix III, they could also be characterized in terms of reverberation and echoing. After understanding the acoustics of those soundscapes, one could predict how something would behave acoustically in a given soundscape, or additionally, one could design an instrument or sound sculpture that would perform well in said soundscape. An arrangement of these instruments, designed acoustically for the soundscape they are established in, could create an out-door orchestra that not only works with the acoustics of the environment, but was specifically designed for and inspired by it, representing the landscape acoustically.

The Environmental Orchestra could go in two directions. It could be a group of instruments that are established within earshot from a common location, and listened to from that location, or it could be a collection of sound sculptures, not necessarily within earshot of each other, that are all monitored by microphones, and collected digitally, to be listened to simultaneously. Either way, the concept remains that the environment dictates the kind of sounds present, through its soundscape characteristics, and those sounds are collectively listened to, and possibly even arranged to be musical.

5.Recommendations

5.1 Sound Analysis

5.1.1 **Equipment**

It is recommended that future groups conducting sound analysis use additional equipment than used during this project. This includes, an external sound card and equipment to take better distance measurements.

Even under ideal situations, the handheld GPS measurements have a tolerance of 7m. This is accurate enough for long distance tests, especially those conducted at distances greater than 400m. During this project, the readings were far less accurate and were unusable for data analysis. For this reason, a more accurate method of measuring distance should be used. A total station is a commonly used piece of equipment for measuring distances in surveying. Total stations are much more accurate, there tolerances are generally around 2-3 millimeters per kilometer. The main drawback to using a total station is its cost and limited use. The cost of an accurate total station is over $1000. The limitation of the total station is that it can only measure distances that are visible. When testing in a forest, the air horn is not visible from the recorder, making a total station useless. There are still a number of tests that would make use of a total station, such as the tests conducted over water, a grassy field or from mountain to mountain. In order to get accurate measurements in the forest, it is recommended to use a GPS with smaller tolerances.

Figure 94 - Total station

The air compressor used for the long range testing was very large and heavy. This limited long range tests to areas easily accessible by car. There are many locations that would have different and interesting data that are not accessible by car. It is recommended that future sound analysis groups use a smaller and more portable compressed air tank. Research could be done into the use of CO_2 tanks, which are much smaller but are under high pressure.

5.1.2 **Testing**

There are many locations that were not tested with a long distance test. This was due to both time and feasibility constraints. The large air compressor did not allow for testing away from car accessibility. Areas that would have been tested had it been feasible with the air compressor include: the top of Norumbega mountain, between North and South Bubble peaks, islands to the shore of Bar Harbor.

Norumbega Mountain lines one side of Somes Sound. On the other side of Somes Sound is Acadia Mountain. Testing between these peaks would be very interesting as this area is a rare land formation called a Fjord. Originally test had been planned for this location using the loud speaker, but was impossible due to harmonic distortion.

The Bubbles are small peaks covered by dense trees. Testing between these peaks was planned with the loud speaker but was not feasible. The air compressor was too large to carry to the top of a mountain, but testing could be done with an improved loud speaker or a smaller air compressor.

Islands are proposed locations for installations. Testing has already shown that the air horn travels well over Lower Hadlock Pond. Short distance testing of the rocky shore was not enough to understand fully how sound travels over long distances. For this reason, it is proposed to test from Bar Island or another Island to the shore of Bar Harbor. A long distance test could also be done over the rocky shore to better understand its effect on sound.

5.2 Archiving Sound

Mount Desert Island is a popular tourist area. People enjoy coming to see a rustic fishing town in Maine. This has led to an increase in traffic and noise on the island. During field tests, background noise was picked up from automobiles and aircraft. In order to preserve the sounds of the island for future generations, an archive of sounds should be compiled. The soundscape of Bar Harbor is likely to change over time and documenting the sounds of Bar Harbor now may be useful data for future studies. Bar Harbor is trying to reduce the noise from aircraft flying over the island. Taking recordings now will give a baseline that can be used to show improvement or deterioration in the quality of the soundscape.

A database of recordings could be compiled and follow the model set up by the Cornell Lab of Ornithology. The Cornell Lab has created an online database of birdcalls and relevant information on bird communication. The Cornell website is an educational resource that engages the browser to learn about birds and shows how the database is helping the study of ornithology. A database of the sounds of Arcadia could help raise awareness of problems and projects relating to sound on the island.

5.3 Installation design and implementation

Figure 95 - View from Mount Cadillac overlooking Bar Harbor and islands

The town of Bar Harbor is surrounded by small islands as seen in the image above. These islands would be an ideal location for installations of the Environmental Orchestra. Sound produced by the installations would travel over the water to reach the town. The long distance tests showed that mid-range frequencies traveled well over water. High frequencies did not travel over water or through foliage as well. The design of the Environmental Orchestra must account for this by producing more intense high frequencies or by placing the high frequency installations closer to Bar Harbor. The image above shows five different islands, which could have installations. The low frequency and mid frequency waves traveled the best during testing, so it is recommended that these be installed on the islands furthest from the town. The high frequency installation could be placed on the near island. This would be a natural form of equalization and further sound analysis would be needed to get the levels correct.

The Environmental Orchestra focuses on producing sounds that work with the soundscapes and landscapes of the area. While air horns are man-made, they are used by boats commonly in Bar Harbor and have almost become part of the soundscape. For this Environmental Orchestra, air horns powered by compressed air would be welcomed in sound sculptures used in the Bar Harbor Environmental Orchestra

An alternate arrangement of the Environmental Orchestra could be a collection of sound sculptures, not necessarily within earshot of each other, which are all monitored by microphones. Those microphones could all be interconnected, so that all the sounds sculptures could be listened to simultaneously. In this case, the sound sculptures could be all over Mount Desert Island. The environment would still dictate the kind of sounds present, through each sound sculpture being built to fit a soundscape. With the help of microphones and a connected network, those sound sculptures could be collectively listened to, and possibly even arranged to be musical. The microphone recordings could be broadcast across the Internet for listeners all over the world.

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8.Appendix I LoudspeakerSystem

8.1 Drivers

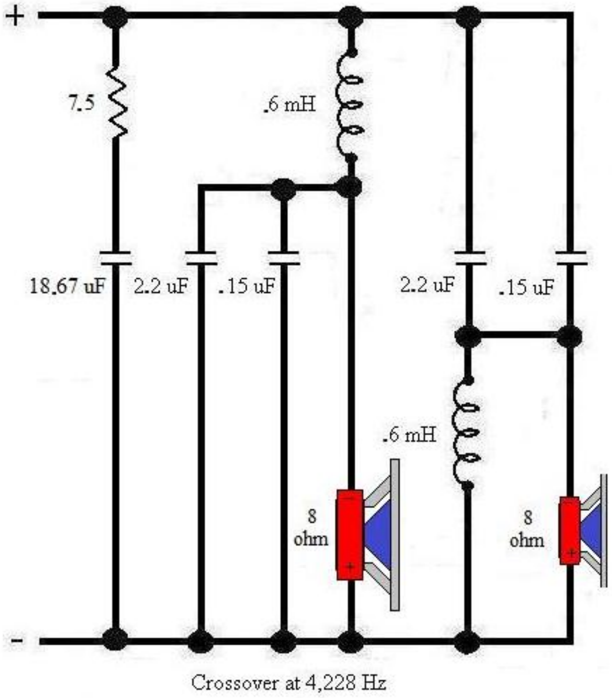
Aura NS6-255-8A 6" Paper Cone Neodymium Magnet Woofer - • Power handling: 50 watts RMS/100 watts max • VCdia: 1" *Impedance: 8 ohms • Re: 6.0 ohms • Frequency response: 55-5,500 Hz • Fs: 55 Hz • SPL: 91 dB 1W/1m • Vas: 0.58 cu. ft. • Qms: 10.8 • Qes: 0.58 • Qts: 0.55 • Xmax: 3.9 mm • Dimensions: Outside diameter: 6-1/8", Cutout diameter: 5-3/8", Depth: 3-3/8".

http://www.parts-express.com/pe/showdetl.cfm?Partnumber=299-030

Goldwood GT-520 1" Soft Dome Horn Tweeter - Power handling: 50 watts RMS/100 watts max • VCdia: 1" • Impedance: 8 ohms • Fs: 1000 Hz • Frequency response: 2,000 - 20,000 Hz • SPL: 92 dB 1W/1m • Dimensions: Overall diameter: 4-1/2", Cutout diameter: 3-1/4", Depth: 2".

http://www.parts-express.com/pe/showdetl.cfm?Partnumber=270-180

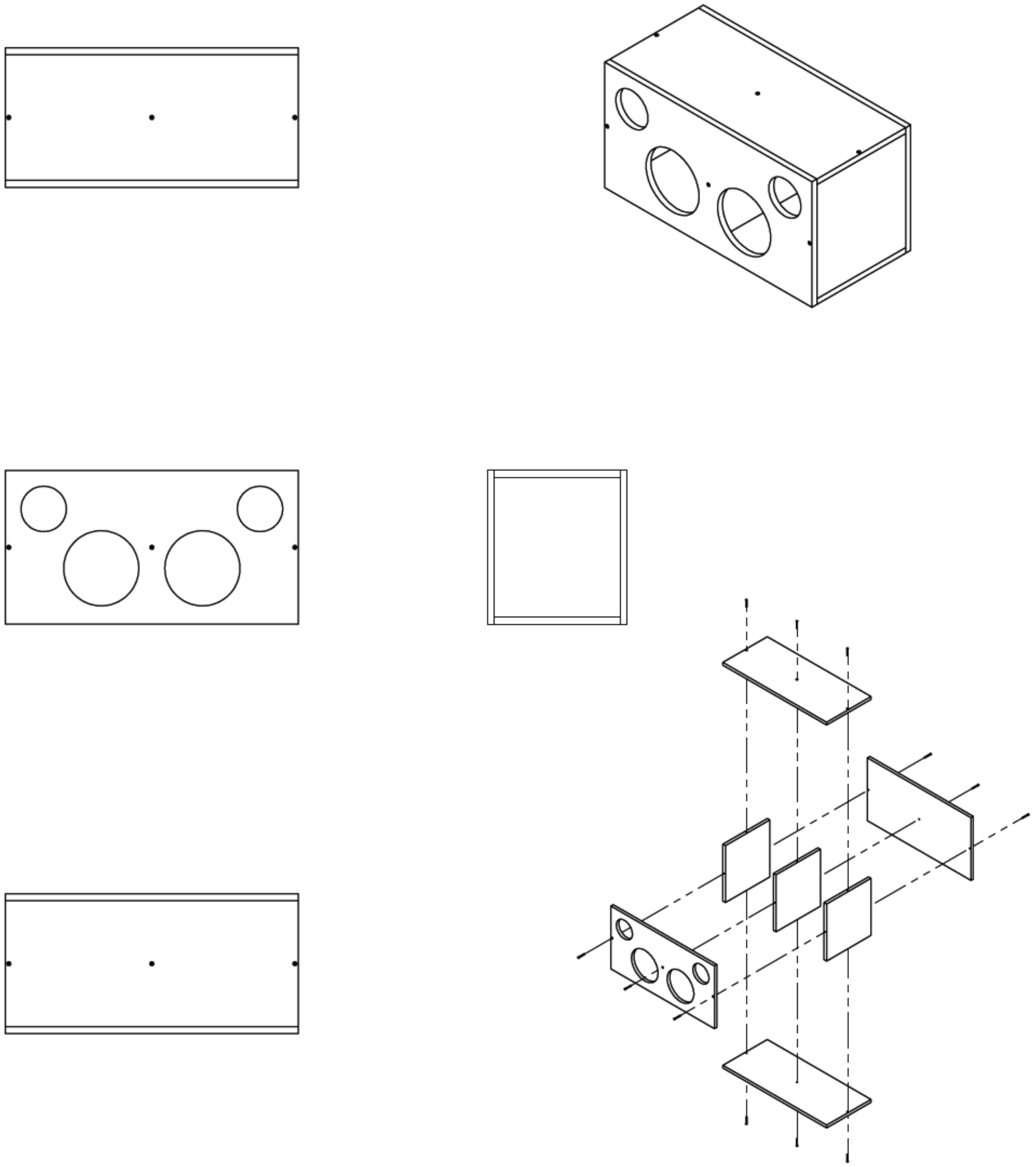
8.2 Circuit Design



Appendix 1 - Crossover circuit for the portable loudspeaker system

8.3 Enclosure design

The enclosure was designed and built to be carried as a back pack, and also to have two sealed internal volumes of 0.5 cubic feet, one volume per pair of 6 inch driver and tweeter. These two symmetric volumes were to be used for two separate channels, with a crossover circuit in each volume. The enclosure was assembled with glue and 1 ¼” drywall screws. Additionally, the joined edges of the box were sealed, from the inside, with silicone caulking, to keep the enclosure air tight. The drivers and crossover circuits were installed into the enclosure, and input terminals fixed to the outside of the box. Both halves of the enclosure were then stuffed with polyester Polly-Fill. Drawings for individual pieces of the enclosure, and the assembly of those pieces are included below:



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF CHRISTOPHER MAINO. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF CHRISTOPHER MAINO IS PROHIBITED.

NEXT ASSY | USED ON

APPLICATION

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL
Medium Density Fiberboard

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	CAM	07/22/12
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

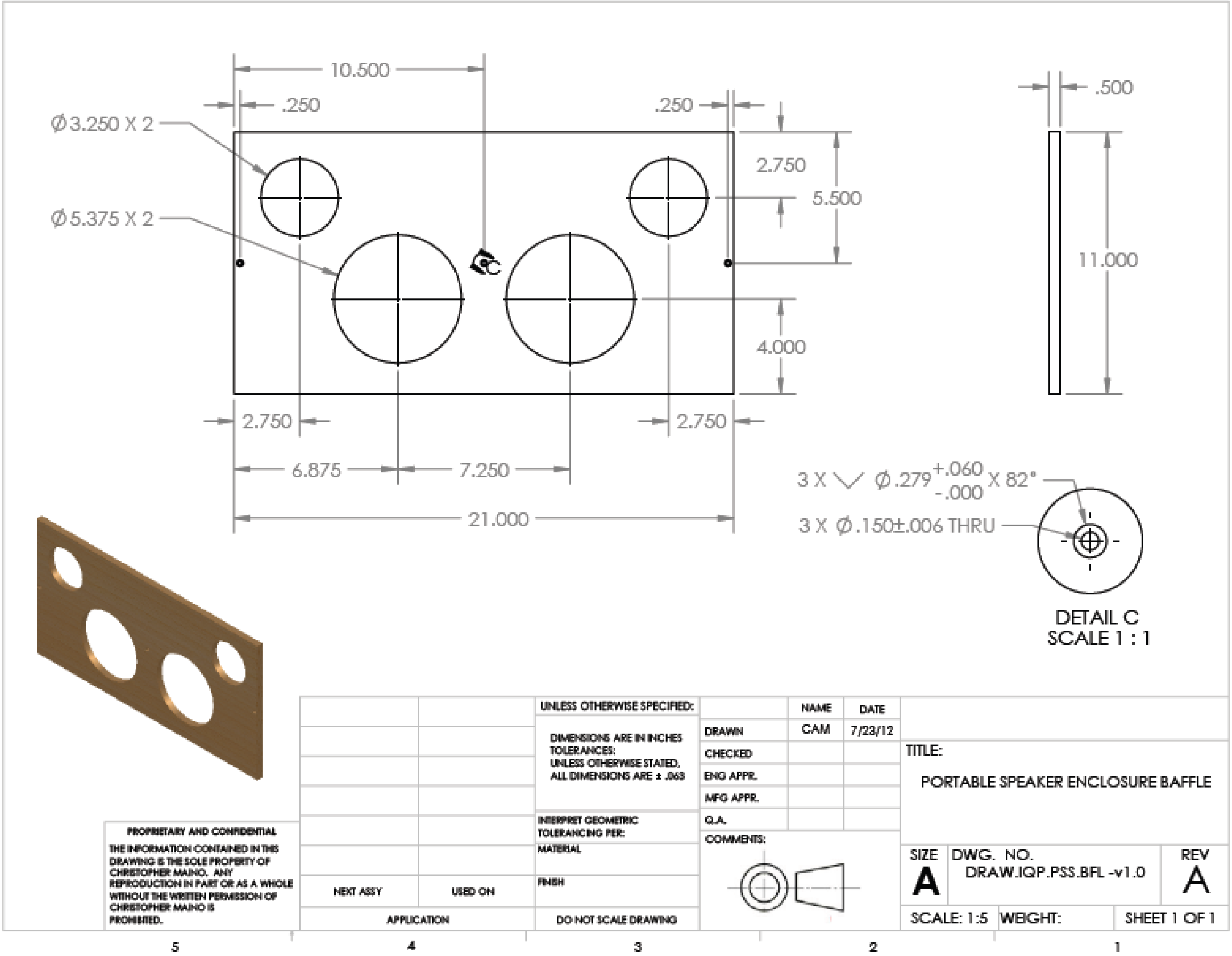
ALL EDGES SHARED BY TWO PIECES ARE FIXED TOGETHER WITH WOOD GLUE FOR THE FINAL ASSEMBLY.

