

Talking Kivas

A Frequency Response Analysis of Human Voice Range Frequencies in Southwestern Kivas

by

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Stephanie Helleckson

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Talking Kivas: A Frequency Response Analysis of Human Voice Range Frequencies in
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***Abstract:** Archaeoacoustics can be applied to Southwestern kivas in such a way that it gives insight into the use and human perception of kivas. Using sine sweep technology, a full spectrum of frequency responses was measured in Kivas C and D of the Spruce Tree House site in Mesa Verde National Park. The results were then compared to human voice frequencies and activity to ascertain likely patterns of acoustic use. Generally, high child and female voice frequencies are emphasized while male voice frequencies are dampened. This information adds to the general knowledge and conversation surrounding the perception and use of kivas in the Southwest.*

1. Introduction

The study of archaeoacoustics attempts to bridge the gap between the visually- and materially-oriented science of archaeology and the multi-sensory human experience. As humans, our perceptions of spaces and areas rely almost as much on the sound of those spaces as they do the visual and palpable aspects. Within archaeology, the acoustic aspects of most sites go unnoticed and unrecorded because they are far more difficult to quantify and measure than their tangible counterparts, particularly when many of the sites are no longer completely intact. However, whether our archaeological methods are up to the task or not, the effect of sound on the human perception of environment is undeniable. Thus the field of archaeoacoustics steps in to give both qualitative and quantitative analysis of the soundscapes of archaeologically relevant spaces.

Though the field is rather new, having sprung up in the last fifty years and gained popularity within the last twenty, archaeoacoustics is an increasingly known and respected component of the archaeological process. Most prevalent within the field of archaeoacoustics is the ongoing exploration of the acoustics of Stonehenge, though other projects include the “Singing Staircase” of the Kulkukan Pyramid, Chauvet Cave, and various rock art sites in Horseshoe Canyon. In each case, however, the technique used to measure the acoustics varies greatly, from complex diaural systems that mimic the human ear to simply popping balloons and recording the bangs (Policardi 2011:91). This great diversity of methods leads to a great diversity of results, most of which cannot be productively compared to each other. The system of measurement is constrained by the budget of the project, the accessibility of the site, and technological expertise of the archaeologist. Thus many acoustically significant sites are never studied because the technique is impractical. This, along with incomplete or ruined sites, is the primary hinderance to the growth of the field.

Much of the technology used to explore these sorts of questions comes from the architectural field of Room Acoustics. Used primarily in the designing and fine tuning of concert halls and other venues where control of sound is important, Room Acoustics seeks to measure the behavior of sound in a confined space with the end goal of altering that behavior. While modifying archaeological sites to fine-tune their acoustics would be counterproductive, the measuring technique used in this process can easily be applied to archaeoacoustics. While impulse sounds, such as a balloon popping, can give a certain set of data at a certain frequency in the given space, one of the most common and broadly useful forms of acoustic testing is the sine sweep. Used by aerospace engineers in testing frequencies at which large sections of spacecraft

resonate dangerously well, the sine sweep is a controlled sweep through the frequency spectrum, often from a very low frequency, such as 10 Hertz, to a very high frequency, such as 25000 Hertz (Fey and van Liempt 2002:1-3). This gives a data point at each frequency and shows areas of interest in acoustic resonance. In Room Acoustic design, this can then be used to tune up the resonance of various frequencies within the room to attain the ideal resonance space for a certain type of use. In archaeoacoustics, however, this same process can be used to uncover acoustic anomalies or patterns that might suggest or favor one use of a structure over another. Running a sine sweep in an archaeologically significant structure can produce a map of the frequency resonance of the structure and reveal any strengths, weaknesses, or anomalies in the soundscape of that structure.

One of the many understudied structures of acoustic interest are kivas in the Puebloan Southwest, whose function and purpose are widely debated. Generally portrayed as some form of ceremonial structure, the kivas have also been hypothesized to be living structures, among other things (Lekson 1985:1-3). The number of people who would be utilizing the structure at a given time fluctuates depending on the use proposed. Acoustically, any structure that is circular or near-circular creates an interesting acoustic space that responds in a certain way at different frequencies. Thus an acoustic study of kivas is intrinsically interesting due to the unusual acoustic properties, and might give us some insight into the purpose of the mysterious kiva.

Comparing an acoustic map of kivas to acoustic analyses of various sounds known to be in use by Puebloan peoples, we can then predict the sounds to which the structure is most suited. Sounds such as the human voice, flute, and drum all have distinctive frequencies that can be compared to the soundscape of the structure to determine the resonance behavior of the

structure during the use of any of these sounds. By making this comparison, it is possible to glean some previously unknown information regarding the use of a kiva and its acoustic properties.

2. Sites

The sites examined in this thesis are Kiva C and Kiva D at the Spruce Tree House site in Mesa Verde National Park. These are reconstructed kivas, which gives a closer approximation of how the original structure would have sounded than kivas whose structural integrity has been compromised. Room acoustics rely on interactions of sound waves bouncing off all surfaces, and if some surfaces are missing or altered, the acoustics can be very different. Thus, it is better to use structures that are the closest possible representation of the original structure while in use.

The parameters of Kivas C and D, according to the National Park Service record by Jesse Walter Fewkes, are as follows:

“KIVA C

This kiva is circular; it measures 13 feet in diameter, and 5 feet 6 inches from the floor to the top of the pilasters. The height of the banquette is 3 feet. The number of pilasters is 6; their average breadth is 2 feet.

The deflector is a stone wall laid in mortar; its width is 3 feet 6 inches; the thickness, 8 inches. From the flue to the deflector is 2 feet 4 inches, and from the same to the fire-hole, 8 inches. The diameter of the fire-hole is 2 feet, its depth 1 foot. The sipapu is 2 feet from the fire-hole; it is 6 inches deep and 4 inches in diameter.

The masonry of this kiva was in very poor condition, most of the upper part being wholly broken down. There are 4 niches in the walls. The surface is thickly plastered and shows a deposit of smoke. The pilasters are of uniform size. The deep banquette is situated above the flue back of the deflector.

KIVA D

Kiva D is square, with rounded corners; it is 13 feet in diameter; its walls are 10 feet high and measure 7 feet from the floor to the top of the pilasters. The height of the banquette is 4 feet. The number of pilasters is 6; their average distance apart is 4 feet 6 inches, and their width 2 feet. The eastern wall of this kiva is the side of the cave, and the whole was inclosed by high walls. On the southern side of the kiva is a passageway. The walls of the kiva and the cave roof above it are blackened with smoke. There are two deep banquettes.

The flue opens in the western wall of the kiva; its height is 2 feet, and its width at the top is 13 inches. The distance from the flue to the deflector is 2 feet 6 inches; from the deflector to the fire-hole, 13 inches. The diameter of the fire-hole is 2 feet and its depth 1 foot. The distance from the fire-hole to the sipapu is 2 feet 2 inches; the diameter of the latter is 3 inches. This kiva has 5 finely made rectangular niches in the walls. The walls are well plastered and were painted yellow. Wherever the masonry is visible it is found inferior to none except possibly that of kiva Q.” [Fewkes 1911: section 8a page 12].

From personal observation, the base of Kiva D is more round than square, while the shape at ground level approaches the square with rounded corners shape that Fewkes mentions.

3. Equipment and Procedures

Using a microphone, portable Bluetooth speaker, and laptop, with the appropriate connecting cords and silent portable generator, the acoustic response of Kivas C and D was measured using a 30 second sine sweep from 1 Hertz to 20,000 hertz at 40 decibels. This was done by moving the speaker on a 2 meter grid both at the floor level and 1.5 meters above floor level, and recording the room response from a central location. Multiple small control tests on other factors were also performed, such as location of the microphone, height of the speaker, number of body masses in the kiva, and duration of the sweep. Finally, a set of tests was performed around archaeologically significant features, such as the deep banquette and sipapu, as well as some experiments with other sounds, including finger-snapping, clapping, singing, and both male and female vocal range tests, all for reference and curiosity purposes.

Equipment

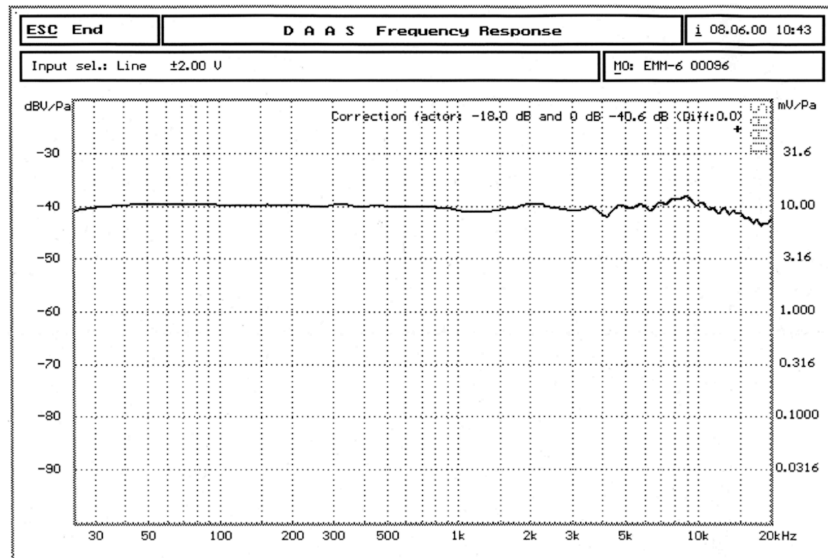
The goal with the equipment design was to collect a set of equipment that was easily portable by a single individual, powered in such a way that it could be used at a remote site, affordable for a tight budget, and sensitive enough to measure acoustic anomalies and characteristics of a magnitude recognizable by the human ear. Measuring any acoustic

characteristics at a sensitivity outside the perceptions of the human ear would be extraneous and unnecessary for the purpose of this study, because such characteristics would not have been perceived by the original users of Kivas. In some cases, portability and power usage trumped finesse in measuring technology, because of the implications of equipment use in remote archaeological studies.

The microphone used was a Dayton Audio EMM-6 Electret Measurement Microphone. It was selected for its low frequency distortion, portability, and ability to use phantom power. The frequency response is remarkably even across all frequencies, and it runs on low voltages, removing the need for a large power generator. The sensitivity is sufficient to pick up acoustic anomalies large enough to be registered by the human ear. See figure 1.1 for detailed frequency response

specifications (Dayton 2009:1).

The portable speaker used was an HDMX Jam commercially-sold speaker. This was selected for its portability, battery life, omnidirectional projection, and ability to interface via Bluetooth, removing the need



Typical Frequency Response

Figure 3.1: Frequency Response of Dayton Audio EEM-6 Electret Measurement Microphone

for additional connecting cables and/or generators. The detailed specifications of this speaker

were not available, but the range is sufficient to cover all frequencies audible to humans. The speaker is simple, with minimal distortion, and is sufficient for measuring acoustic anomalies large enough to be discernible by the human ear (HDMX 2014:1).

All data was recorded using a Macbook Pro operating on an OS X 10.8.5 operating system. The program used for generating the sine sweep and recording the data was FuzzMeasure Pro 3 version 3.3.1, a simple room acoustic measurement software suitable for Mac operating systems (SuperMegaUltraGroovey 2014:1).

Other equipment included a Phantom II Pro Two Channel 48 Volt Phantom Power Supply as a power generator, a USB to three-prong jack cable, a three-prong jack to three-prong jack cable, 9 volt batteries, foam markers, notebook, pencil, 2 measuring tapes, and a metal boom microphone stand. All tests on Kiva C were performed on the 26th of November, 2013. All tests on Kiva D were performed on 27th of November, 2013.

Procedures

While a test that includes all infinite possibilities of acoustic productions and measurements within the structure would be scientifically ideal, such a survey is impractical and impossible, not to mention less than useful. For the purpose of this study, the focus was on ways in which humans might have perceived and utilized sound within the kivas, so the project was designed with human physiology and perception in mind. Also, due to limited time and resources, the speaker was moved to various points throughout the kivas, while the microphone remained stationary near the center of the kiva. For all tests, one body mass was present within the kiva room, for logistical purposes. A 30 second full spectrum sine sweep from 1 to 20,000 Hz at an amplitude of 40 dB was used as the standard of measurement. A sine sweep for the purpose

of this test is defined as a smooth, continuous projection of all of the aforementioned frequencies, from least to greatest, over the time noted at the decibel level stated. The effects of body masses and the microphone/speaker movement choices were tested in a control sample test of each factor (see Control Tests below). The range of the sine sweep was selected based on the fact that the human ear can only perceive frequencies between 20 and 20,000 Hz (Berg 2014:12). The duration was selected as a mid-duration sine sweep to allow accurate measurement at all frequencies, but also allow for adequate testing of multiple points within the time frame allowed.

Within each kiva, a 2 meter grid was measured using magnetic compass points for reference, with the intersection of north-south and east-west lines in the center of each structure acting as the local horizontal datum. Each 2 meter intersection point was assigned an arbitrary number designation then measured both at floor level and at 1.5 meters above floor level. These are approximately the heights of a seated or prone adult human body and a standing adult human body. This grid system generated 18 data points in Kiva C and 26 data points in Kiva D. A sine sweep as defined above was completed and recorded at each data point.

