BACHELOR THESIS

Assessing Acoustic Issues and Electrical Interference in Breda University’s XR Stage

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Abstract

This research investigates the acoustic challenges and electrical interference issues encountered in the Extended Reality (XR) stage at Breda University of Applied Sciences (BUas). XR technology, which encompasses Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), has significantly transformed content production and experience in fields such as entertainment and education. The BUas XR stage, maintained by the Cradle research and development lab, features advanced equipment, including a curved LED volume wall and ceiling, controlled by a brainbar. Despite these state-of-the-art facilities, audio recording during production has faced several issues, particularly with background noise, sound reflections, and electromagnetic interference from the LED setup. This study aims to identify and analyze these audio problems, drawing on examples from BUas and industry case studies, to develop comprehensive guidelines for achieving optimal sound quality in immersive production environments. The findings highlight the need for improved soundproofing, proper microphone techniques, and regular equipment maintenance to mitigate the identified issues and enhance the overall audio recording quality in XR stages.

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List of Abbreviations

XR Extended Reality
Extended Reality is an umbrella term encompassing Augmented Reality, Virtual Reality, and Mixed Reality, combining real and virtual environments to create immersive experiences.

VR Virtual Reality
Virtual Reality is a technology that creates a fully immersive, computer-generated environment, allowing users to interact with and experience a simulated world as if they were actually there.

AR Augmented Reality
Augmented Reality is a technology that overlays digital information and virtual objects onto the real world, enhancing the users perception and interaction with their environment.

MR Mixed Reality
Mixed Reality is a technology that blends real and virtual worlds, allowing physical and digital objects to interact in real-time, creating new environments where both can coexist and interact seamlessly.

VP Virtual Production
Virtual Production is a filmmaking method that combines virtual and augmented reality with computer-generated imagery (CGI) and game-engine technologies to enable filmmakers to visualize and modify scenes in real-time during the production process.

CGI Computer Generated Imagery
Computer-Generated Imagery is the creation of still or animated visual content using computer software for use in films, television, video games, and other forms of media.

ADR Automated Dialogue Replacement
A postproduction technique where audio is re-recorded in a controlled, quiet environment, typically within a studio setting.

BUas Breda University of Applied Sciences

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1.0 Introduction

Extended Reality, XR, is an umbrella term that refers to a range of immersive technologies, including Augmented Reality, AR, Virtual Reality, VR, and Mixed Reality, MR (What Is Extended Reality (XR)?, 2024). These technologies have transformed how content is produced and experienced, especially in entertainment and education. A Virtual Production, VP, studio is a prime example of the latest innovation in XR technology.
At Breda University of Applied Sciences (Breda University of Applied Sciences | BUas.nl, n.d.), BUas, a VP studio is available. The studio features a curved LED volume wall that is 16 modules wide and seven modules high according to de Groot, the senior programmer who operates this stage, accompanied by an LED ceiling. This setup is controlled by the brainbar as seen on the right of figure 1.1, a set of computers digitally controlling the LED screens, the environment and more, allowing filmmakers to create dynamic environments, with real-time game engines enabling rapid transitions from one setting to another. For actors and production teams, this offers unprecedented flexibility and immersive experiences.

Figure 1.1 XR stage BUas
(State of the Art of Virtual Production in the Netherlands | Buas Content Hubs | BUas Games, n.d.)

The XR stage at BUas is maintained by Cradle (Cradle – Cradle Is the Knowledge Centre Within the Domain of Media and Games With a Focus on Digitally Enhanced Realities (DER) and in Which the Three ADE Research Lines Are Present, n.d.), a research and development lab within the academy of AI, Games and Media. Aside from developing tools for the XR stage Cradle works on various VP projects which are often connected to research in VR, AR, XR, AI and more. The responsibilities of the author within this team encompass the roles of audio recordist and audio editor.

Cradle plays a crucial role in maintaining and advancing the technology within the studio. Despite the state-of-the-art equipment, the studio has encountered several issues with audio recording. Which was most noticeable during a project recorded and edited by the by the researcher of this project. The process of attaching the lavalier microphone is shown in figure 1.2. Because of the large number of people participating in this project in front of the camera, the set was forced to be closer to the back LED volume in order to fit everyone. On figure 1.2 and 1.3 there are 14 participants visible, this was only a small portion of the final group. Whilst recording the audio in the front area there were already several problems arising, most noticeable, the background noise. When the microphone eventually moved to the back of the stage, different problems came to light that were not known before. These issues ranged from hollow spots, where sound reflections cause uneven audio, to electrical interference that produces undesirable noise or distortion.

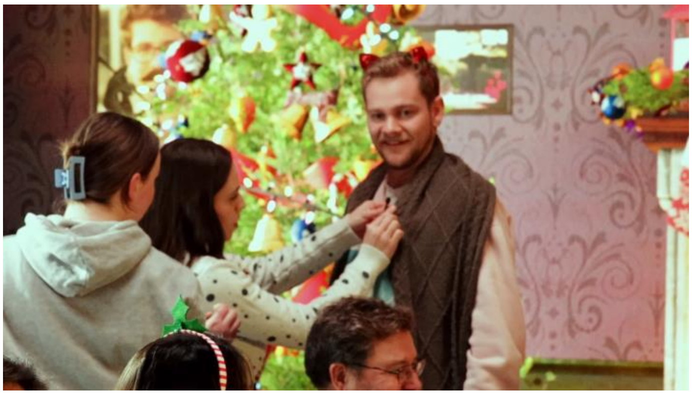


figure 1.2 Still shot, Cradle Christmas shoot BTS. https://www.youtube.com/watch?v=rcLfnBPSk9E (Cradle ADE, 2023).

figure 1.3 Still shot, Cradle Christmas shoot BTS. https://www.youtube.com/watch?v=rcLfnBPSk9E (Cradle ADE, 2023).

These problems do not only occur at BUas XR stage.
As the production sound mixer of The Mandalorian, Shawn Holden, explained(The Sound of the Mandalorian: Rising to the Star Wars Standard | Sonos Blog, n.d.).
The reflective surfaces created by the LED walls and ceiling can lead to complex acoustic conditions, resulting in echoes, reverb, and other distortions. These acoustic artifacts can affect the clarity of audio recordings and complicate post-production processes.
Additionally, the high electrical demands of the LED setup can create electromagnetic interference, potentially causing buzzing, signal loss, or other audio issues. These challenges call for a deeper examination of the XR studio's environment to understand and lessen the factors that impact audio quality.

Given these challenges, this study aims to explore and address the specific factors affecting audio quality in the XR studio at BUas. By investigating the unique acoustic characteristics of the space and analysing the sources of electrical interference. With the aim of establishing clear guidelines for optimal audio recording. The goal is to improve the quality of audio in immersive production environments, ensuring that the final output meets industry standards and provides a seamless experience for audiences.

Through this research, the aim is to make clear guidelines for the audio challenges faced in the BUas XR stage, and support future productions of Cradle. To answer the question ´´How can Breda University's XR stage effectively address challenges in audio recording to establish comprehensive guidelines for achieving optimal sound quality in immersive production environments?´´.
Developing comprehensive guidelines for optimal audio recording will contribute to the broader field of virtual production. The results of this study will also guide future developments in XR technology, helping to refine production practices and enhance the overall quality of immersive experiences. This study will give future productions done by Cradle and students attending the XR production house course a clear understanding of the acoustics of the VP studio. This will help with microphone placement and help avoid potential problems in post-production.

2.0 Literature review

This literature review examines existing research on addressing acoustic issues and electrical interference in Breda University's XR Stage. It reviews various studies, theories, and ideas to establish the current state of knowledge and identify unresolved questions. This review provides essential context and underscores the significance of this research.

2.1 The Basics of Virtual Production

Li et al. (2022) explains that VP merges VR and AR with computer-generated imagery, CGI, and game-engine technologies, allowing film crews to see their scenes come to life as they are composed and filmed on set. Virtual Production, VP, is a filmmaking technique that uses computer-aided production and visualization. First officially utilized in 2009s 'Avatar,' directed by James Cameron (Avatar (2009) ⭐ 7.9 | Action, Adventure, Fantasy, 2009). A decade later, Jon Favreau used it for 'The Lion King' in 2019 (The Lion King (2019) ⭐ 6.8 | Animation, Adventure, Drama, 2019). VP is powered by Unreal Engine, a game engine made by Epic Games (The Most Powerful Real-time 3D Creation Tool, n.d.). As written by Epic (2023) Unreal Engine is used to create a virtual version of the set which will be used inside of the game engine. The digital version will be visible on the LED walls for the actors, using performance capture technology whilst acting out the scene together with a virtual camera to change angles at any time.

2.2 Incorporation of Audio within Established Virtual Productions

The Mandalorian, a Lucasfilm production.

Figure 2.1 (TechCrunch Is Part of the Yahoo Family of Brands, 2020)

One of the biggest series using a Virtual Production set is the Mandalorian (The Mandalorian &Bull; Lucasfilm, 2024).
As seen in (figure 2.1). The LED volume used whilst shooting the Mandalorian is made by Industrial Light & Magic, ILM, it is ‘’ in an immersive and massive 20’ high by 270-degree

semicircular LED video wall and ceiling with a 75’-diameter performance space, where the practical set pieces were combined with digital extensions on the screens.’’ (Ggrusby, 2023). Shawn Holden, production sound mixer and Matthew Wood, supervising sound editor on the Mandalorian set, stated their audio production process and problems in an interview with Sonos (Sonos: Save 20% on Ray, Beam, Sub Mini, Move 2, & Roam SL, n.d.-b). During the interview with Saftig (n.d.) Holden stated that the LED Volume used was daunting and caused a lot of reverberation. Whilst figuring out how to work around the reverb they decided to call in some help from an acoustical engineer. This engineer made screens that do not absorb nor reflect the audio to lose the reverberation of the LED volume.

Another example of a production that used a LED volume *is How to Be Good.* A short film project in the Stockwell Street Studios at the University of Greenwich in London (Nelson-Tabor, 2022)

According to Nelson-Tabor (2022) in traditional filmmaking, a sound designer typically begins their work in pre-production, collaborating with the writer and director to envision how scenes will both look and sound in the final cut. This process involves analysing the script and developing sound concepts based on the imagined settings and actions. However, in modern VP environments, such as those utilizing Unreal Engine for pre-visualization (pre-viz), the exact look and feel of locations are often already established.

This pre-viz serves as an ideal reference point for sound designers, enabling them to start recording and creating essential sound design assets even before shooting begins. By having access to detailed visual representations of the scenes, sound designers can tailor their work more precisely to match the envisioned final cut, streamlining the integration of sound elements and enhancing the overall production quality.

2.3 Audio Issues During Recording at an XR Stage.

Whilst recording audio different types of issues can occur. Artifacts from echoes in the room and background noise can distort recordings. Echoes are influenced by the room shape and materials, blurring both timing and frequency in the sound. Meanwhile, background noise is affected by other sounds present in the recording (Audio Recording Location Identification Using Acoustic Environment Signature, 2013).

There are many common audio issues to consider when recording. Of which some are more frequently occurring during recording at an XR stage environment. The issues explained in this section relate to known problems at the BUas XR studio. For instance, one recording of the production mentioned in the introduction exhibited an excessively bass-heavy sound during editing, whereas other recordings did not display this issue. Additionally, some recordings contained more pronounced echoes and reverberations, which affected the overall audio clarity. Furthermore, the use of handheld microphones frequently resulted in the occurrence of harsh squealing noises, likely due to feedback issues.

The common issues when recording at BUas XR stage are the following:

Amplified Bass Sounds
This issue occurs when low frequency sounds are picked up and amplified by the recorder, also known as the proximity effect. (Audio Solutions Question of the Week: What Is Proximity Effect? | Audio-Technica, n.d.).

The proximity effect impacts the frequency response of directional microphones. Starting just a few inches from the sound source, you will notice the bass response increase as you bring the microphone closer. This effect can be useful or problematic, depending on how it is managed. A singer can achieve a deep, rich tone by singing very close to the mic, and then switch to a more piercing sound by moving the mic farther away while singing louder. This kind of technique requires practice but can be very effective. However, if a performer moves the mic in and out while singing at a consistent volume without intending for special effects, it can lead to issues with tonal balance and fluctuations in overall volume. Some performers prefer to stay close to the mic to *thicken* a naturally light voice, a technique often used by announcers for added emphasis (Audio Solutions Question of the Week: What Is Proximity Effect? | Audio-Technica, n.d.).

A solution to this problem is an equalizer to reduce the low-frequencies, have a greater distance between the microphone and the audio source and add a pop filter to the microphone at hand. (Recording Audio: Common Issues and How to Avoid Them, 2022)

Harsh Squealing or a high-pitched noise.

This issue is mostly caused by feedback when using a speaker. The speakers sound is picked up by the microphone and amplified making a high pitched noise. A noise gate can be to fix the problem. Or, simply moving the microphone away from the speaker. (Recording Audio: Common Issues and How to Avoid Them, 2022)

echoes and reverberations

A short explanation on the difference between reverbs and echoes.
Reverb creates a diffuse, continuous sound field that adds depth and richness to audio, while echo produces distinct, delayed repetitions of sound. Both reverb and echo contribute to the overall acoustic environment and can have different perceptual effects on listeners.

Why is testing reverberation time important?

A study by the Acoustical Society of America, Battaglia (2017), conducted by architecture students at the University at Buffalo, found that comprehension decreases as reverberation time increases.

To summarize the test researched by Battaglia (2017), the experiment took place in Crosby 125 at the University at Buffalo. This room is a typical classroom, about 6.6 x 7.2 x 3.6 meters, with terrazzo floors, plaster walls and ceilings, and two large windows. Initially, it had a high reverberation time of 2.2 seconds, making it ideal for testing sound absorption. The students got some melamine-based foam from a local factory and built sound absorption panels by attaching the foam to hollow core door panels. They added and removed these panels as needed, which brought the reverberation times down to 0.79, 0.92, 1.01, and 1.19 seconds. They played recordings of short statements and had people listen to them under different reverberation and background noise conditions. Afterward, the listeners tried to repeat the statements and rated how easy they were to understand on a scale from one to ten. The results showed that as the reverberation time increased, it became harder to understand the statements. This was true even for young, native English speakers with no hearing issues.

To translate this study into BUas XR stage environment; Reverberation time is a key component for the clarity of sentences spoken by actors which ultimately effects the dialogue recording.

A simple fix is to use foam or carpet to reduce the audio reflection on the walls and floor. Besides, moving closer to the audio source can fix this problem as well. (Recording Audio: Common Issues and How to Avoid Them, 2022)

2.4 Reverberation Time, Its Importance and How It Is Tested

The explanation of reverberation is ''When a sound is made, the sound energy reflects off the surrounding surfaces such as ceilings, floors, tables, and even people. Those sound reflections mix to create what is known as reverberation. '' Conwed_Dev (2023)

Reverberation is a normal occurrence in larger open areas. To test the reverberation rate there are a few methods available. Conwed_Dev (2023) narrowed down a study by Battaglia (2017) explaining the importance of researching sound reverberation levels.
The reverberation time in a room affects how clearly a persons speech is perceived. ''This sound clarity we strive for is known as “speech intelligibility.” The term was coined by acoustical engineers and refers to the proportion of sound output that a listener can readily understand. '' Conwed_Dev (2023). The ideal reverberation time is somewhere between 0.3 and two seconds.'' It can be too high (generally, > 2 seconds), and the room is considered"echoic." It can be too low (< 0.3 seconds), and the room is called acoustically dead.'' (Reverberation Time in Room Acoustics, n.d.)

According to Conwed_Dev (2023) the way reverberation is tested is based on room size. A small room can be tested with a simple clap of your hands. A medium sized room can be tested with a box, balloon or clapperboard and large rooms, such as a concert hall, are better off using a PA system. The test steps however, stay the same:

1: Create a stable sound field using a sound source.

2: Start a sound measurement instrument, such as a sound level meter.

3: Switch off the sound source and allow the sound to decay.

4: Wait for the background sound to stabilize and stop the measurement.

Understanding reverberation and its impact on speech intelligibility is crucial for optimizing acoustic environments, particularly in XR stages. By comprehensively testing and addressing reverberation, we can enhance the clarity of recorded audio This foundational knowledge sets the stage for further exploration of acoustic challenges and solutions in the context of Breda University's XR stage.

2.5 What Is Background Noise and How Do You Test It.

2.5.1 Background noise

The definition is ‘’Background noise is defined as an ambient sound that is not the specific sound that you are paying attention to. It can have a profound impact on the effectiveness of communication in several different ways.’’ (How Does Background Noise Affect Communication? - Fleximize, 2020)

Whilst background sounds can distract you in day to day conversations. Its effect on audio recordings can make or break your film.‘’ Background noise can ruin the quality of your audio and make your film sound unprofessional. Whether it's traffic, wind, air conditioning, or other unwanted sounds’’ (What Are Some Effective Ways to Deal With Background Noise While Recording Audio on Set?, 2024). There are many solutions to dealing with background noise on a professional film set. Such as, choose a quiet location, use a directional microphone, adjust the microphone lever and position and use a separate recorder. (What Are Some Effective Ways to Deal With Background Noise While Recording Audio on Set?, 2024)

2.5.2 What if you do not have access to these solutions?

During school productions the only available equipment is easy to use. There may not be a directional microphone available or it may not be possible to move to a quiet area.

