Audio Theory and Acoustics

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Studio Design Project

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Contents

Project Summary

This design brief outlines detailed plans to convert an existing room in the home of a client into a music studio, suitable for recording and mixing live music performances.

The room chosen for this project is located on the ground floor of the building, as it is well insulated, and its shape is ideal for conversion into two separate booths. One of these will be suitable for recording live sound, and the other will be used as a control room and mixing studio.

The room is in dual-purpose use as a spare bedroom and as storage for construction equipment.

The conversion aims to preserve the existing storage function of the room, while providing easy access to musical equipment and recording space, however and whenever needed by the artist.

Room Dimensions

The dimensions of the room as it currently stands are stated below:

Length: 4.97m

Width: 2.62m

Height: 3.40m

The chosen room is rectangular in shape, with a surface area of 77.65m^2 and a volume of 44.27m^3 :

Surface Area	=	2 (4.97 * 2.62) + 2 (3.40 * 2.62) + 2 (3.40 * 4.97)	= 77.65m^2
Volume	=	(2.62 * 4.97 * 3.40)	= 44.27m^3

Room Description

A large bunk bed is positioned in one corner of the room and a thin wooden door located on the adjacent wall. A small cupboard sits near to this door, opposite to the bed. This will remain in the room and be restated for the purpose of storing musical equipment.

Walls in the room consist of 2 pairs of parallel surfaces. The ceiling is flat, forming a rectangular space. The 2 smallest walls in the room are constructed out of brick, and have been plastered and coated with paint. This also applies to one of the remaining walls; however, the final wall is constructed from raw plasterboard and MDF panels.

Peak noise floor of the room was measured to be 48.9dB, with a 1-hour average noise floor of 27.3dB

This measurement was taken using a smartphone and sound level analyzing software during daytime hours, when there were numerous factors contributing to external noise propagation in the room. This level of noise is regarded as being adequate for recording music in a studio *(What is a good signal to noise level/noise floor?).* Ideally, the maximum noise floor for this room would be maintained below 65dB. Since this conversion project will decrease the noise floor of the room, this will be achieved without further noise level considerations.

Desired Acoustic Properties of the Studio

Desired acoustic properties differ between the 2 separate booths:

Ideal acoustic properties of both the mixing studio and recording booth include a low reverb time and an unbiased, flat frequency response. These characteristics are desirable in a mixing environment, as they result in accurate representations of recorded sound, with little influence from reverb and other noise. However, a short reverb time in the recording studio is more suited to recording contemporary music and percussion, as orchestral music is usually written and performed in large concert halls, with a long reverb time greatly influencing the character of the sound.

This project also aims to achieve the lowest possible noise floor in both rooms, so that the processes of recording and mixing audio can be precise and accurate.

Noise Theory and Issues in the Room

Most of the noise problems in this room are the result of airborne sound energy transmission, but the most invasive sources of noise are structureborne, such as the sound of water running through the pipes underneath the floorboards. These are usually low frequency sound waves and require isolation from the studio in order to mitigate their propagation into it.

Structureborne sound refers to sound energy which is generated by an impact force through any medium other than air, such as hitting a nail with a hammer *(Structure-borne sound)*, while airborne sound refers to sound energy which is transmitted directly through the air *(Airborne Sound)*. These are closely related, and only differ in terms of the material and density of the medium through which sound energy is transferred *(Airborne noise vs. Structure-borne noise).*

Existing origins of potentially problematic noise in this room consist of internal and external sources:

Creaking Floorboards	Internal	Momentary	Structureborne
Water pipes	Internal	Momentary	Structureborne
Incandescent lightbulb hum	Internal	Constant	Airborne
Radio Playing in the adjacent room	External	Momentary	Airborne
Planes flying overhead	External	Momentary	Airborne
Sirens outside	External	Momentary	Airborne
Traffic outside	External	Momentary	Airborne
Doors slamming in the building	External	Momentary	Structureborne
Birds singing outside	External	Momentary	Airborne

Solutions to Noise Issues in the Room

As outlined above;

External noise issues present in the room include sound energy generated by road traffic and sirens outside. There is also an unpredictable level of sound energy propagation from people talking and moving in the adjacent room. These issues can not be resolved at their sources, and must be addressed through adequate insulation and isolation of the room and the equipment within it. These treatment methods will not only absorb sound energy before it reaches the interior of the room, but also decouple the room from surfaces through which noise can travel, resulting in cleaner recorded sound.

Internal noise problems in the room include the constant hum of incandescent lightbulbs, which is to be addressed by removing the existing fixtures and replacing them with LED lights. The existing bulbs generate a significant level of heat and sound energy. Combined with the lack of proper ventilation in the room, this results in an uncomfortable working environment. Replacing these with LED lights will help to minimize both problems, increasing the room's energy efficiency and decreasing the cost of supplying electricity to the room *(How Energy-Efficient Light Bulbs Compare with Traditional Incandescents)*.