Kiva C Test Grid:

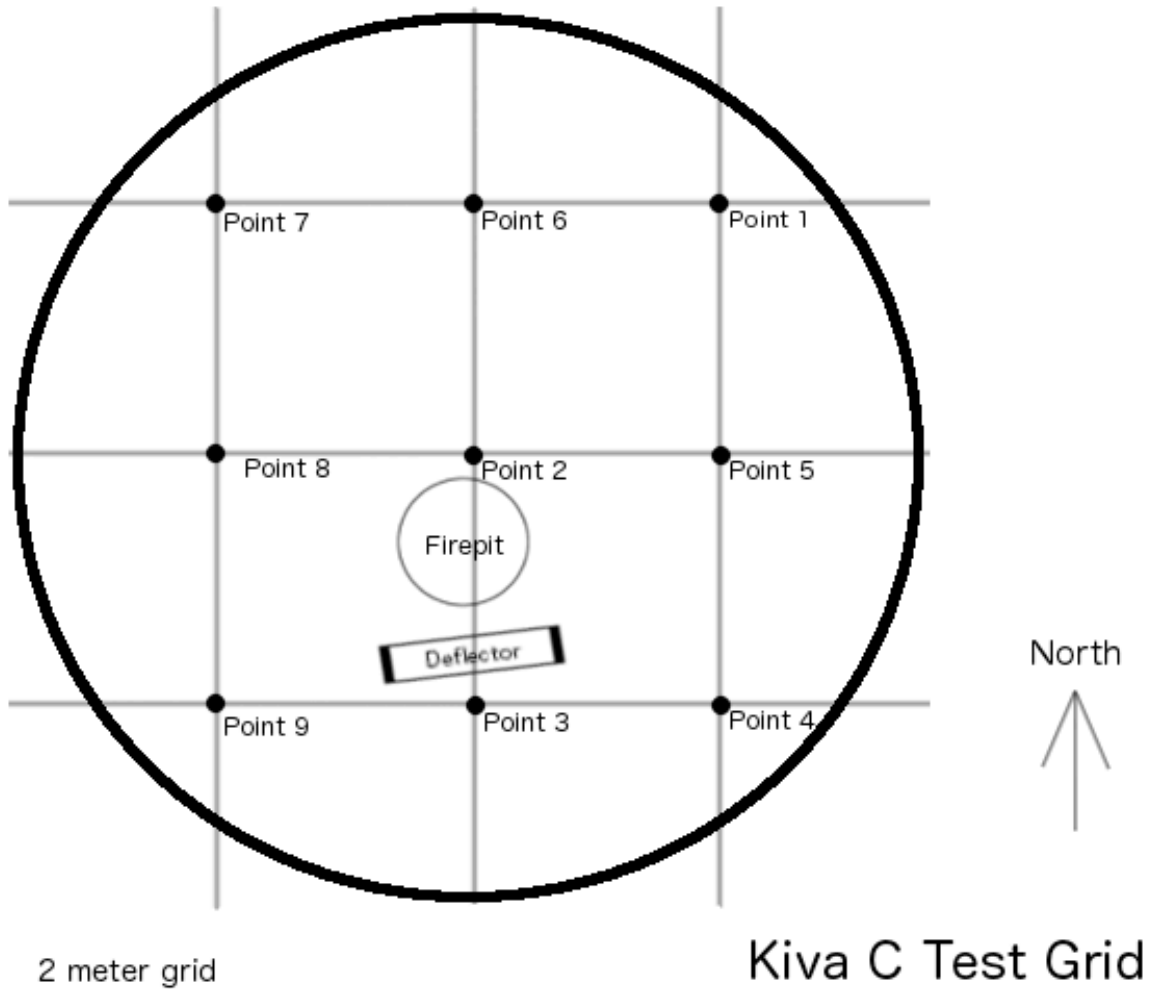


Figure 3.2: A referential diagram of the test grid for Kiva C, based on field notes. The grid is 2 meters by 2 meters, measured from the center of the kiva along the compass points. This is an approximate schematic, for orientation purposes only.

Kiva D Test Grid:

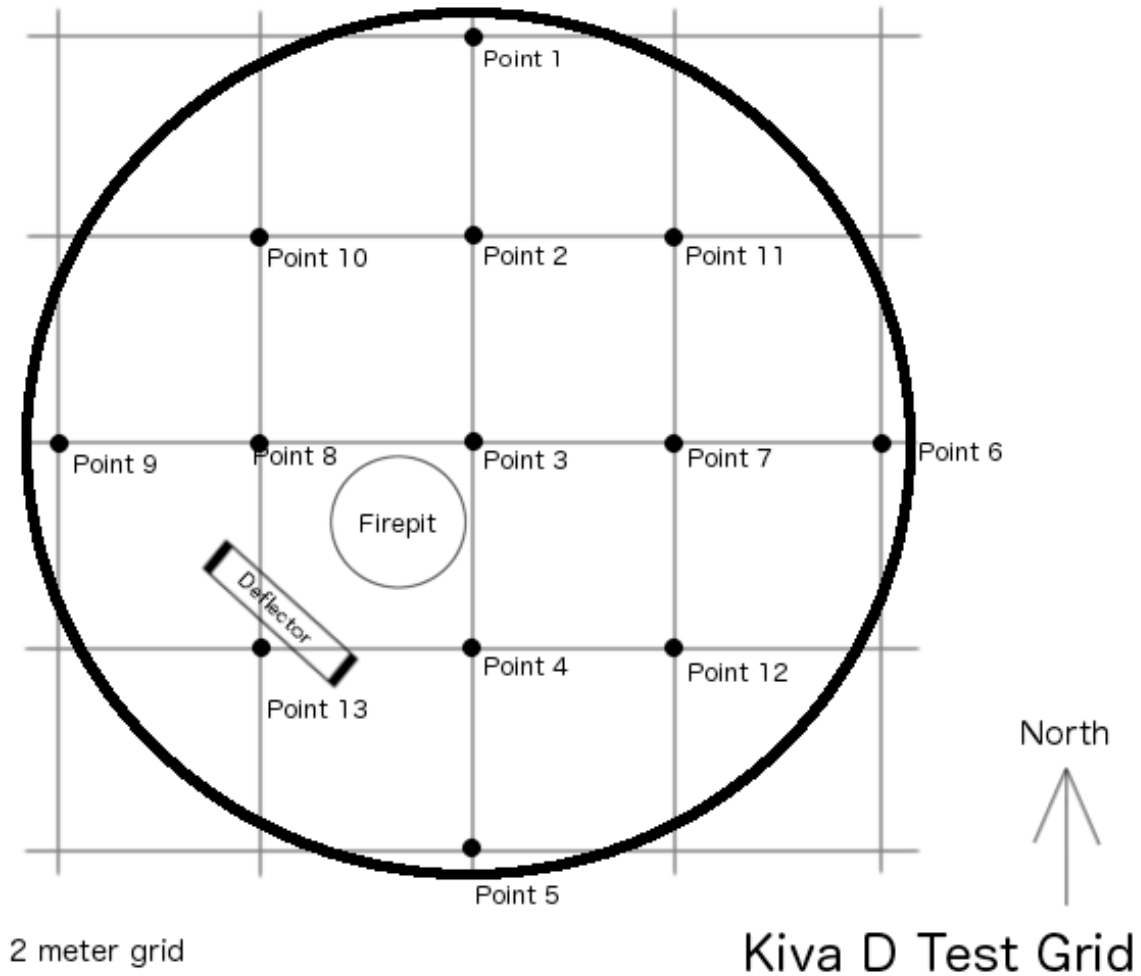


Figure 3.3: A referential diagram of the test grid for Kiva D, based on field notes. The grid is 2 meters by 2 meters, measured from the center of the kiva along the compass points. This is an approximate schematic, for orientation purposes only.

Control Tests:

The following control tests were performed to determine the effects of multiple variables on the results of the main tests. The amount of acceptable error in these tests is rather large, since any acoustic properties too localized or finessed to be perceived by the human ear are irrelevant to this analysis, as they would not have been observed by the original inhabitants in the course of daily use. However, many factors can have large enough effects on the data to be of note. One of these is the effects of body masses within the kiva, as kivas were more often than not used by more than a single individual, as was present for the tests. Figure 3.4 shows the effects of body masses to the kiva's frequency response. While the presence of body masses may affect the frequency response slightly, it is less than the natural jitter of the tests, and the general shape of the frequency response curve is preserved with more than enough integrity to draw conclusions about audible effects.

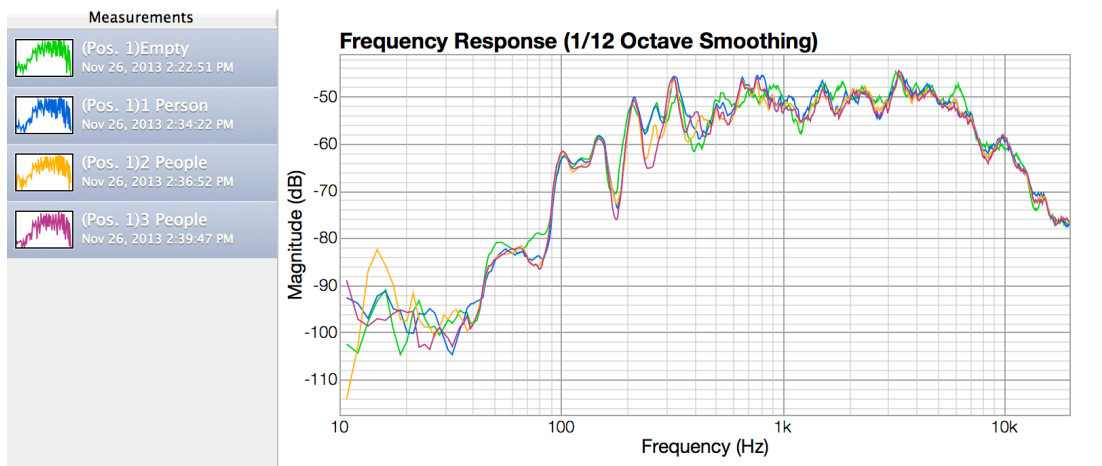


Figure 3.4: Body Mass Control Test. Sine sweep test results of four tests, with 0, 1, 2, and 3 body masses respectively within Kiva C. Sine sweep settings and microphone/speaker positions remained constant.

The second rather large variable is the placement of the speaker versus the placement of the microphone. There are two options for this; the first is to move the speaker while the

microphone remains constant, while the second is to move the microphone and while the speaker remains constant. While this effects the data slightly more, as shown in Figures 3.5-3.8, the general shape of the data in both configurations is once again preserved in such a way that allows for productive analysis of the effects the soundscape might have had on daily life. The speaker was more portable than the microphone and stand, so the rest of the data was collected by moving the speaker to the points indicated on the grids in Figures 3.2 and 3.3 above while the microphone remained in the center of the structure.

Test 1

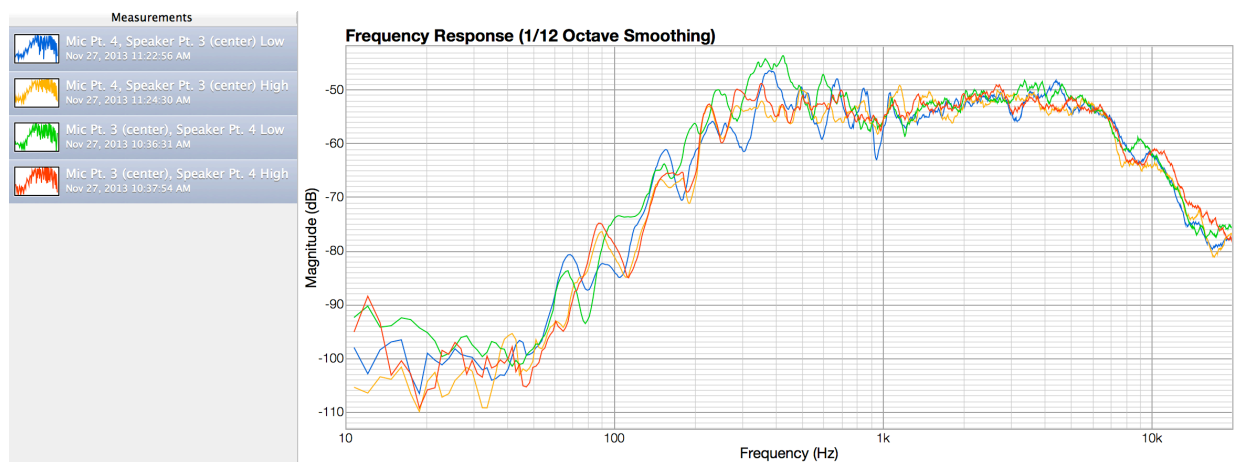


Figure 3.5: Microphone vs. Speaker Movement Control Test 1. Point 4 in Kiva D was tested first with the speaker at the center of the room and the microphone at Point 4, then with the microphone at the center of the room and the speaker at Point 4. In both tests, the height of the microphone remained at 1.5 meters and the speaker was tested both at the High position (1.5 meters) and the Low position (0 meters) above floor level. Sine sweep frequency range, decibel levels, and duration remained constant. The contour of the frequency response in both cases is similar, though the absolute values differ slightly.

Test 2

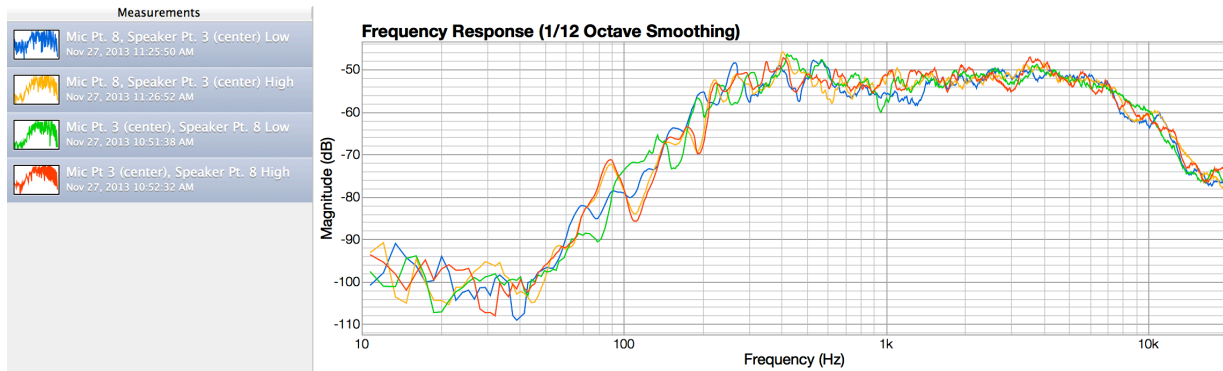


Figure 3.6: Microphone vs. Speaker Movement Control Test 2. Point 8 in Kiva D was tested first with the speaker at the center of the room and the microphone at Point 8, then with the microphone at the center of the room and the speaker at Point 8. In both tests, the height of the microphone remained at 1.5 meters and the speaker was tested both at the High position (1.5 meters) and the Low position (0 meters) above floor level. Sine sweep frequency range, decibel levels, and duration remained constant. The contour of the frequency response in both cases is similar, though the absolute values differ slightly.

