A Case Study on Small Room Acoustics

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ABSTRACT

This paper details an acoustic review of a small live performance space, as well as the production of a document to be presented to the owners of the space so that they may identify the best ways to improve the sound. The data considered comes from a series of measurements taken with SMAART software, and is interpreted in the context of the design of the room. Due to the large boost detected in the ~350 Hz range, a series of bass attenuation devices are recommended as the first step.

1. INTRODUCTION

CFUV 101.9 FM, the University of Victoria's campus and community radio station, has a number of studios within its leased broadcasting space. The station produces a weekly concert series that is broadcast live to an audience of a few thousand listeners. The performances are produced within CFUV's studio space, in a room referred to as the "Basement Closet". This room was not built to function as a studio, and as such, has various acoustic deficiencies that can detrimentally affect the recordings and broadcasts.

2. ROOM CHARACTERISTICS

As depicted in Figure 1, the "Basement Closet" is a small room in the basement of the UVIC student union building. There are two large windows in the space: one leading next door to the broadcast studio and the other leading to a large foyer in the building. The walls in the room are standard drywall, and there are two metal doors, one which leads into a smaller closet and one which leads into the hallway outside. The floor is carpeted and the ceiling is dropped, taking away 15 inches from the total height of the space. On the walls are a collection of dampening panels installed previously to improve the sound of the space. These panels are made of basic acoustic foam and are installed in corners and wherever else they fit. Opinions on the sound of the room vary significantly amongst groups that have performed in the space. Interestingly (though not surprisingly) these opinions seem to be somewhat correlated to the genre of the group performing (e.g. garage rock groups seem to have an indifferent or positive impression of the room sound, while singer songwriter types tend to be less appreciative).

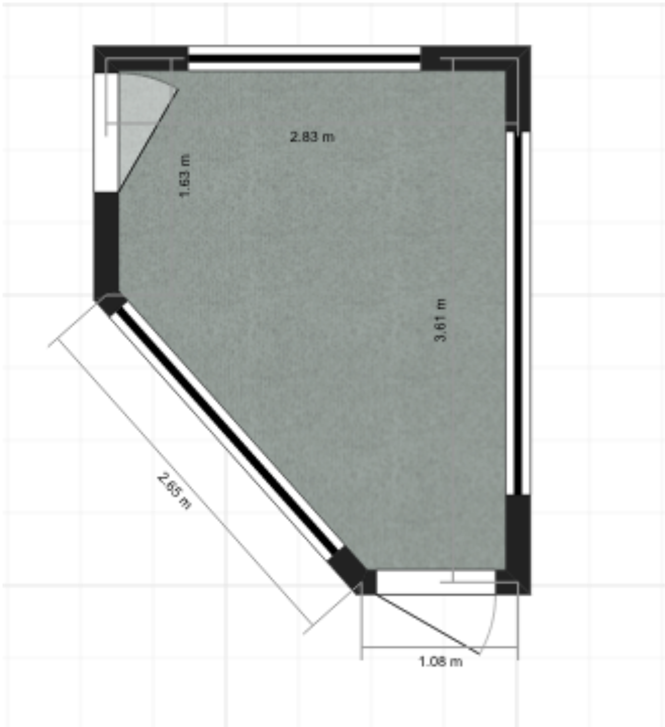


Figure 1. A simple blueprint of the Basement Closet showing dimensions and window/door placement.

3. THE SOUND OF A ROOM

3.1. Variables

When discussing room sound, the most recognizable measure is the T_{60}. This metric acts as a composite of other metrics by simplifying the components of reverb into a decay time in seconds; it can be thought of as the final result of reverb. Interestingly, the T_{60} is the most used metric for judging the similarity in sound between two rooms (Zahorik). However, there are many other important variables that account for the sound of a room. The initial time delay gap, also known as "pre-delay", is the amount of time after the direct sound reaches the listener before the first reflections hit. If this time is greater than 35 ms, the perceived size of the room can drastically increase and the sound becomes more disjointed. The quantity and distribution of early reflections within 100 ms of the direct sound is another important variable, as it is largely responsible for the "texture" of a space. These early reflections contribute not only to the distribution of acoustic energy, but also to the Apparent Source Width perceived by the listener (Berenak). However, because the Basement Closet is so small the progression of the sound is compacted and these variables are less relevant. For such small rooms, their resonant frequencies or "room modes" are the defining factor. These modes exist as a function of the dimensions of the room. Axial modes, caused by parallel walls, create the strongest resonances and thus are the most undesirable.(Tangential and oblique modes, though present, are usually not the focus of attenuation efforts due to their low amplitude and higher frequencies).