‘’The final step to deal with background noise is to edit and clean up your audio in post-production. You can use software tools such as Audacity, Adobe Audition, or Pro Tools to remove or reduce the noise from your audio tracks. You can also use equalizers, compressors, limiters, or other effects to enhance your audio and make it sound more consistent and balanced. You can also add sound effects, music, or voice-overs to your film to create a richer and more immersive sound design.’’ (What Are Some Effective Ways to Deal With Background Noise While Recording Audio on Set?, 2024).

2.5.3 *How do you test for background noise*?

With the use of *open sound meter (Smokotnin, n.d.)*, a real time tuning system.
There are many aspects to the program, for testing background noise magnitude is the best option. Magnitude, or sound intensity, ‘’ Sound intensity measurement is a powerful technique that allows us to measure the flow of sound energy as a time-averaged vector quantity. The properties of sound intensity allow us to separate sound sources and to distinguish direct sound from reverberant sound in a room‘’ (Sound Intensity - What Is Sound Intensity?, n.d.).
‘’ The Time Average algorithm calculates a time-weighted average of the values in a sample.’’ (Trends Guide - Time Average (Understanding Trends), n.d.)

2.6 Plosives and Sibilance

According to Admin (2023) Plosives and sibilance are used in testing to identify and analyse potential issues with audio clarity, such as distortion from excessive air bursts and high-frequency hissing, which can reveal problems with microphone placement, room acoustics, and sound system calibration. It cannot only be used for testing integrity and equipment settings. Plosives can be used to test out a rooms acoustics. This is important when simulating a recording environment in a test aimed for reverberation for example.

''Plosives get their name from the low-end kaboom created when the talent pronounces a B, P or T sound. These sounds require an extra burst of air from the lungs, which creates a micro windstorm at the microphone. This temporarily overloads the mic and distorts your recording.'' (Robertson, 2022)

''Sibilance is an excess of high frequencies created by S and T sounds. While it won't typically overload the recording chain, the end result is distracting and wears on the listener over time.'' (Robertson, 2022)

According to Admin (2023) sound engineers use de-essers, a specialized compression technology that reduces or diminishes the sibilant "hiss" while preserving the integrity of the vocals. As for plosives, various pieces of equipment can help manage plosives. For instance, strategically placing a pop filter in front of a microphone can significantly reduce the impact of plosive sounds.

As explained above plosives and sibilance affect recordings in different ways. Taking into account that plosives create a low-end kaboom as mentioned by Robertson (2022) they are useful to check for reverbs and echoes.

With the use of plosives it is easy to check echoes and reverberations made by the human voice. Making a participant repeat the same sentence with plosives rather than one without is a great way of replicating a real recording environment whilst checking for the effects of echoes and reverberations on audio recordings.

2.7 Open Sound Meter

The explanation of Open Sound Meter magnitude testing provided above is based on general principles and practices of sound measurement and acoustic analysis such as Svantek (2024) explains. While Open Sound Meter (Smokotnin, n.d.) is a specific tool, the process described involves standard procedures used in acoustic testing and sound analysis, which are common knowledge in the field of acoustics and audio engineering.

Open Sound Meter magnitude testing is a method used to measure the magnitude of sound at various frequencies within a given environment. This test helps identify specific acoustic properties and potential issues in the space being analysed. Here is a detailed explanation as found on the Open Sound Meter GitHub Page (Build Software Better, Together, 2024).

2.7.1 Open Sound Meter Magnitude Testing

Purpose: Magnitude testing aims to analyse the sound pressure levels across different frequencies in a particular area. It helps identify how sound behaves in that environment, including areas of resonance, acoustic dead spots, and interference from external sources.

2.7.2 How It Works:

Setup: Speaker Placement: A speaker is placed in a central location within the testing area to emit a controlled audio signal. This signal typically covers a wide range of frequencies to ensure a comprehensive analysis.

Microphone Placement: A calibrated microphone is used to capture the sound at different points within the environment. The microphone should be capable of accurately recording the emitted frequencies without adding any coloration or distortion to the measurements.

Audio Signal Emission: The speaker emits a test signal, which can be a sweep tone (a sound that moves through a range of frequencies) or pink noise (a noise with equal energy per octave, often used in audio testing).

Data Collection: The microphone captures the sound at various locations within the testing area. This is done for a fixed duration (e.g., 15 seconds) at each point to gather consistent data.The captured sound data is fed into the Open Sound Meter software, which analyzes the sound pressure levels at different frequencies.

Analysis:
Spectral Analysis: The software performs a spectral analysis, breaking down the captured sound into its constituent frequencies and displaying the magnitude (amplitude) of each frequency.

Frequency Response: The resulting frequency response shows how different frequencies are amplified or attenuated in the environment. Peaks in the response indicate frequencies that resonate strongly, while dips indicate frequencies that are absorbed or canceled out.

2.7.3 Benefits:

Identifying Problem Areas: Magnitude testing can highlight areas with excessive resonance, standing waves, or acoustic dead spots. These problem areas can then be addressed with acoustic treatments or adjustments in sound system placement. Optimizing Sound Systems: Understanding the frequency response of a room allows for better calibration of sound systems to ensure even and balanced sound distribution.

Improving Recording Quality: For environments used for audio recording, magnitude testing helps identify and mitigate issues that could negatively affect the quality of recordings, such as unwanted resonances or background noise.

2.7.4 Practical Example in XR Stage:

In the context of the XR stage at BUas, magnitude testing with Open Sound Meter could be used to analyse the acoustic properties of the stage. The speaker would emit a test signal, and the microphone would capture the sound at various points within the stage. The software would then provide a visual representation of the frequency response, identifying any acoustic anomalies caused by the LED walls, ceiling, or other elements in the environment.

3.0 Methodology

This section will contain the details of the method chosen for the testing regarding audio in the XR stage, to answer the research question: How can Breda Universitys XR stage effectively address challenges in audio recording to establish comprehensive guidelines for achieving optimal sound quality in immersive production environments? the goal is to give Cradle practical advice on how to handle audio recording at the XR stage.

3.1 Research Design

To answer the research question, qualitative data was essential. Frequency and wavelength analyses were conducted to gain deeper insights into the topic. The primary analysis involved data collected through recordings, while the frequency analysis relied on findings that were secondary to existing data.

3.2 Data Collection

In order to gather the data for this research question, various tests were done at the BUas XR stage to get information about reverbs, background noises and magnitudes.

To measure the reverberation time of the test space, a clapperboard test was conducted. Research done by Conwed_Dev (2023) shares their use of clapperboard, which produces a sharp, impulsive sound, was used to generate a sound in the space. The decay of this sound was recorded and analysed to determine the reverberation time of the room.

An open sound meter was used to measure the frequency response of the test space. This allowed for identification of any significant differences in frequency magnitudes that could impact the perception of sound in the environment.

Based on another test done by Conwed_Dev (2023).
To evaluate the intelligibility of speech in the test space, a participant was asked to repeatedly say a sentence containing both plosive and sibilant sounds. This allowed for assessment on how the room acoustics affected the clarity and articulation of these speech sounds. Finally, a silent test was conducted to measure the background noise level in the space. This provided important context for understanding the acoustic conditions that would be present during the actual use of the space.

3.3 Method of Analysis

The magnitude test was evaluated via the use of open sound meter (Smokotnin, n.d.). The remaining tests will be evaluated through the use of *Adobe Audition.* With their waveforms- and spectral frequency display. Adobe Auditions Spectral Frequency Display can be used to localize and remove any additional background noise that may have been picked up during the recording. As Hiebner (2015) explains. In spectral frequency analysis, also known as the spectral view, the application analyses the audio and displays a colourful representation. The lower part of the view corresponds to the low bass frequencies, while the higher frequencies are shown at the top. Brighter colours indicate stronger frequencies in those regions. The timeline is displayed from left to right, similar to the standard audio waveform view as shown in Figure 3.1.

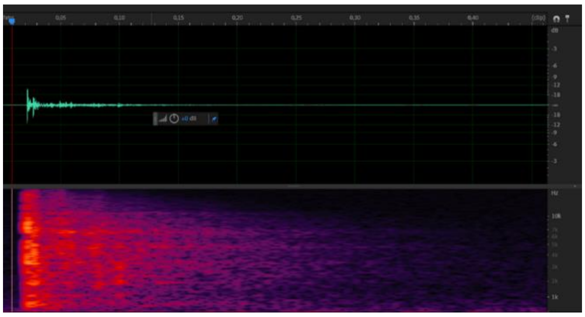


Figure 3.1, Adobe Audition: Spectral Frequency Display example.

Justification

The methods employed in this research were chosen for their suitability given the specific context and constraints of the BUas XR stage. The decision to utilize only the equipment available at the BUas XR stage was made to align with the resources accessible to students and the Cradle team, who currently lack access to high-end equipment.
For the impulse test, a clapperboard was used. While not the most reliable method for large areas, it was deemed appropriate for the approximately eight by four meters covered by the LED volume at the XR stage. Due to the absence of funding for the tests, there were no resources to purchase additional items such as balloons or a sound system, making the already available clapperboard a practical choice.
Adobe Audition was selected for its ability to display both a Spectral Frequency Display and a waveform simultaneously. Additionally, the researcher has extensive experience and proficiency with Adobe Audition, further justifying its use. The recommendation to use Open Sound Meter came from the audio engineer at Cradle, adding professional validation to its selection.

Layout:

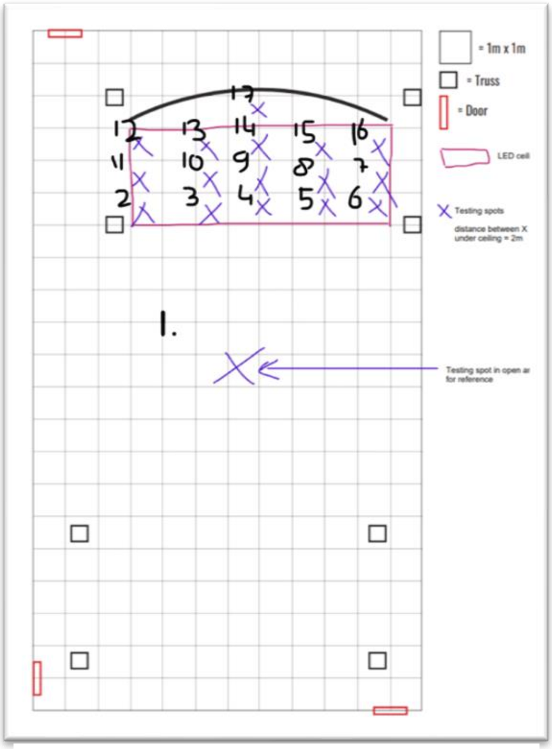


figure 3,2 testing layout XR stage.

Figure 3.2: XR stage layout

A truss is ‘’ a framework, typically consisting of rafters, posts, and struts, supporting a roof, bridge, or other structure.’’ (Oxford Languages and Google - English | Oxford Languages, 2024). In this case, the truss is supporting the LED ceiling and wall.

As shown on Figure 3.2 there are 17 spots in total. The spot shown in the open area is used is a reference point when analysing the outcomes. It will show the difference between the area directly at the LED volume and being in an open space. The 15 spots directly below the ceiling are two meters apart.

A two-meter spacing ensures that the entire area of interest is adequately covered while maintaining operational efficiency. This spacing strikes a balance between thoroughness and practicality, enabling a comprehensive assessment without requiring an impractical number of measurements.

The one spot directly in front of the screen is not covered by the ceiling, it is usually too close to the screen to be able to record at. Since this could very well change in the future it will be covered in this test.

3.4 Testing in Detail

Before commencing the main data collection, an initial testing phase was conducted to verify the functionality and reliability of the equipment and procedures. This involved setting up the audio recording equipment and conducting a series of trial runs within the BUas XR stage. The purpose of these preliminary tests was to identify any potential issues with the equipment, such as faulty XLR cables or malfunctioning headsets, and to make necessary adjustments to the setup. During this phase, the clapperboard method was tested to ensure it provided consistent and reliable impulse responses. Additionally, the placement of testing spots was evaluated to confirm that a two-meter interval would effectively capture the spatial variations in acoustics without redundancy. These initial tests were crucial in refining the methodology and ensuring that the subsequent data collection would be accurate and effective.

3.4.1 Magnitude Test

The first test is magnitude measurements via Open sound meter(Smokotnin, n.d.).

As explained in the literature review. Magnitude testing aims to analyse the sound pressure levels across different frequencies in a particular area. It helps identify how sound behaves in that environment, including areas of resonance, acoustic dead spots, and interference from external sources.

The magnitude test was done following the steps given by open sound meter.

This program sends a sweep tone out from a speaker placed roughly in the middle of the area directly below the LED ceiling. Before starting the test a microphone needs to be calibrated to open sound meter. The tone was repeated on each marking for approximately 15 seconds to get the best reading. If one of the marks showed an unclear reading, the sweep tone was left on for a longer duration till a stable reading was shown. The captured data was saved in a separate folder each as well as screen recorded. To have an clear visual. After the final marking, all waves were shown simultaneously in the final render.

3.4.2 Impulse Test

Impulse tests can be used for multiple outcomes. For this specific test the impulse was aimed to only measure the reverberation time in the room. When compared, the waveforms can show inconsistencies and point out echoic or acoustically dead areas.

The impulse test was done follow the steps as explained by Conwed_Dev (2023).
As the stable sound source a clap board was used. The microphone was placed on each marking whilst the participant with the clap/clapperboard was standing approximately two meters away. The microphone was connected to an audio recording software and recorded between 10 and 15 seconds after each clap to let the audio decay naturally.
All recordings were done in separate files and exported without any adjustments to keep the integrity of the waveforms.

3.4.3 Silent Reading

The third test is a silent reading of the room.
The aim of this test was to show differences between background noises as well as testing if the usage of the LED volume had an effect on the noise generated.
This test will be done twice. Once in the morning when the LED volume has not been turned on. Once in the evening when the screen has been operating during the day. During the final round the screen was still turned on.

This test required the room to be completely silent. The microphone was placed on the marking in the centre of the LED volume for both tests. An audio recording software attached to the microphone recorded the silence for approximately 10 seconds.
Everything outside of the XR stage is public area. The noise generated by students walking in

these areas cannot by influenced by the researcher. This could affect the outcome of the silent reading with additional background noises.

3.5 Assessing issues on the XR stage with the microphones available on campus

During this testing round it is necessary to have a participant repeating the same sentence in the same tone multiple times. This will keep the reading consistent whilst also recreating a real recording environment. The sentence used during this test will be ‘’ This is a practical audio test ‘’. The plosives will reflect on the LED volume, giving a more detailed reading of possible echo and reverberation issues.

The microphones used during this testing round will be the ones available on campus. In this case, a shotgun microphone connected to a boom pole with an XLR cable. Together with a wireless lavalier microphone attached to a blouse or shirt near the face, carefully placed to minimize the chance of it touching the skin or other clothing / jewelry items. Both microphones are simultaneously recorded with a Zoom H5 handy recorder.

3.5.1 Stationary Spot Test

The aim of this test is to see the effects of a human voice on the acoustics at the XR stage, replicating a recording environment.
The microphones used during this test were available for rent on campus. In this case, a shotgun microphone attached to a boom pole, connected to the Zoom H5 with an XLR cable. Together with a wireless lavalier microphone attached to a blouse or shirt near the face, carefully placed to minimize the chance of it touching the skin or other clothing / jewellery items. The receiver was connected to the same Zoom H5 recorder with an XLR cable, on a separate input channel. Both microphones were recorded simultaneously.

During this test the participant was standing stationary on each marking. The boom microphone must be above the participant at the same distance for each marking and the lavalier microphone must remain in the same spot connected to the participant. This test is recorded in one continues recording.

3.5.2 Simulated Recording Environment Test

This test aims to replicate a recording environment. The participant will walk in one continued line across all markings. The microphones used during this test were available for rent on campus. In this case, a shotgun microphone attached to a boom pole, connected to the Zoom H5 with an XLR cable. Together with a wireless lavalier microphone attached to a blouse or shirt near the face, carefully placed to minimize the chance of it touching the skin or other clothing / jewellery items. The receiver was connected to the same Zoom H5 recorder with an XLR cable, on a separate input channel. Both microphones were recorded simultaneously.

Starting from the marking outside of the LED volume, walking from the left most marking in an S motion, finishing at the marking closest to the curved LED volume.
The sentence ‘’ This is a practical audio test ‘’ will be repeated continuously till the last marking is reached. This specific sentence contains plosives. As explained by Robertson (2022) plosives express a low- end kaboom sound, which will be used to assess the echoes/reverberation spots in the XR stage during this test.

3.5.3 Second Simulated Recording Environment Test

This test aims to assess the effects of noise made by the participant on the acoustics of the XR stage. In this case, the participant is encouraged to walk around in a loud manner to create an impulse effect on a smaller scale.

The test will be done in the same manner as the first simulated recording environment test. The microphones used during this test were available for rent on campus. In this case, a shotgun microphone attached to a boom pole, connected to the Zoom H5 with an XLR cable. Together with a wireless lavalier microphone attached to a blouse or shirt near the face, carefully placed to minimize the chance of it touching the skin or other clothing / jewellery items. The receiver was connected to the same Zoom H5 recorder with an XLR cable, on a separate input channel. Both microphones were recorded simultaneously.