Test 3

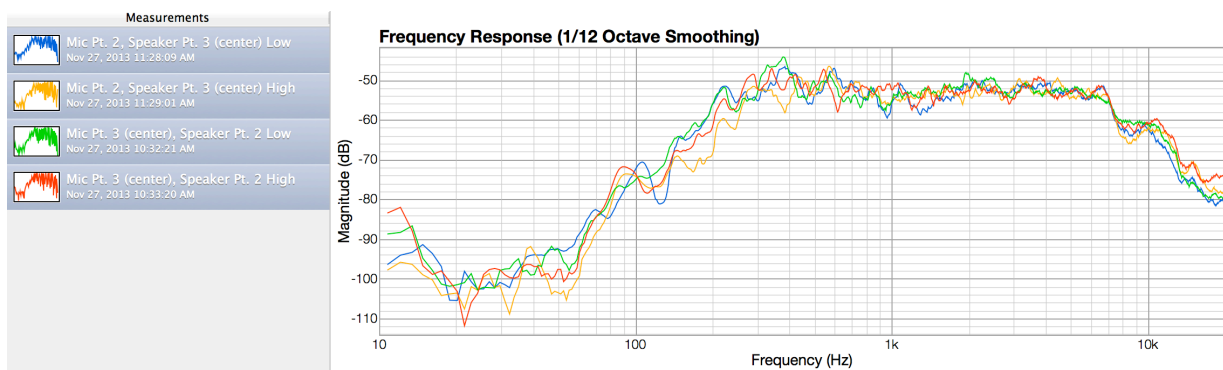


Figure 3.7: Microphone vs. Speaker Movement Control Test 3. Point 2 in Kiva D was tested first with the speaker at the center of the room and the microphone at Point 2, then with the microphone at the center of the room and the speaker at Point 2. In both tests, the height of the microphone remained at 1.5 meters and the speaker was tested both at the High position (1.5 meters) and the Low position (0 meters) above floor level. Sine sweep frequency range, decibel levels, and duration remained constant. The contour of the frequency response in both cases is similar, though the absolute values differ slightly.

Test 4

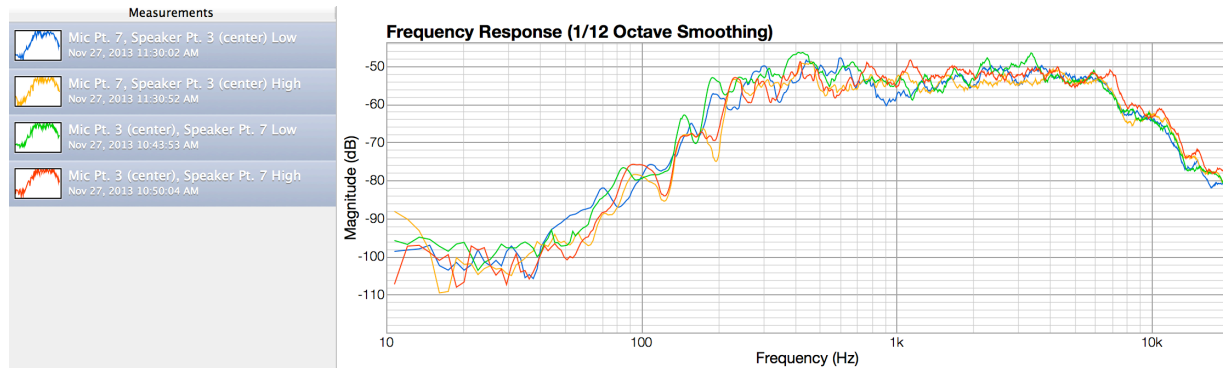


Figure 3.8: Microphone vs. Speaker Movement Control Test 4. Point 7 in Kiva D was tested first with the speaker at the center of the room and the microphone at Point 7, then with the microphone at the center of the room and the speaker at Point 7. In both tests, the height of the microphone remained at 1.5 meters and the speaker was tested both at the High position (1.5 meters) and the Low position (0 meters) above floor level. Sine sweep frequency range, decibel levels, and duration remained constant. The contour of the frequency response in both cases is similar, though the absolute values differ slightly.

Other control factors include the amplitude and duration of the sine sweep. These were selected after a few brief trials in a separate unrelated structure that showed little difference in the general shape of the response curve. The differences were that the response was shifted up in decibel level if the amplitude of the original sweep was raised, though the shape remained virtually identical. Alternatively, if the duration was increased, the jitter and finessed information increased slightly, though no effect could be seen on a useful level. These, in combination with the sensitivity of the microphone, where the elements that affected the choice of a 30 second sine sweep at 40 decibels.

4. Data

The primary data collected for the study was, again, based on a 30 second sine sweep from 1 Hz to 20,000 Hz at 40 dB performed on a two meter grid (see Figures 3.2 and 3.3 above) at both high (speaker at 1.5 meters above floor level) and low (speaker at 0 meters above floor

level) elevations. This created a total of 18 data points in Kiva C and a total of 26 data points in the slightly larger Kiva D. The frequency response was measured at each point, the data recorded, and graphed.

Kiva C

Kiva C yielded a total of eighteen data sets. Nine of these readings were taken at 1.5 meters above the floor, while the other nine were taken from floor level in the same locations. For reference as to placement of data points, please refer to Figure 3.2.

Point 1 Data

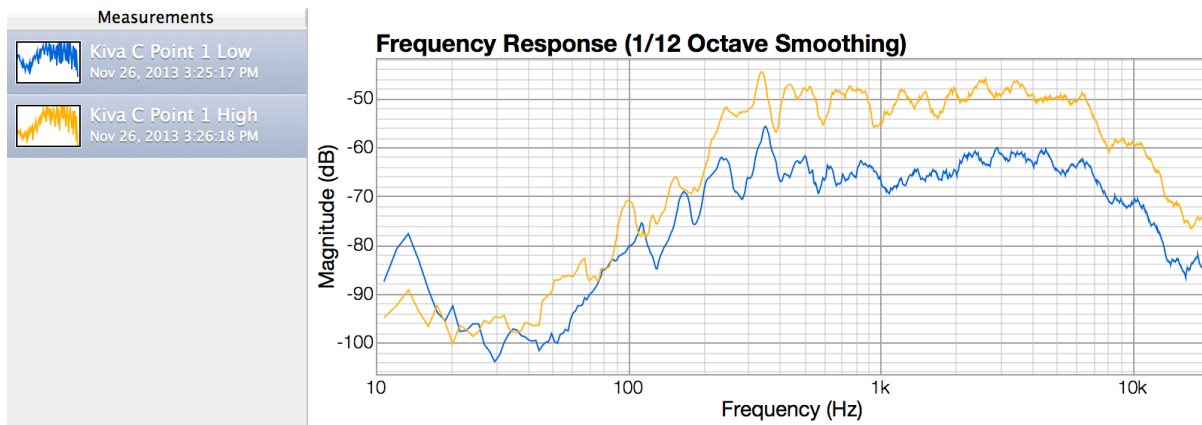




Figure 4.1: Point 1 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High).

Point 2 Data

 Kiva C Point 2 (center) Low
 Nov 26, 2013 3:37:09 PM
 Kiva C Point 2 (center) High
 Nov 26, 2013 3:38:02 PM

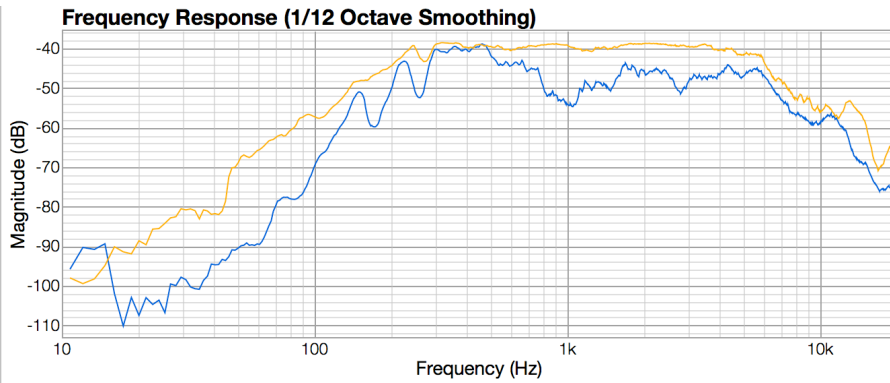




Figure 4.2: Point 2 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High). Note that Point 2 is also the location of the microphone, which is at 1.5 meters. This means that the microphone and speaker are in essentially the same place for the 1.5 meter elevation test.

Point 3 Data

Measurements
 Kiva C Point 3 Low
 Nov 26, 2013 3:39:07 PM
 Kiva C Point 3 High
 Nov 26, 2013 3:40:40 PM

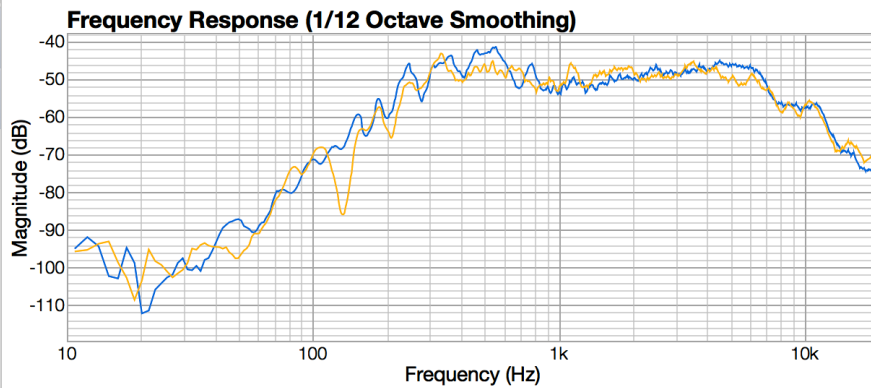


Figure 4.3: Point 3 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High).

Point 4 Data

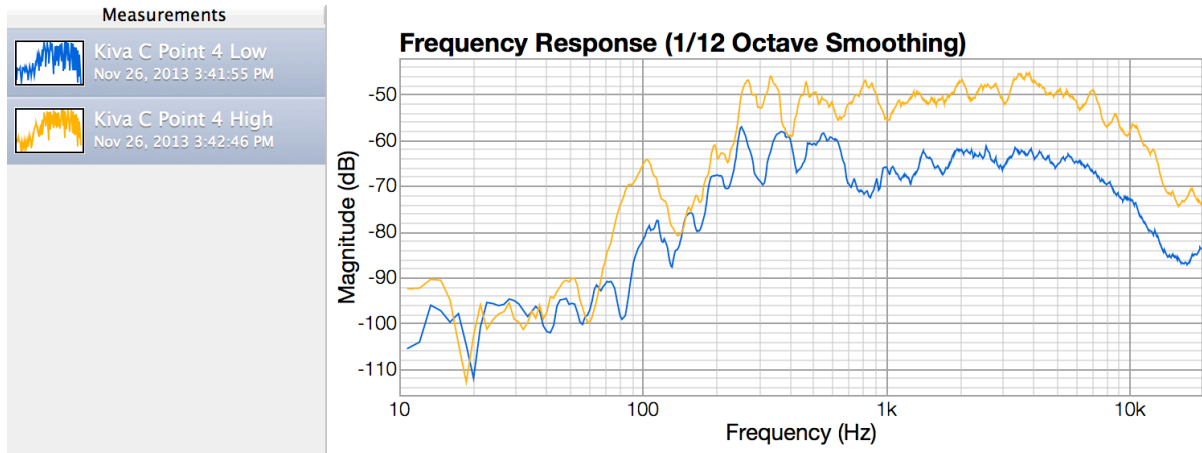


Figure 4.4: Point 4 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High).

Point 5 Data

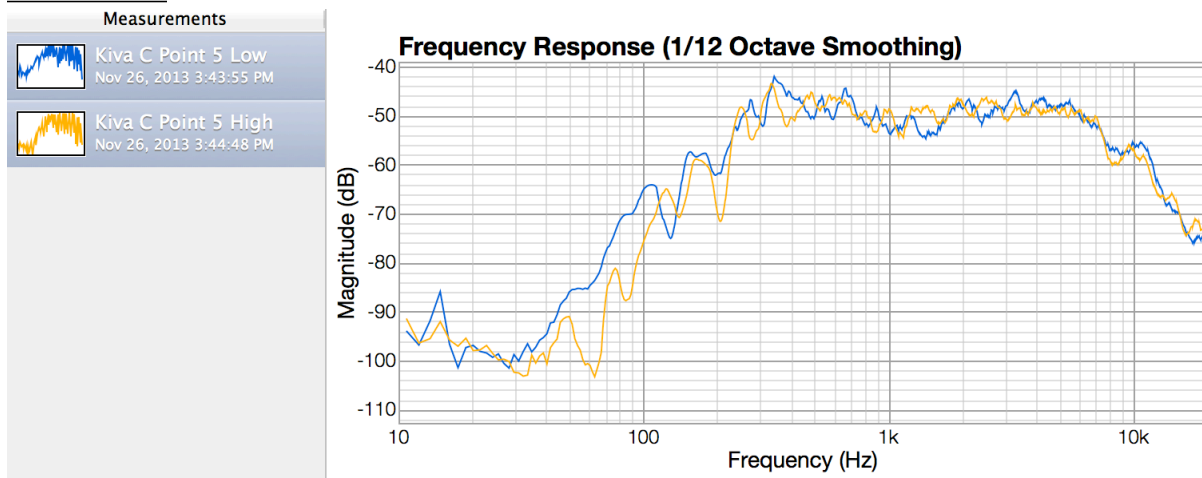




Figure 4.5: Point 5 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High).

Point 6 Data

Measurements

-  Kiva C Point 6 Low
Nov 26, 2013 3:45:56 PM
-  Kiva C Point 6 High
Nov 26, 2013 3:46:45 PM

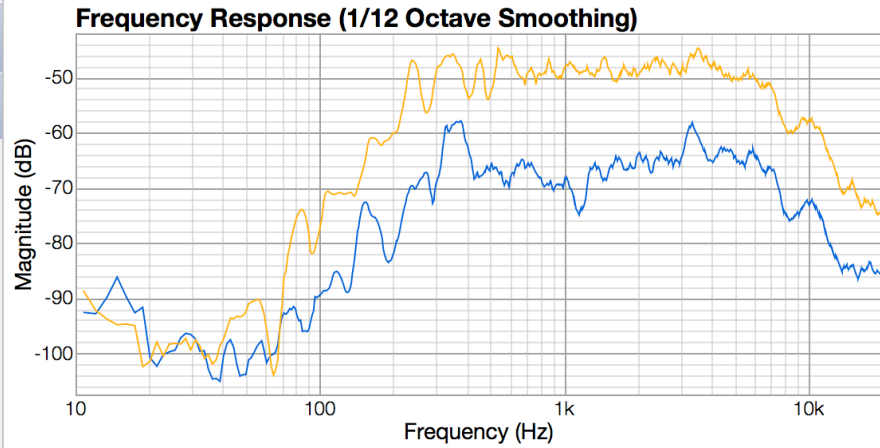




Figure 4.6: Point 6 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High).