Another contributing factor to noise problems in the room is caused by creaking floorboards. This is momentary noise which has the potential to ruin an otherwise perfect recording take. The cavity directly beneath these floorboards will be padded with acoustic insulation*)*, as there is a significant volume of air in this space. This has been demonstrated as an effective method by which to absorb sound energy and will prevent its transfer to and from the room below *(Underfloor Insulation Of Suspended Timber Floors).*

Wood filler will be applied to seal the air gaps between floorboards. After this procedure, the entire floor will be set with acoustic carpet underlay *(MuteMat^{TM} 2),* followed by a layer of thick carpet. This will greatly improve the overall comfort of the room, in addition to further decreasing the levels of energy transmission into the basement below.

The most significant source of noise in the room is water running through pipes underneath the floorboards. This results in constant noise propagation, and occasionally produces a percussive water-hammer sound, which must be eliminated. In order to address this problem, the pipes running below the room will be disconnected from the rest of the building's plumbing system. This is not ideal, as it will result in a disrupted hot water supply in one area of the building. However, this procedure is necessary in order to achieve optimal acoustic conditions in the room and to ensure that the room stays cool during recording sessions.

Almost all the noise in the room is ultimately airborne, even when originating through structureborne energy transmission. For this reason, in order to achieve optimal acoustics, every piece of equipment involved in the creative process must be suitably isolated from potential sources of noise, including feedback and undesirable reverb.

In planning a studio conversion in an existing room, it is vital to consider not only external noise spilling into the room, but also sound energy transferring from the studio to the rest of the building. The room chosen for this project is located within a semi-detached residential building, meaning that without proper isolation, significant levels of sound energy generated in the studio would transfer to the neighbouring apartment, potentially leading to noise-level violations or complaints.

Reverb Theory and Measurements in the Room

In audio theory, reverb time (or $RT_{(60)}$) refers to the length of time taken for sound energy at a specific frequency (usually 500Hz) to decay by 60dB. This standard originates from Sabine's observation of the loudest standard concert crescendo being roughly 100dB. Decaying by 60dB to reach a sound pressure level of 40dB, this would become indistinguishable from background noise *(Modern Architectural Acoustics' Founding Father*). Sabine's formula provides the standard equations by which to calculate the reverb time of any space. An $RT_{(60)}$ of between 0.2s and 0.5s is considered ideal for a recording studio, depending on what styles of music are being recorded *(Reverberation time in control room, RT60).* A longer reverb time is generally better suited to slow-moving classical music, and can cause faster and more transient music to feel oversaturated and muddy.

Using Sabine's formula, theoretical reverb time of the room as it currently stands can be calculated as follows:

$$\text{Time (s) to decay by 60dB} = ((24 * \ln(10) / 343) * \text{Volume}) / \text{Surface Area}$$