Starting from the marking outside of the LED volume, walking from the left most marking in an S motion, finishing at the marking closest to the curved LED volume. The sentence ‘’ This is a practical audio test ‘’ will be repeated continuously till the last marking is reached.

3.6 Testing Handheld Microphone Integrity and Interference in LED Volume Environment.

This research aims to identify and analyse potential audio disturbances, such as high-pitched ringing sounds, in the use of handheld microphones connected to the audio system in a specific environment. The microphones, typically utilized during presentations and workshops, are connected to the speakers above the LED volume. The study involves a series of tests conducted at varying loudness levels to determine the microphones' integrity and susceptibility to interference.

3.6.1 Preliminary Silent Walkthrough

First, a preliminary silent walkthrough will be conducted to detect any inherent audible disturbances in the testing environment without active microphone use. The researcher will walk through the area, noting any disturbances at different locations within the LED volume.

3.6.2 Interference Testing with Mobile Devices

evaluates the impact of mobile devices on the microphone's performance. Multiple mobile phones will be distributed throughout the testing area, ensuring they are active and emitting standard electromagnetic signals. The researcher will walk around the area with the active handheld microphones, repeating the predetermined sentence. Variations in audio quality, particularly high-pitched ringing sounds or other forms of interference, would be monitored and recorded.

4. discussions and findings

4.1 Overview and Key Findings

This section presents the key findings from the various tests conducted to address the challenges of audio recording in the XR stage at Breda University of Applied Sciences . The research focused on investigating the unique acoustic properties of the XR stage, identifying potential sources of interference, and evaluating the effectiveness of different audio equipment and techniques. The tests included magnitude measurements, impulse tests, silent reading tests, and practical microphone tests, each designed to reveal specific aspects of the acoustic environment and recording conditions. The results highlight critical areas for improvement and provide a foundation for developing guidelines to optimize sound quality in immersive production environments.

4.2 Expert Interviews on Acoustic Challenges in the BUas XR Stage

This section presents the findings obtained from interviews conducted with individuals experienced in audio recording within the XR stage at Breda University of Applied Sciences. The aim of these interviews was to identify and analyse various audio challenges encountered in the XR stage environment.

the participants were asked to answer the following questions:
What specific acoustic characteristics are observed in different areas of the XR stage, such as variations in sound resonance or reverberation?

Have participants encountered any technical challenges or operational difficulties while utilizing diverse microphone types during productions within the BUas XR stage?

Are there additional observations or insights related to the XR stage environment or production process that participants deem noteworthy for consideration?

The answers, summarised to their key findings;

Jens Hagen: Research Developer and Audio Expert at Cradle:

Identified variations in sound perception underneath the ceiling screen, suggesting potential audio reflections.

Noted interference issues with handheld microphones in the presence of numerous mobile phones, indicating susceptibility to external signals.

Raised concerns about potential audio hotspot formations due to the curved setup of the screen.

Viktoriya Atanasova: Capstone Student and Audio Expert, Cradle

Highlighted spot-specific sound variations, particularly under the ceiling and near the LED wall, attributing these to differing levels of sound reflection.

Reported technical challenges with the Zoom H5 recorder, including battery life limitations and booking delays.

Suggested the need for clear settings or equipment tailored to the XR stage environment to improve audio quality.

Jens Mathijssen: Audio Recordist for XR Production House Shortfilm, BUas.

Observed increased background noise near the screen, particularly noticeable when using the boom microphone.

Experienced technical issues such as battery drainage and cable limitations with recording equipment.

Advocated for specialized equipment or settings optimized for the XR stage to improve audio recording capabilities.

Ella Betts: XR coordinator and Production House Teacher, BUas.

Noted echoey sound reflections directly under the XR stage and near the screen due to its curvature.

Lacked specific knowledge of audio-related problems, indicating limited experience in this aspect of production.

4.3 Analyzation of the Tests - Frequency

The first round of testing aimed towards finding frequency peaks with the use of *open sound meter.*
The analysis of the open sound meter magnitude test, as depicted in the graph, reveals a generally consistent magnitude across different frequencies, with no significant peaks within the noticeable decibel ranges. Each coloured line represents a different spot in the XR stage, and their close alignment suggests uniform sound behaviour across the various locations tested.

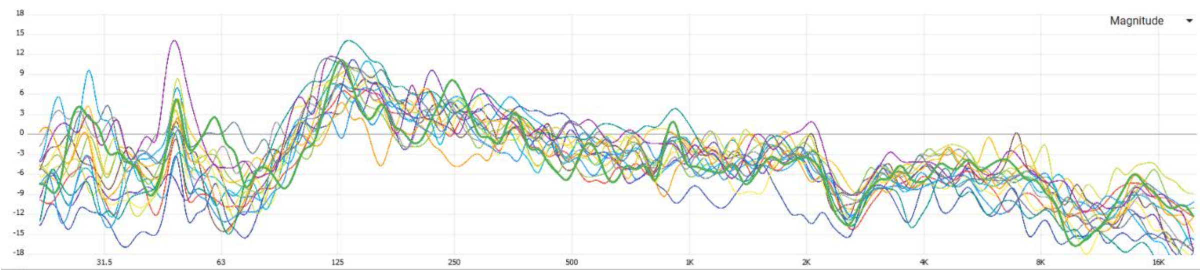


figure 4.0 Open Sound Meter magnitude test – all recordings

However, there is a notable low-end spike around the 31.5 Hz mark. This spike, although present, would likely be inaudible during typical recording scenarios and does not significantly affect the outcomes of this particular study. The overall consistency observed in the magnitude levels across all other frequency ranges reinforces the conclusion that the XR stage maintains a stable acoustic environment. This stability is crucial for ensuring reliable and clear audio recordings, as it indicates an absence of unexpected acoustic anomalies that could interfere with sound quality.

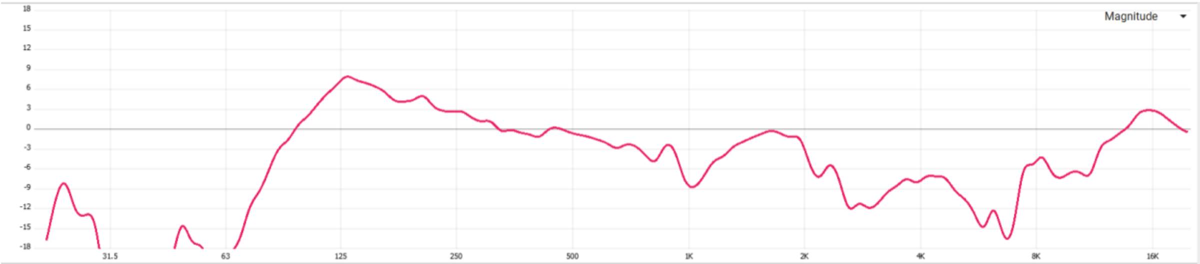


figure 4.1 Open Sound Meter – baseline

4.4 Impulse Test

The impulse test aimed to measure the reverberation time within the XR stage, with the objective of identifying inconsistencies that indicate echoic or acoustically dead areas. The test was conducted following the methodology outlined by Conwed_Dev (2023), using a clapboard as the sound source and recording the subsequent decay of sound.

'' Waveform analysis looks at the shape and form of the sound wave produced by equipment or machinery. Specific issues can produce unique waveforms, helping to diagnose problems.'' (Fiix, 2023)

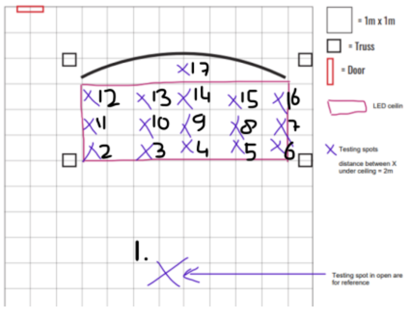


Figure 4.2, XR stage test markings, numbered one to 17.

The analysis of the soundwaves generated by the impulse test involved both visual examination of the waveforms and auditory evaluation of the recordings. This dual approach provided a comprehensive understanding of the acoustic characteristics of the XR stage. The first reference point, situated in the open area of the XR stage (1), served as a baseline for comparison with other locations near the LED volume.

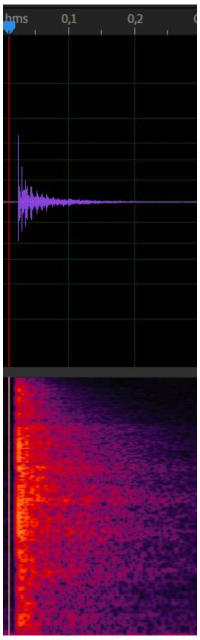


figure 4.3, Impulse test. Spot 2

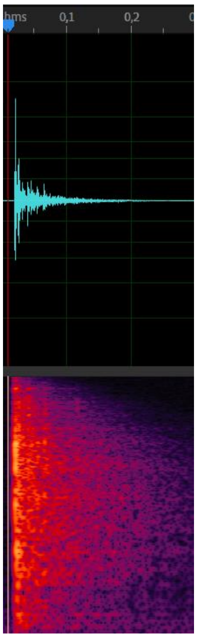


figure 4.4, Impulse test. Spot 4

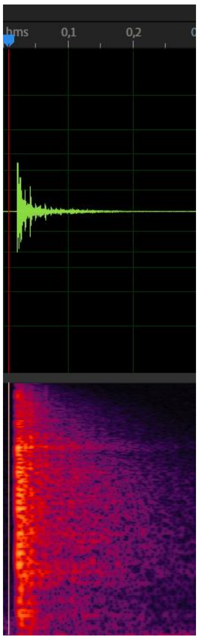


figure 4.5, Impulse test. Spot 6

Significant differences were observed between the left and right sides of the LED volume. In figure 4.3, representing the left side, the waveform displayed an almost perfect curvature as the sound faded, indicating minimal reverberation. In contrast, figure 4.5, representing the right side, exhibited a second impact point, visible as a secondary spike, suggesting increased reverberation. The front middle of the screen, shown in figure 4.4, also showed several additional spikes following the initial impact, indicating the presence of reverberation.

In the second row of measurements, similar outcomes were noted, with some variations. Figure 4.6, the left side of the screen, revealed an extra spike in the waveform, suggesting increased reverberation compared to the corresponding spot in the first row, figure 4.3

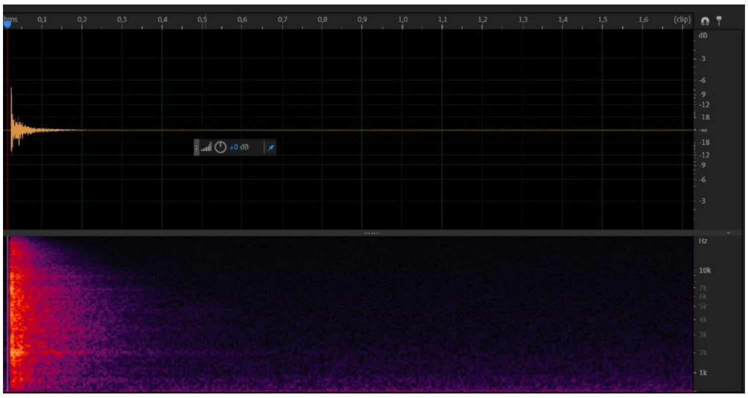


figure 4.6 , Impulse test. Spot 11

The last row, positioned closest to the screen, displayed considerable variability among the three points. The left corner, shown in figure 4.7, exhibited an additional spike, indicating higher reverberation. The centre spot, shown in figure 4.8, had a relatively flat waveform, suggesting an acoustically dead spot with minimal reverberation. The right side, represented by figure 4.9, demonstrated a nearly perfect curvature, similar to the left side in the first row, indicating low reverberation.

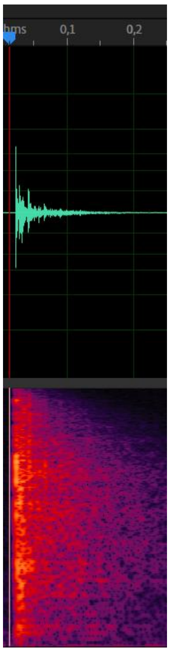


figure 4.7 Impulse test. Spot 12

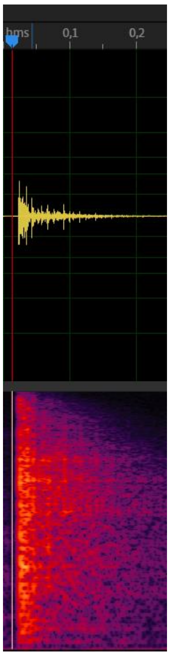


figure 4.8 Impulse test. Spot 14

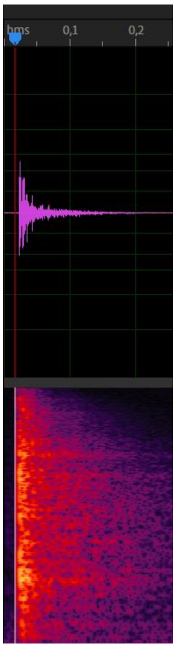


figure 4.9 Impulse test. Spot 16

Additionally, figure 4.10 revealed a distinct second spike occurring almost immediately after the first, indicative of an echo and highlighting the presence of immediate sound reflections.

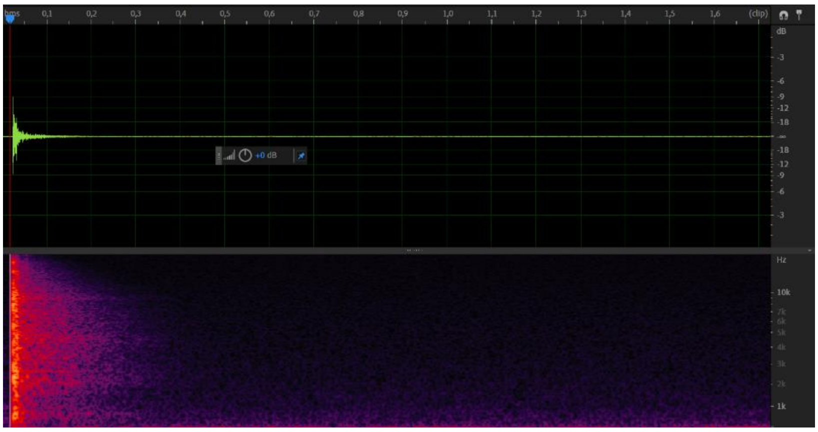


figure 4.10 Impulse test. Spot 17

Overall, the impulse test findings revealed varying acoustic properties within the XR stage, with differences in reverberation and echo noted between different locations, particularly between the left and right sides of the LED volume and the proximity to the screen. These insights are crucial for optimizing audio recording conditions within the XR stage, highlighting areas that may require acoustic treatment to minimize undesired reflections and enhance sound quality.

4.5 Silent Reading

the analysis of silent reading sessions aims to understand the acoustic environment and the impact of ambient sound on the reading experience. Given that traditional decibel measurements often fail to account for perceived loudness, Loudness Units relative to Full Scale (LUFS) was employed as the primary metric for measuring audio levels. LUFS provides a more accurate representation of how loudness is perceived by human listeners, making it particularly suitable for environments where subtle audio nuances can affect concentration and comfort. By using LUFS, this research ensures a precise assessment of the soundscape during silent reading, offering insights into how ambient noise levels influence the reader's experience and overall acoustic quality.
‘’LUFS are units of audio loudness. The acronym stands for loudness units relative to full scale. Essentially, it's a standard way of measuring audio that blends the perceived loudness from human hearing and the true intensity of an audio signal together.’’ (What Are LUFS: The Complete Beginner’s Guide, n.d.)
Finding
The silent reading test revealed no discernible dB or waveform fluctuations, indicating that the background noise remained consistent throughout the test. The audio reading measured in LUFS ranged from approximately -50 to -60 LUFS. This range suggests a relatively low level of background noise, which is crucial for maintaining high audio quality in recordings, as it ensures minimal interference from ambient sounds. This finding is essential for establishing a controlled acoustic environment in the XR stage, supporting accurate and clear audio capture for various applications.

File	Peak	Clip	LUFS-M	LUFS-S	LUFS-I	LRA
silent-001.wav	-51.0	0	-64.5	-66.0	-66.8	1.6
silent-002.wav	-41.9	0	-62.1	-65.5	-66.8	1.7

figure 4.11, LUFS reading, silent reading

4.6 Stationary Spot Test

The stationary spot test, which overlaps with the impulse test discussed earlier, aimed to examine the impact of human voices on the reverberation spots within the XR stage. The analysis focused on the same spots previously evaluated in the impulse test to maintain consistency.