3.2. Measurement Techniques

For each variable associated with room sound, there is at least one corresponding method for measuring it. However, because most of the reverb variables are unimportant in a room as small as the Basement Closet, I chose to focus my attention on three measurements afforded by the Smaart software: a spectrum snapshot, transfer function, and impulse response. The spectrum snapshot shows the spectrum of the mic input at a point in time. This measure was useful for comparing the differences in frequency content in different parts of the room. The transfer function is a characterization of the room as a system. Essentially, it outputs a graph of the difference between the output from the speaker and the input from the mic, highlighting which frequencies are boosted and cut. The impulse response shows how the sound decays in the room.

4. SOUND MITIGATION

The cause of most unwanted reverberation is the presence of room modes. Though a number of options are available to the architect to improve room acoustics while building, there are limited solutions once the construction has finished (Cox 2004).

4.1. Absorption

Objects like carpet, acoustic foam, and even full bookcases are often used in amateur settings to help absorb unwanted sound in a room. When sound waves come into contact with an absorptive material they lose some of their energy trying to vibrate the soft and flexible surface. The amplitude of the corresponding reflection is a function of both the energy of the wave and the absorption coefficient of the material they hit (Everest). The effectiveness of objects like drapes and carpets is determined by the absorption coefficient of the boundary they are in front of, as well as the frequencies they are being utilized for (they are typically an effective choice for higher frequencies) (Cox 2005). An extreme example of absorption is an anechoic chamber: a room designed to completely absorb all acoustic energy before any reflections can take place. However, this situation is not ideal for performance or music recording: as John Cage learned after hearing distinct sounds in Harvard's chamber, "The high one was your nervous system in operation. The low one was your blood in circulation." (Cage).

4.2. Diffusion

To obtain an ideal room sound, a combination of absorption and diffusion is often used. Instead of eliminating the sound, diffusers break up the energy and diffuse the wave fronts into many smaller (and less powerful) fronts. This keeps the room "sound" while mitigating the build up of undesirable room modes. Some diffusers simply deflect energy, while others capture the energy in a "well" and introduce phase changes. However, passive diffusers are limited by the depth of their well as the well depth must be significant compared the the wavelength of the frequency they are meant to attenuate. This becomes unreasonable for lower frequencies where an effective diffuser would stick out 2 meters from the wall. However, diffusers are very useful for keeping desirable high frequency content in the room without strong resonance.

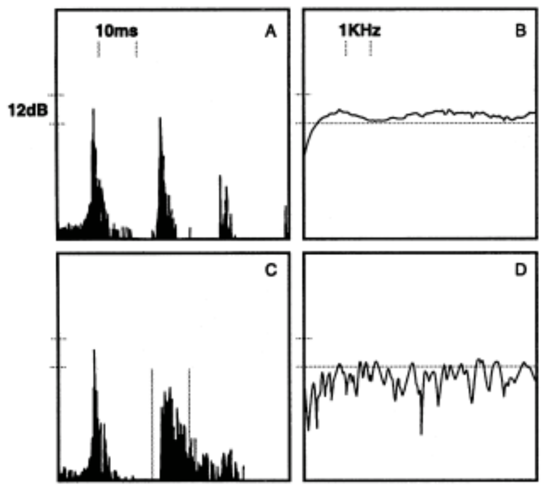


Figure 2. Time and frequency response of a flat reflector (top) and diffusor (bottom) (D'Antonio).

5. TECHNIQUE

To get the information most relevant to the scenario at CFUV, I chose to focus on the transfer function as my main metric. This is the ideal metric for this application because it clearly shows the impact of the room on the final sound's frequency content. However, information gleaned by a frequency response and impulse response is still significant (Frey), so those measurements were taken as well.

All three measurements were made separately with Schoeps omni and cardioid microphones, and the input signal was given by a Mackie HR824 active monitor speaker. For each measurement, the speaker was placed as shown in figure 3 and each microphone position shown was used (In the end, mic position did not significantly affect anything but the first frequency spectrum test so the central mic position tests are the ones shown in the results).

The input signal used for the transfer function and spectrum snapshot was pseudo-random pink noise. The signal output was driven by the Smaart software on a Macbook going through a DigiDesign-3 audio interface. The signal was looped back into input 2 as a control signal against which to compare the mic input. The signal used for the impulse response was a series of 8 fast pink noise sweeps. These 8 sweeps were averaged to give the final response.