PORTABLE SPEAKER
SYSTEM ENCLOSURE

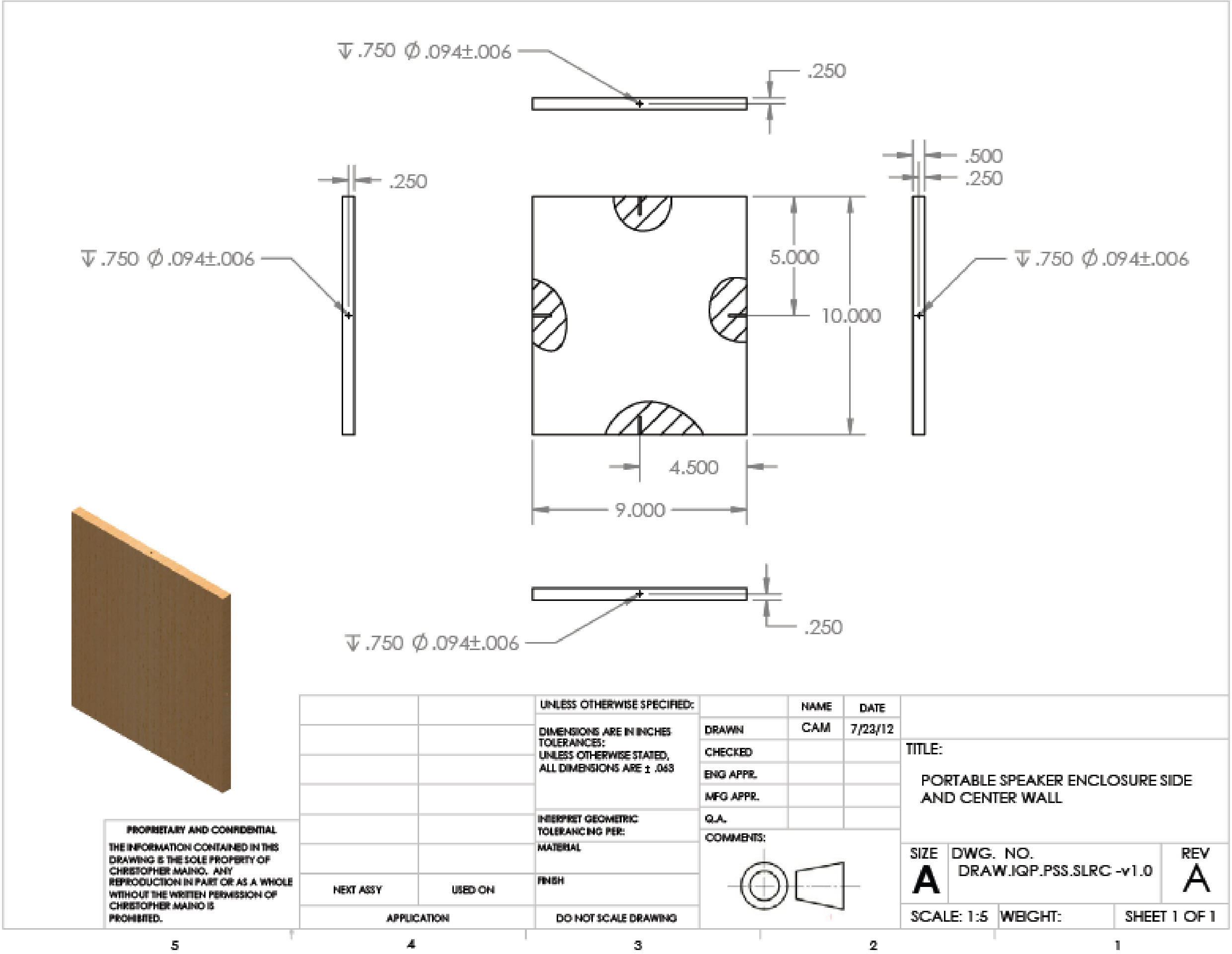
SIZE A | DWG. NO. DRAW.ASM.IQP.PSS.WHL -v2.0 | REV. A

SCALE:1:10 | WEIGHT: | SHEET 1 OF 1

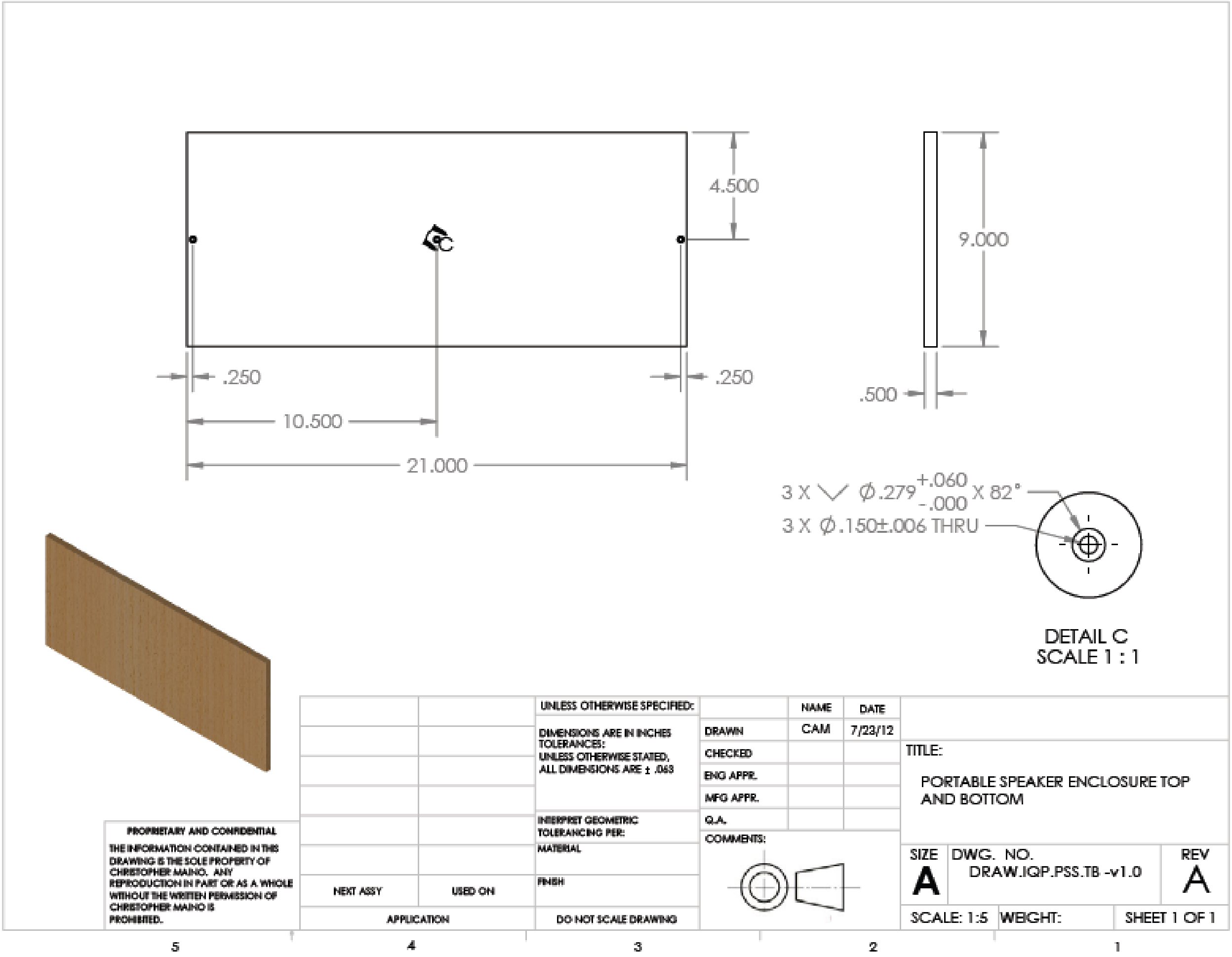
Appendix 2 - Portable speaker enclosure assembly drawing



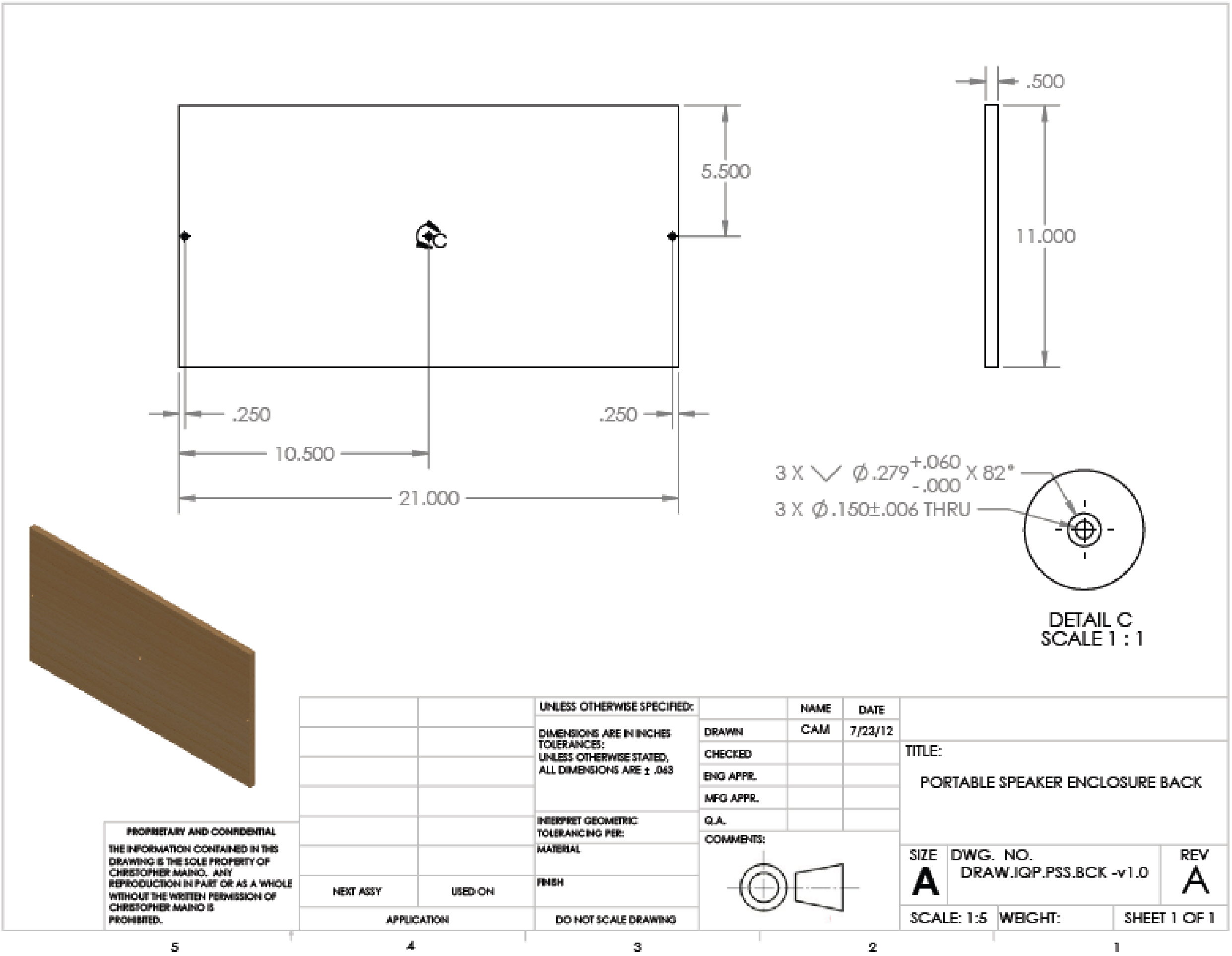
Appendix 3 - portable loudspeaker front wall, or baffle, drawing



Appendix 4 - portable loudspeaker left, right, and center wall drawing



Appendix 5 - This is the portable speaker top and bottom wall drawing.



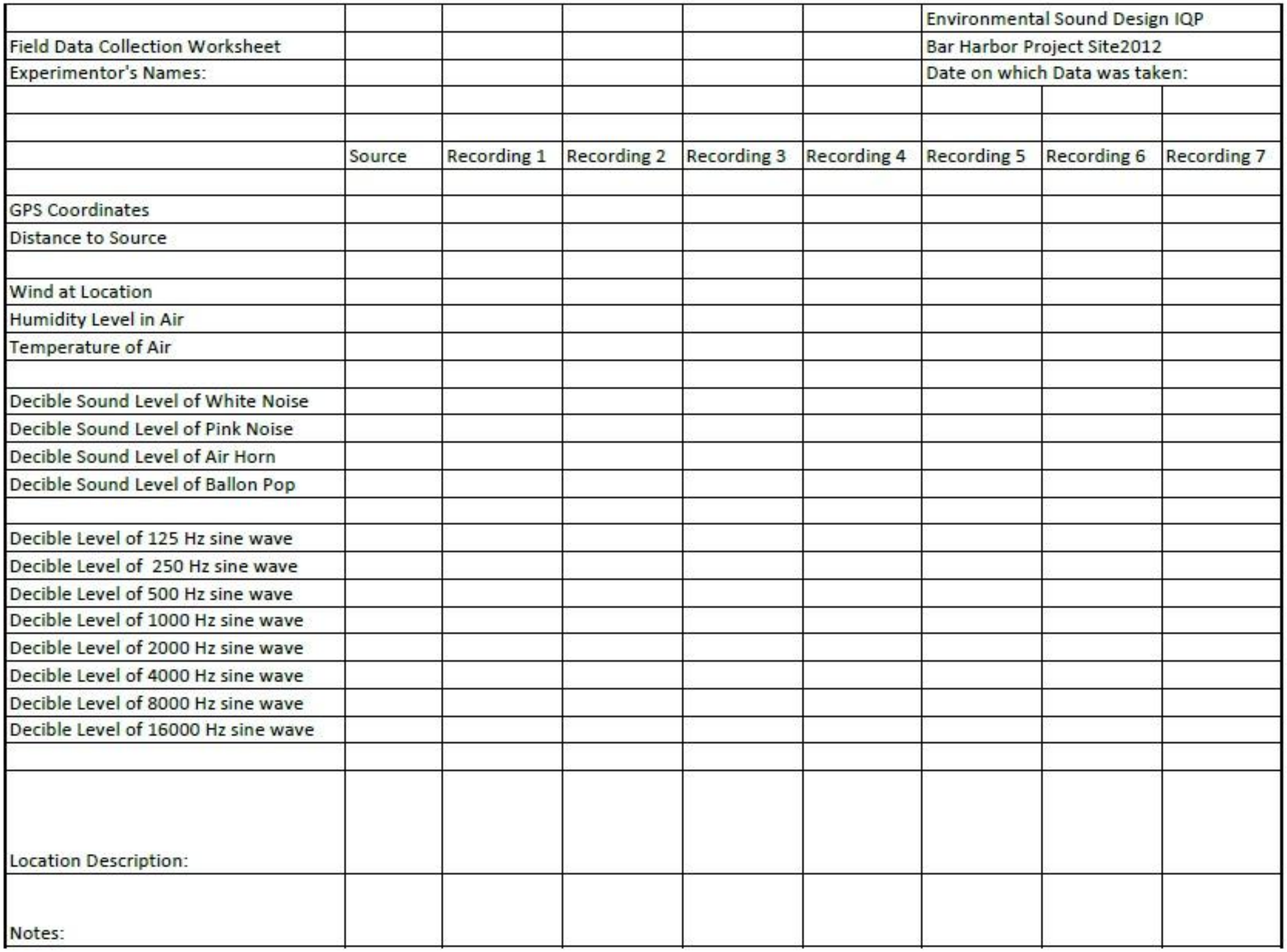
Appendix 6 - Portable loudspeaker back piece drawing