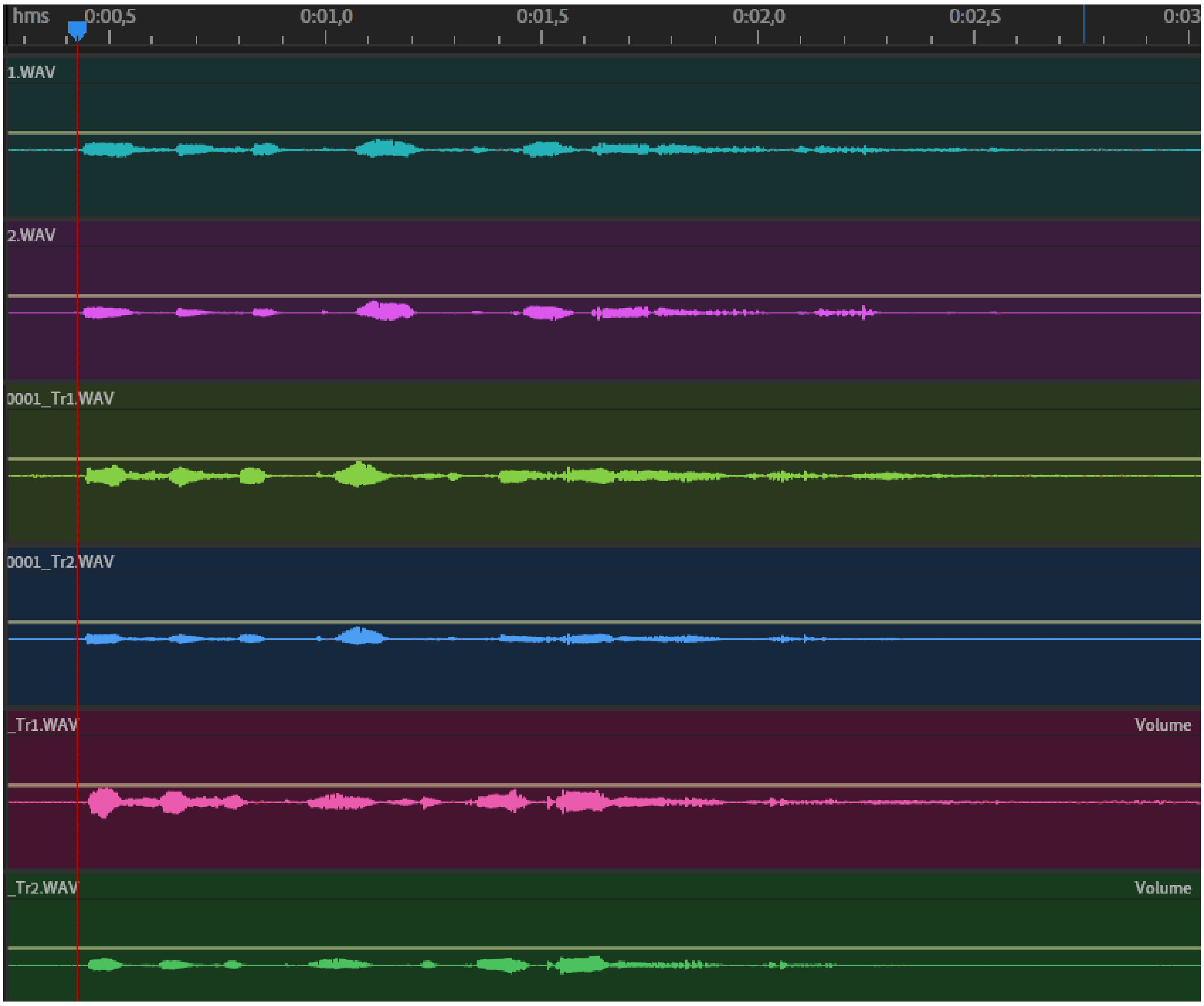


figure 4.12 Stationary Spot Test, spot 2, 4 and 6

In Figure 4.12, the first two rows represent spot 2, the second two rows represent spot 4, and the final two rows represent spot 6.
The waveform for spot 2 closely resembles that of spot 1, the reference spot in the open area, indicating a consistent acoustic profile between these two areas. Spot 4 shows more visible peaks in both the boom and lavalier microphones. Notably, the waveform exhibits a noticeable spike at the word "practical," with the plosive "P" being heavily picked up by the equipment. Towards the end of the sentence, there is no visible gap between the words, indicating that reverberation affects the sentence's clarity, as discussed in the section on reverberation.

At spot 6, the word "practical" is elongated, and the "C" sound in "practical" spikes, while other soundwaves do not exhibit this additional spike. This pattern suggests that reverberation is more pronounced on the right side of the LED volume. The results in the second row align with the reverberation test, showing overlapping reverberation in the middle and right sides. However, spot 11 (figure 4.13) now shows more reverberation, despite previously exhibiting the least amount of reverberation in the impulse test.

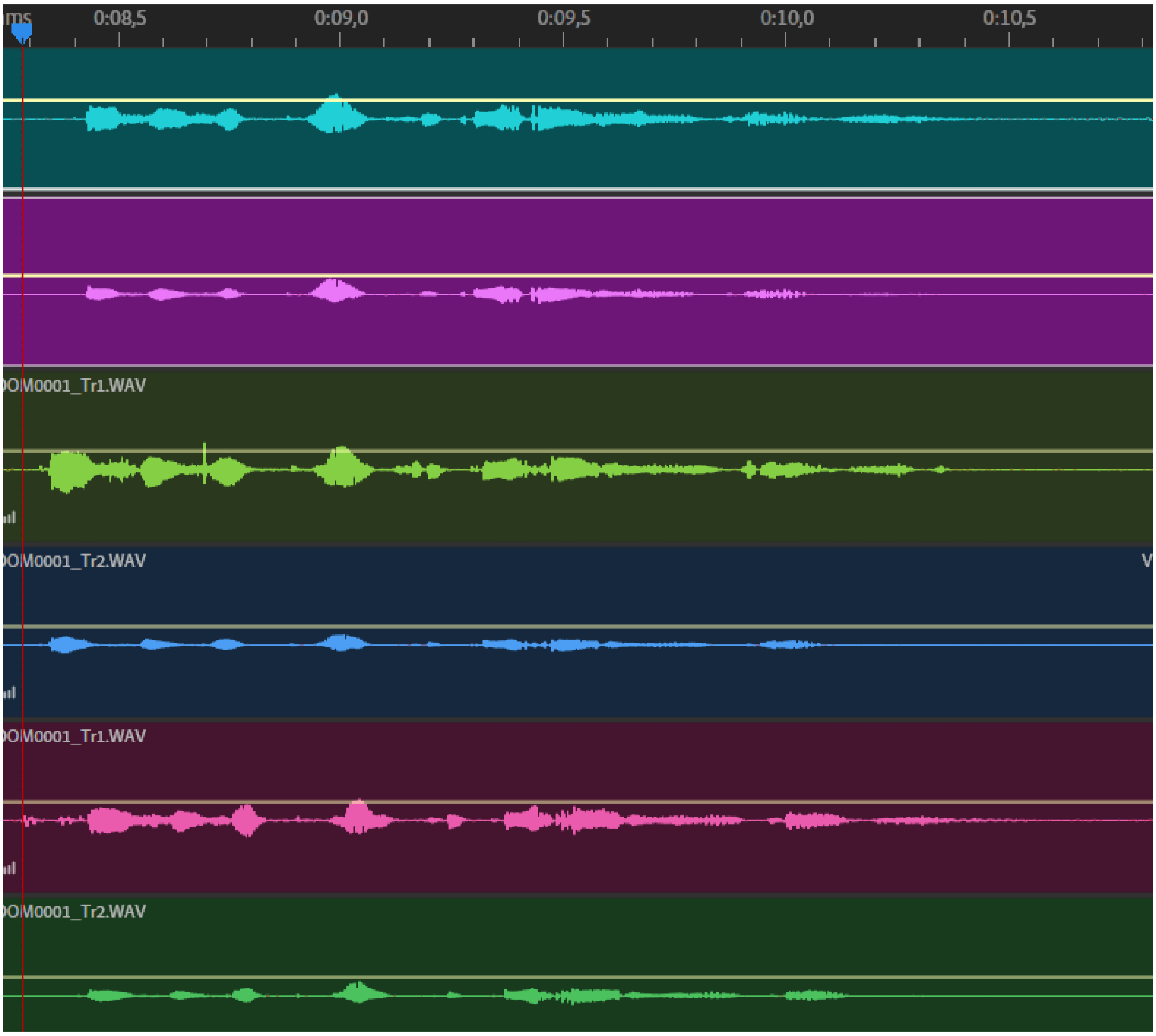


figure 4.13 Stationary Spot Test, spot 7, 9 and 11

The row closest to the screen revealed differences from the impulse test. The left and right sides of the screen showed nearly identical waveforms, indicating good acoustical overlap. However, the middle spot displayed a flatter waveform, consistent with the impulse test results, suggesting the presence of an acoustically dead zone. Comparing spot 17 to spot 1, there is a clear difference in how the "P" in "possible" is picked up. At spot 17, a reflection is evident, shown not as an additional spike but as an almost block-like waveform.

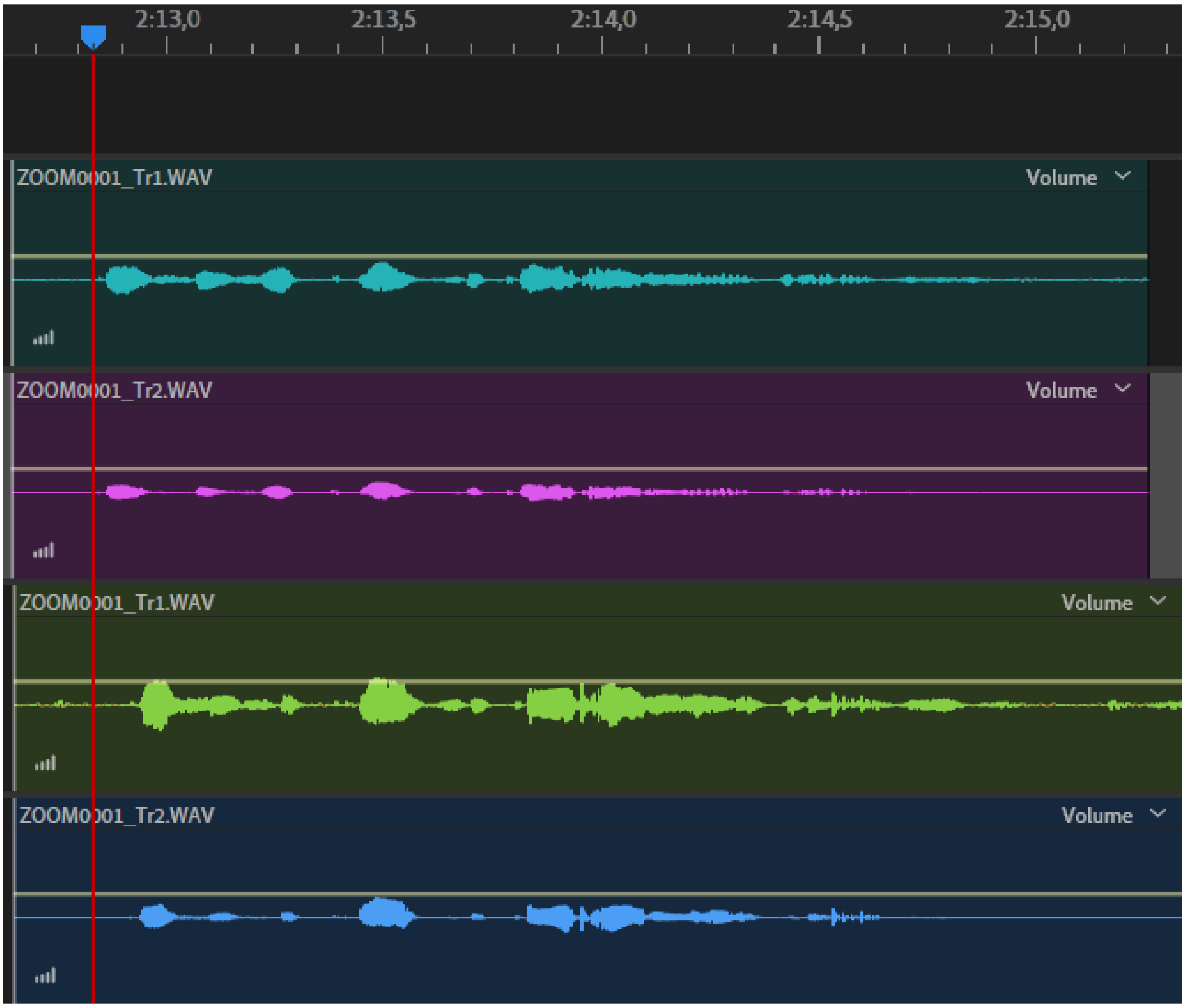


figure 4.14 Stationary Spot Test, spot 1 and 17

The stationary spot test confirmed that human voices impact the reverberation spots within the XR stage, with varying degrees of reverberation and clarity across different locations. The findings highlight specific areas with increased reverberation and potential acoustically dead zones

4.7 Simulated Recording Environment Test One and Two

In the first part of the Simulated Recording Environment test, where the participant walked continuously, no significant acoustic issues were detected. The constant movement seemed to reduce the impact of reverberation, which is more noticeable when standing still. Therefore, reverberation was less evident during this phase.

However, in the second phase, where there were quiet moments in the recording, the participant's footsteps were clearly audible and visible in the soundwave analysis.

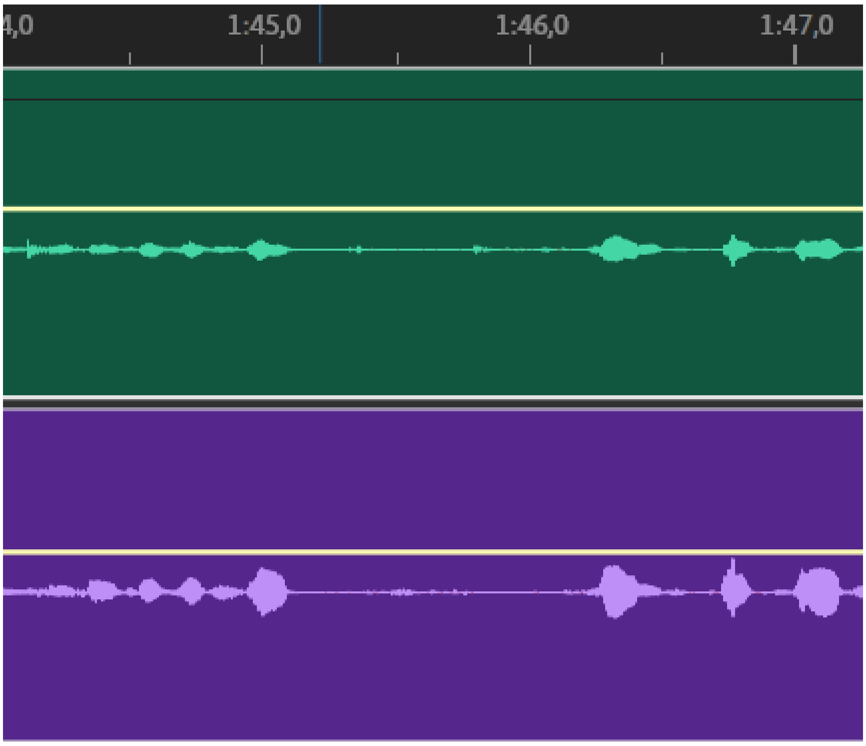


figure 4.15 Simulated recording environment test two. 2 second screen capture.

This indicates that the audio equipment picked up the footstep noise significantly. Some footsteps sounded more hollow than others, suggesting a slight reverberation effect. This points to minor reverberation, even during movement.

4.8 Testing Handheld Microphone Integrity.

The testing of the handheld microphones revealed a straightforward outcome. When both the audio levels for the speakers and the microphones were maximized simultaneously, significant feedback was generated. If either the speaker volume or the microphone volume was reduced, the feedback was eliminated. Additionally, the presence of electrical equipment did not influence the amount of feedback produced. This suggests that the primary factor in feedback generation is the relative audio levels of the speakers and microphones, rather than any external electrical interference.

5. Conclusion

The comprehensive analysis of the XR stage's acoustic environment, using various tests and measurements, reveals a stable and controlled setting conducive to high-quality audio recordings. The open sound meter magnitude test indicated consistent sound levels across different frequencies with a minor, non-impactful low-end spike, underscoring the stage's uniform acoustic behaviour. The impulse test further highlighted differences in reverberation across locations, particularly around the LED volume, identifying areas with increased reflections and potential acoustically dead zones. The silent reading test, measured in LUFS, confirmed low background noise levels, crucial for maintaining clear audio capture. The stationary spot test validated the influence of human voices on reverberation, with specific spots showing distinct acoustic characteristics. The simulated recording environment test demonstrated that constant movement minimizes reverberation effects, while quiet moments expose footstep noise, hinting at minor reverberation. Finally, testing the handheld microphones confirmed that feedback is primarily a function of audio levels rather than electrical interference. Collectively, these findings provide a detailed understanding of the XR stage's acoustic properties, guiding optimization for superior sound quality in various recording scenarios.

5.1 Limitations

During the course of this research at the XR stage, several limitations were encountered that may have impacted the study's outcomes and reliability. One significant issue was the uninformed removal of test spots. Throughout the testing process, instances occurred where test spots were removed without prior notification or replacement. Additionally, the functionality of audio equipment posed a significant limitation. For example, XLR cables were found to be broken internally, resulting in disruptions to data collection and potentially inaccurate recordings. The presence of damaged equipment, such as broken headsets, further hindered the research process. The inability to utilize essential tools properly may have compromised the quality of data obtained.