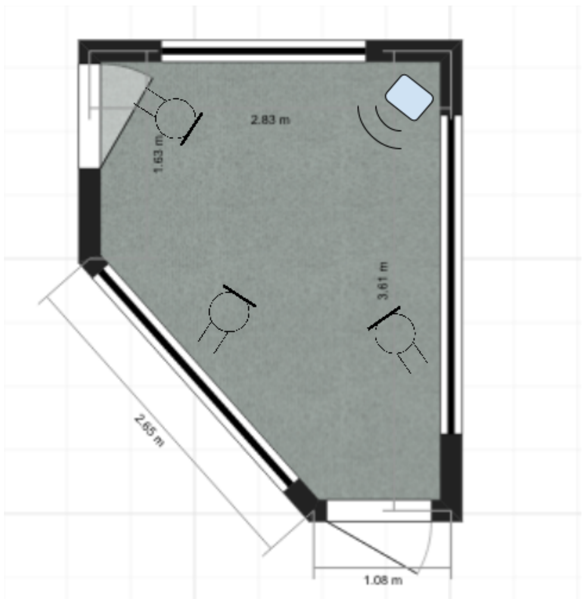


Figure 3. Position of speaker and microphones in room layout.

Both of the microphones had positive and negative attributes with regards to the measurements. Despite the omni pickup shape seeming like the better option because of it's more uniform pickup of the room, it had much lower levels of coherence than the cardioid did (suggesting that the results from the omni were potentially less reliable). After comparing the frequency responses for both microphones (Figure 4) it was apparent that the omni would be less biased, even if the data was somewhat less reliable.

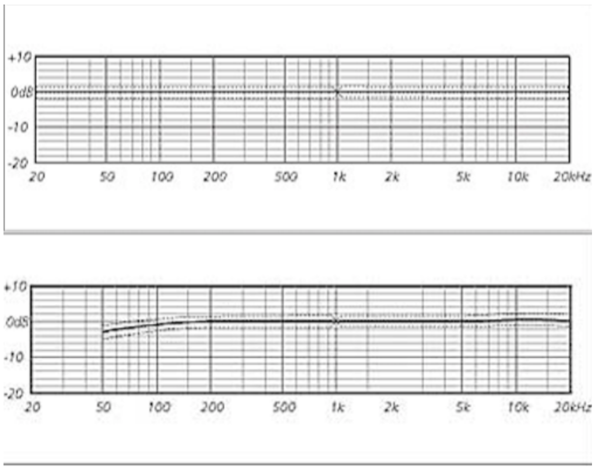
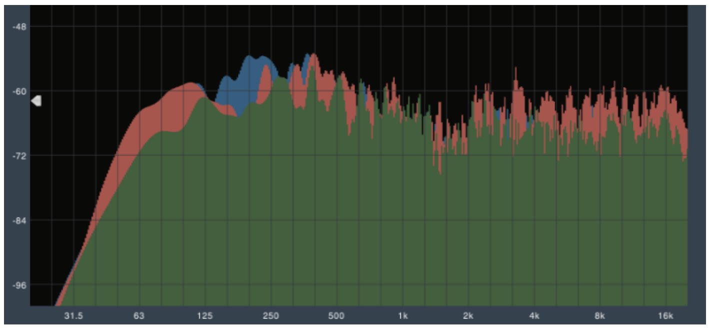


Figure 4. Frequency response of Schoeps MK2 omni (above) and MK4 cardioid (below).

6. RESULTS

The spectrum snapshot in figure 5 with the three mic positions overlaid shows relative cohesion between most of the frequency content in the different locations. However, there are serious discrepancies between the microphones in the 125-350 Hz range, with the microphone closets to the bottom door having the biggest spike.

Figure 5. Spectrum snapshot. Middle mic is red, left of



speaker is blue, and right of speaker is green.

The impulse response in figure 6 shows a T_{60} of .227 seconds with an early decay time of .118 seconds.

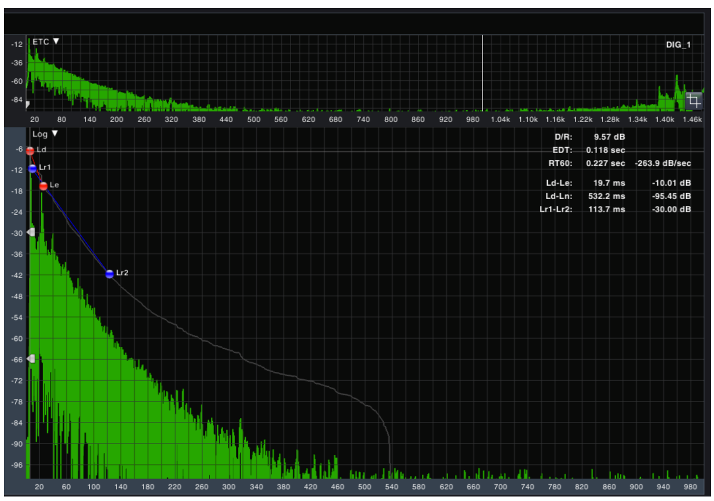


Figure 6. Impulse response measured in the Basement Closet.