8.4 Amplifier

Pyle PLMRMP3A 4 Channel Waterproof Marine Power Amplifier –

4 x 100 Watts RMS at 4 Ohms • 4 x 200 Watts Max at 4 Ohms • 4 x 300 Watts RMS at 2 Ohms • Electronic Crossover Network • 2 Ohms Stereo Stable • Anti-Thump Turn-On • Soft Turn On/Off • Adjustable High Low Level Inputs • RCA Line Input • Power Protection Circuitry • Volume Gain Remote Control • T.H.D: <0.05% • S/N Ratio: >95dB • Channel Separation: >65dB • Frequency Response: 10Hz- 40kHz • Fuse : 10A • Dimensions: 6.10”Lx3.35”Wx1.38”H

9.Appendix II Field Data Sheets



						Environmental Sound Design IQP		
Field Data Collection Worksheet						Bar Harbor Project Site2012		
Experimentor's Names:						Date on which Data was taken:		
	Source	Recording 1	Recording 2	Recording 3	Recording 4	Recording 5	Recording 6	Recording 7
GPS Coordinates								
Distance to Source								
Wind at Location								
Humidity Level in Air								
Temperature of Air								
Decible Sound Level of White Noise								
Decible Sound Level of Pink Noise								
Decible Sound Level of Air Horn								
Decible Sound Level of Ballon Pop								
Decible Level of 125 Hz sine wave								
Decible Level of 250 Hz sine wave								
Decible Level of 500 Hz sine wave								
Decible Level of 1000 Hz sine wave								
Decible Level of 2000 Hz sine wave								
Decible Level of 4000 Hz sine wave								
Decible Level of 8000 Hz sine wave								
Decible Level of 16000 Hz sine wave								
Location Description:								
Notes:								

Appendix 7 - Data Collection Worksheet page 1 of 2

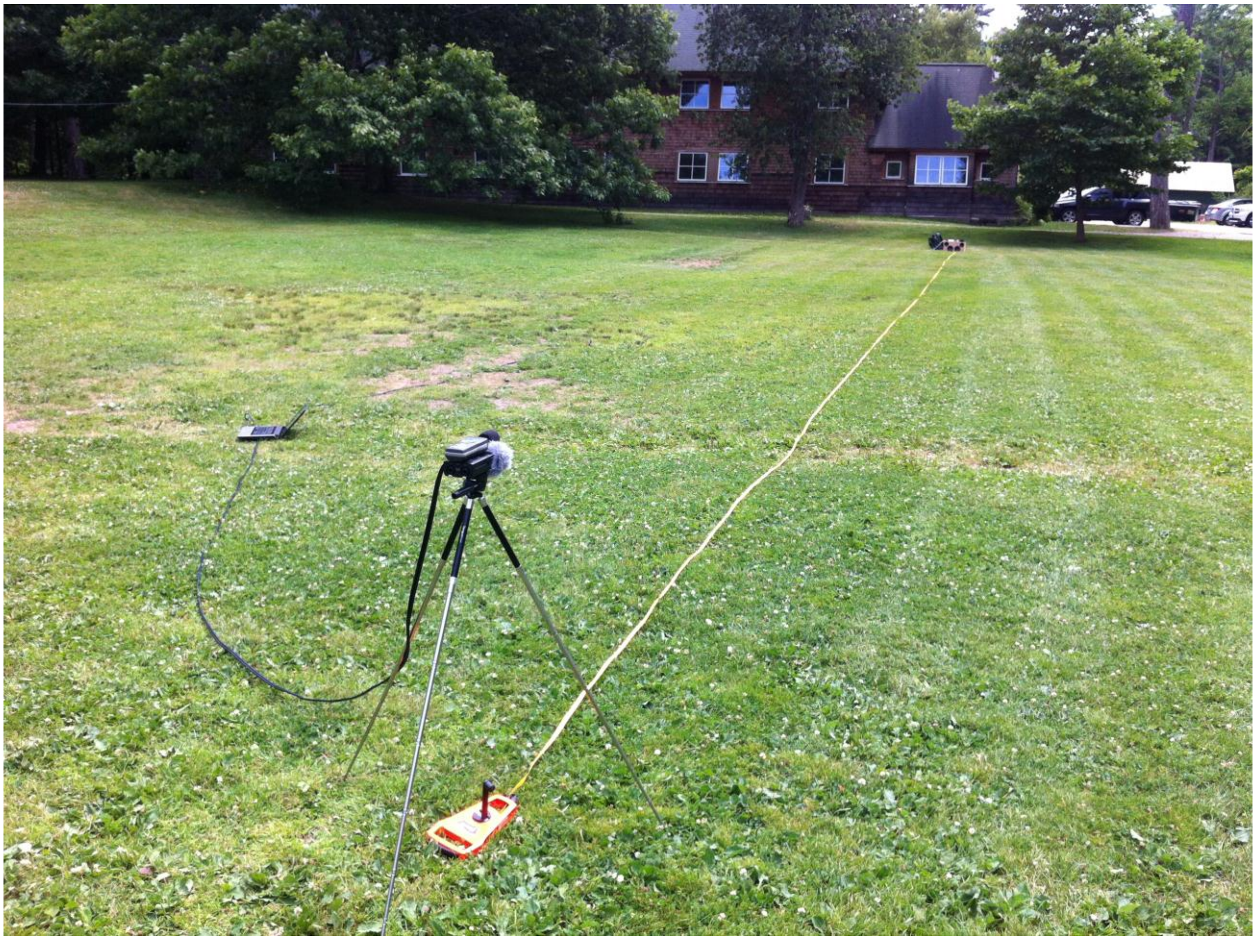
							Environmental Sound Design IQP		
							Bar Harbor Project Site2012		
							Date on which Data was taken:		
Recording 8	Recording 9	Recording 10	Recording 11	Recording 12	Recording 13	Recording 14	Recording 15	Recording 16	Recording 17

Appendix 8 - Data Collection Worksheet page 2 of 2

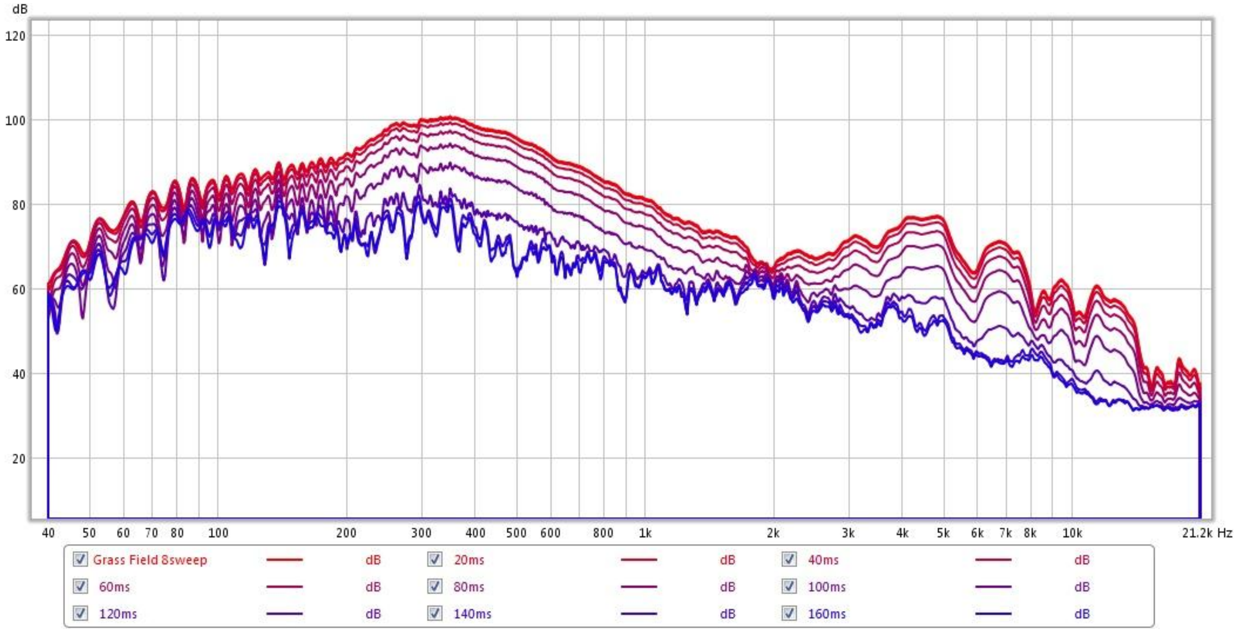
10. Appendix III Short distance test data

This appendix features additional data collected during the short distances tests. It is organized by soundscape, and includes photographs and decay graphs. The decay graphs show a series of curves, where each curve represents a measured frequency response at a given time. There are curves for 20 millisecond time intervals starting at zero. These curves are labeled in the legend of each graph.