Point 7 Data

Measurements

-  Kiva C Point 7 Low
Nov 26, 2013 3:47:51 PM
-  Kiva C Point 7 High
Nov 26, 2013 3:48:43 PM

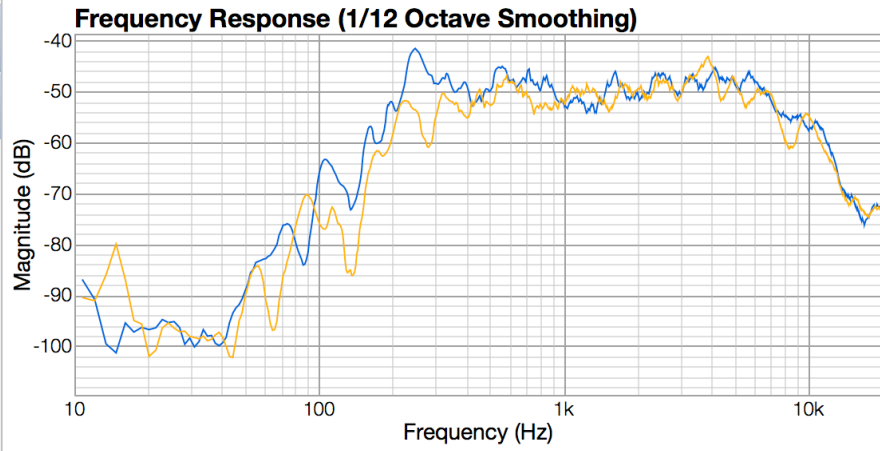


Figure 4.7: Point 7 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High).

Point 8 Data

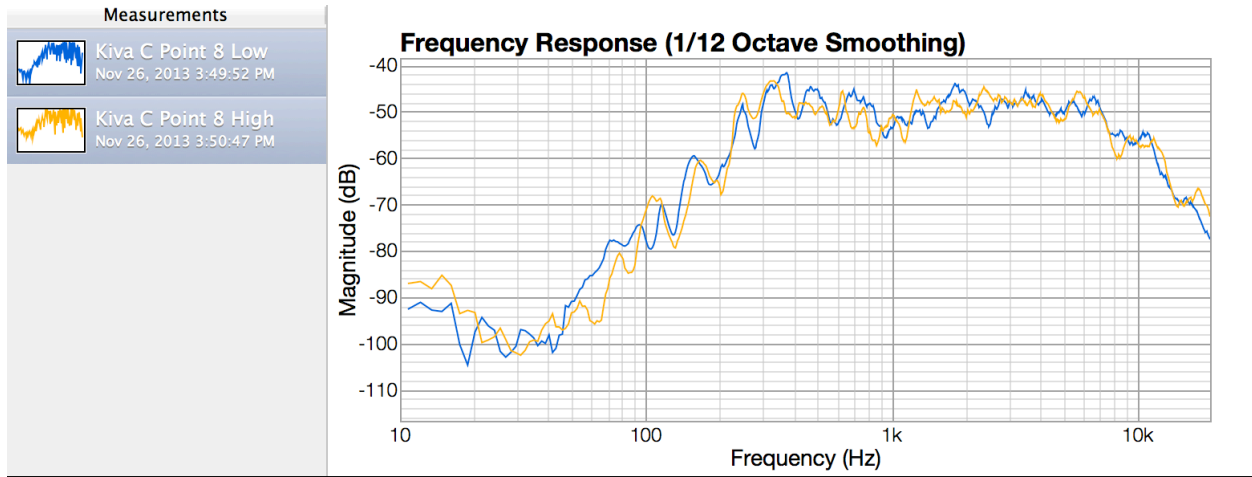


Figure 4.8: Point 8 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High).

Point 9 Data

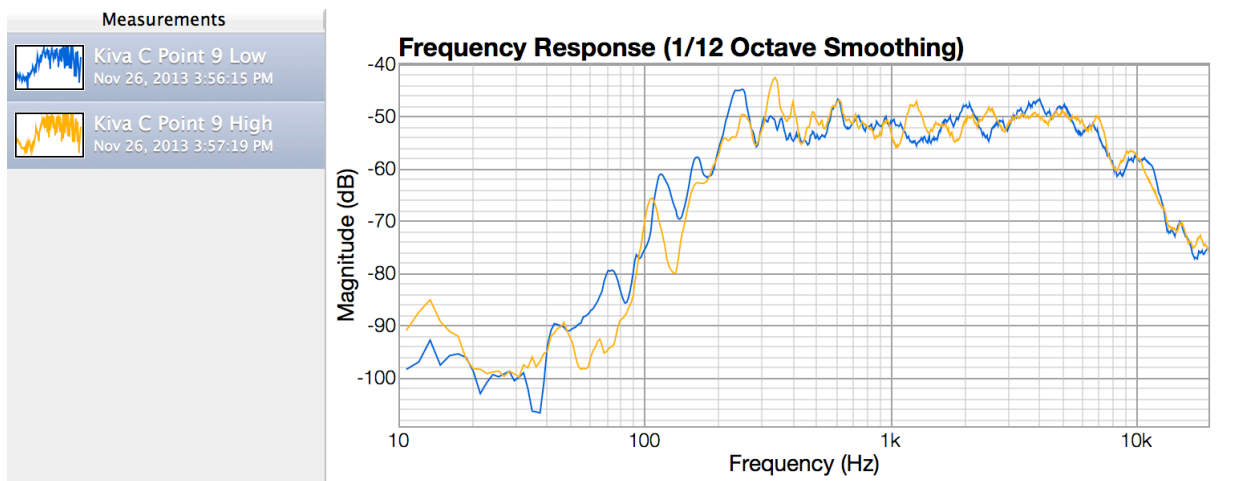


Figure 4.9: Point 9 data from Kiva C. The blue line represents the sine sweep performed at 0 meters above floor level (Low), while the yellow line represents the sine sweep performed at 1.5 meters above floor level (High).

After collecting all data from all points, smoothing the frequency response to show the general frequency response of the Kiva, and eliminating the compromised data from high elevation test at Point 2, the following frequency response curve emerges (Figure 4.10):

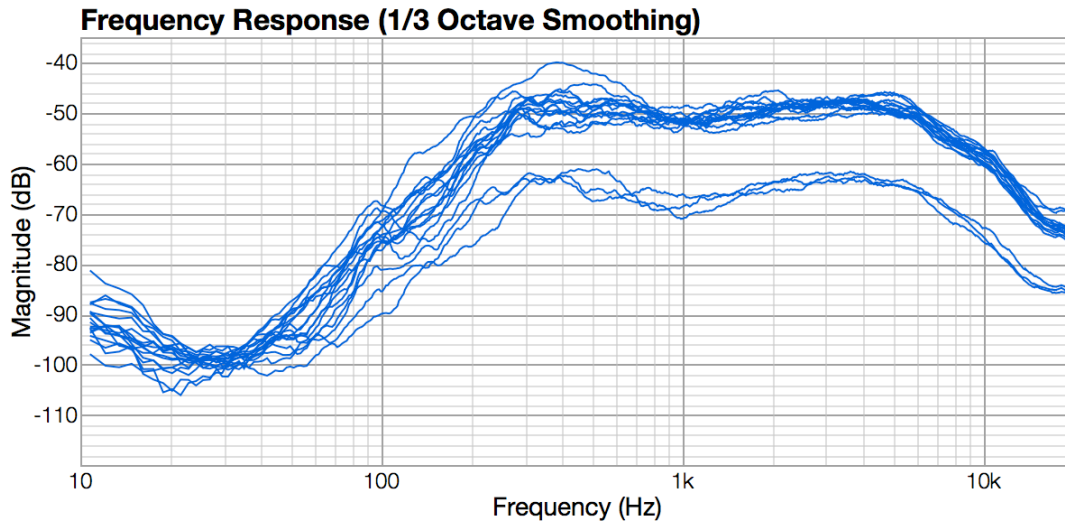


Figure 4.10: Combined data from all test points except the high elevation Point 2 test. Two trends can be seen, both with the same general shape.

The low-elevation (floor level) tests appear as follows:

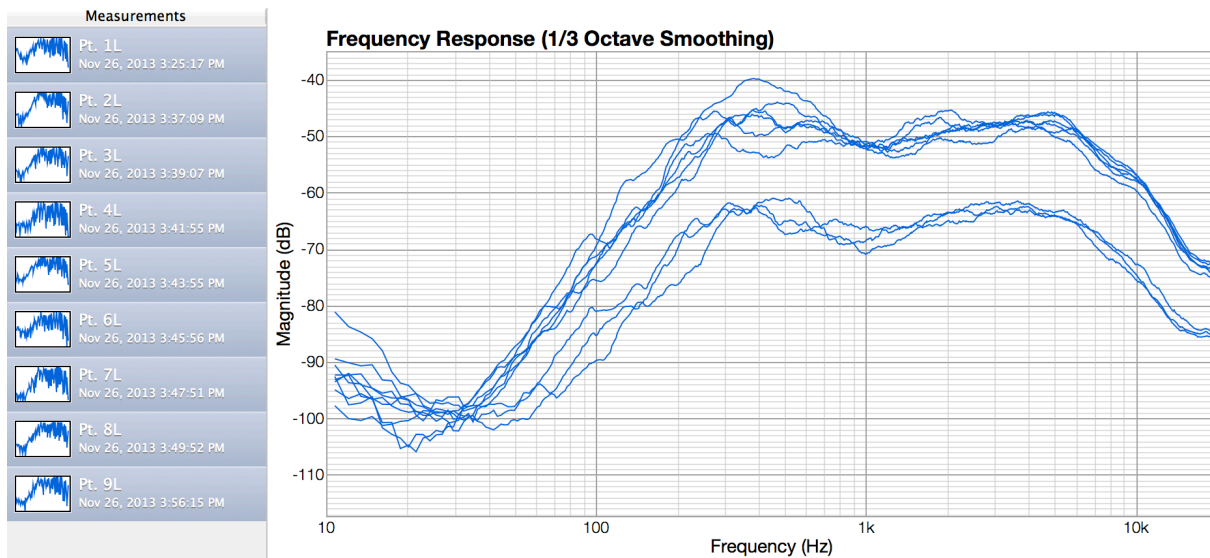


Figure 4.11: Low-elevation data results.

The three deviant decibel values are the low-elevation tests at points 1, 4, and 6.

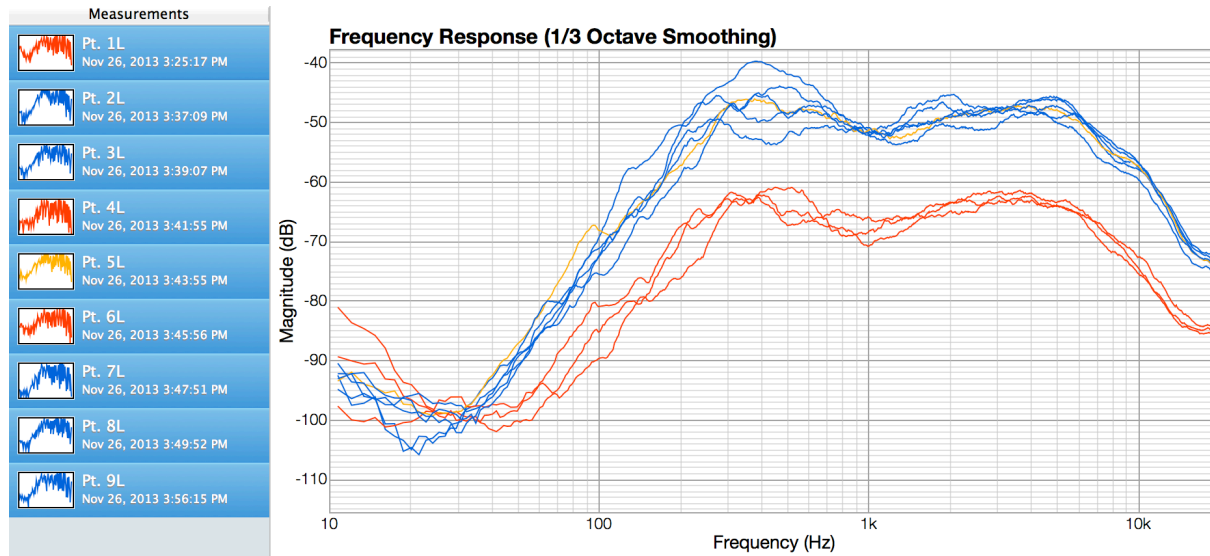


Figure 4.12: Low-elevation data results, highlighting the three deviant decibel values, marked in red. All are located on the west side of the Kiva, though Point 5 (marked in yellow) is also on the west side of the Kiva and does not show a comparable decibel shift.

These deviant decibel readings might be caused by a structural anomaly, or a testing anomaly, such as the body mass being placed between the speaker and microphone. The relative shape remains consistent, however, rendering the information still useful.