The XR stage environment was also susceptible to external disturbances, particularly loud conversations in nearby halls. This interference could have affected participants' focus and concentration during testing sessions, potentially impacting the validity of results. Unexpected interruptions occurred when individuals entered the testing area without prior warning, disrupting the experimental setup and potentially influencing participant responses.

Technical issues with the Brainbar, a crucial component of the XR stage operation, resulted in occasional malfunctions and the loss of valuable testing time. This technical setback hindered the smooth execution of experiments and may have affected the overall research timeline. Furthermore, the limited accessible testing equipment posed another challenge. To effectively test reverberation, the use of a clapperboard is the least reliable method. A more effective approach would have been to use a large balloon or a separate audio box.

However, I was restricted to using the equipment provided by Cradle and BUas, limiting the reliability of the reverberation tests.

In conclusion, these limitations underscore the challenges encountered during the research process, including equipment malfunctions, external interferences, and restricted access to more effective testing tools. Despite these obstacles, the research aimed to provide valuable insights into the acoustic environment of the XR stage, though the results must be interpreted with these limitations in mind.

5.1.1 Implications

Acknowledging these limitations is essential for interpreting the findings of the research accurately. While efforts were made to mitigate these challenges during the study, their presence may have introduced biases or inconsistencies that warrant consideration when interpreting the results. Future research endeavors should address these limitations to enhance the robustness and validity of findings in similar experimental settings.

5.2 Recommendations

Based on the identified limitations and challenges encountered during the study, several recommendations are proposed to enhance the quality and reliability of future research conducted within the BUas XR stage environment. One of the primary recommendations is the comprehensive testing of XLR cables. To mitigate issues related to malfunctioning audio equipment, it is recommended to conduct thorough testing of all XLR cables within the BUas XR stage for their integrity. Regular maintenance checks should be implemented to identify and replace damaged cables promptly, ensuring uninterrupted data collection during experimental sessions.

Furthermore, establishing a clear storage room protocol is essential. Protocols for students with access to the storage room should ensure that equipment is returned and stored correctly after use. Implementing training sessions or instructional materials can help promote awareness and adherence to proper storage procedures, minimizing the risk of equipment damage or loss. This will help maintain the reliability and availability of the necessary tools for future research.

To prevent unauthorized removal or tampering with test spot markings, it is advisable to implement measures to safeguard these markings during testing sessions. This may include designating specific individuals responsible for marking placement and ensuring that only authorized personnel handle or adjust the markings as needed. Protecting these markings will ensure consistency and accuracy in data collection.

Addressing external noise interference is crucial for maintaining the integrity of research conducted within the XR stage environment. Investing in better soundproofing materials for the walls, glass doors between the lighthouse and the stage, and the entry door can effectively reduce disruptive ambient noise. Enhanced soundproofing measures will provide a more controlled testing environment conducive to accurate data collection.

In addition to these specific recommendations, involving more participants in future studies could enhance the robustness of the findings. By increasing the number of participants, researchers can obtain a more comprehensive understanding of the acoustic environment and its impact on different individuals. Moreover, conducting similar studies at different XR stages would provide valuable comparative insights. Exploring how different XR stages influence acoustic characteristics can help identify best practices and potential areas for improvement.

To achieve better results and gain more insights, it is also recommended to use more advanced equipment for reverberation testing. For example, using large balloons or separate audio speakers instead of clapperboards could provide more reliable measurements. Additionally, exploring different methodologies and incorporating a variety of testing conditions could yield more comprehensive results.

Implementing these recommendations will contribute to improving the reliability and validity of future research conducted within the BUas XR stage environment. By addressing equipment malfunctions, enhancing soundproofing measures, protecting test spot markings, and involving more participants, researchers can ensure more accurate and insightful findings.

5.3 ethical considerations

Conducting research in the field of virtual production and immersive technologies involves addressing several ethical considerations to ensure the integrity and validity of the study.

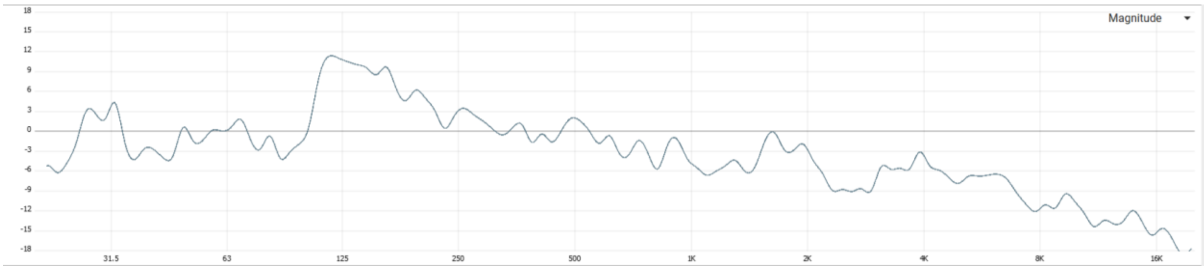
One ethical concern lies in the possibility of biased results due to convenience sampling. This study's participants were chosen based on availability and accessibility rather than through random selection. Such an approach risks yielding a sample that may not fully represent the broader population, potentially skewing the results. Researchers must acknowledge this limitation and interpret findings cautiously, stressing the necessity for more rigorous sampling methods in subsequent studies to bolster result generalizability.

Moreover, the time constraints inherent in completing a bachelor's thesis pose ethical challenges. These limitations can impact the research's depth and breadth, potentially leading to oversights or insufficient exploration of complex topics. Transparency regarding these constraints and their influence on the study's scope is vital. Recommendations for future research with extended timelines should be made to build upon the initial findings.

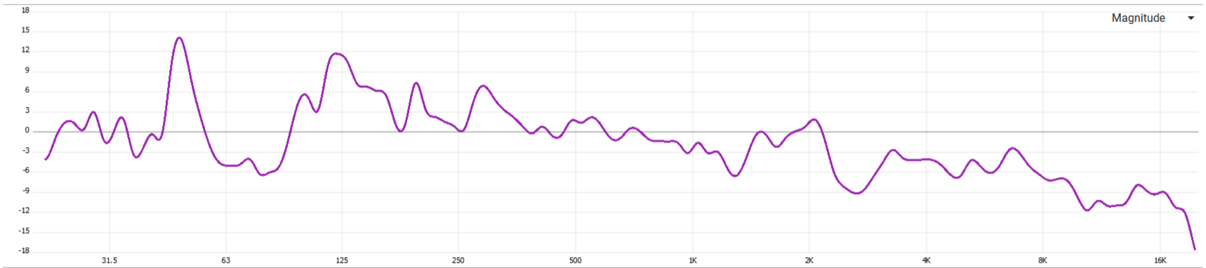
Another ethical consideration arises from the researcher primarily working alone on the project. Solo research may introduce biases linked to the researcher's perspectives and interpretations. Collaborative research efforts, involving multiple researchers with diverse viewpoints, tend to be more robust and less susceptible to individual biases. Recognizing this limitation is essential, and future studies should strive to incorporate collaborative approaches to bolster the reliability and validity of research outcomes.

Implementing these recommendations will contribute to enhancing research practices within the BUas XR stage, fostering an environment conducive to high-quality experimental studies and advancing knowledge in immersive technologies and audio recording methodologies. Upholding ethical rigor and addressing identified limitations will bolster the credibility and impact of future research.

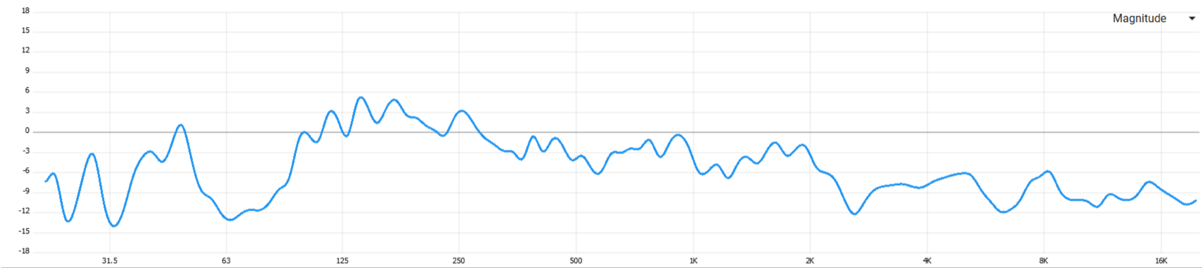
6.APPENDIX



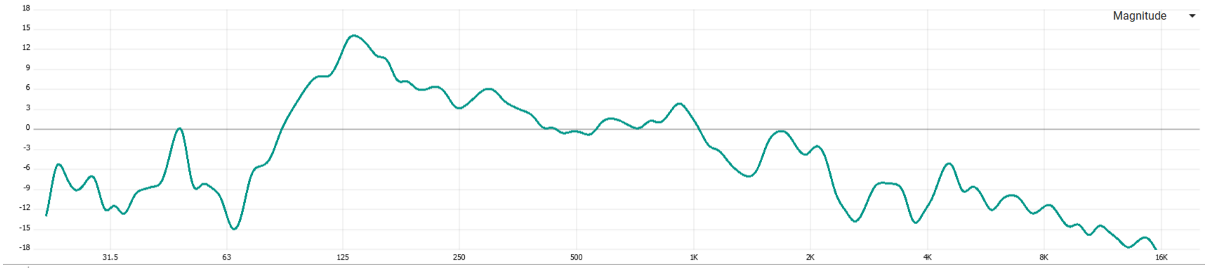
Magnitude test spot 1



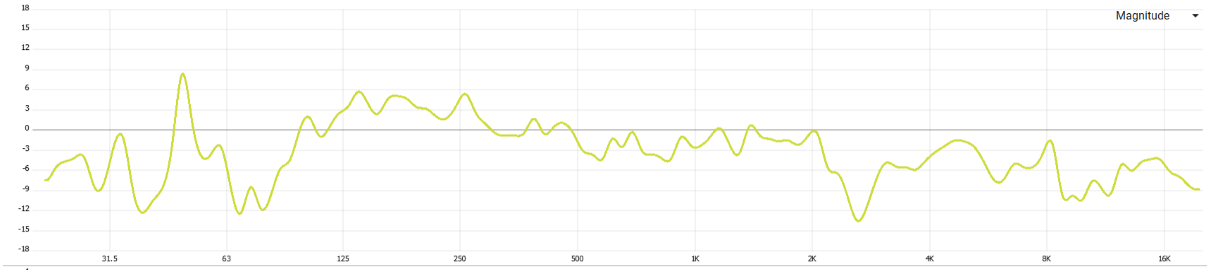
Magnitude test spot 2



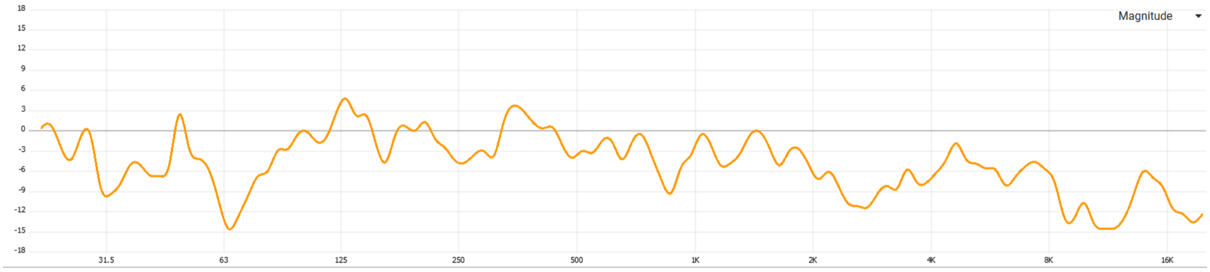
Magnitude test spot 3



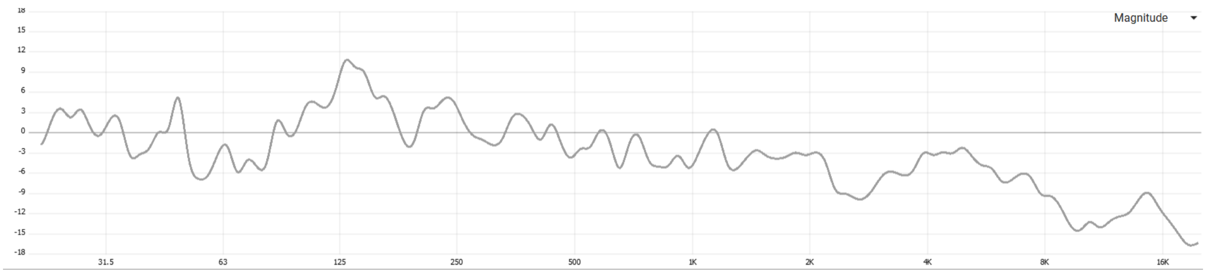
Magnitude test spot 4



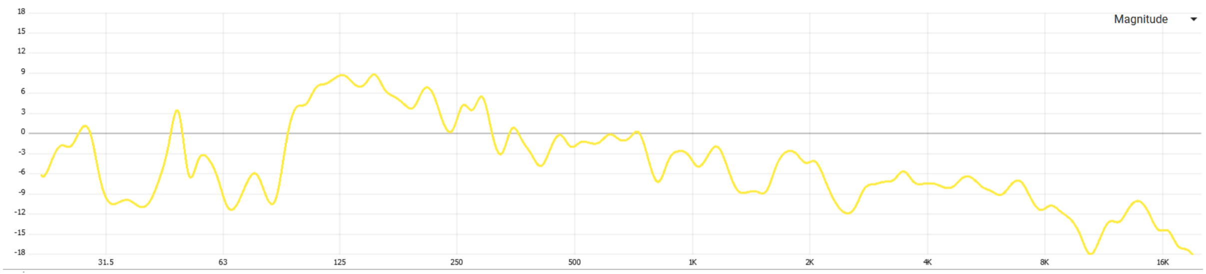
Magnitude test spot 5



Magnitude test spot 6



Magnitude test spot 7



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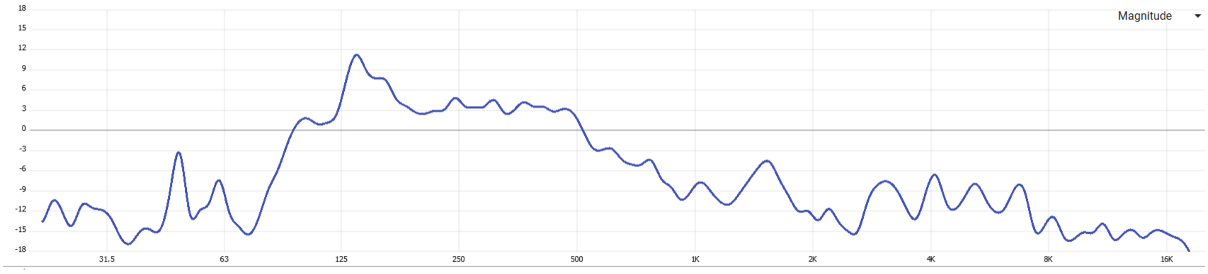

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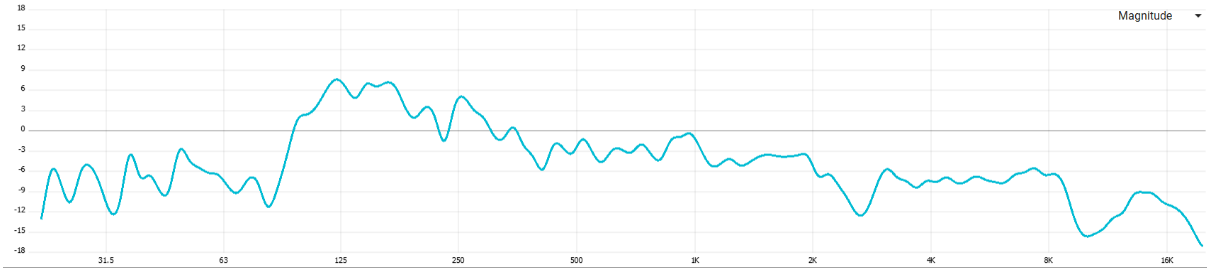

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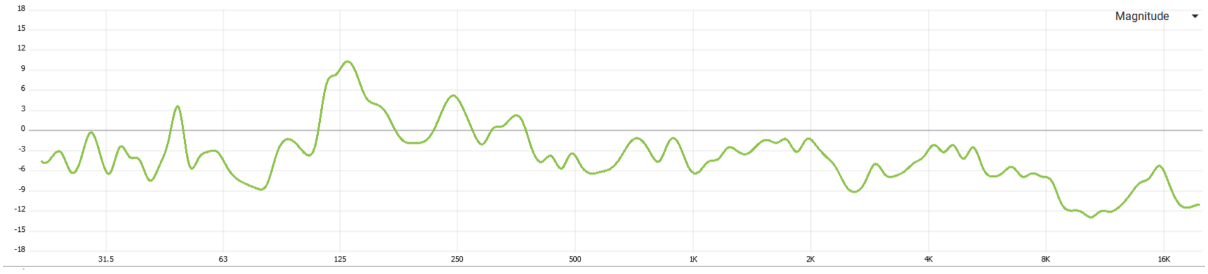