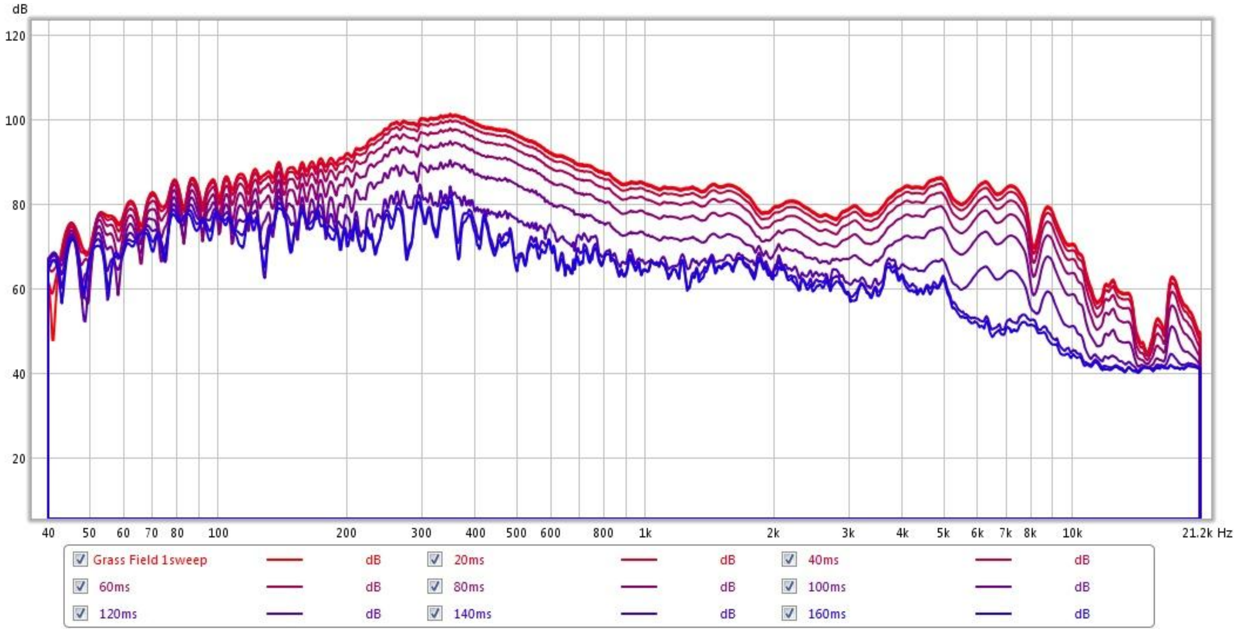
10.1 Grass Field One



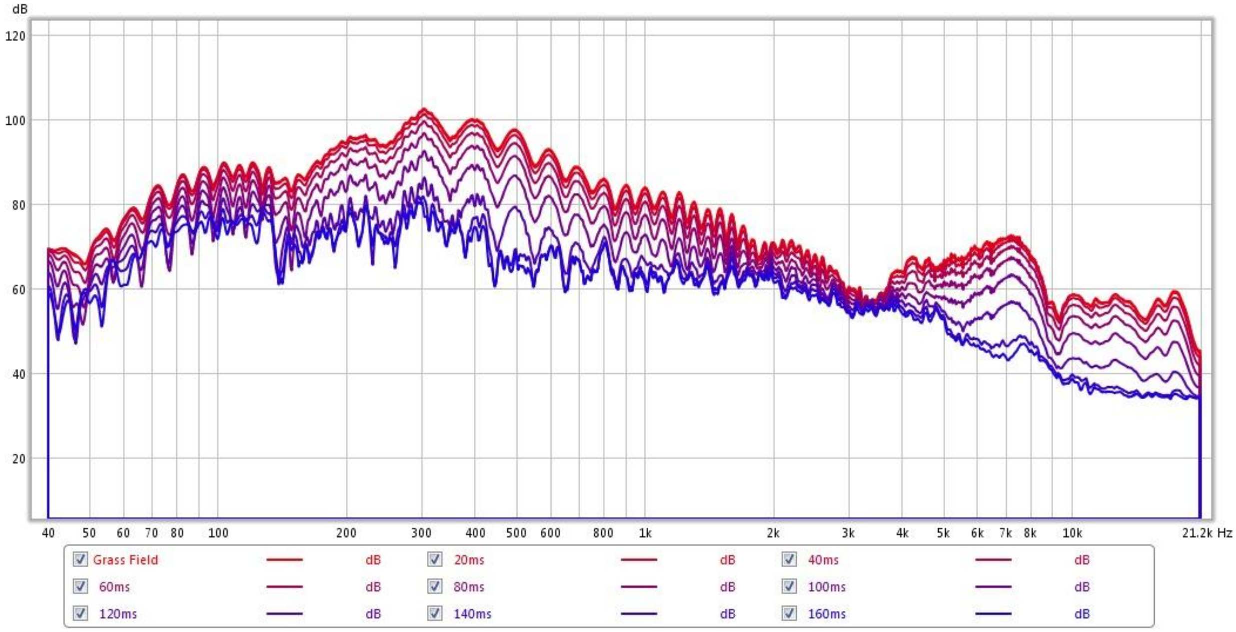
Appendix 9 - Grass Field One



Appendix 10 - decay graph of 8 sweep measurement

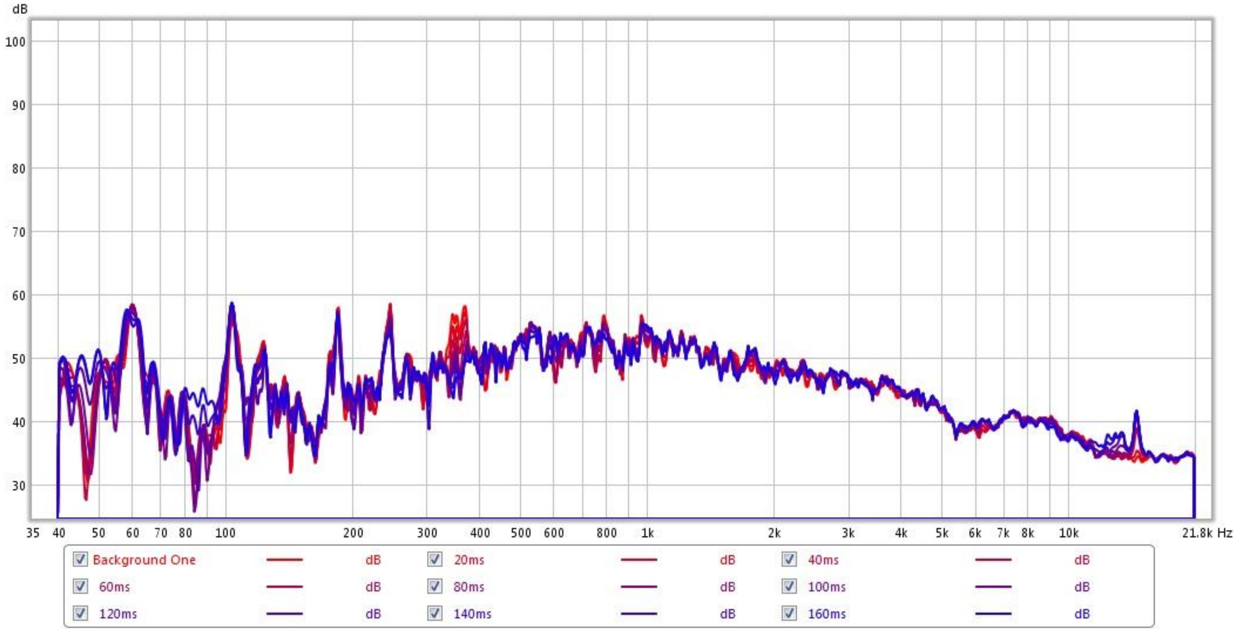


Appendix 11 - decay graph of single sweep measurement

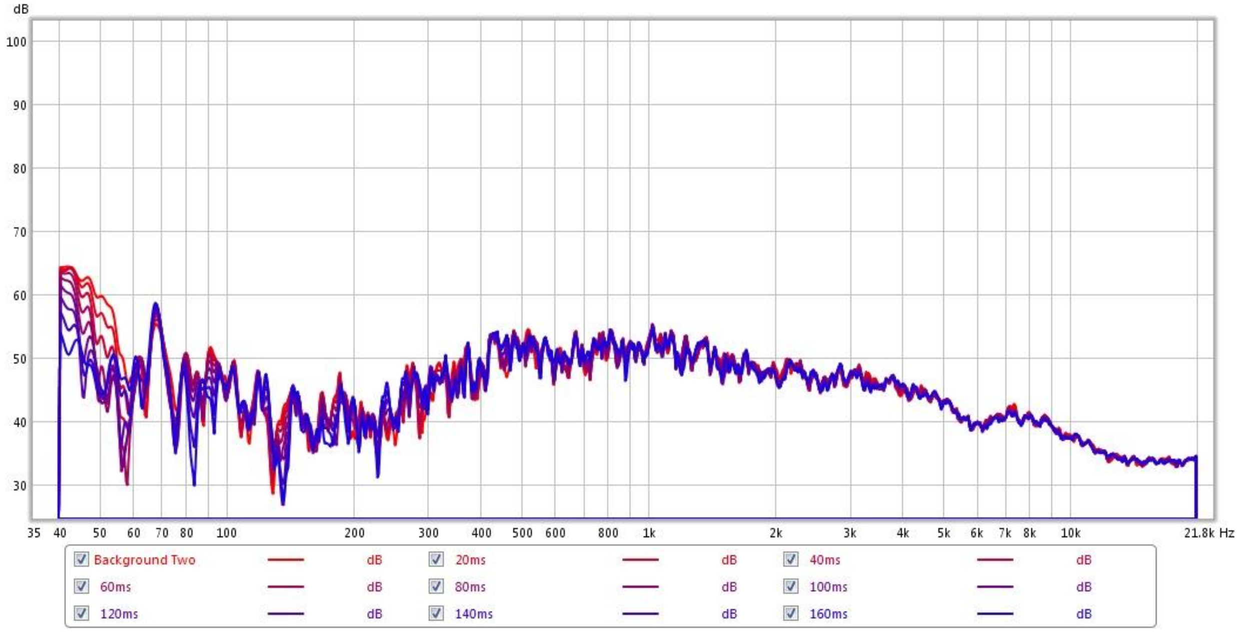


Appendix 12 - decay graph of 8 sweep measurement with periodicity issues

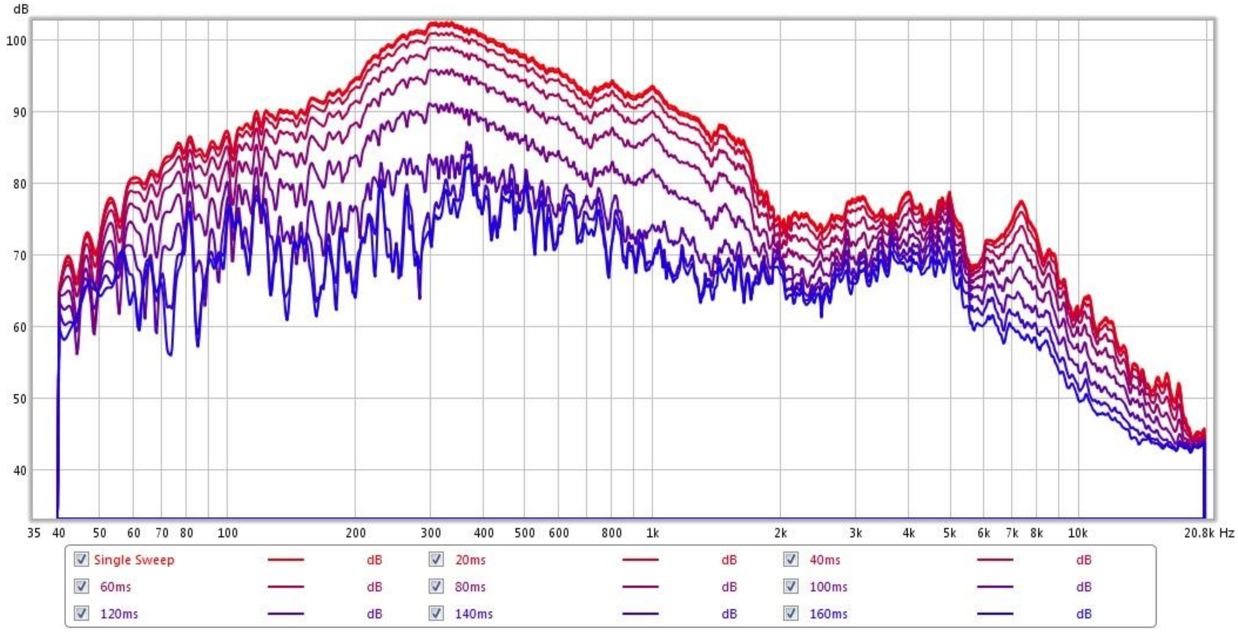
10.2 Grass Field Two



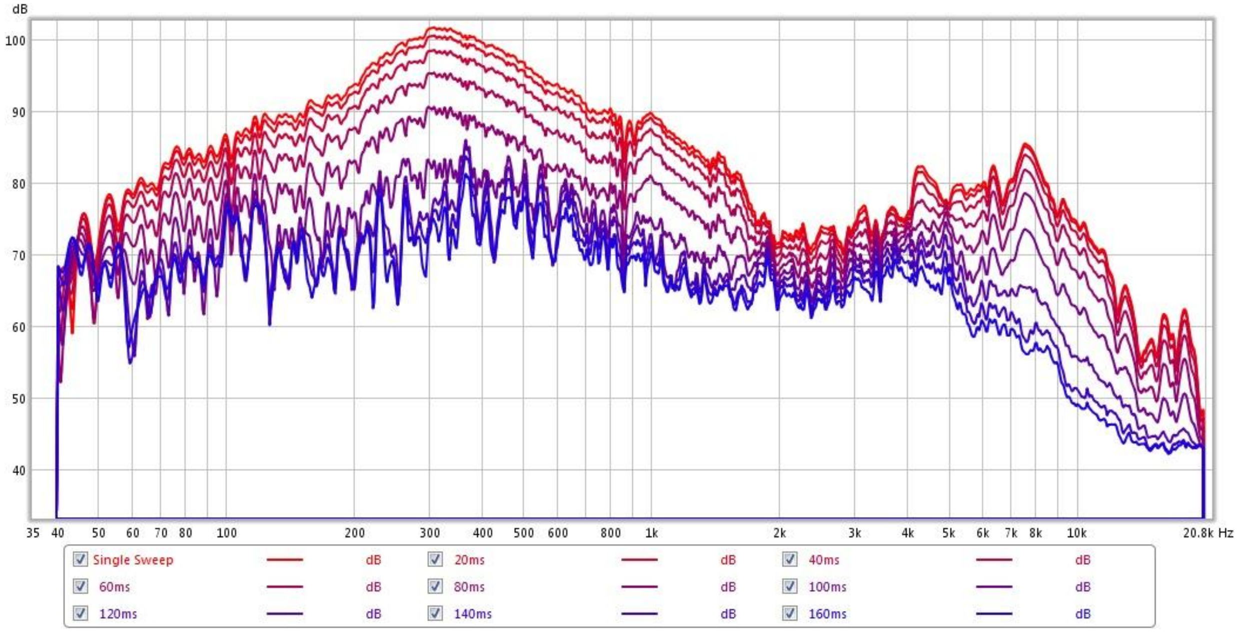
Appendix 13 - decay graph of background measurement one



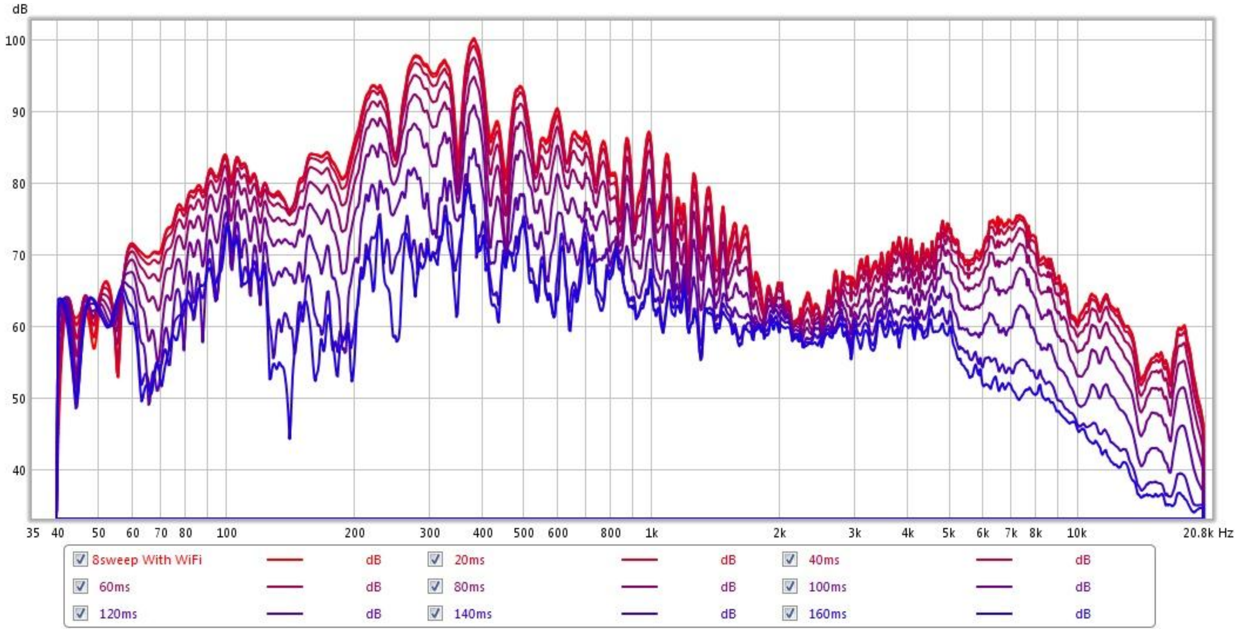
Appendix 14 - decay graph of background measurement two



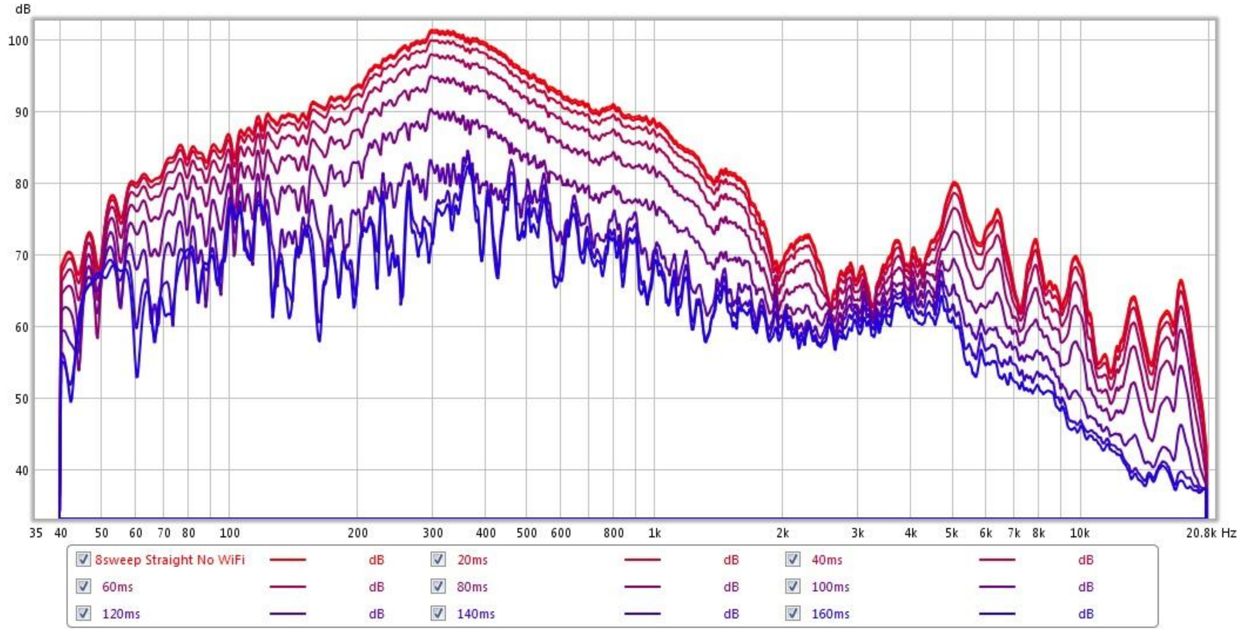
Appendix 15 - decay curve of single sweep measurement one



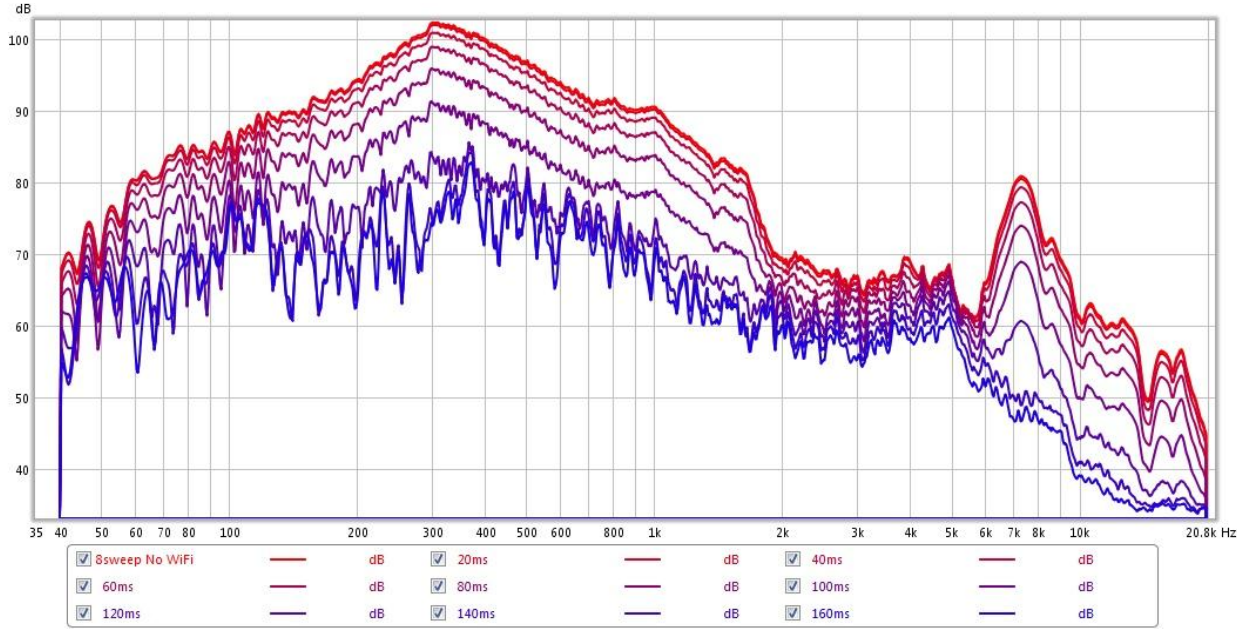
Appendix 16 - decay curve of single sweep measurement two