The high-elevation data appears as follows:

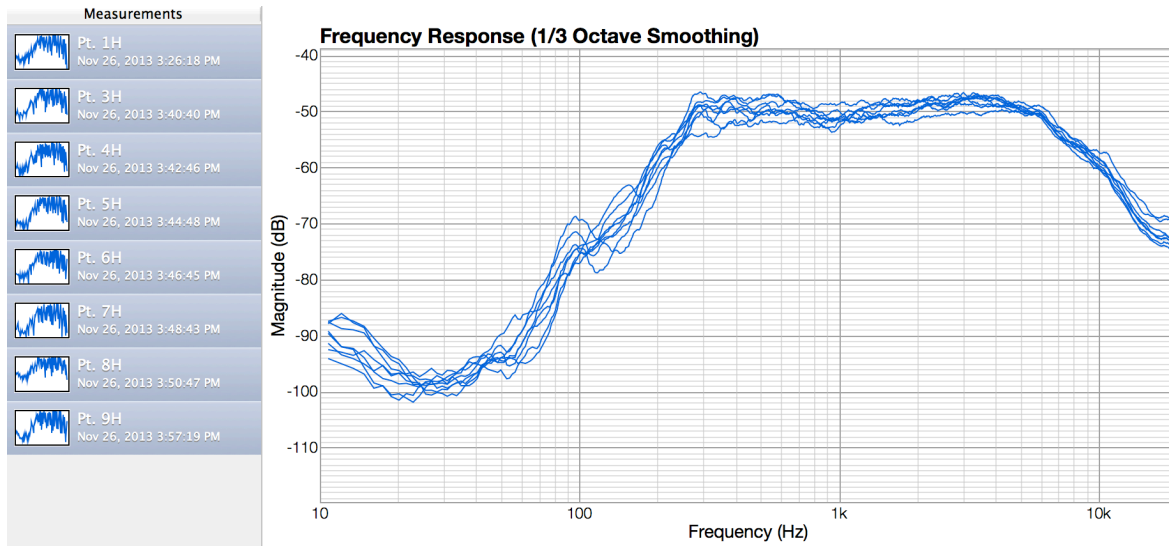


Figure 4.13: High-elevation data results. These are very similar to the low-elevation results, except for the slightly more pronounced dip in response between 100 and 200 Hz and a lesser dip in frequency response around the 1000 Hz mark.

Kiva D

Kiva D yielded a total of 26 data points. 13 of these data points were recorded at 1.5 meters above the floor, while the other 13 were recorded from floor level. For reference as to placement of the data points, refer to Figure 3.3.

Point 1 Data

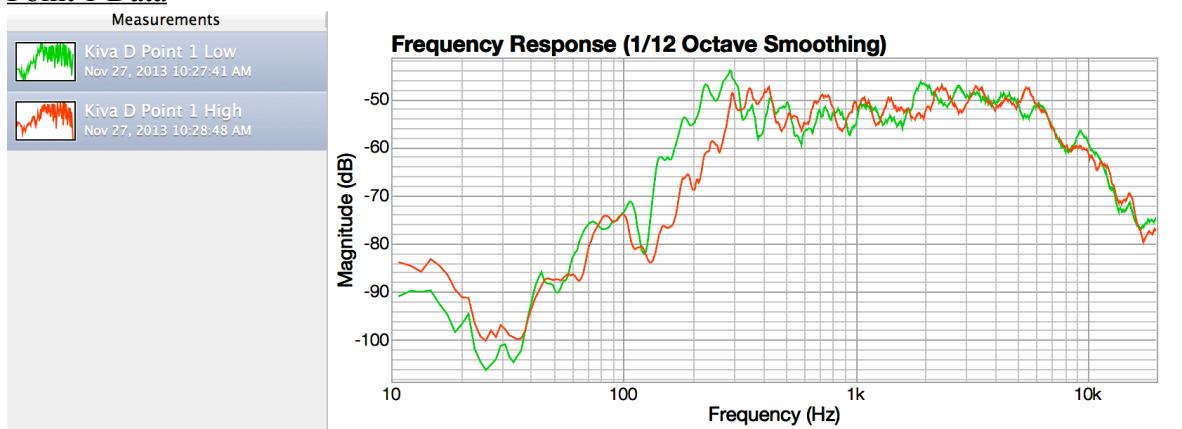


Figure 4.14: Point 1 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 2 Data

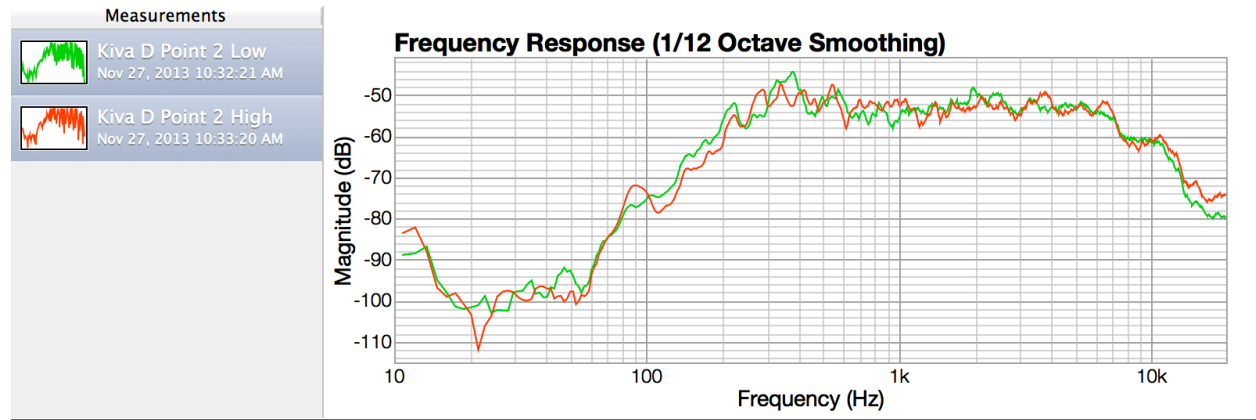


Figure 4.15: Point 2 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 3 Data

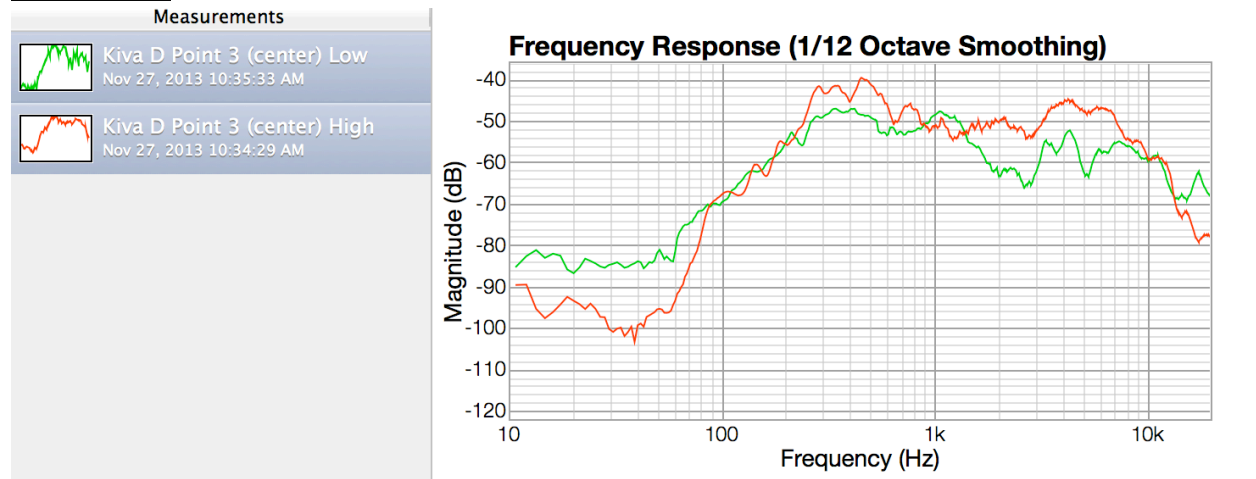


Figure 4.16: Point 3 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level. Note that Point 3 is also the location of the microphone, which is at 1.5 meters. This means that the microphone and speaker are in essentially the same place for the 1.5 meter elevation test.

Point 4 Data

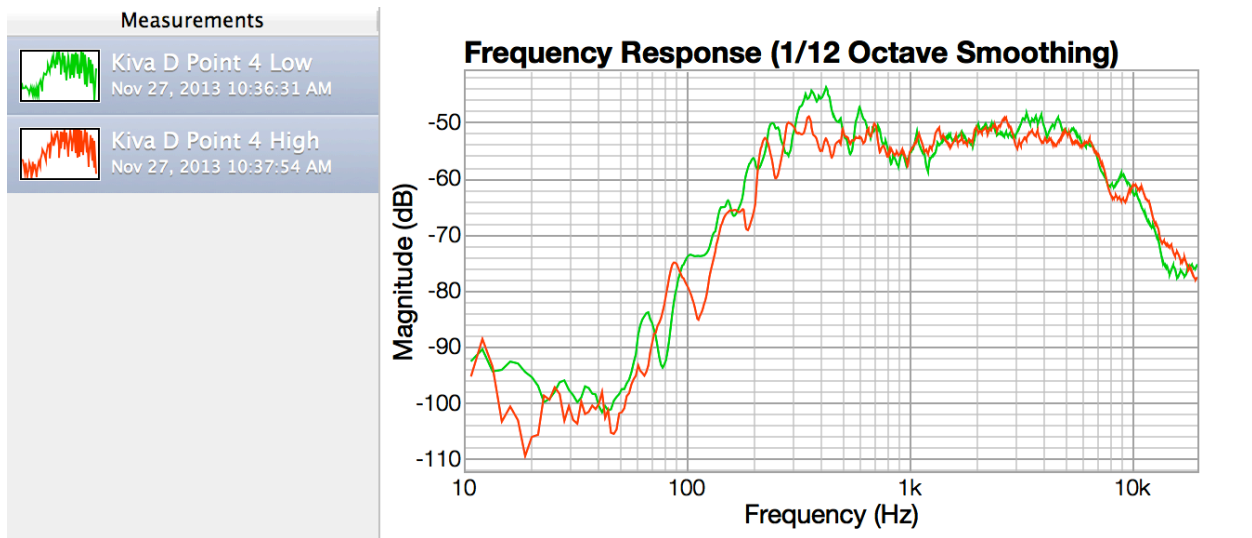


Figure 4.17: Point 4 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 5 Data

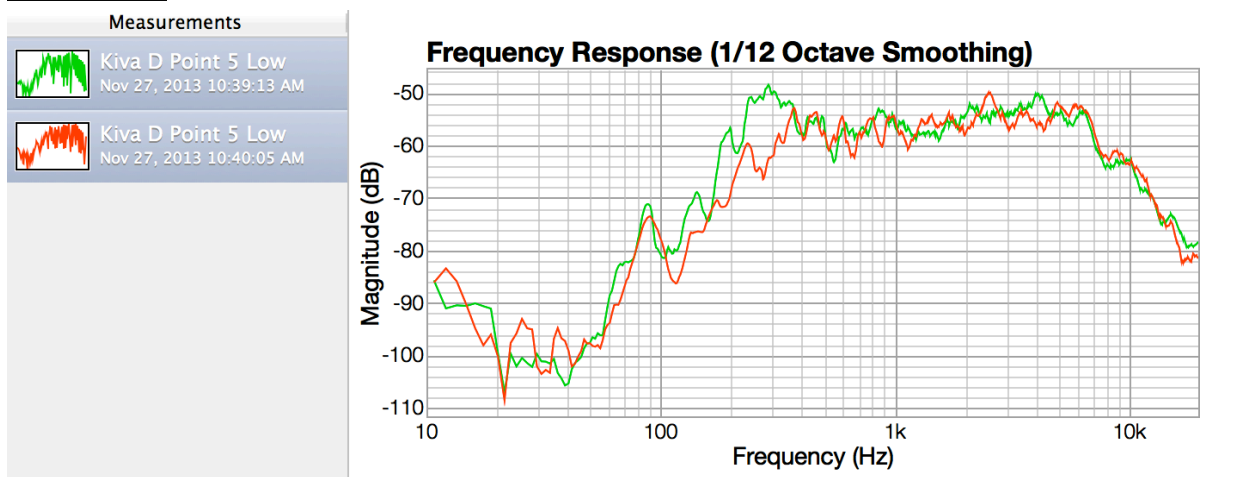


Figure 4.18: Point 5 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 6 Data

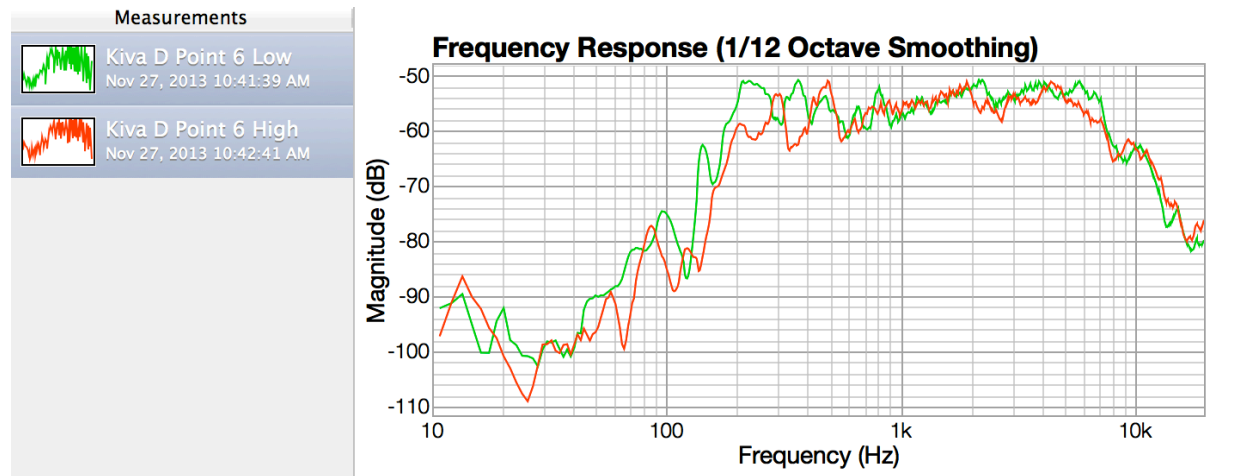


Figure 4.19: Point 6 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 7 Data