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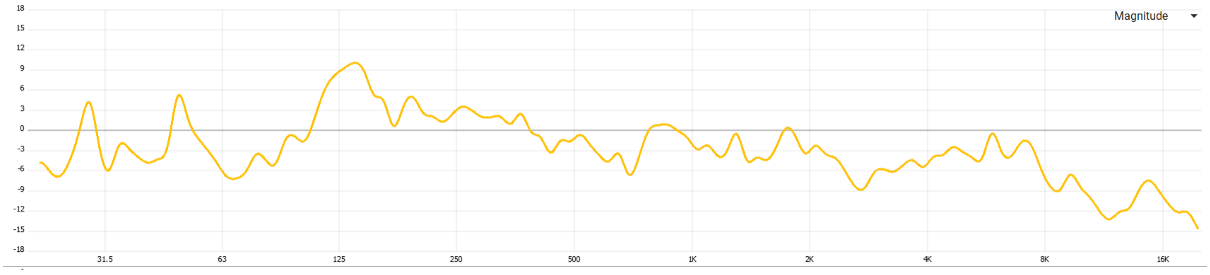

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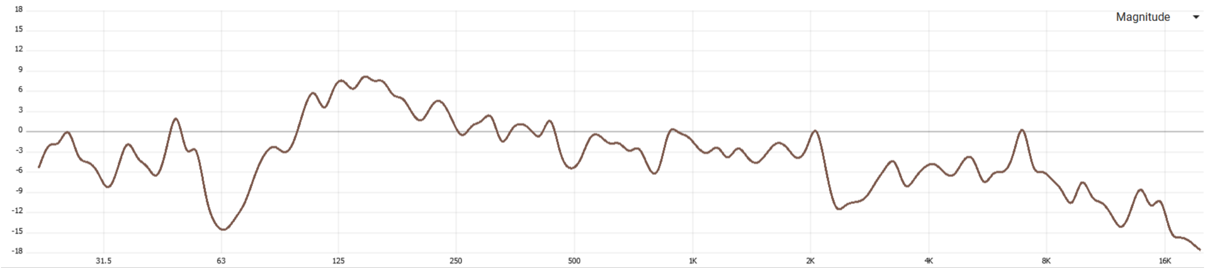

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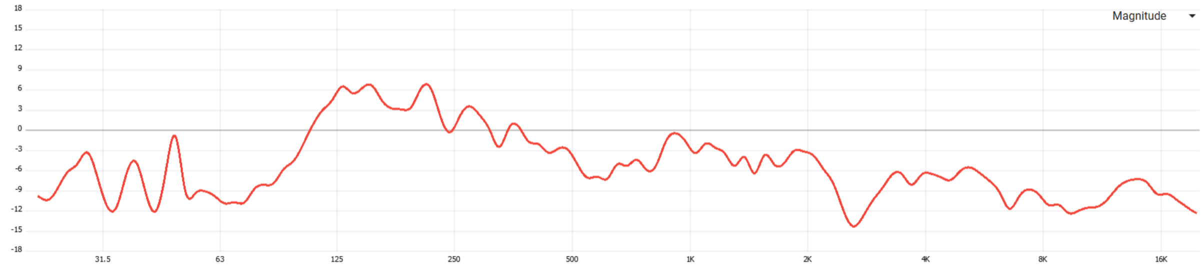
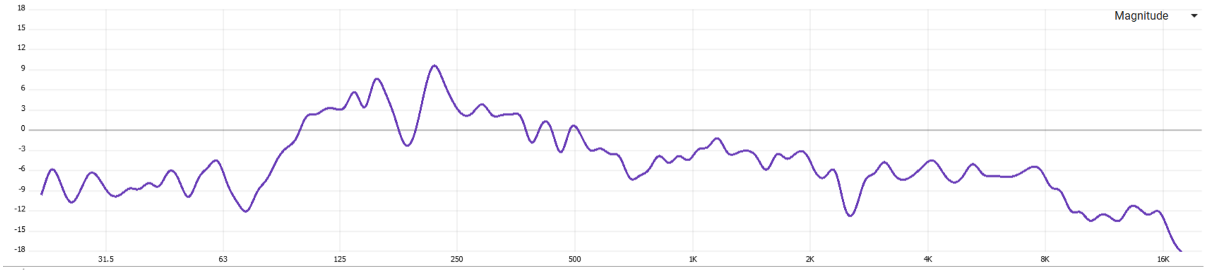
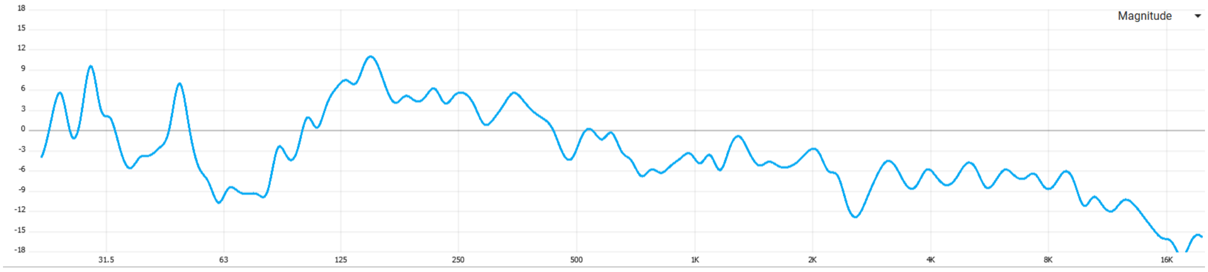