Appendix 17 - decay curve of measurement with wireless communications



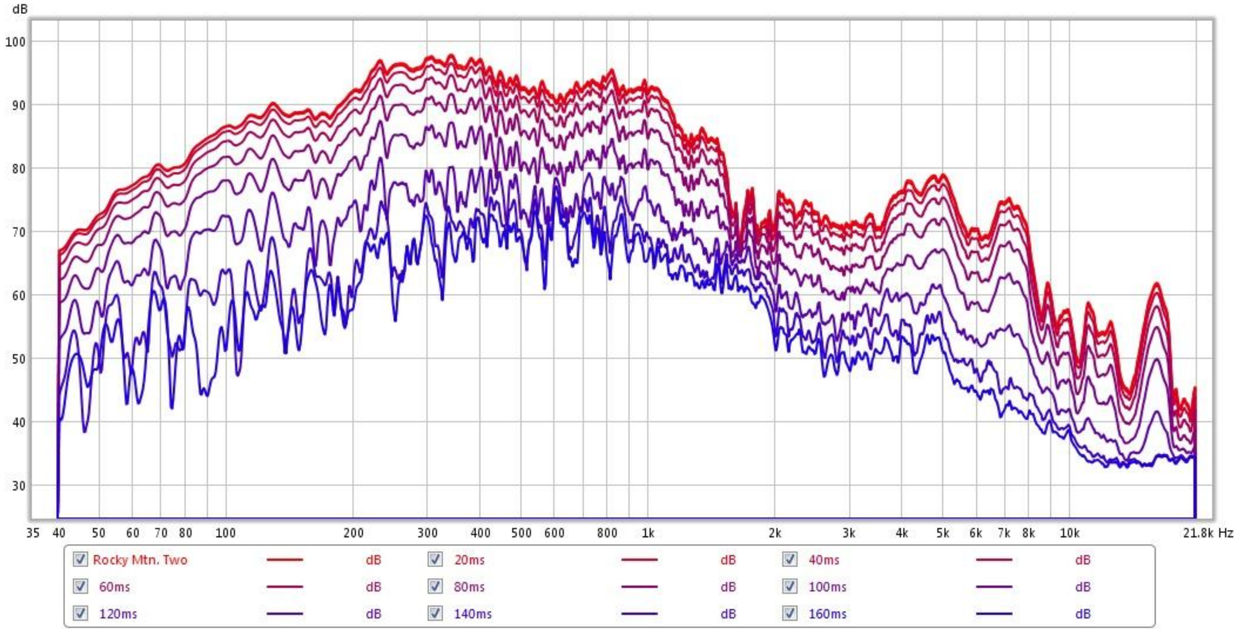
Appendix 18 - decay curve of measurement with straghtened cables



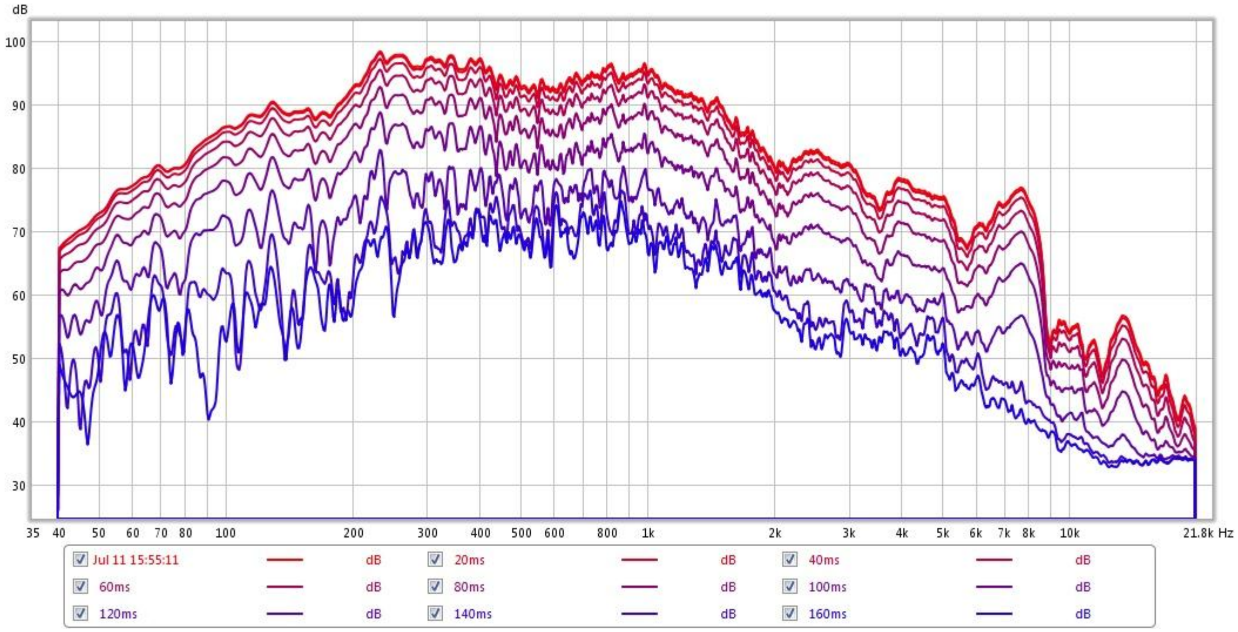
Appendix 19 - decay curve of measurement without straightened cables

10.3 Rocky Mountaintop

Appendix 20 - Rocky Mountaintop

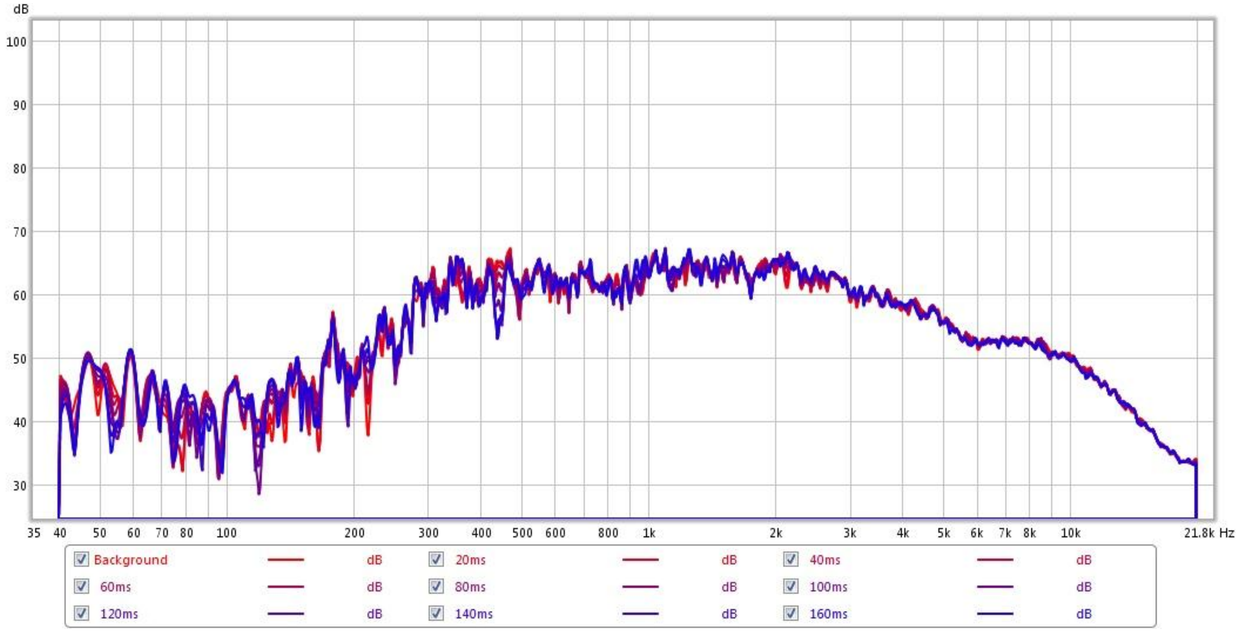


Appendix 21 - decay curve of measurement two

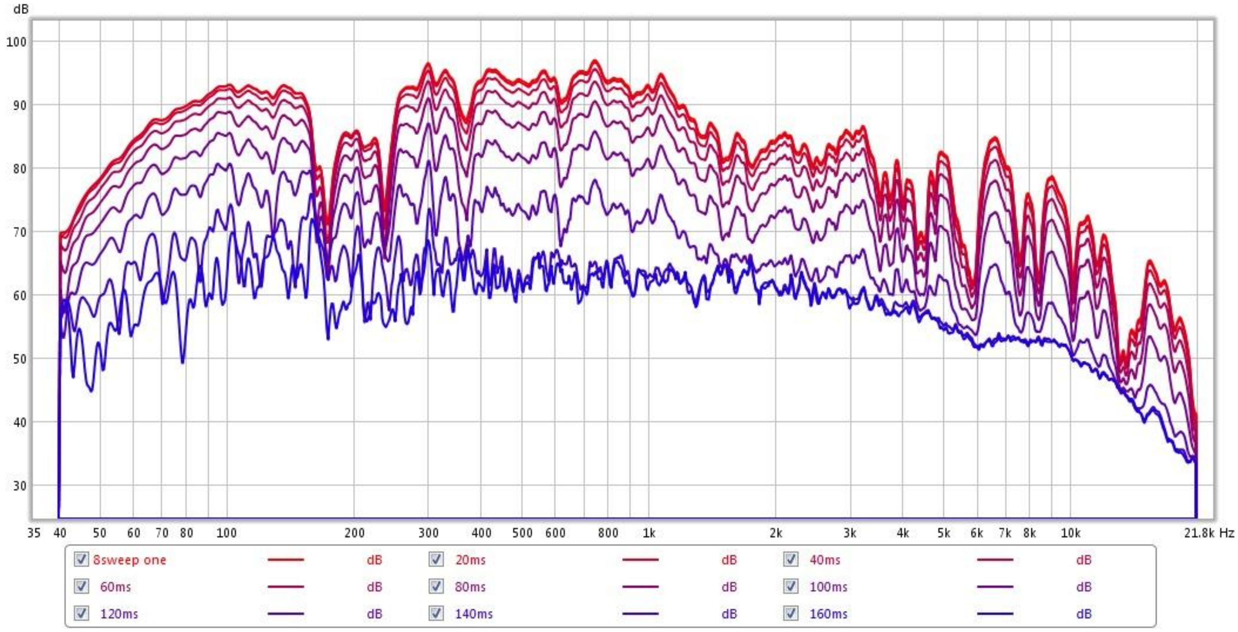


Appendix 22 - decay curve of measurement one

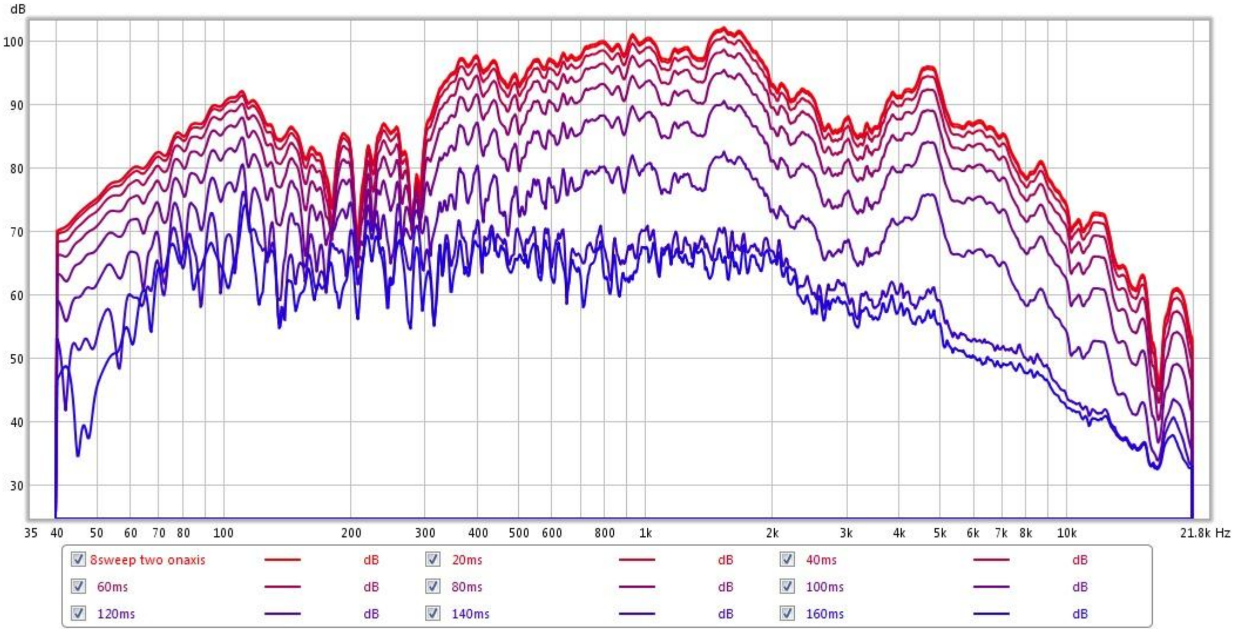
10.4 Rocky Shoreline



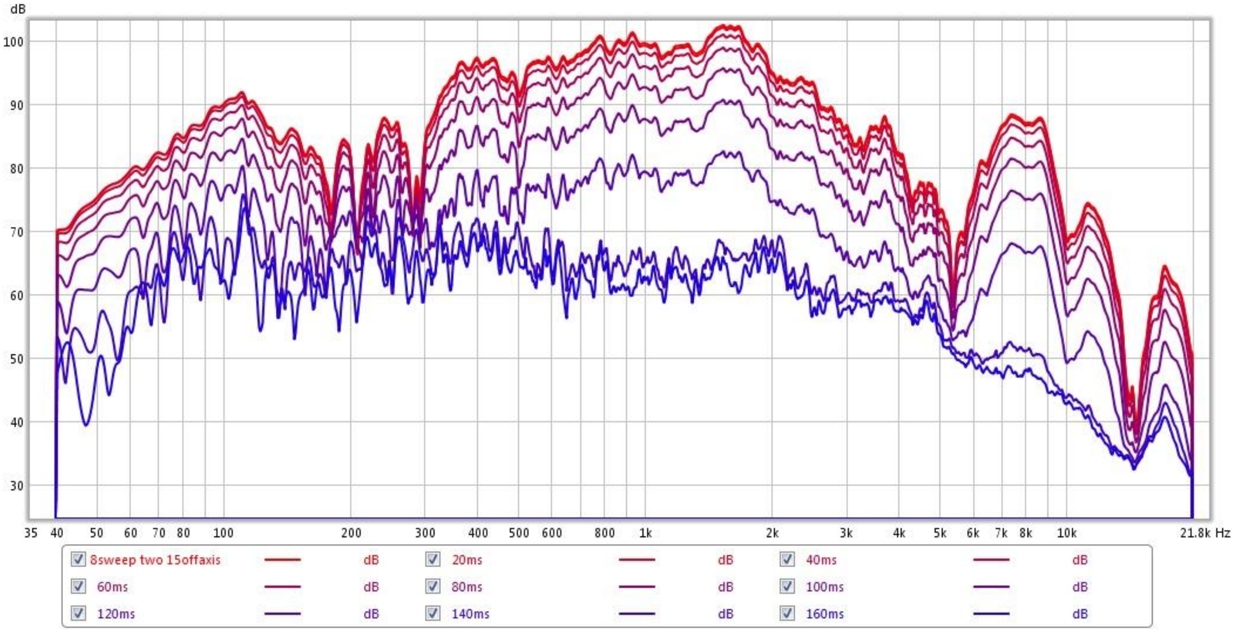
Appendix 23 - decay curve of background noise measurement



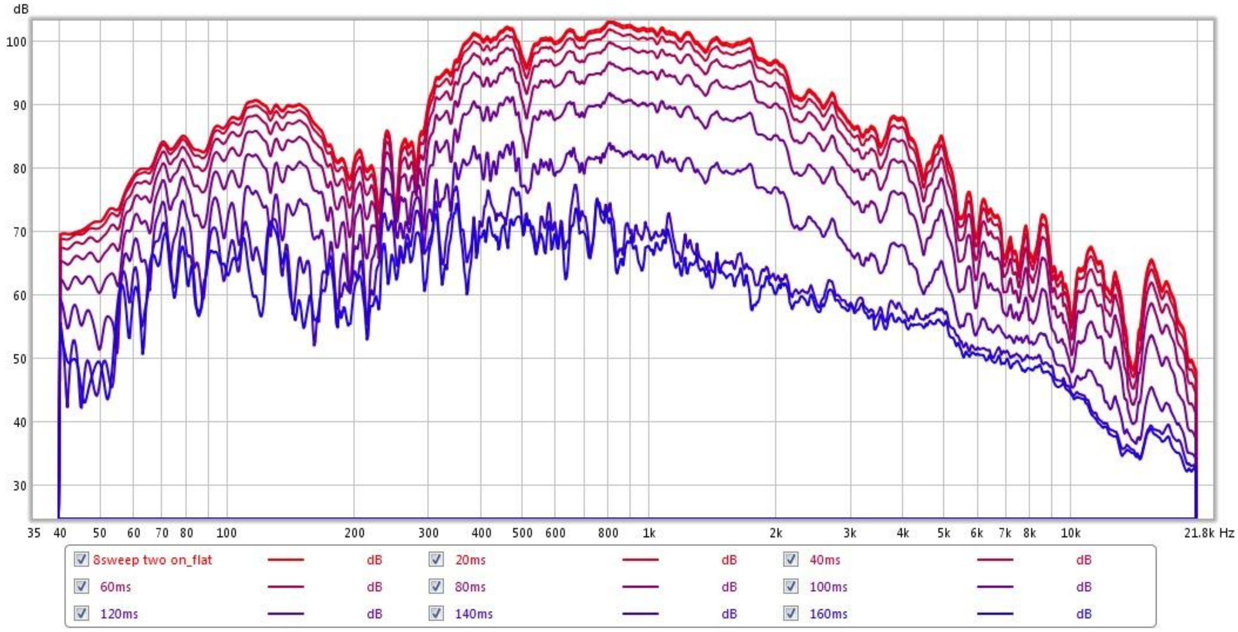
Appendix 24 - decay curve of measurement 1.0