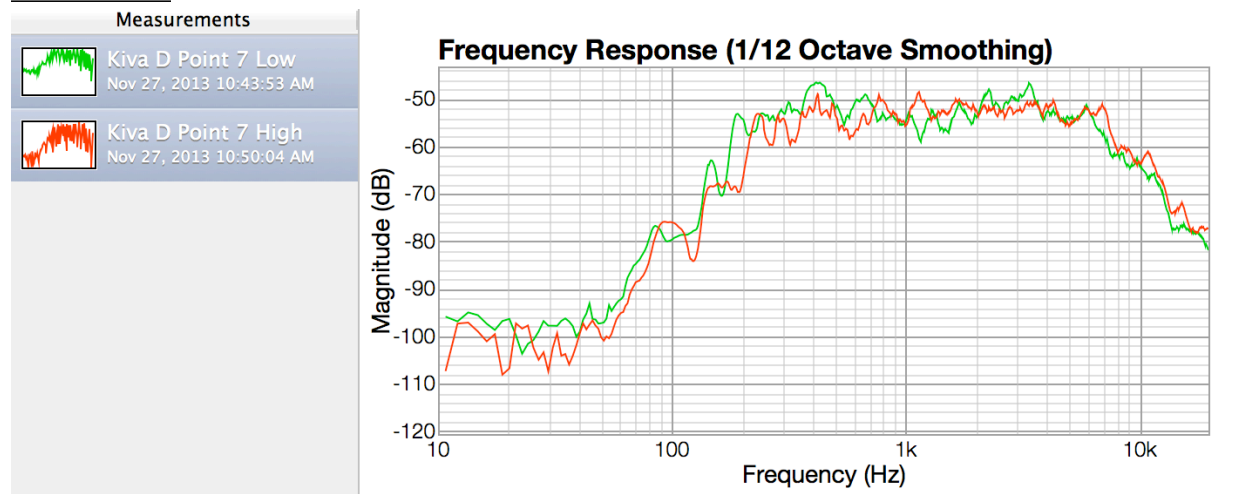


Figure 4.20: Point 7 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 8 Data

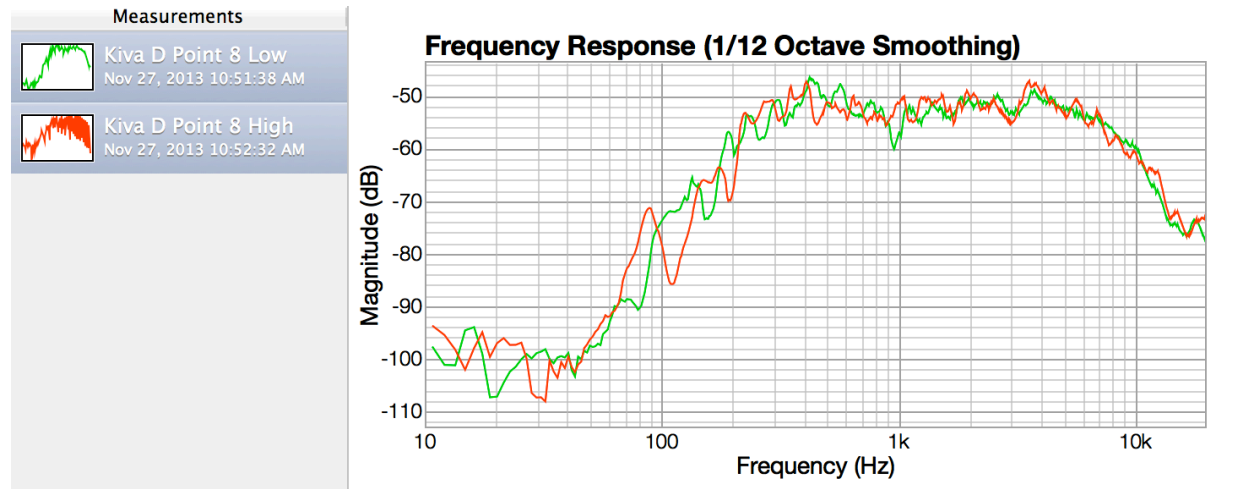


Figure 4.21: Point 8 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 9 Data

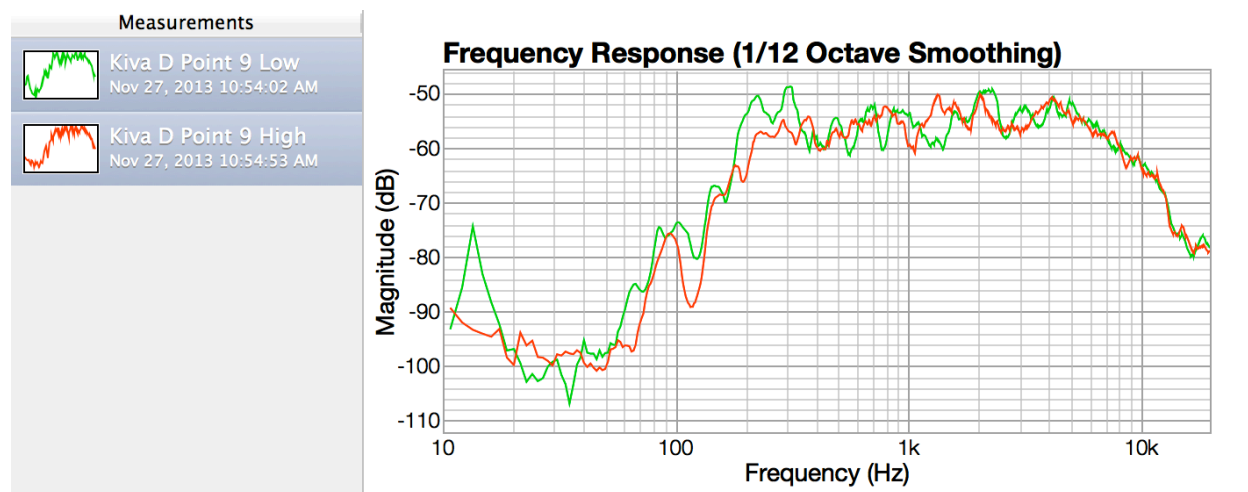


Figure 4.22: Point 9 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 10 Data

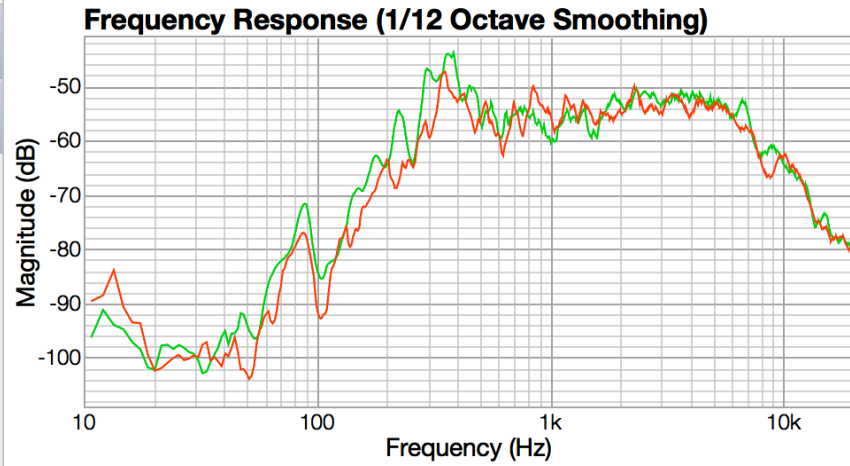
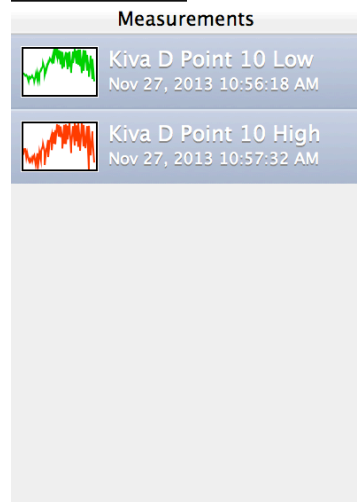


Figure 4.23: Point 10 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 11 Data

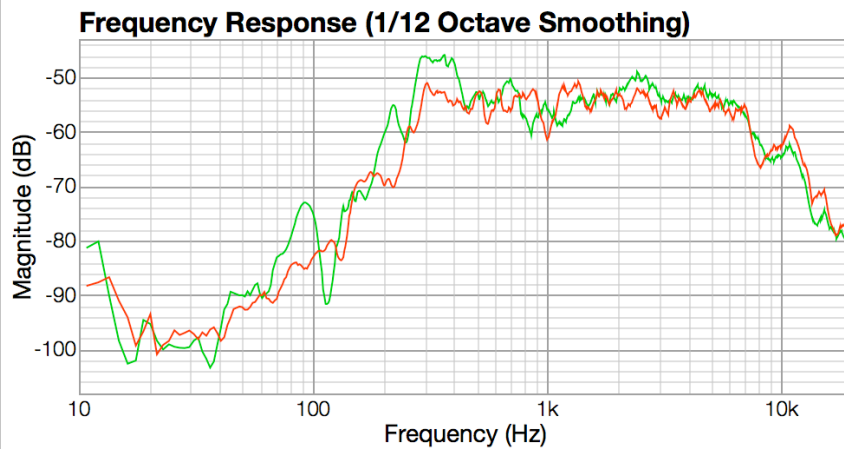
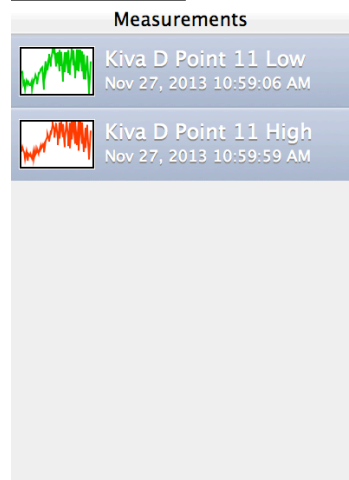


Figure 4.24: Point 11 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 12 Data

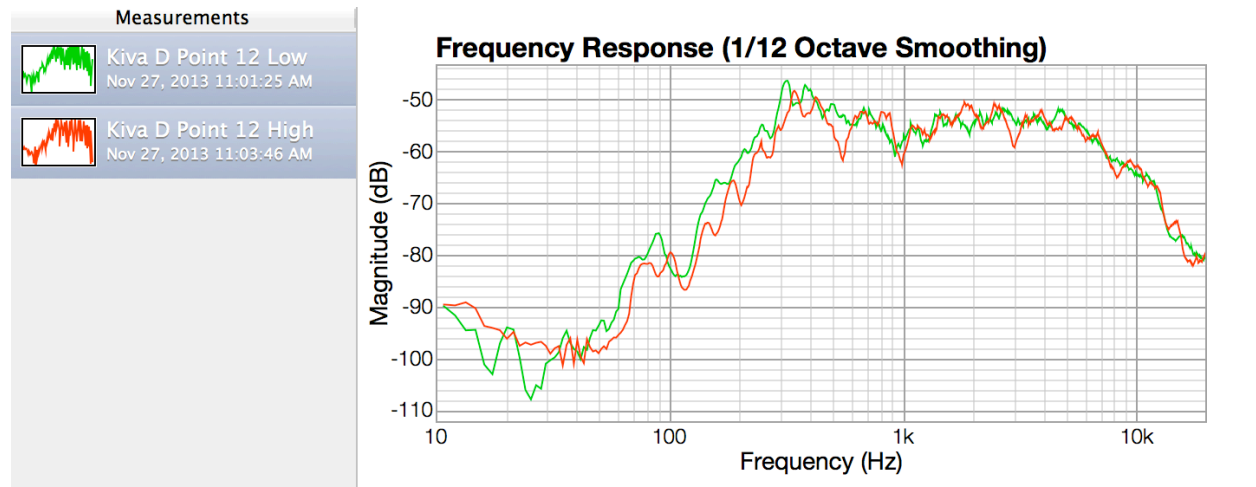


Figure 4.25: Point 12 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Point 13 Data

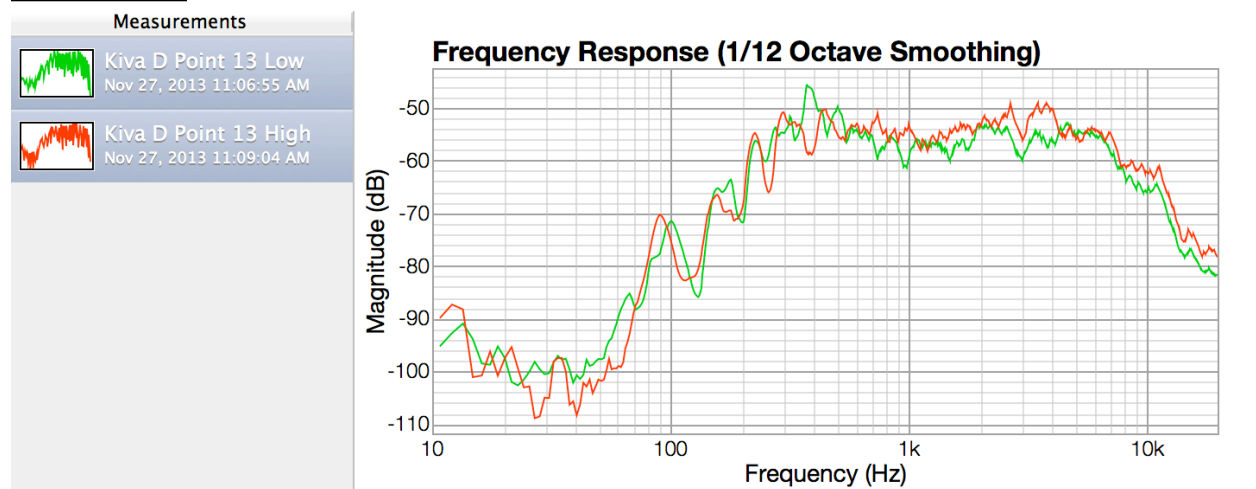


Figure 4.26: Point 13 data from Kiva D. The green line represents the sine sweep performed at 0 meters above floor level. The red line represents the sine sweep performed at 1.5 meters above floor level.

Once again, using all data from all points and smoothing the frequency response to show the general frequency response of Kiva D, having eliminated the compromised data from the high elevation test at Point 3, the following frequency response curve emerges:

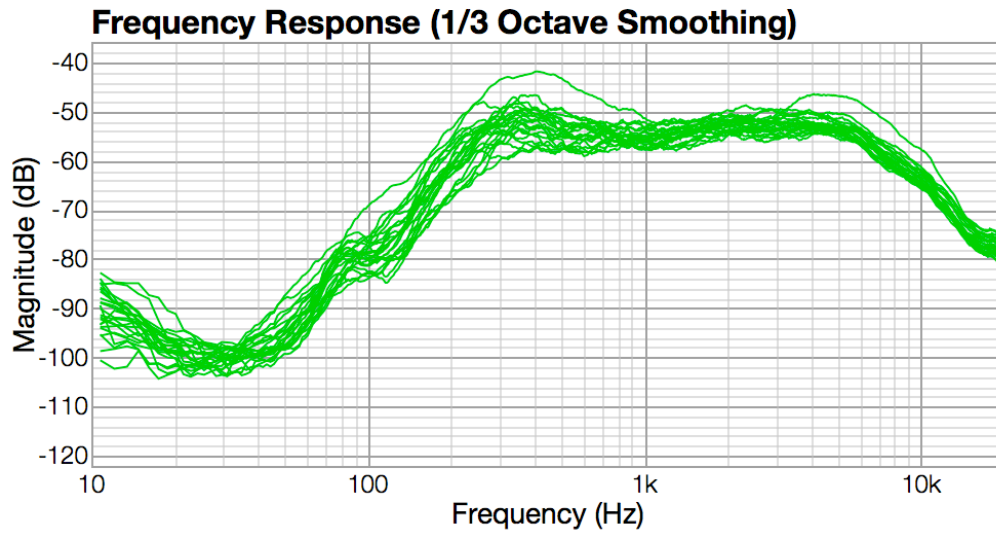


Figure 4.27: Combined data from all test points except the high elevation Point 3 test. A single response curve emerges.