The transfer function taken with the omni microphone, shown on the following page in figure 7, provides the most relevant information about the room's sound. It shows a distinct bass boost around 350 Hz that gradually fades to 0 at 200 Hz on the low end and at 600 Hz on the higher end. It also shows a wideband, deep cut between 600 and 8k Hz that drops below -9dB at its lowest. A comparison between the cardioid and omni results is shown in figure 8.

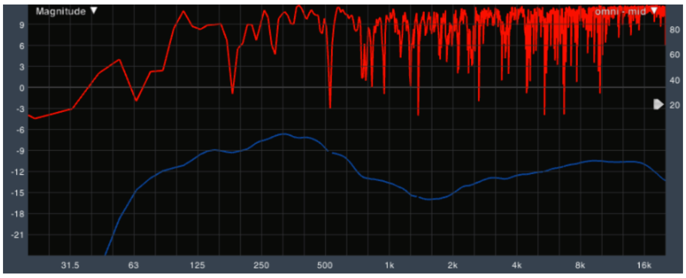


Figure 7. Transfer function taken with omni microphone. Octave smoothing is used for magnitude.

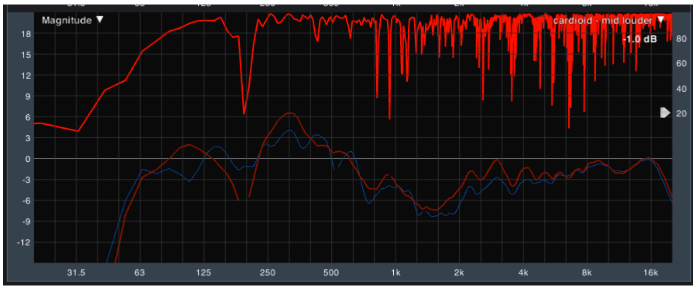


Figure 8. Overlay of cardioid and omni transfer function results. 1/3 octave smoothing is used to illustrate discrepancies.

7. ANALYSIS

The results from the measurements present a main concern of the ~350 Hz boost. Although the cut in the vocal range is significant, bringing it back up would likely be harder and less noticeable then attenuating the bass. The boost, with a wavelength of just under 1 meter, corresponds to the second overtone of the fundamental formed between the two sets of parallel surfaces (ceiling/floor and left/right wall). At 2.8 meters, the fundamental axial mode is ~120 Hz. In figure 8 above, the boosts at the both frequencies are apparent. Interestingly, the omni spectrum shows a cut at 120 Hz while the cardioid shows a spike; I assume this is due to some change in microphone position between the two. Because the axial modes are the same on two axes, the buildup is much louder. Due to the space limitations in the room, the most practical response would be to install bass traps in the corners above the hanging ceiling. In addition to being a calculated way to improve the sound, it would have the added bonus of being out of sight. Another inexpensive solution would be to cover the large window on the right wall with drapes during performances. This could have a noticeable effect on bringing down the bass boost associated with the right/left mode, but it could contribute to a deeper cut of the mid range. The windows probably absorb the high frequencies that hit them to some extent but could resonate together with the low end, contributing to the 350 Hz boost (Szymanski).

To bring back some of the mid range sound that is cut in the room, some of the many absorption panels could be replaced with Schroeder diffusers to instead scatter the energy (D'Antonio). A coherent list of options and their cost effectiveness is included in the attached letter to the station manager.

8. FUTURE WORK

The Basement Closet could benefit from a more thorough analysis of it's acoustic properties. However, CFUV's status as a non-profit broadcast space implies that it will not have serious funding to put into investigating and improving the acoustics of the room. The upside of this position is that it gives future students a place to hone their skills in a low risk environment. Because CFUV is unlikely to pay for acoustic analysis and treatment, they could benefit from any free services provided. Likewise, most students will not have experience in this realm and could practice their skills while provided the station with a useful service free of charge.

The first step for future work is to identify acoustic variables in the room and attribute components of the sound to features of the room. This could be done by manipulating attenuators/absorbers in the room and taking a new series of measurements. A correlation between aspects of the room and the room's frequency content could be helpful in guiding future design and recording decisions. Additionally, a new series of measurements with attenuators in place would quantify the value of the absorbers and diffusers. A full model of the space complete with absorption coefficients would be ideal and could help serve as an ongoing case study for different attenuation approaches.

9. REFERENCES

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