Appendix 25 - decay curve of measurement 2.2



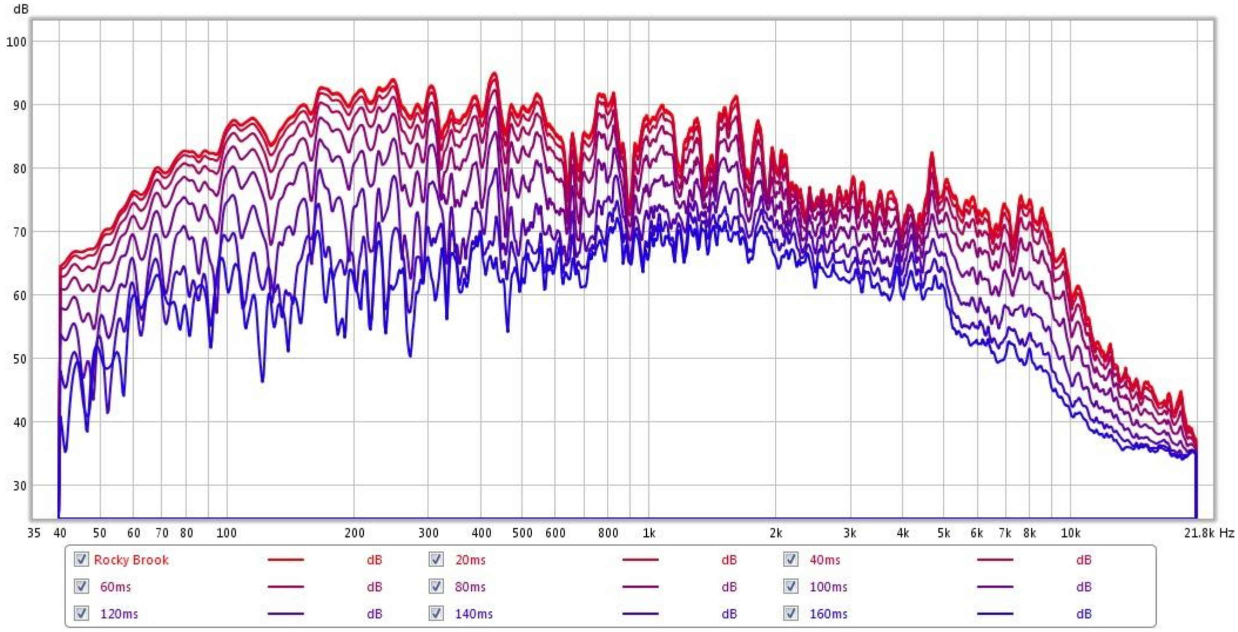
Appendix 26 - decay curve of measurement 2.1



Appendix 27 - decay curve of measurement 2.0

10.5 Rocky Brook

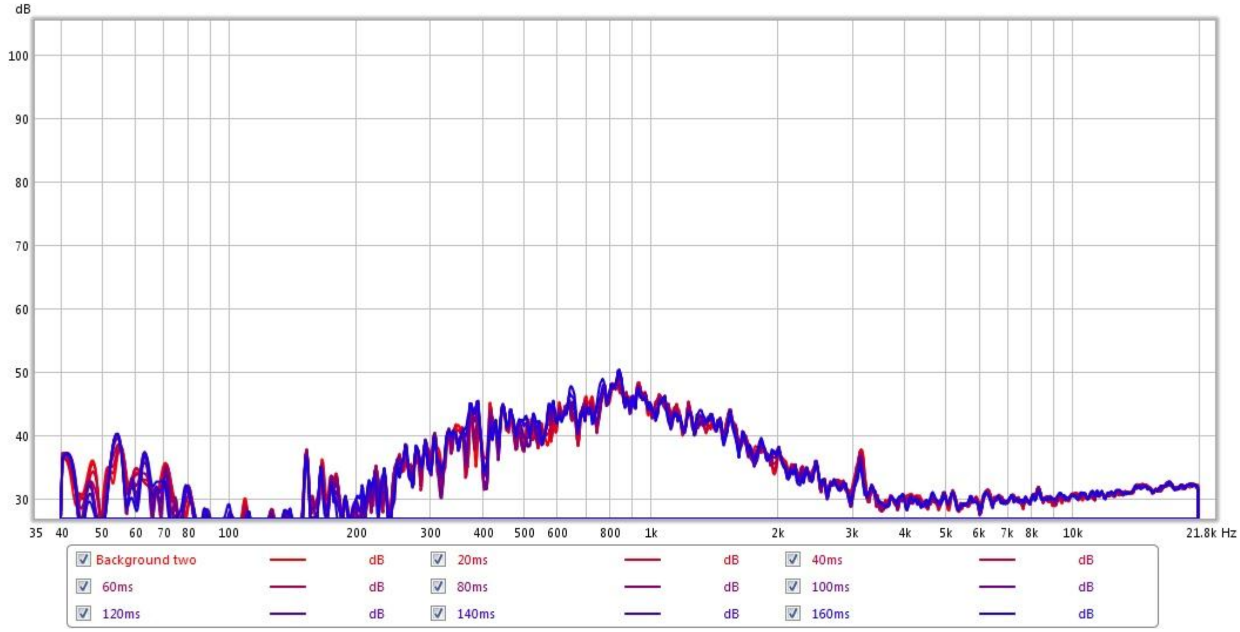
Appendix 28 - Rocky Brook



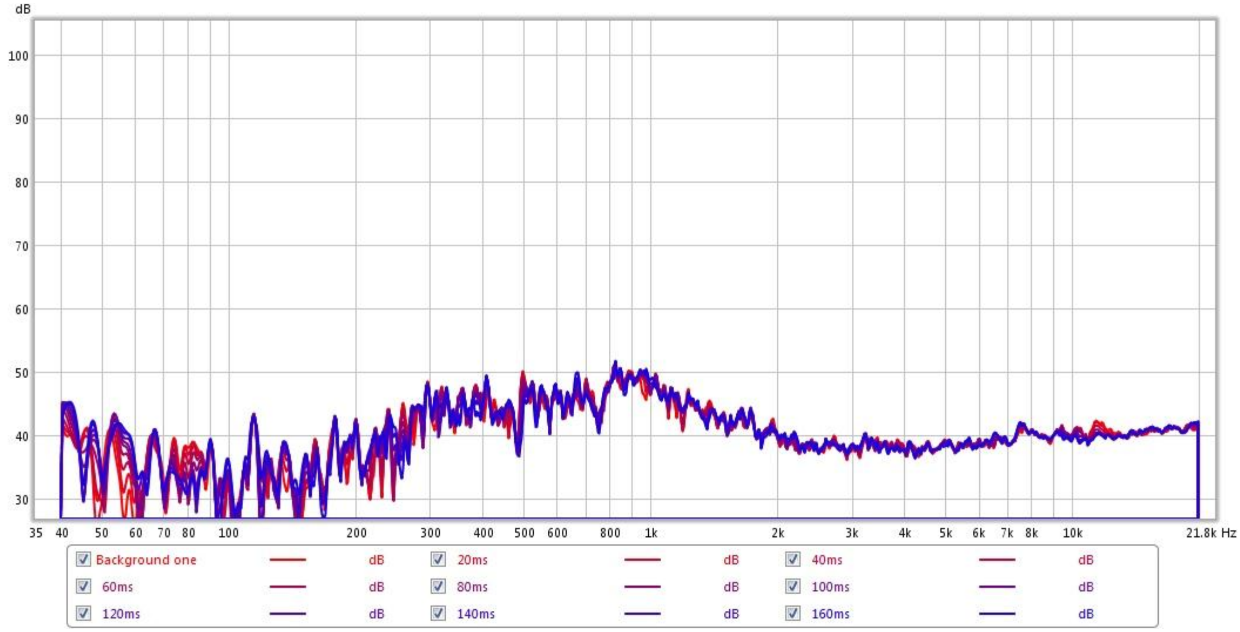
Appendix 29 - decay curve of rocky brook measurement

10.6 Mossy Forest

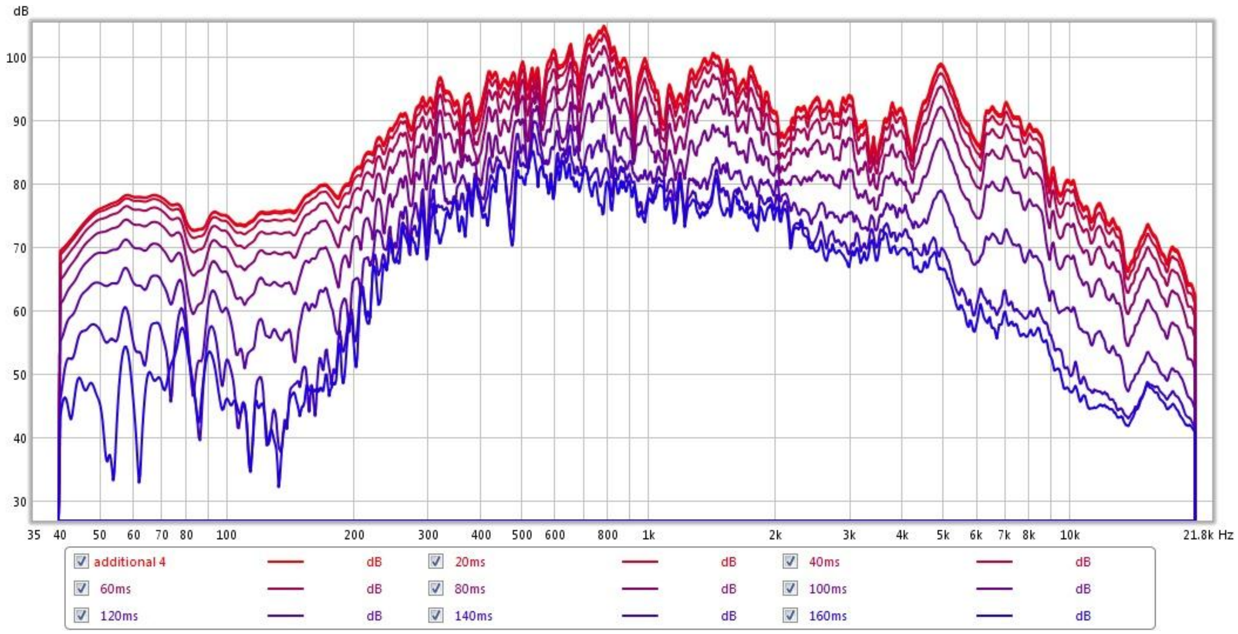
Appendix 30 - Mossy Forest



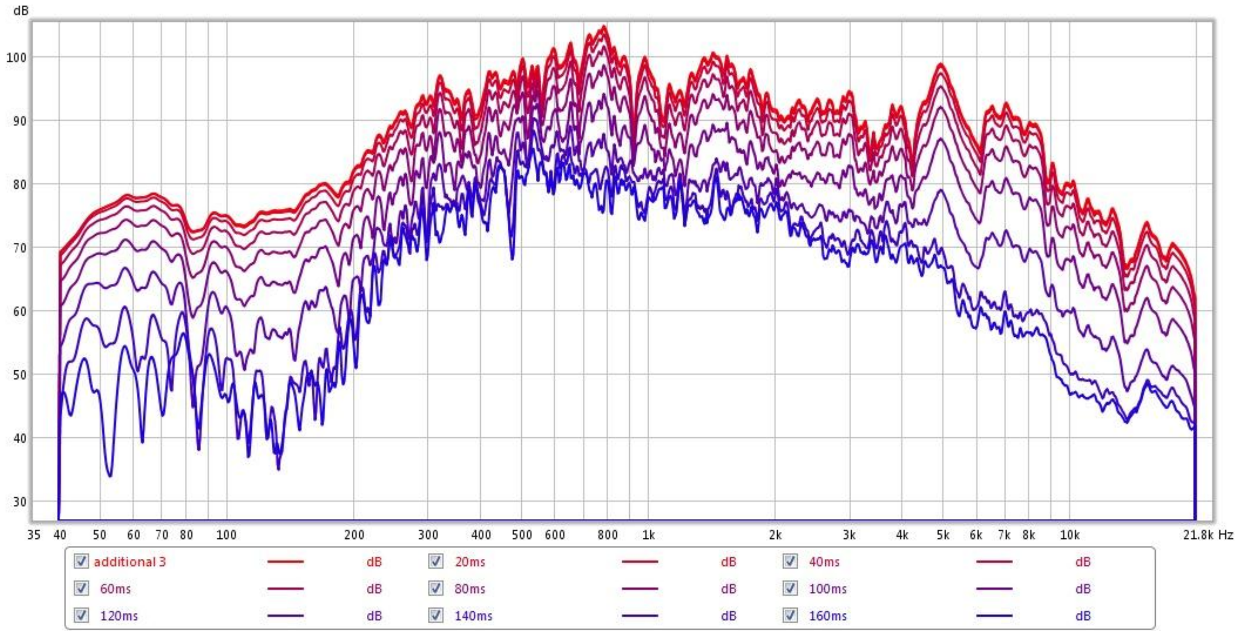
Appendix 31 - decay curve of background noise measurement two



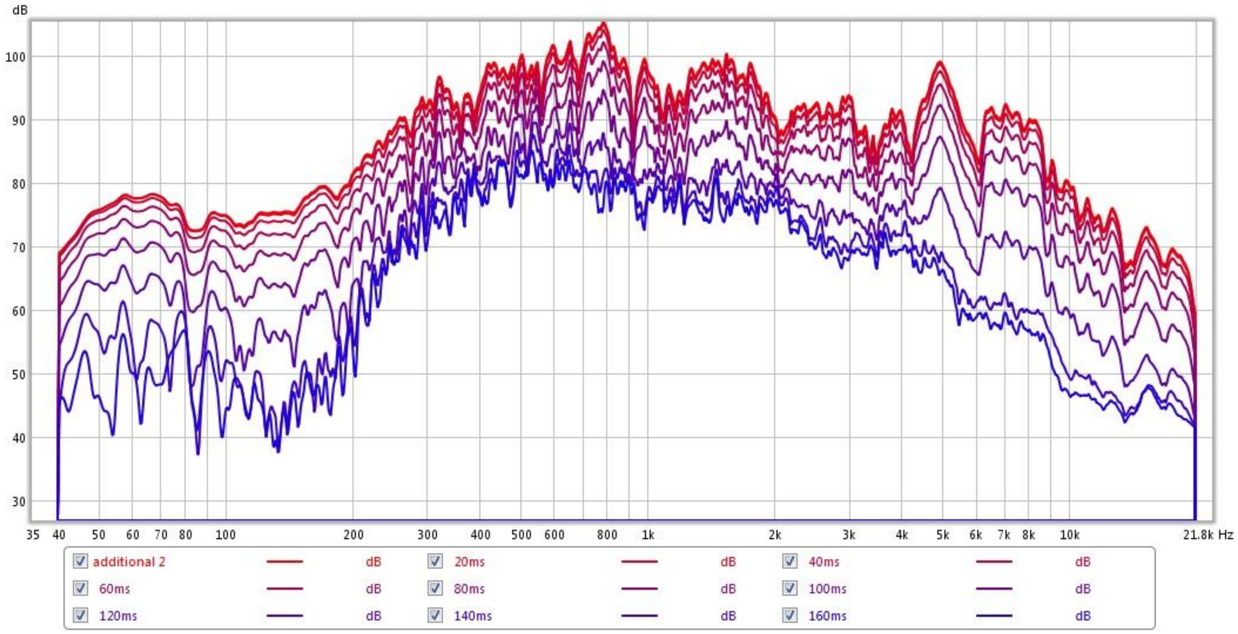
Appendix 32 - decay curve of background measurement one