The low-elevation (floor level) tests collectively appear as follows:

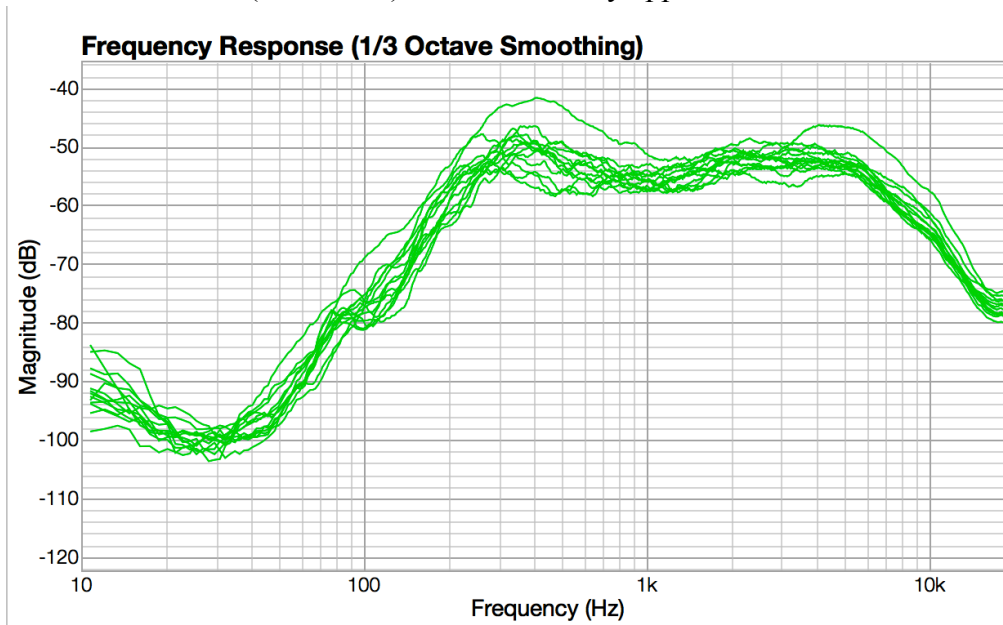


Figure 4.28: 0 meter elevation data results for Kiva D.

The high-elevation (1.5 meters above floor level) data set is as follows:

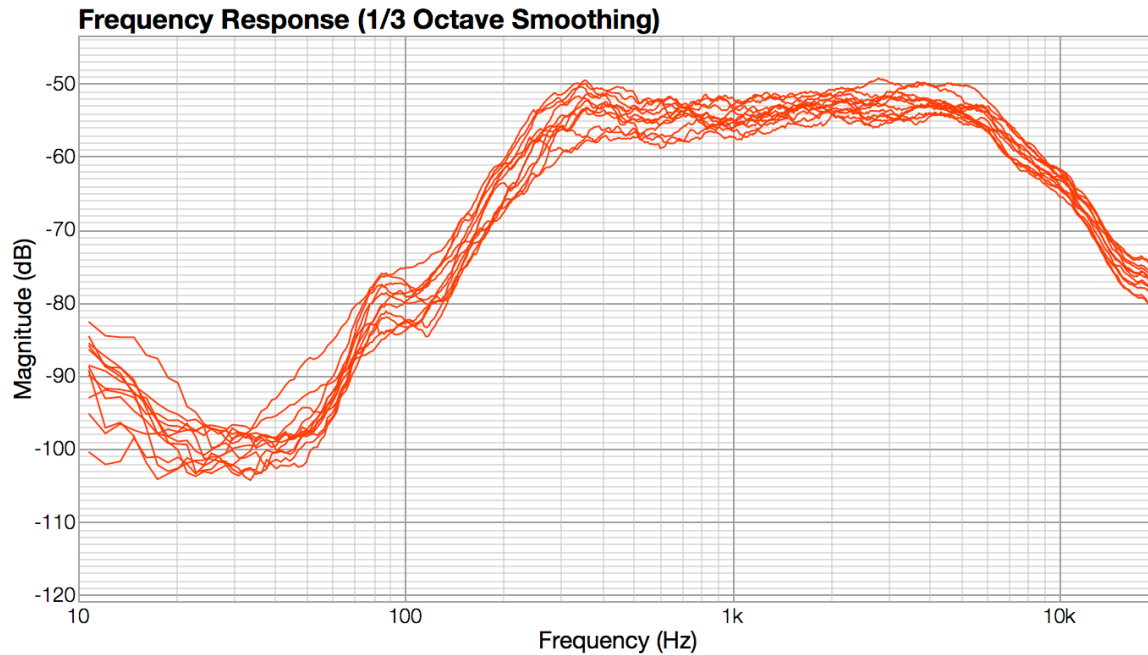


Figure 4.29: 1.5 meter elevation data results for Kiva D.

Allowing for a small amount of fuzziness and inaccuracy at the beginning and end of the tests, as well as a linear dip in frequency below 300 Hz that is probably caused by speaker interference (see 1.5 meter elevation data from Point 2 in Kiva C and Point 3 in Kiva D), this measurement gives us a look primarily at the ranges which would have been used most often by the people who used the Kivas. The range from about 15 Hz to about 2700 Hz is the most commonly used in human interaction, and includes most drum frequencies, all human voice frequencies, and all Native American flute and whistle frequencies (“Flute Keys” 2014:1, Berg 2014:12). Generally, Kivas C and D are very similar in their response, with similar frequency response curves. Within the parameters of human sound, both kivas seem to have soundscapes that emphasize higher frequencies.

Non-Quantitative Tests

Besides the sets of data accumulated from Kivas C and D, several less formal tests of various acoustic elements were performed, specifically finger-snapping at each point and both male and female vocal range tests. These supported the evidence of higher frequency response at higher frequencies. The finger-snapping indicated a slightly sharper impulse response at Kiva D Point 10 at about .75 meters from the floor, which was not reflected in the data from that point, but probably had something to do with functioning as a parabolic focal point for that corner of the kiva.

5. Analysis

As mentioned previously, the uses of kivas are widely debated. Theories range from purely ceremonial use to everyday living structures. Due to modern use of kivas by living descendants of similar nations, it is widely considered reasonable that kivas would have been used as some combination of the two. Since all functions of kivas would involve human vocal sound of some sort, be it speech, chant, or song, this analysis will focus on the significance of frequency response within the range of the human voice. This is not to say that other frequencies are irrelevant: on the contrary, they are very important. From a general analysis of the data presented in figures 4.10 and 4.27, the soundscape of both kivas is such that it would dampen low frequencies, such as drum frequencies, to the point where they would not have carried far beyond the walls of the kiva. Contrastingly, flute and whistle frequencies resonate very well, causing the kiva itself to become a sort of amplifier for these types of sounds. In a ceremony with both drums and flutes or whistles for example, the flutes and whistles would be far more pronounced and would be audible at much greater distances than the drums. While all of this is fascinating, anomalies in these registers large enough to indicate kiva use solely for ceremonies

or unique events are not present; neither kiva has frequencies that cause the entire structure to act as a resonating chamber because of a specific overtone series, like the Maes Howe Cairn Site (Murphy 2006:224-225). In this light, analyzing the frequency response of the kivas with respect to the human vocal range will give us the most useful insight into the daily usage of kivas by their human inhabitants.

Human Voice

Most human vocal activities fall between 65 and 1050 hertz (Arnold 2013:1, “Axiom Oddities” 2009:1). This includes speech, song, and chant, which would be the three major potential uses of voice in kivas. On a more specific level, male spoken language tends to fall between 65 and 155 hertz, while female spoken language falls between 165 and 255 hertz and a child’s spoken language typically falls above 250 hertz (“Axiom Oddities” 2009:1). Sung and chanted frequencies are divided around the 200 hertz mark, with male voices primarily between 65 and 200 hertz and female voices primarily between 200 and 1050 hertz, while children’s song and chant frequencies

remain very close to their speaking frequencies (Arnold 2013:1, “Axiom Oddities” 2009:1). Limiting the data to these ranges, we can see that there are several unique frequency response features in kivas

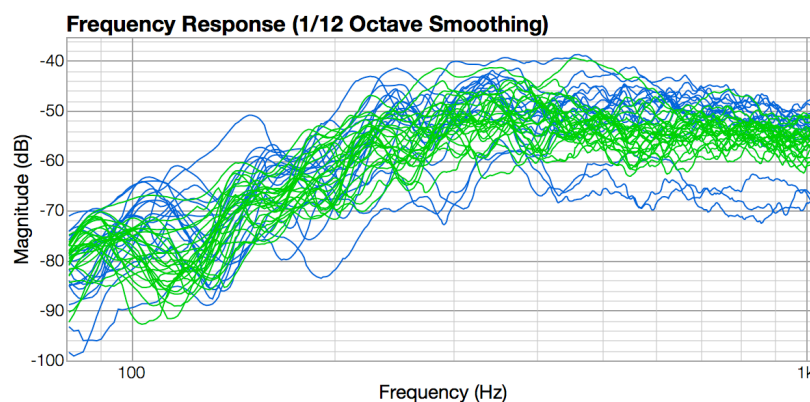


Figure 5.1: Kiva C (blue) and Kiva D (green) frequency response between 80 and 1050Hz, which includes almost all human voice activity. Note the decrease in response in both kivas just above 100Hz, the peak at around 350Hz, and the otherwise general increase in response corresponding to increase in frequency.

that could manifest themselves when human voices are used (see Figure 5.1). From on-site observation, both Kiva C and Kiva D had a dampening effect on male voice range frequencies, while both kivas had a clearer resonance at high female voice frequencies, with the resonance increasing in tandem with the frequency. This is reflected in the data collected; both kivas have a higher frequency response for upper voice frequencies (i.e. 200-1050Hz) than for lower voice frequencies (i.e.80-200Hz).

One of the more interesting results is the noticeable dampening in frequency response that occurs between 120 and 160 hertz in Kiva C and between 100 and 130 hertz in Kiva D (see Figures 5.2 and 5.3). For each point, the anomaly occurs in a slightly different place, but all are clearly within the low male voice range. There are downward dips in most of the tests, indicating less room response at those frequencies. This would produce a dampening effect for all frequencies in the mid range of male voice frequencies, causing male speech, singing, and chanting in those registers to be less clear or resonant within the kivas. Also, these frequencies would not have carried as far, and would likely have not projected far beyond the kiva itself.

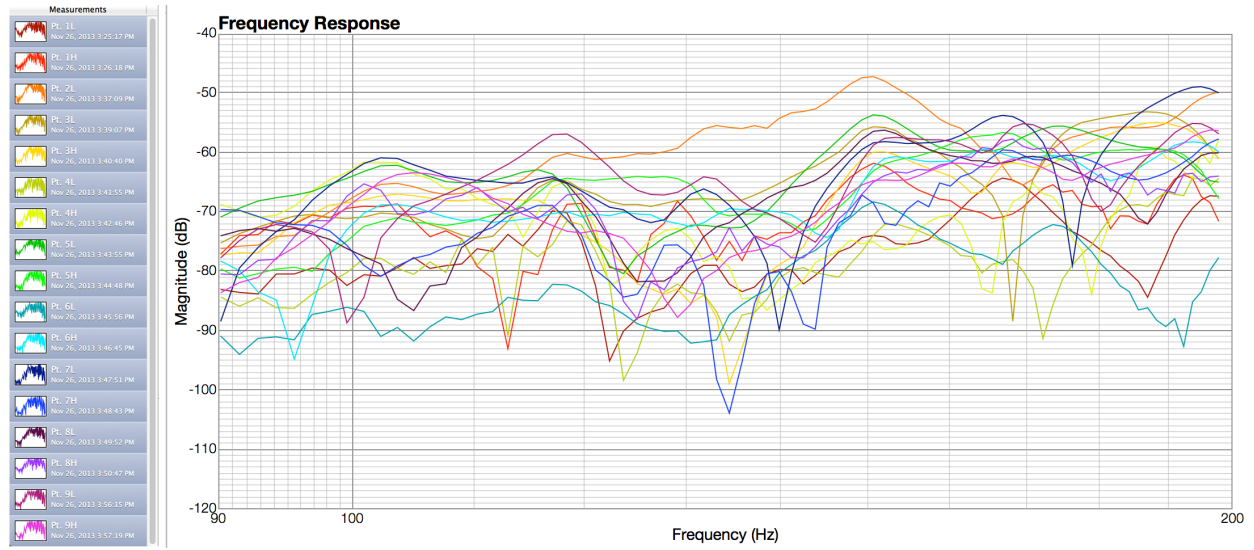


Figure 5.2: Kiva C frequency responses between 90 and 200 hertz, which includes an anomalous dip in frequency for most tests around 120-160 hertz.