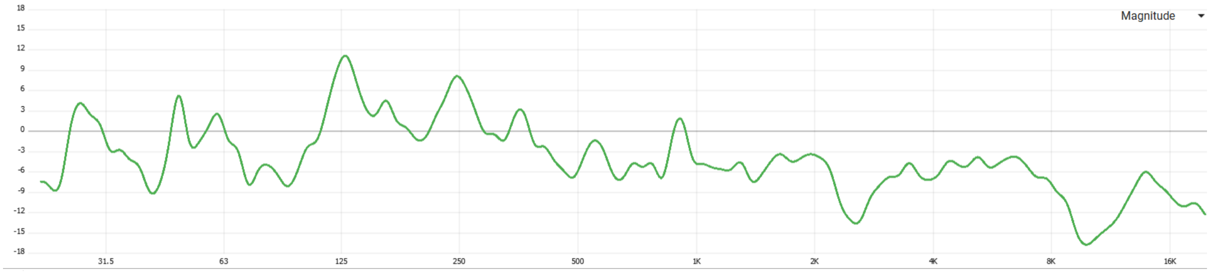
Magnitude test spot 14



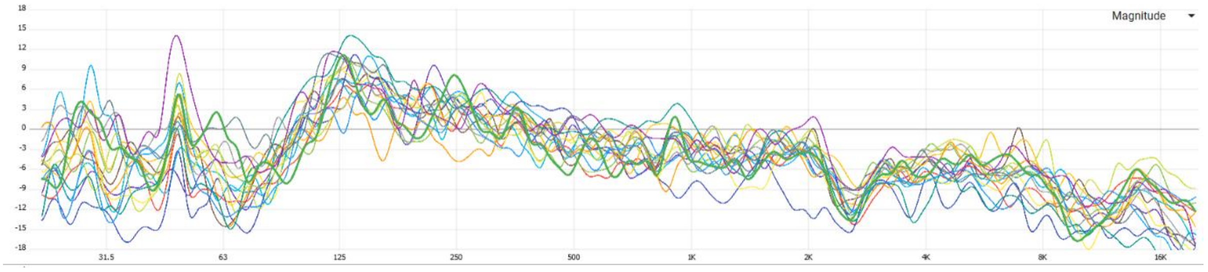
Magnitude test spot 15



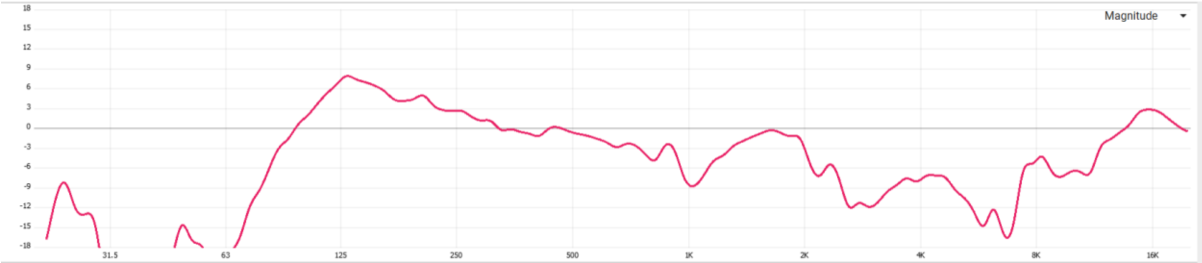
Magnitude test spot 16



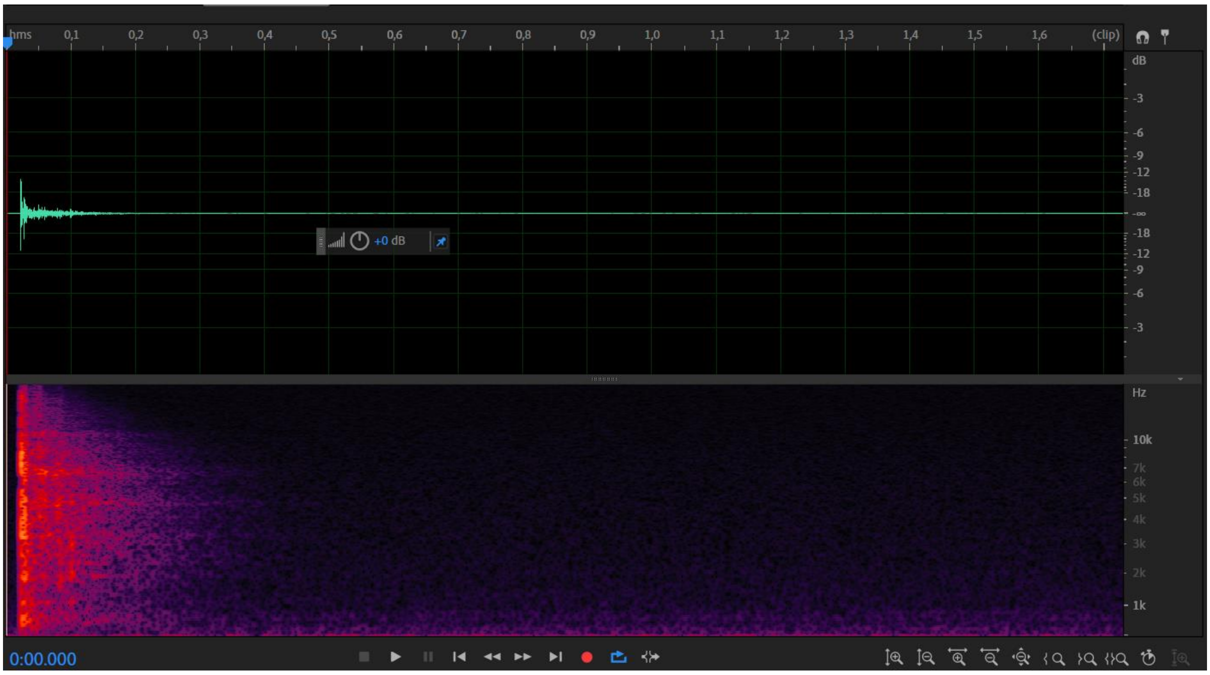
Magnitude test spot 17



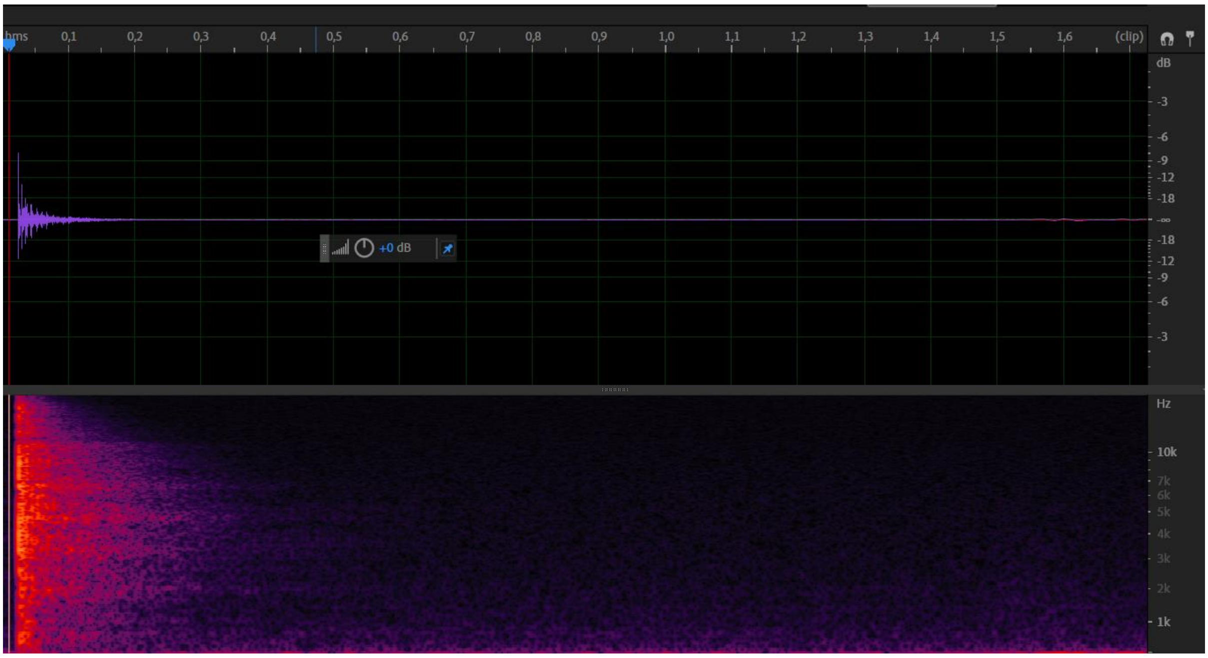
Magnitude test all spots



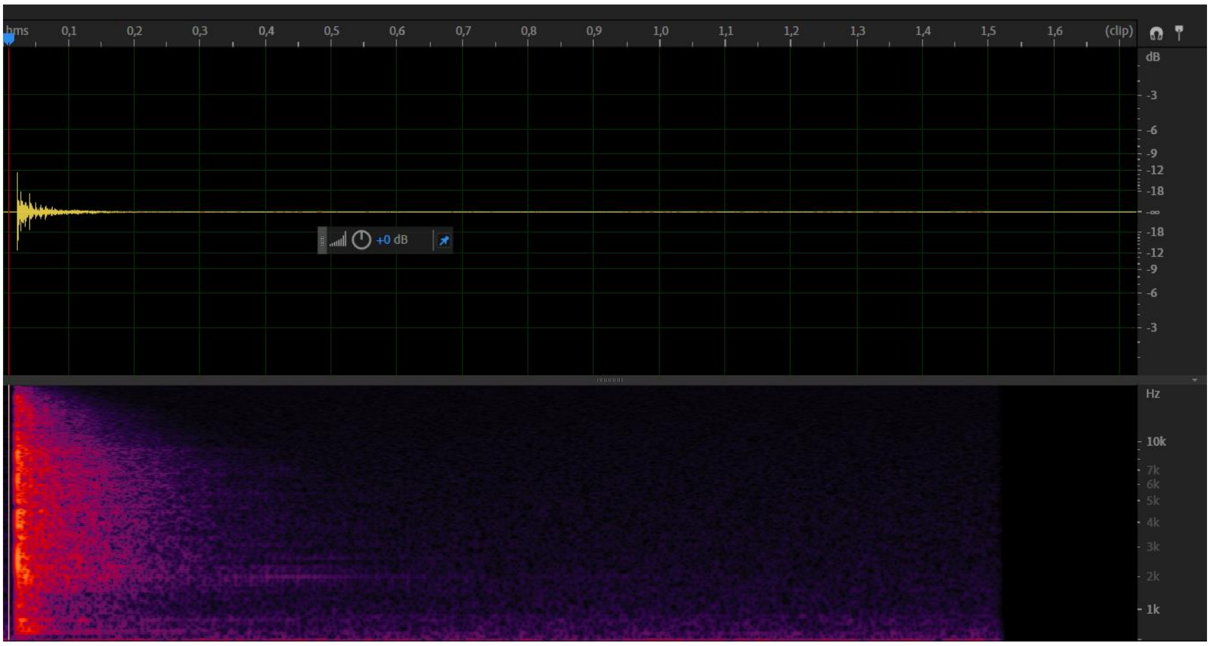
Magnitude test baseline



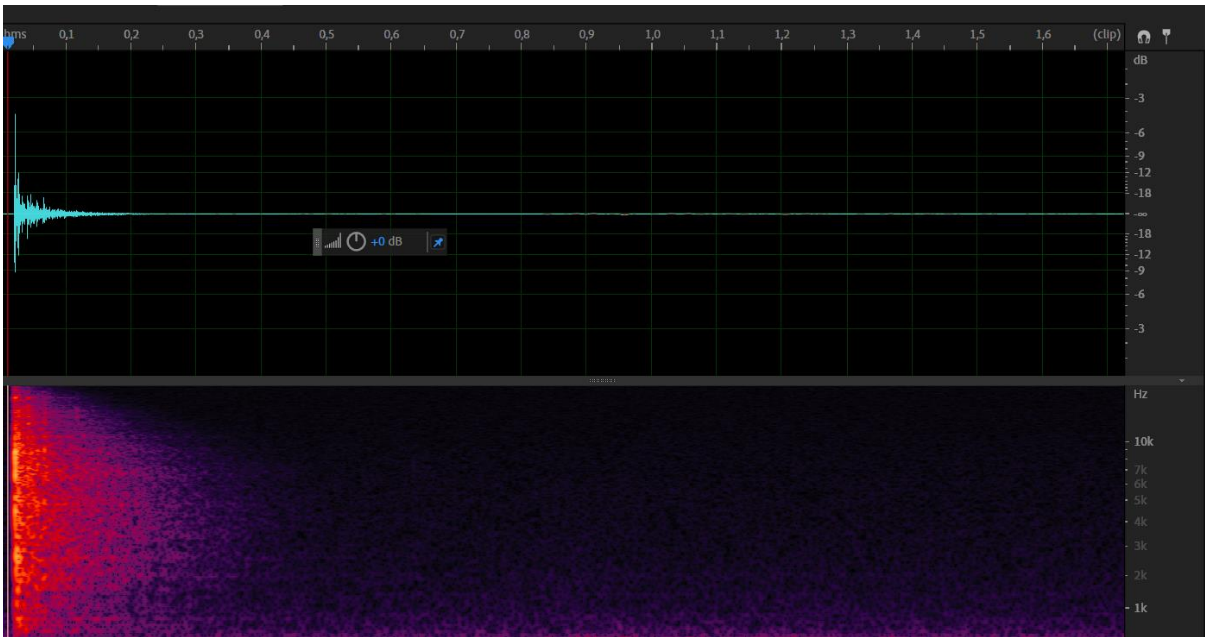
reverberation test spot 1



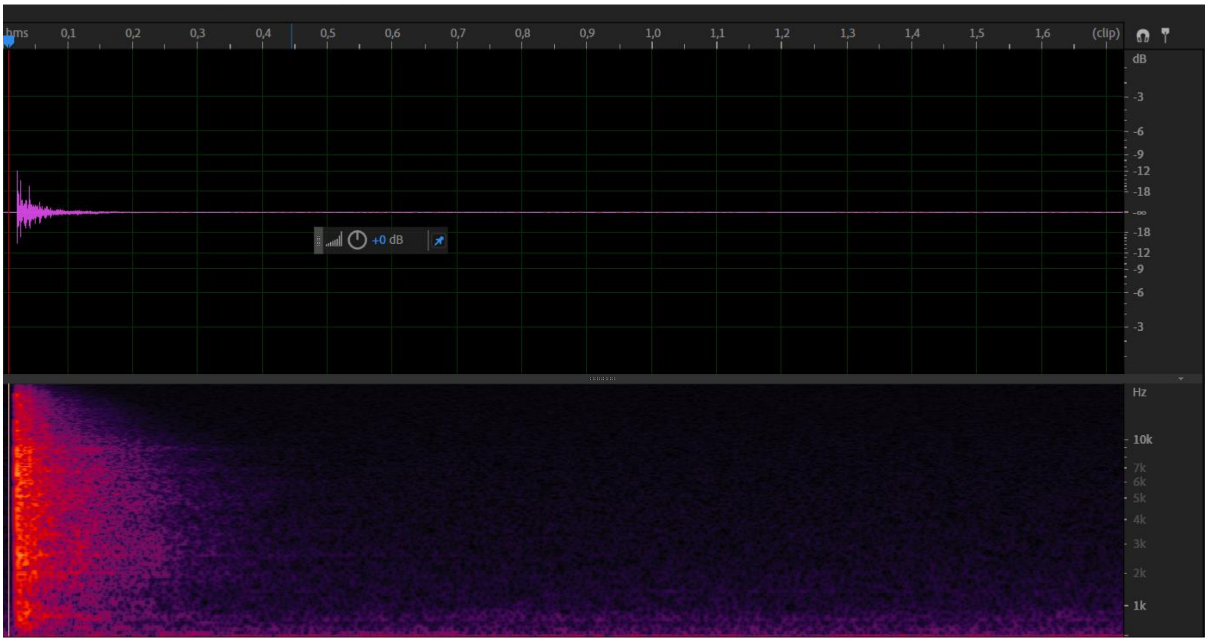
reverberation test spot 2



reverberation test spot 3



reverberation test spot 4



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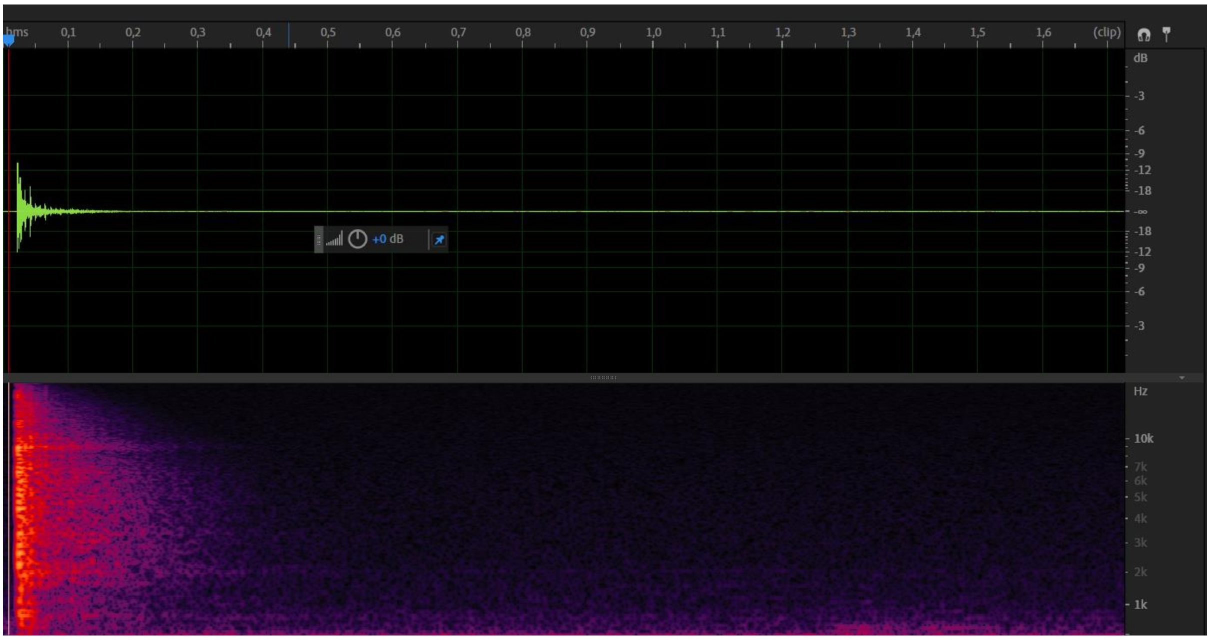
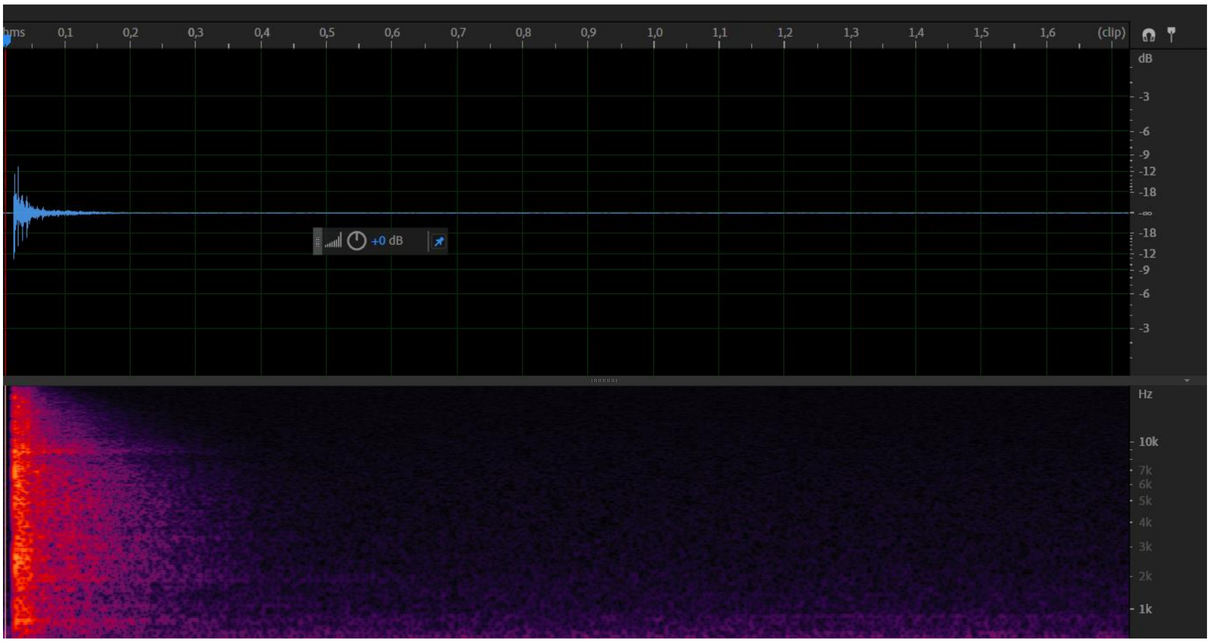
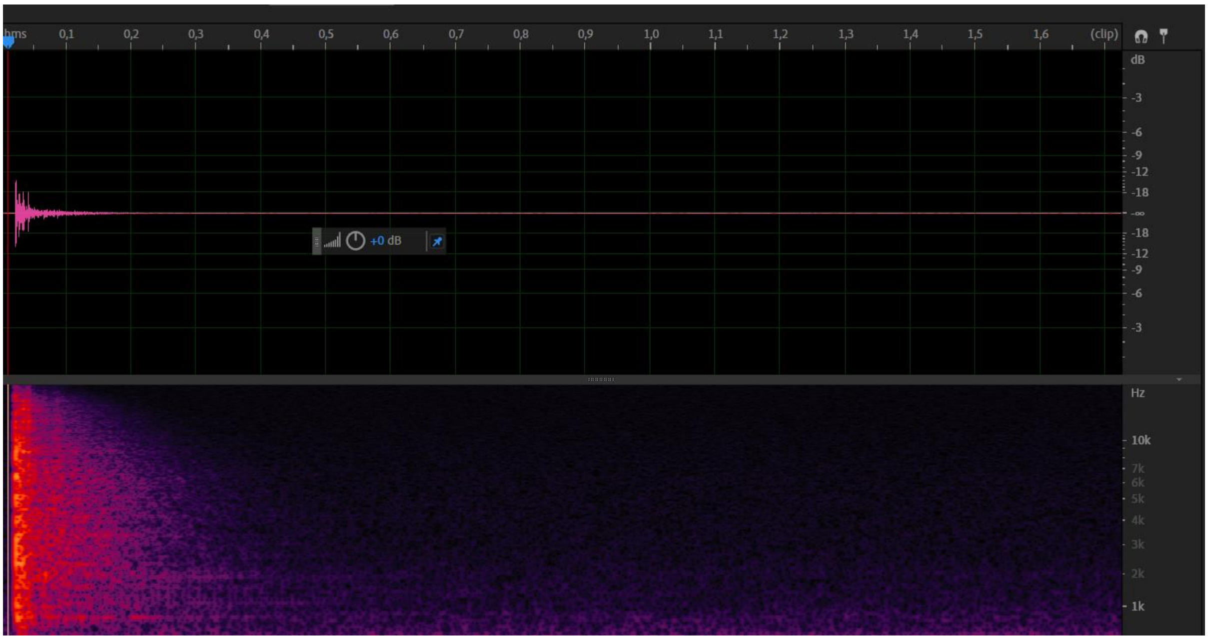


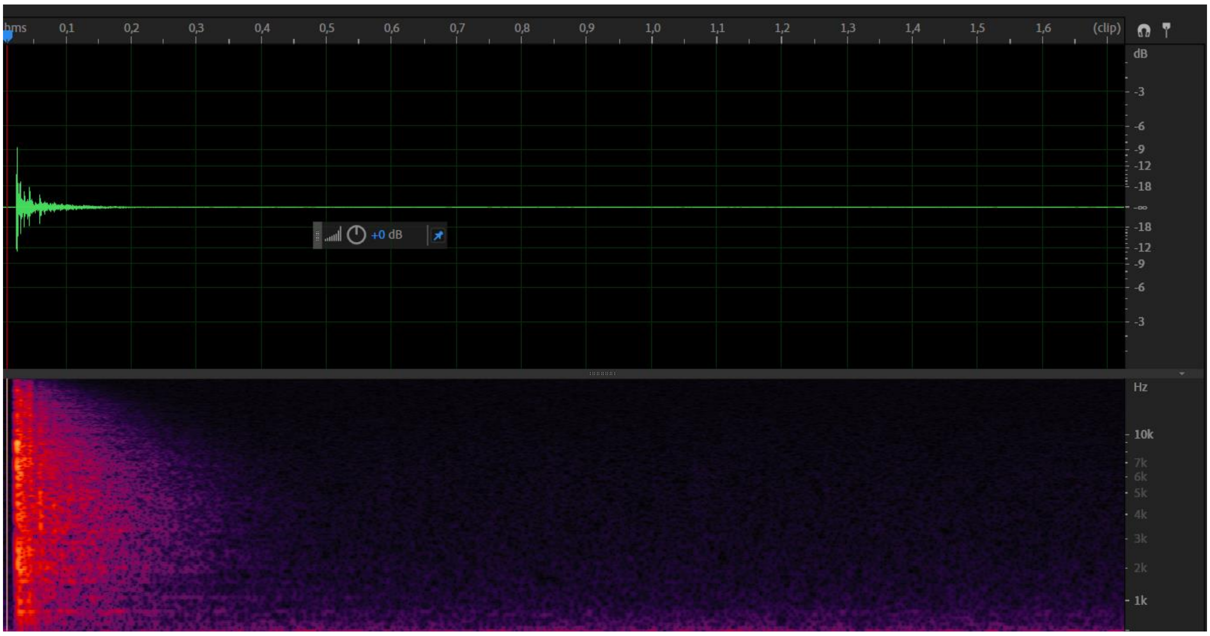
reverberation test spot 6



reverberation test spot 7



reverberation test spot 8



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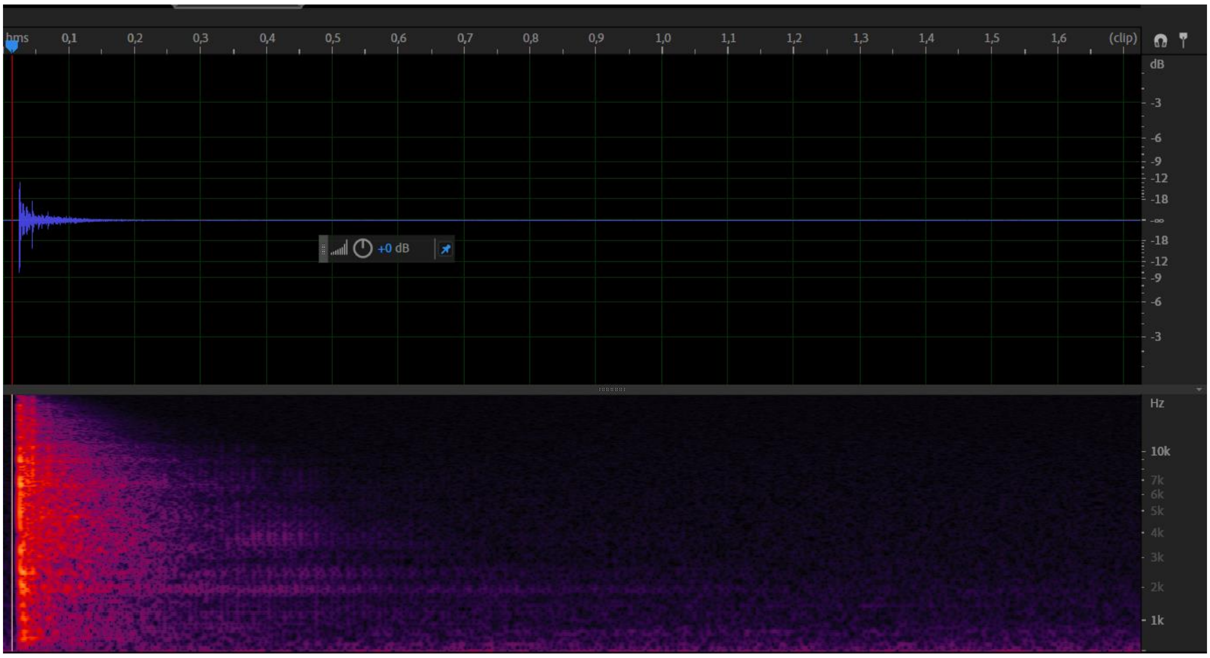