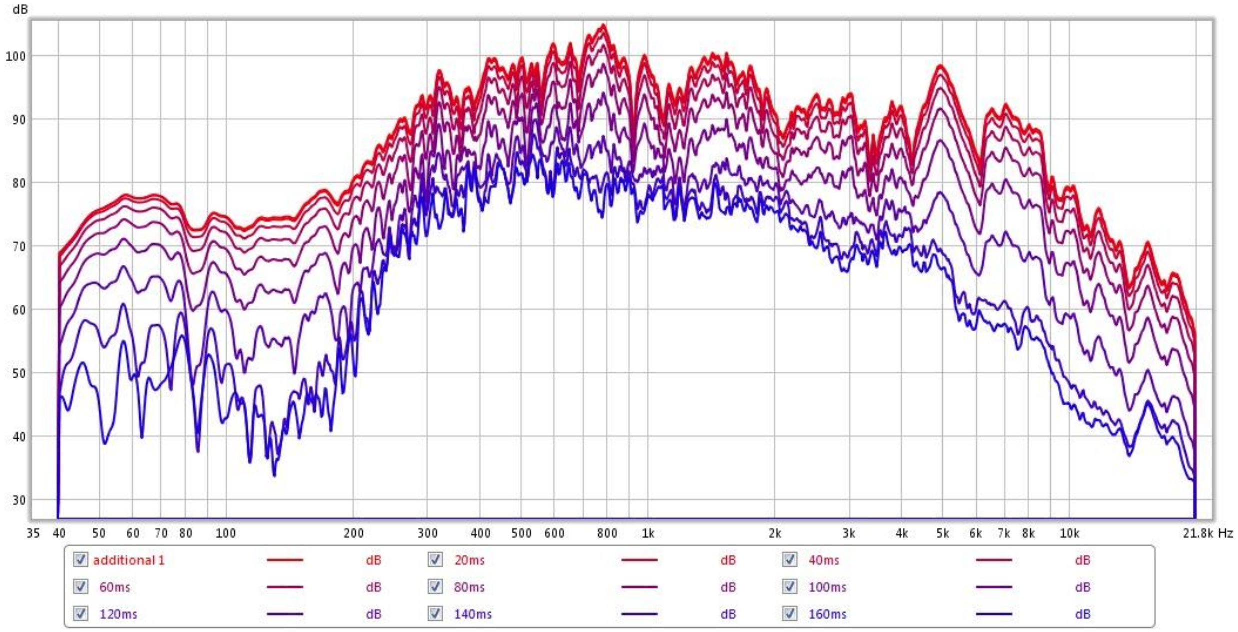
Appendix 33 - decay curve of additional measurement 4



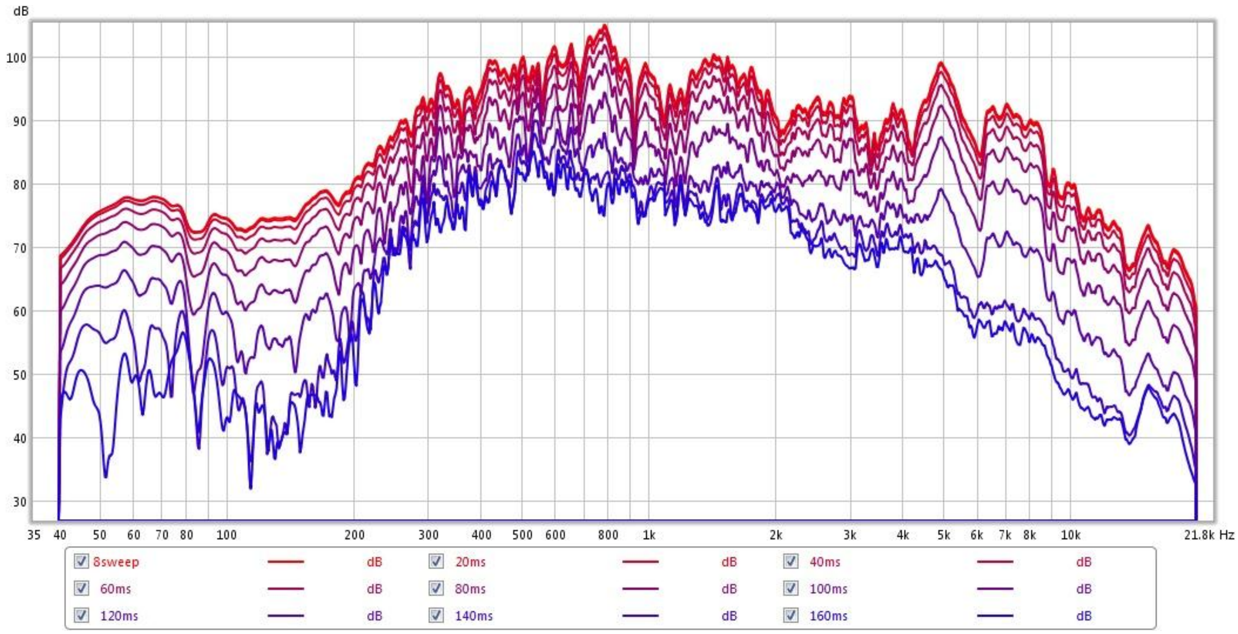
Appendix 34 - decay curve of additional measurement 3