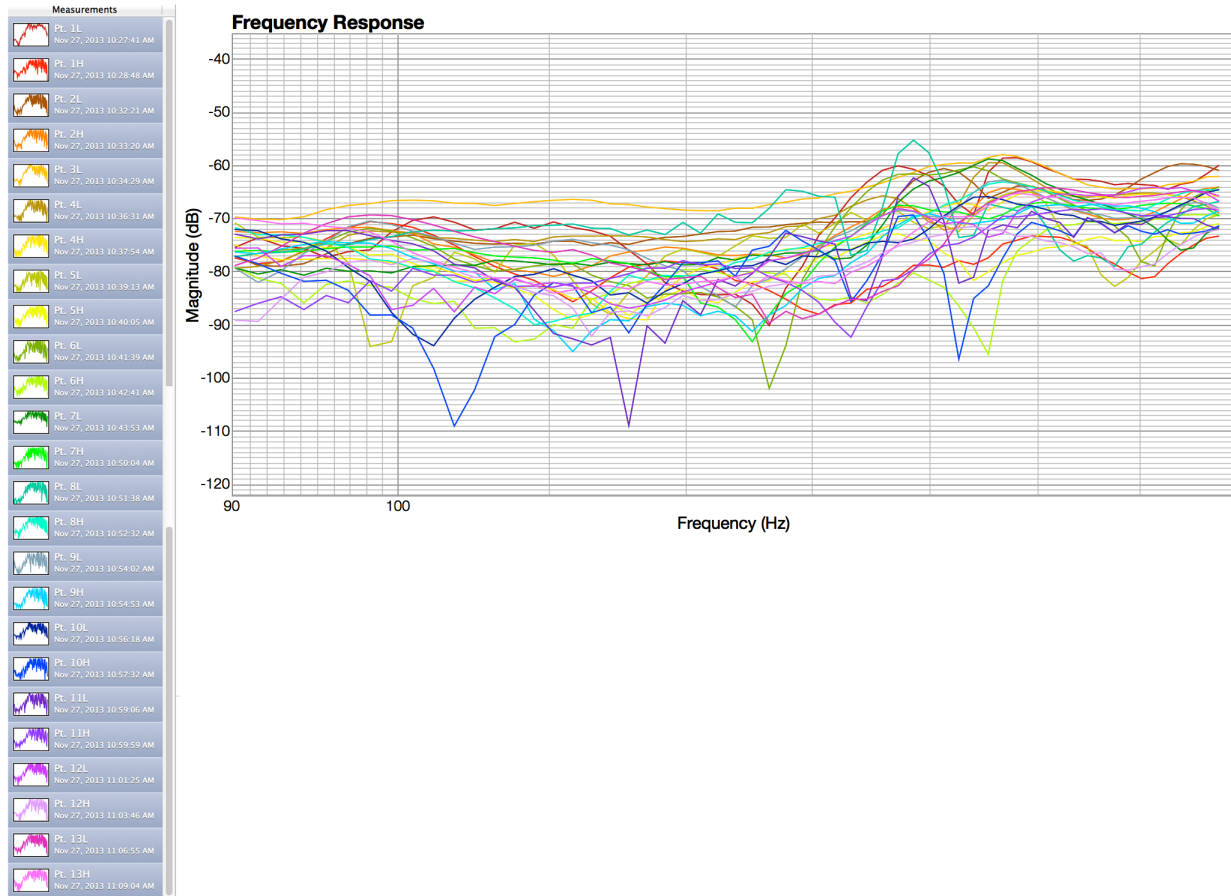


Figure 5.3: Kiva D frequency responses between 90 and 170 hertz, which includes anomalous dips in frequency response for most tests around 100-130 hertz.

A more specific anomaly occurs between 130 and 150 hertz in Kiva D, where there is a clear dip and spike in the frequency response recorded at floor level elevation at points 8 and 11 and 1.5 meter elevation at point 10, as well as lesser dips and spikes at similar frequencies

observed in the Point
1 and Point 2 floor
level tests (see Figure
5.4). All of these
points are in the

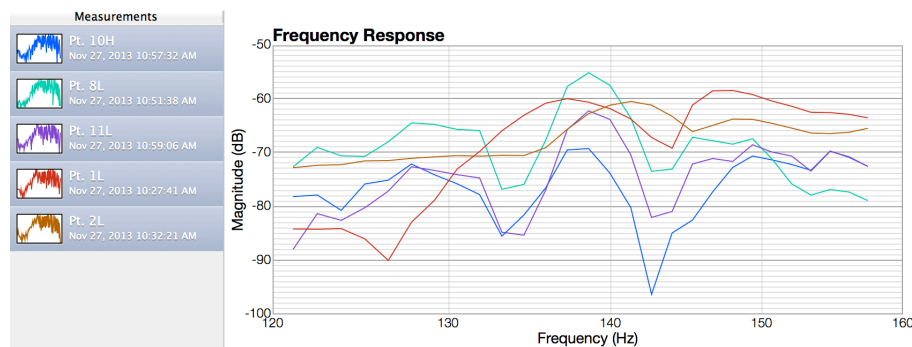


Figure 5.4: Data points 10 High, 8 Low, and 11 Low in Kiva D all exhibit a clear dip-spike-dip in their frequency response between 130Hz and 150 Hz. Points 1 Low and 2 Low exhibit similar but less pronounced trends.

northern half of the
Kiva, suggesting
that the north half

has a unique frequency response within male voice range, possibly a slightly higher resonance in this specific frequency. Generally, however, male voice ranges throughout the kiva are dampened, probably being absorbed by the wall, floor and ceiling materials.

On the other hand, the frequencies of female voice, children's voices, and male falsetto voices are highlighted within both kivas consistently. The frequency response continues to increase in magnitude until around 300 hertz, after which it gradually decreases slightly between 300 and 1050 hertz (see Figure 5.1). Female speech, singing, and chant frequencies fall into this area. Observations while at the site confirm that this leads to a noticeably higher resonance of female voice frequencies, particularly those from around 300 hertz to around 800 hertz. This acoustic characteristic was present in both kivas, and would lead to female, child, and male falsetto voices carrying much better within each structure than their low male counterparts.

The female registers do not seem to have any sharp delineations in frequency response like the drop in lower frequencies. However, the highest frequency response in Kiva C between 200 and 1050 hertz occurs between 330 hertz and 370 hertz, which is also the point at which the

frequency responses converge to have the least variation and deviation from the average response (see Figure 4.10, and compare to Figure 5.5 for more detail).

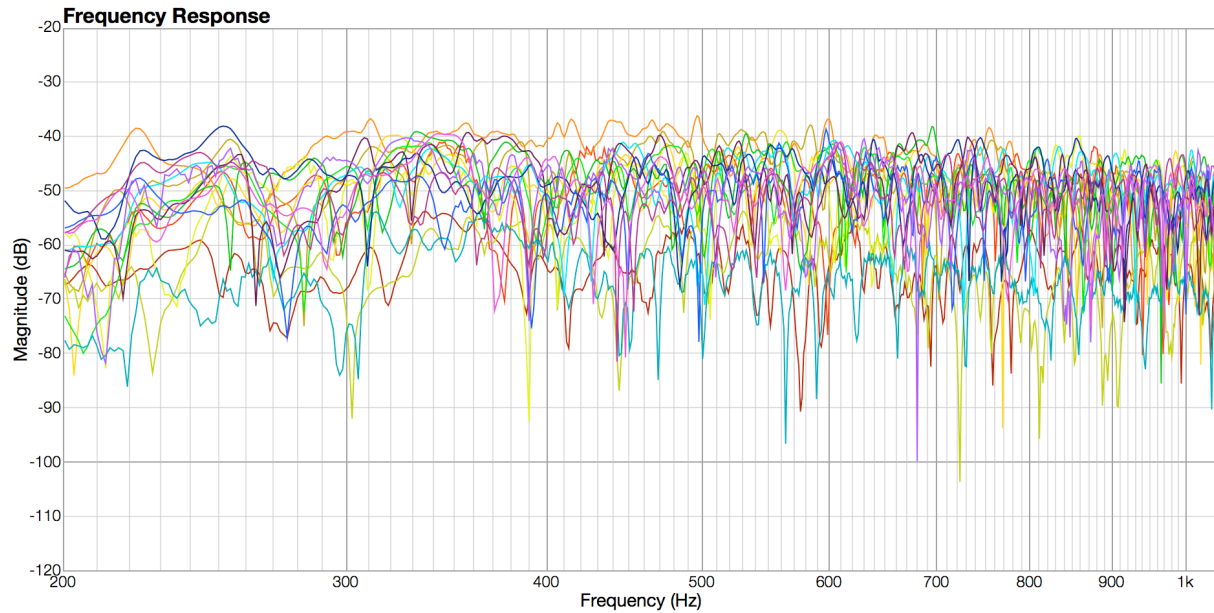


Figure 5.5: Kiva C frequency responses from 200 to 1050 hertz. A convergence of responses occurs between 330 hertz and 370 hertz, which is also the point of greatest resonance.

This suggests that Kiva C has a point of strong harmonic resonance in this area, which is in average range of a soprano female or child range of vocal sound. A similar but less pronounced convergence presents itself in Kiva D, but between 350 Hz and 390 Hz, which is roughly the same register, tending more toward child voice registers (see Figure 4.27, and compare to Figure 5.6 for more detail).

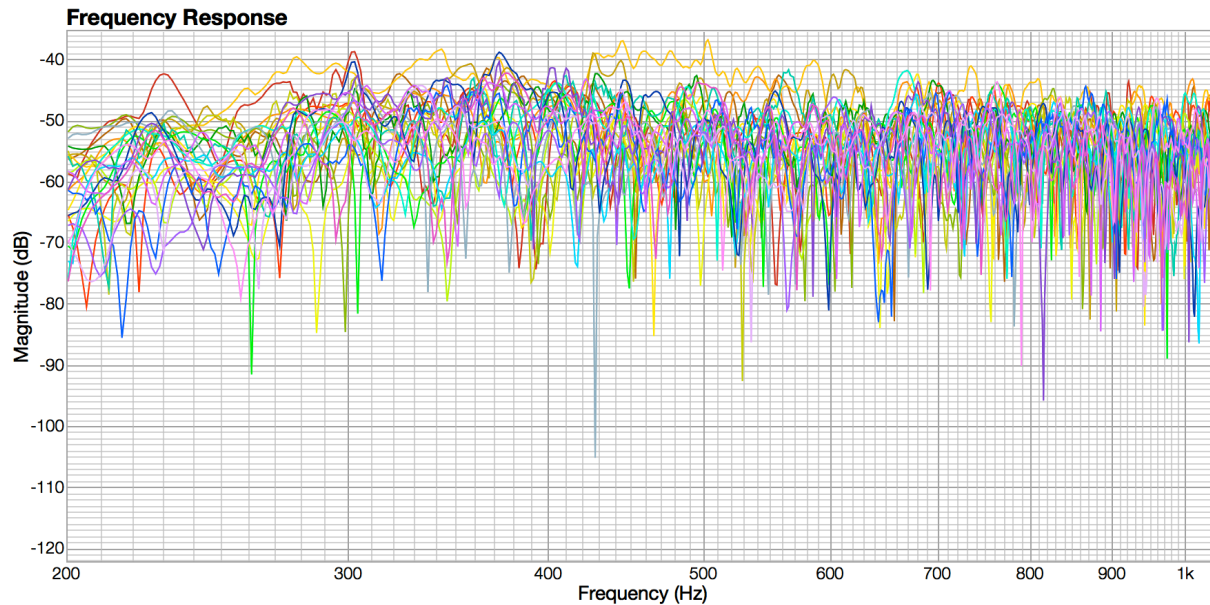


Figure 5.6: Kiva D frequency responses from 200 to 1050 hertz. A convergence of responses occurs between 350 hertz and 390 hertz, which is also the point of greatest resonance.

Kiva D's most resonant frequency response is not quite as clearly marked, probably because of the increased acoustic interference in this Kiva due to the passageways on the Southwest side.

Nevertheless, the greatest frequency response occurs between 350 Hz and 390 Hz, as can be seen clearly in Figure 4.27. This means that the easiest voices to hear in both structures are children's voices and high female voices, while male voices are muted.

6. Conclusions

While no grand, sweeping conclusions can be drawn from this data, the facts presented augment our understanding of kiva usage and might be used as evidence for or against certain theories. For example, using kivas as loud male chanting centers with drumming that is supposed to be heard by the entire city is a highly unlikely and improbable use, based on the fact that drum sounds and low male voice frequencies simply wouldn't carry far enough. On the other hand, the ability to hear children's voices quite clearly within the kiva and the surrounding area, as well as

the high shelves to put items beyond the reach of children would have made the kiva a great place to leave young children to play while working nearby. Also, the dampening of male voice frequencies could have lent the kiva a very hushed and secretive atmosphere during all-male gatherings. In this way, archaeoacoustic analysis can augment other data and disagree with or affirm various theories.

For example, Jeannette Mobley-Tanaka published research in 1997 showing a correlation between kivas and mealing rooms (Mobley-Tanaka 1997:442-445). Based on the coordination of mealing rooms with kivas, it is possible that women working in the mealing rooms would have been able to hear some of what was going on in the kiva, particularly high frequencies. During long male rituals, a high-pitched noise made by men in the kiva could have indicated that they were ready for food, or that some other part of the ritual was now to be performed. Alternatively, the women's work might have become part of the ritual sounds, if the grinding of mano against metate was rhythmic and carried into the kiva.

Kiva passageways, like those present in Kiva D, present a different acoustic feature. Anyone standing in an aboveground room that contained a passageway to a kiva would be able to hear whatever was happening in the kiva. Since many of these passageways are so small as to make the passage of a human nearly impossible, acoustics is a potential explanation for their existence. If the emergence of a group from the kiva needed to be synchronized with something happening above ground, the passageways could be used to keep track of how the ceremony was progressing. In any case, kivas with more passageways would have been less secretive than those with fewer or no passageways, which could have led to different kivas having different uses.

One of the many uses of modern kivas is to teach the dance steps for matachines. This teaching is a ritual that is limited to males, and is highly secretive. While the matachines are a post-colonial idea, the association of kivas with secrecy may not be (Romero 1989:153-160). The natural dampening of male frequencies in kivas could have led to their use in multiple secret male ceremonies and traditions, because those outside the kiva would have been primarily unable to hear what was happening within. While more data is necessary to firmly affirm or deny this or any theory, the trends begin to align and make a stronger case for some theories.

These and many other scenarios are ways in which the sound-based elements of the kiva environment may have affected kiva use. It is unlikely that the ancient Anasazi calculated the acoustic implications of kivas before they were built, and acoustic considerations were almost certainly not the primary reason for building kivas. Nevertheless, the acoustics of the kivas would have made certain uses far more obvious than others, and would have helped to define the day-to-day use of kivas. The human experience is inherently multi-sensory; by studying how sound, sight, and other senses interact to form perceptions of an environment, we can learn more about how the people who created and lived in that environment perceived the world around them. Archaeoacoustics allows us to get another glimpse into the lives of the distant past by adding perceptions of sound to a predominantly visual field of study.

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