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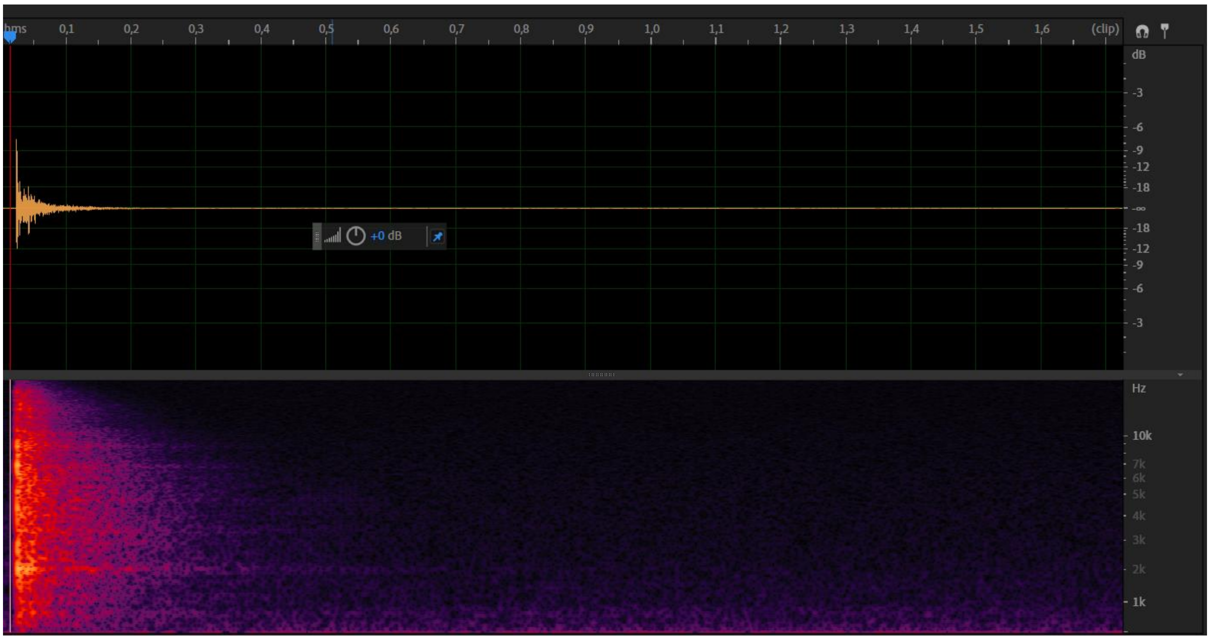

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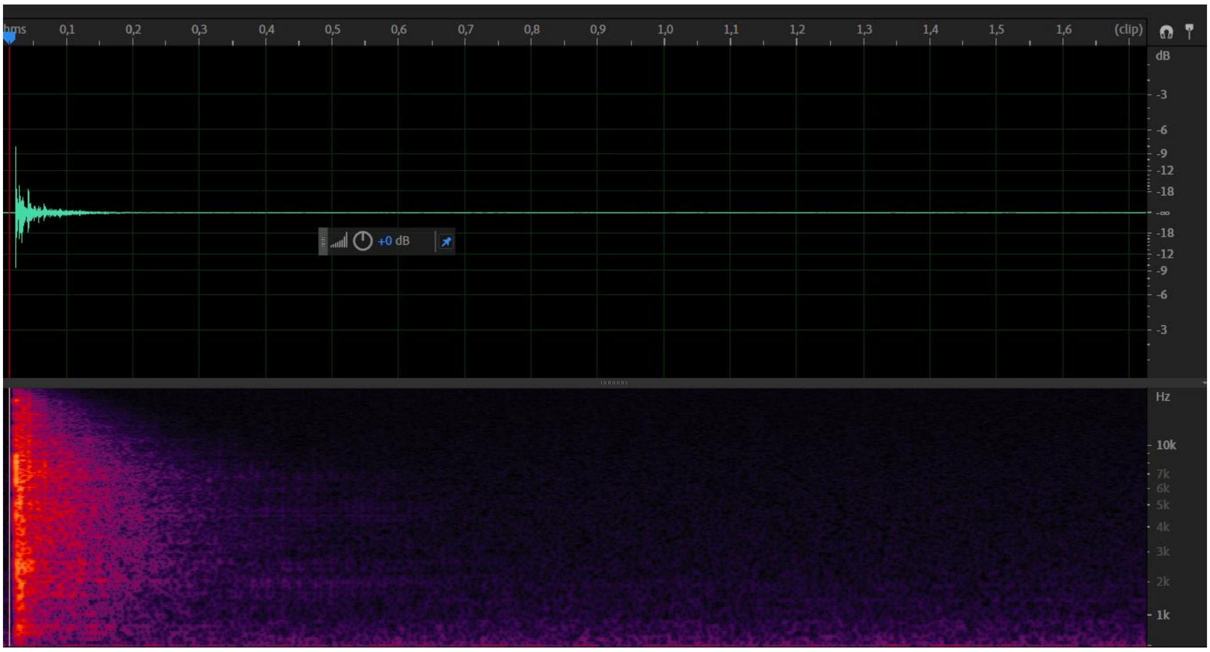

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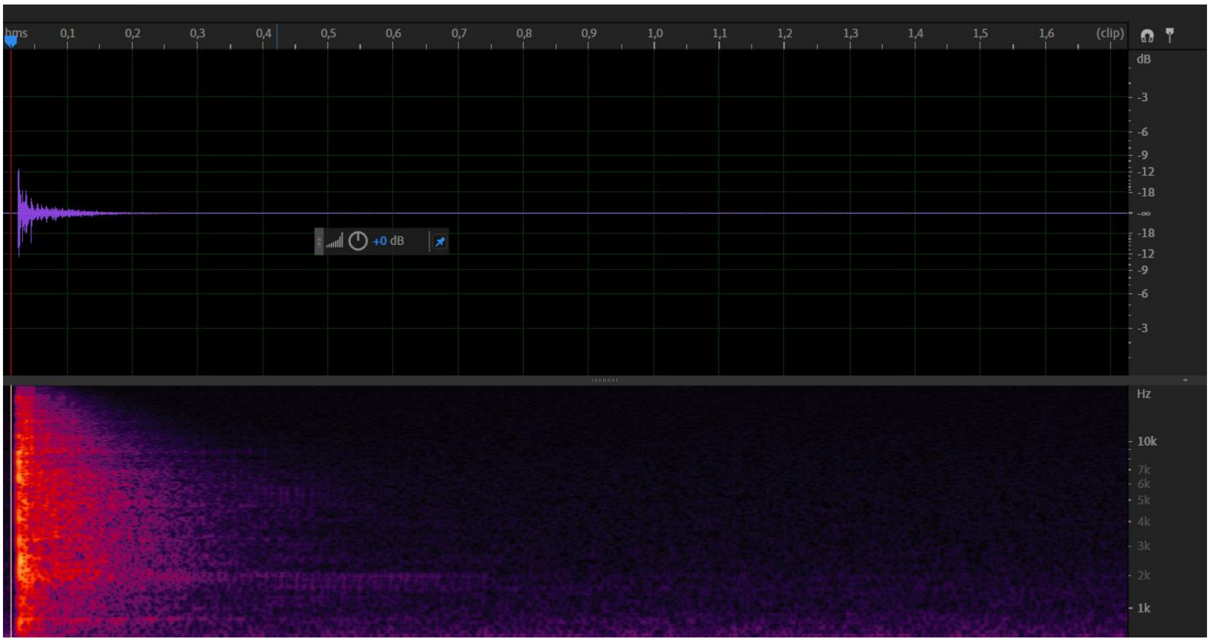

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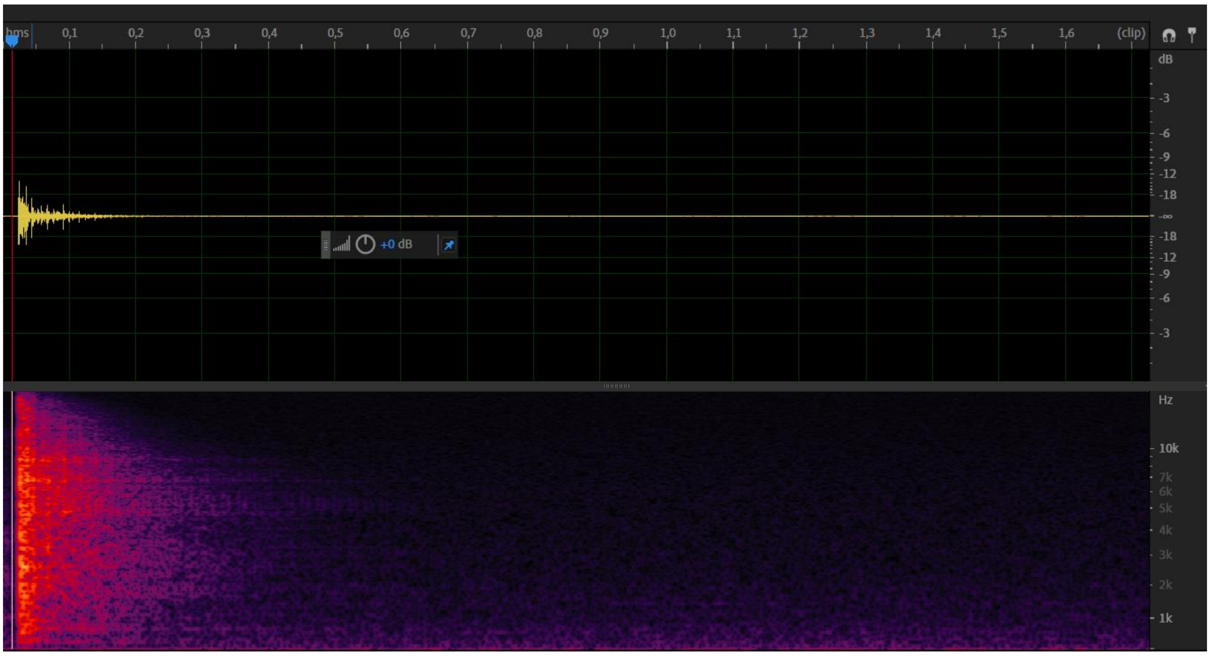

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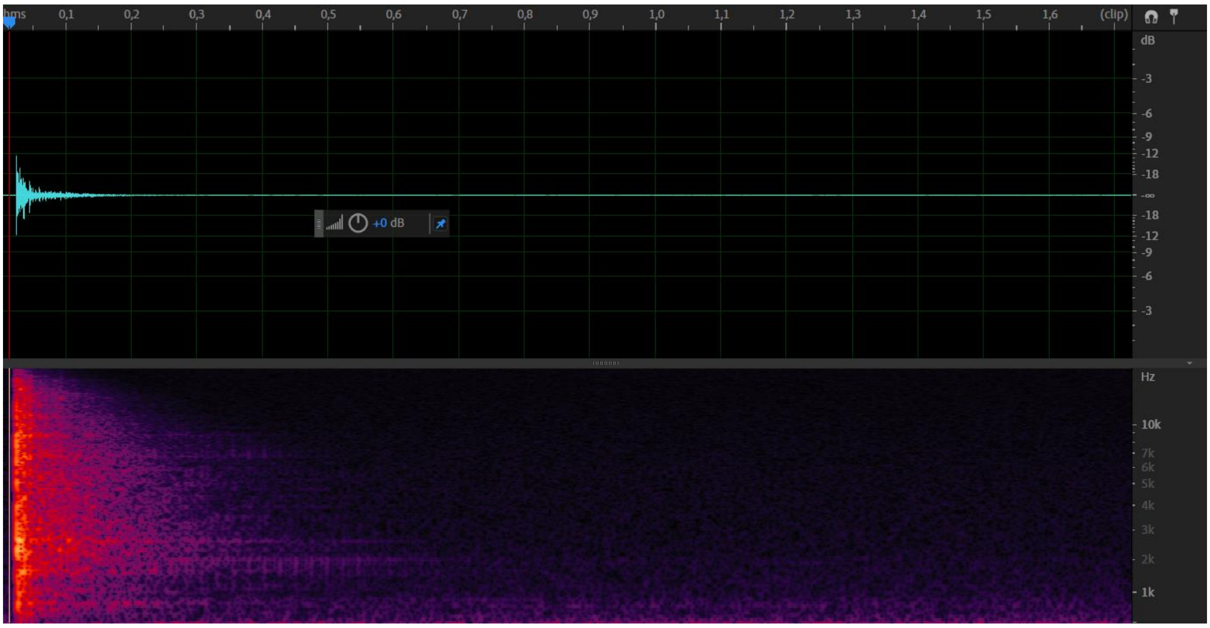

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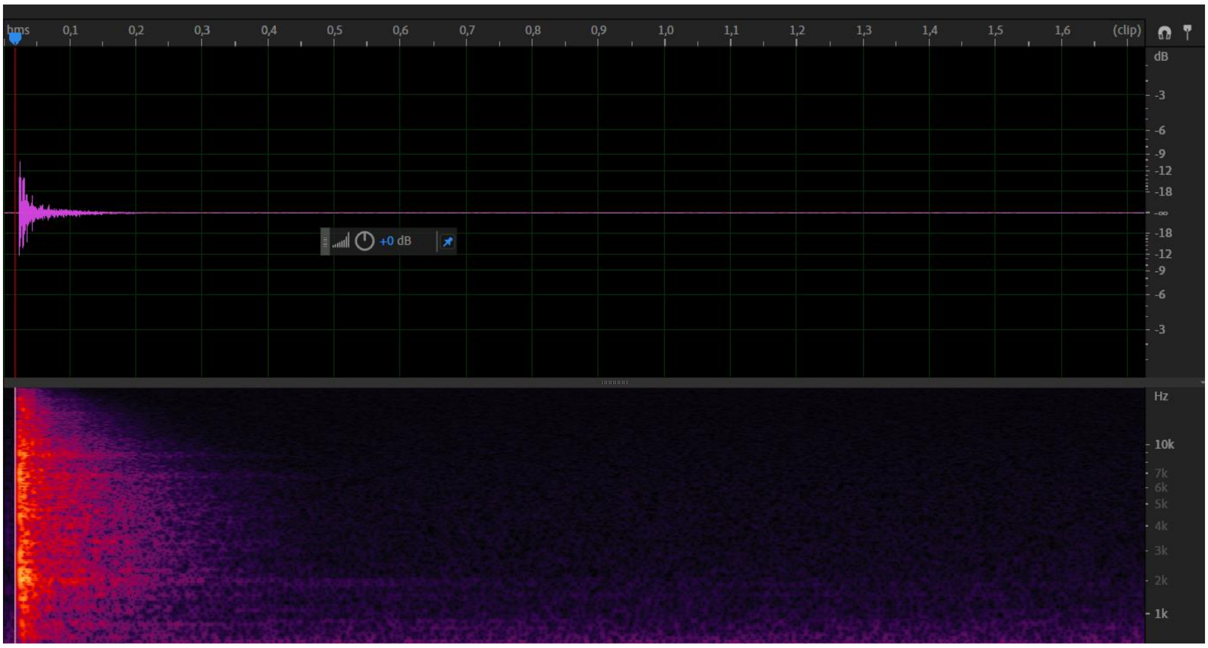

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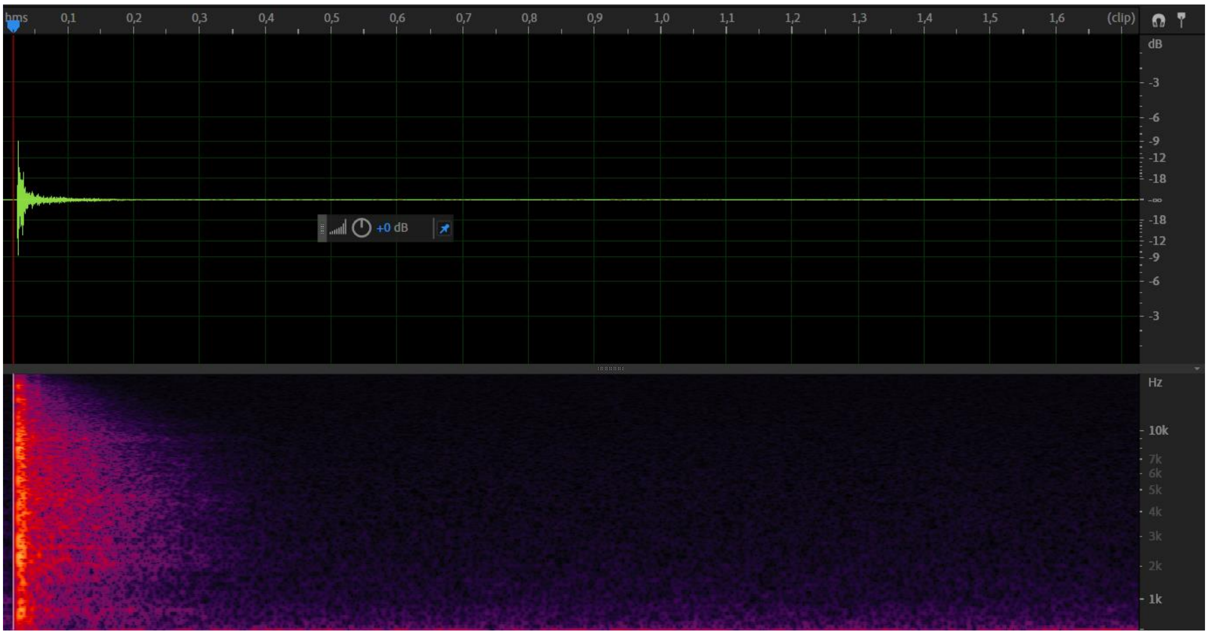

reverberation test spot 17

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