Appendix 35 - decay curve of additional measurement 2



Appendix 36 - decay curve of additional measurement 1

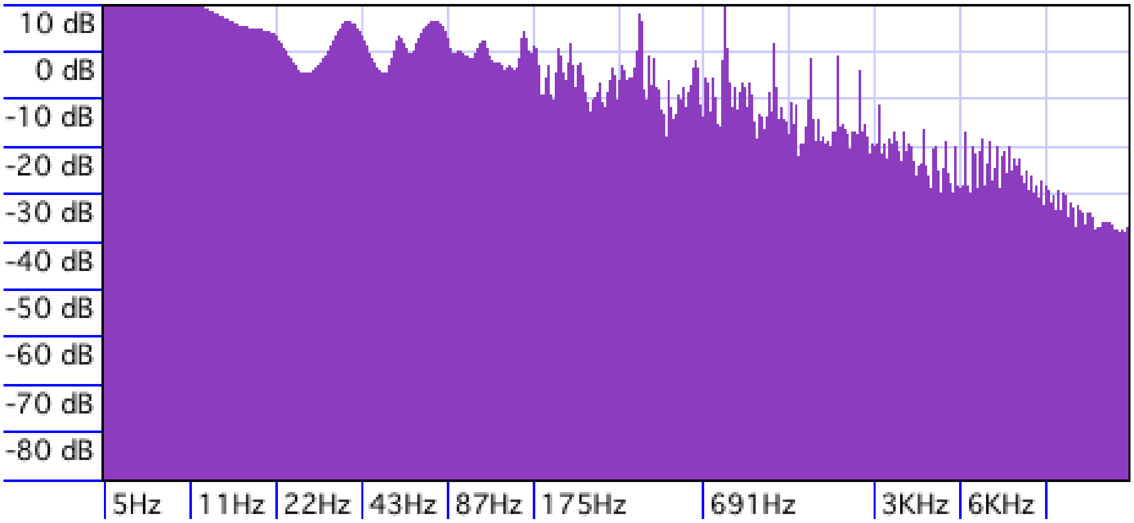


Appendix 37 - decay curve of 8 sweep measurement

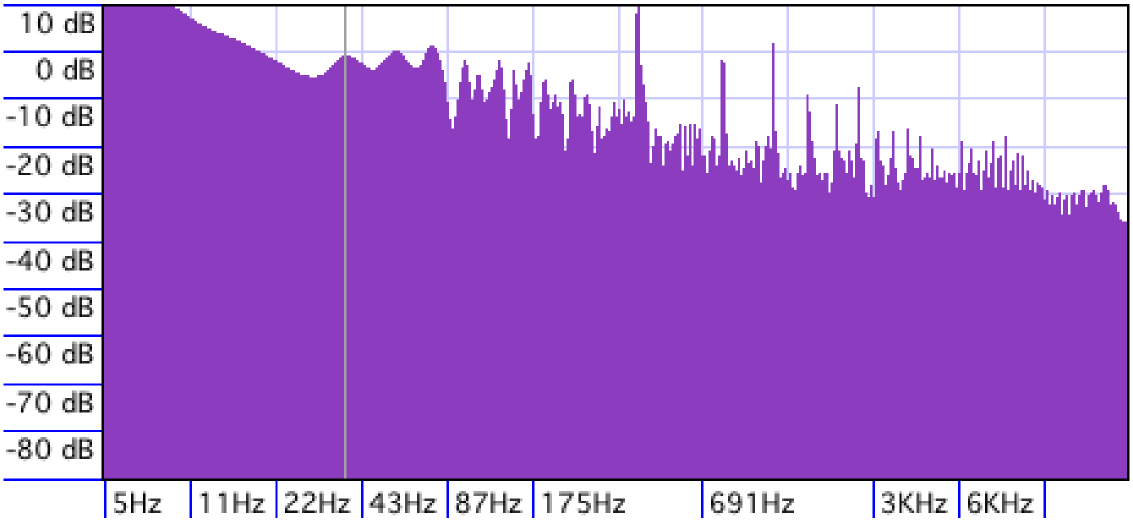
11. Appendix IV Long distance test data

11.1 Lower Hadlock Pond Appendix

Appendix 38 - Photo from Point A facing air horn

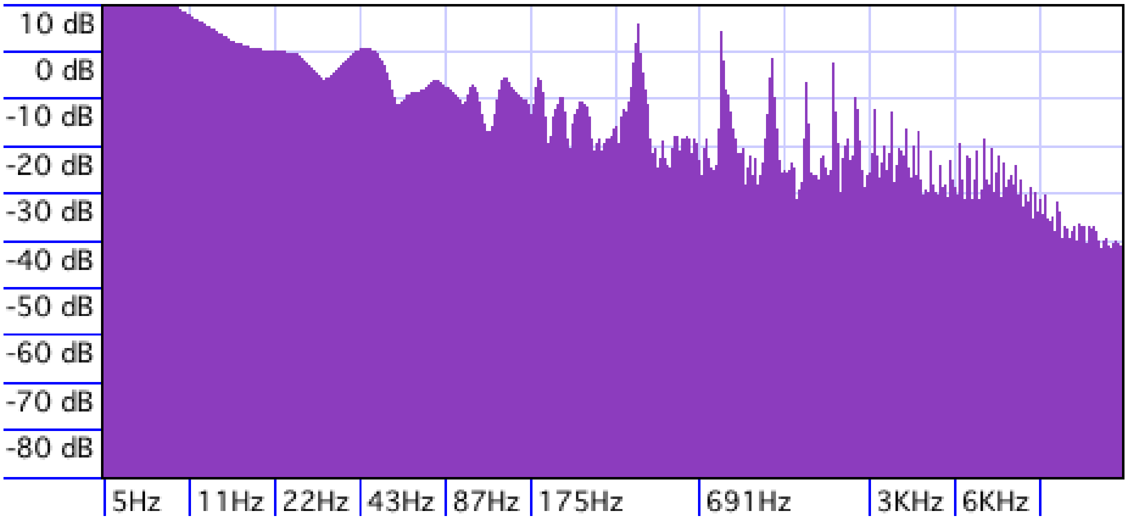


Appendix 39 - Source recording during Point A 30 PSI test

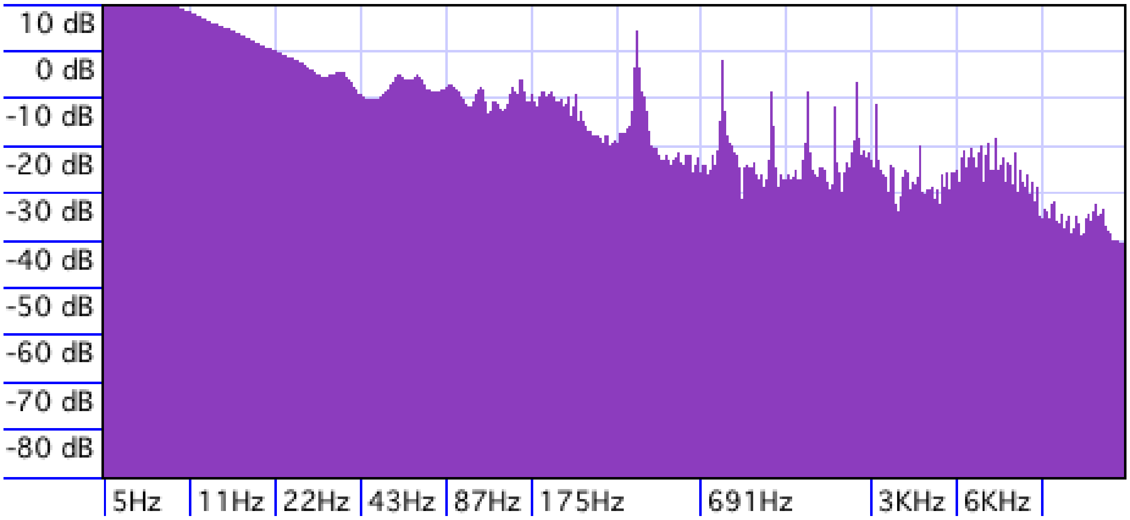


Appendix 40 - Source recording during Point A 50 PSI test

Appendix 41 - Photo from Point B facing air horn

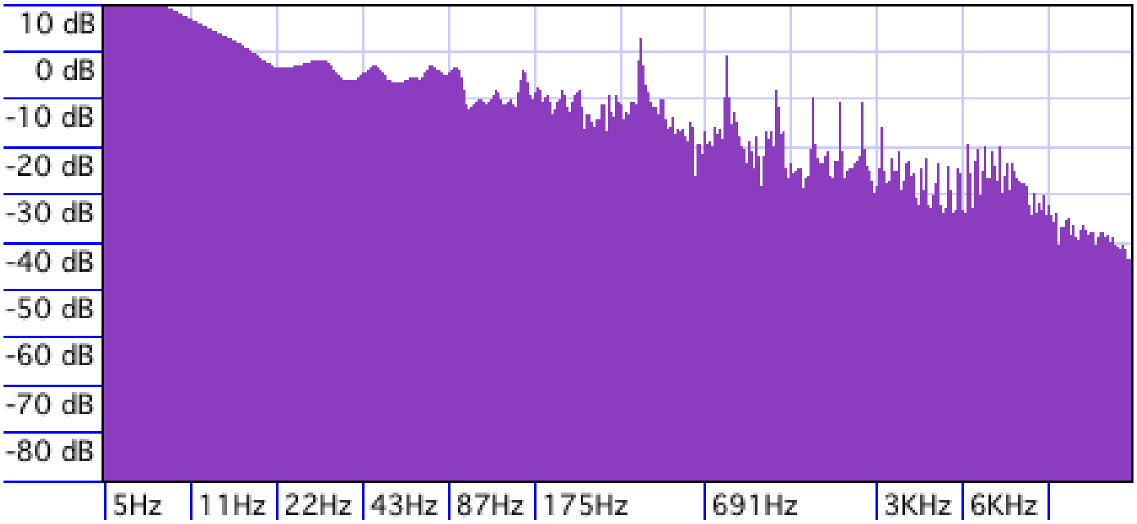


Appendix 42 - Source recording during Point B 30 PSI test

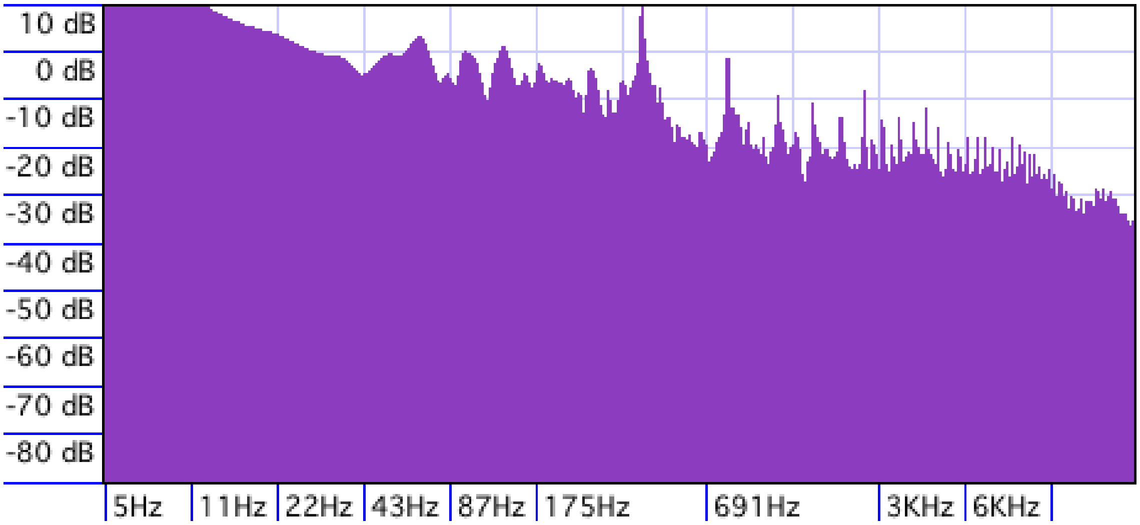


Appendix 43 - Source recording during Point B 50 PSI test

Appendix 44 - Photo from Point C facing the air horn



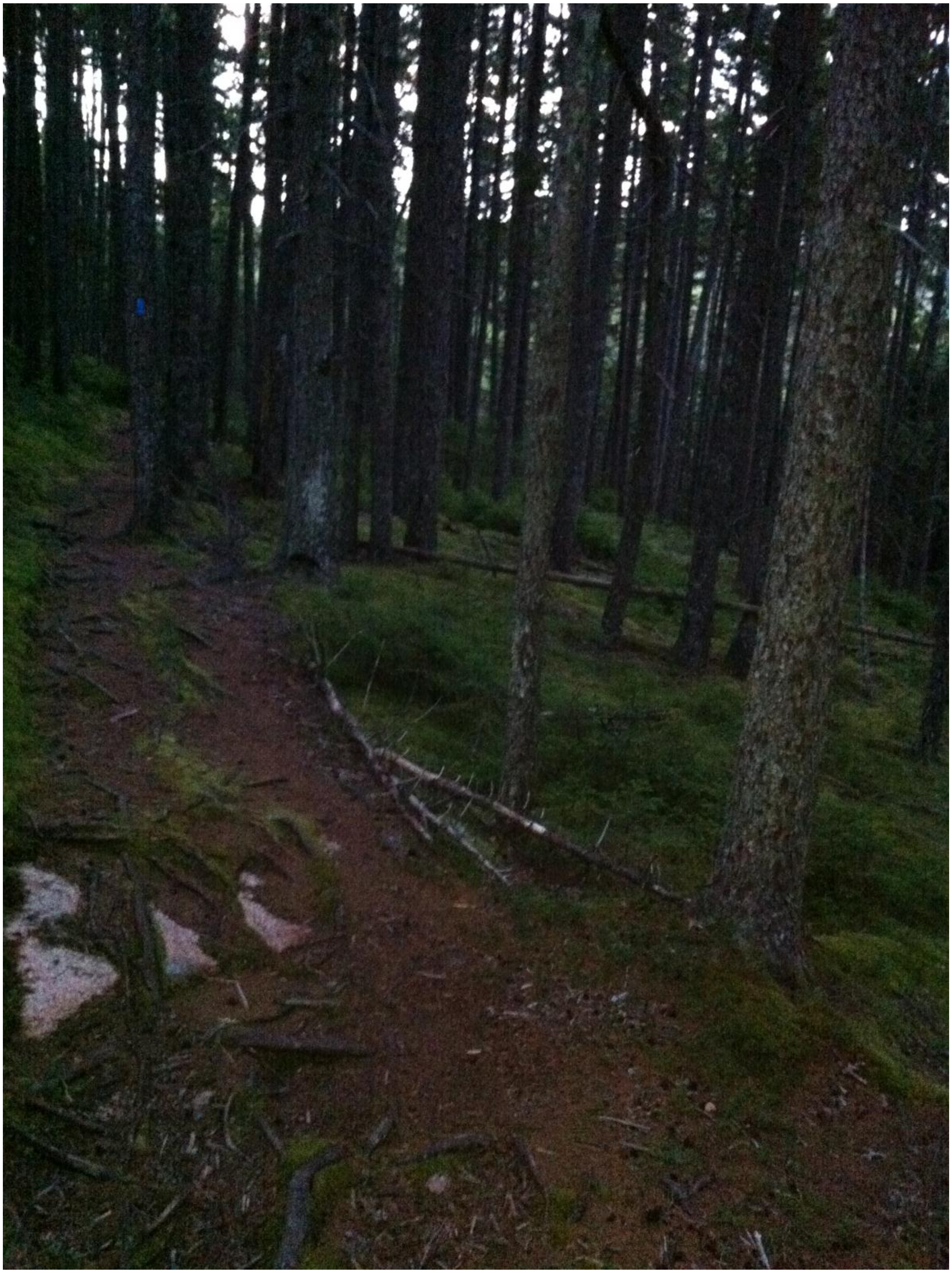
Appendix 45 - Source recording during Point C 30 PSI test



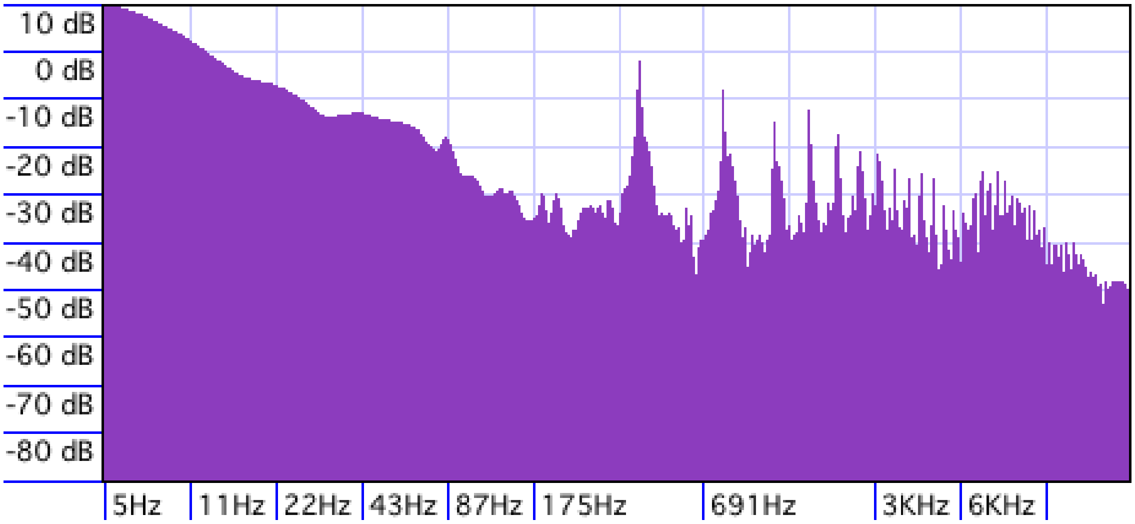
Appendix 46 - Source recording during Point C 50 PSI test

Additional data and calculations can be found in the spreadsheet: hadlock_inversesquaredata.xlsx

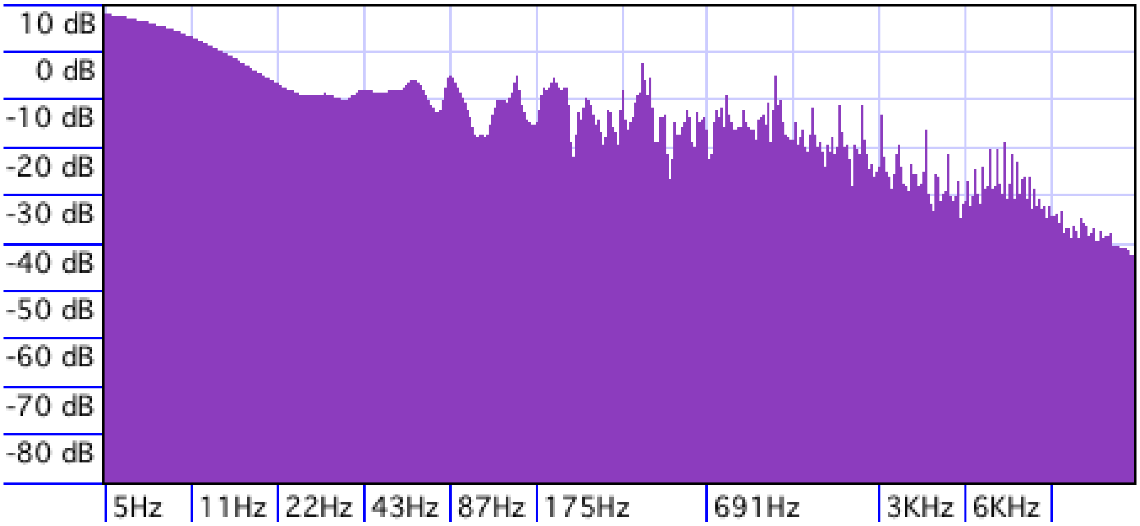
11.2 Forest by Route 3 Appendix



Appendix 47 - Photo from Point A facing air horn

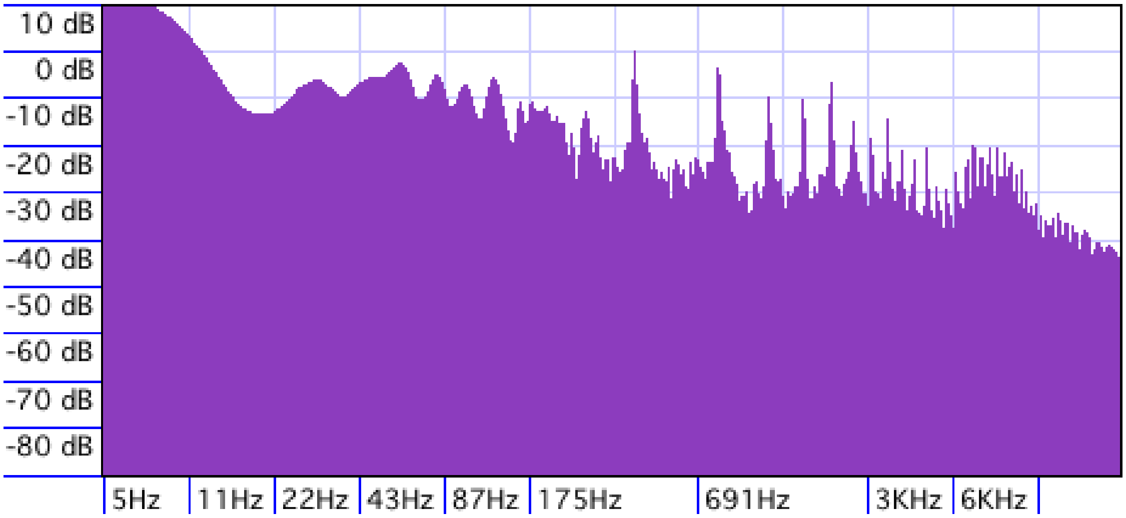


Appendix 48 - Source recording during Point A 30 PSI test

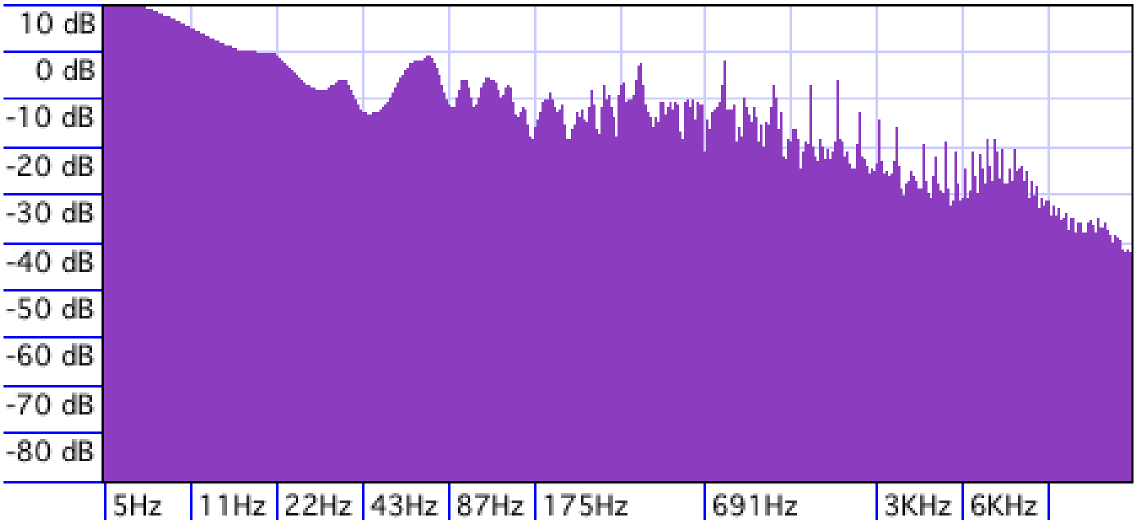


Appendix 49 - Source recording during Point A 50 PSI test

Appendix 50 - Photo from Point B facing air horn

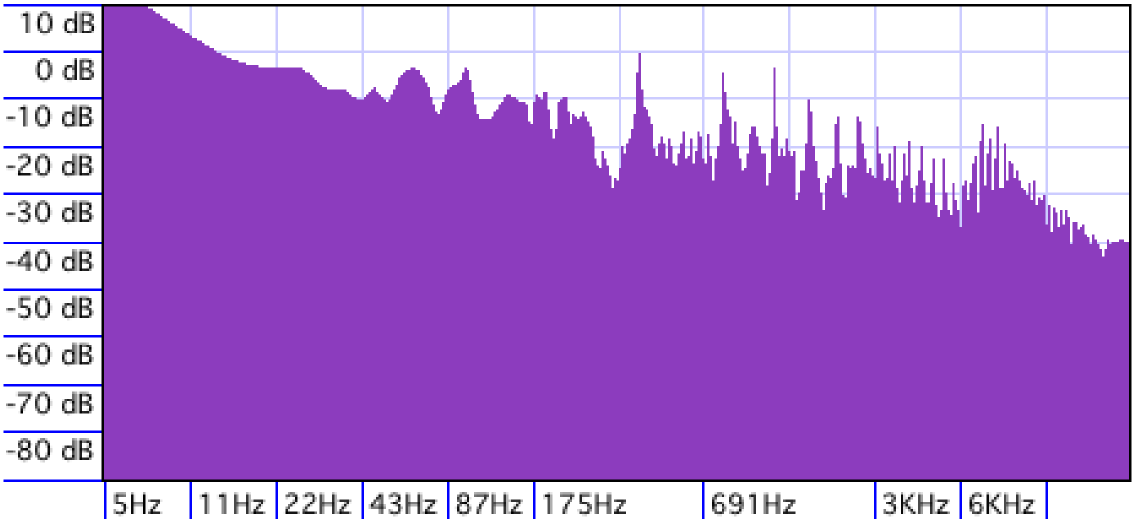


Appendix 51 - Source recording during Point B 30 PSI test

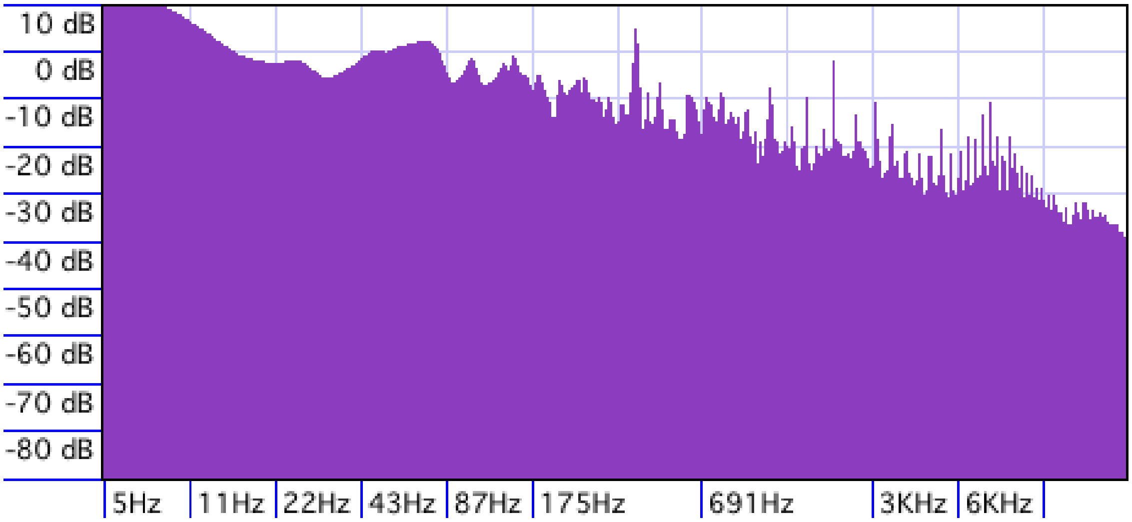


Appendix 52 - Source recording during Point B 50 PSI test

Appendix 53 - Photo from Point C facing air horn



Appendix 54 - Source recording during Point C 30 PSI test



Appendix 55 - Source recording during Point C 50 PSI test

Additional data and calculations can be found in the spreadsheet: forest_inversesquaredata.xlsx