$$RT_{(60)} = (0.161 * \text{Volume}) / \text{Surface Area})$$

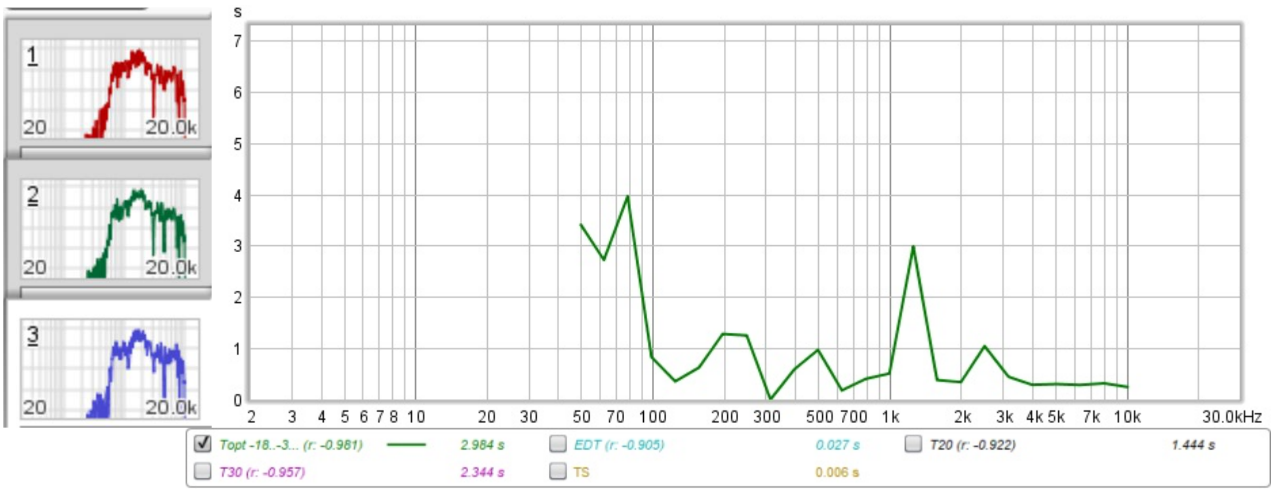
$$RT_{(60)} = (0.161 * 44.27) / 77.65$$

$$\therefore RT_{(60)} = \mathbf{0.09s}$$

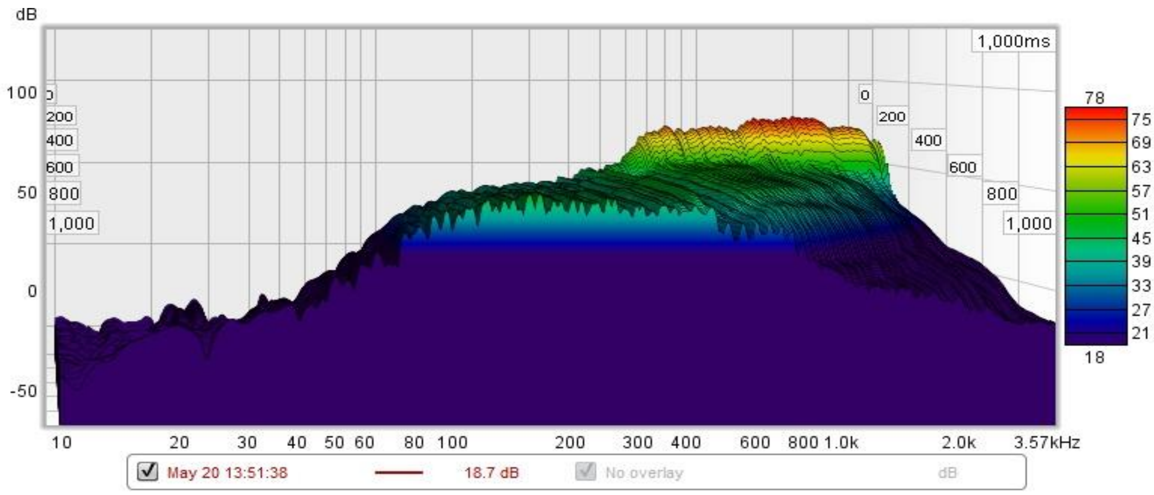
The reverb time ($RT_{(60)}$) of the room was also measured through 2 separate digital techniques. Firstly, sound energy was projected into the room in the form of a sine sweep and its response time measured by computer software (RoomEQWizard). Following this, a balloon was popped in the room and was measured in the same way. Both projections of sound energy were made from the center of the room. This method allows reverberating sound energy to be measured from all directions of the room equally. Using this software, he average $RT_{(60)}$ measurement in the room was calculated to be around 100ms.

The sine sweep method is in some ways preferable to the standard balloon pop measurement. One reason for this is that the technique aims to project all frequencies of sound within a certain range equally. This usually results in more reliable data and is easily repeatable. The balloon pop method, in contrast, generates a different waveform for each test, making calibration and precise measurements difficult. Included below are graphs displaying results of a sine-sweep reverb test in this room.

Graphical representations of the room's acoustic characteristics



This graph shows that the room has resonant frequencies at around 80Hz, 200 Hz, 500Hz and 1.2kHz



This graph shows that higher frequency sound waves are absorbed quicker than low frequency waves

Absorption Theory

Different materials have varying acoustic properties due to many factors, including their density. In acoustics, the absorbance of a material refers to its ability to absorb sound energy and convert it into heat. This varies with the energy level of any incoming wave, therefore it also varies with the frequency at which the wave is oscillating. This property is a crucial factor for consideration when designing and constructing any acoustic space. For this reason, the suitability of acoustic panels in a studio depends on the specific resonances present in the room.

Room Modes and Standing Waves

A room mode is an acoustic phenomenon, demonstrated when the wavelength of a sound wave relates in a specific way to the separation distance of 2 reflective surfaces between which it is projected. When the 2 surfaces are separated by a distance equal to a multiple of half the wavelength of this wave, its amplitude will increase, due to a phenomenon known as interference *(Interference of Waves)*. This leads to static, high-amplitude antinodes in the room. An antinode is a point on a wave where the amplitude is greatest, whereas a node describes the opposite. This form of wave is known as a standing wave.

These waves can present problems in a studio, as these high-pressure antinodes often result in undesirable resonances. It is physically impossible for a room to exist without modes. This project aims instead to mitigate the undesirable effects of the modes found in the room.

In a standing wave, nodes can always be found at the furthest points from the centre of the wave, as well as throughout the wave at equal intervals from each other. These waves can present problems in a studio as they often result in undesirable resonances.

When calculating the location of modes in a room, there are 3 varieties which must be considered. These are known as axial, tangential and oblique room modes, describing the same phenomenon taking place with different direction of wave travel. Axial refers to modes which collect energy in a single dimension in relation to the room, and tangential and oblique refer to 2-dimensional and 3-dimensional modes respectively.

There is a significant axial mode in the room at a frequency of 35Hz with 2 high pressure energy zones, one at each end of the room. In order to counter this, an acoustic panel known as a bass trap will be installed in the recording booth at this position. This will help to absorb low frequency sound energy and prevent this room mode from influencing the quality of recorded sound

Further Procedures

In order to separate the space into two rooms, a self-insulating brick wall will be constructed in the center of the room. This wall will consist of 2 layers of bricks, with an air gap between them. Within this wall, a double-glazed glass window will allow visual communication between the control room and the recording booth. Acoustic curtains will be hung from the open space between the two rooms

(Metal Moondream Sound Insulation) allowing easy and quick access between them. The dividing wall will be lined with carpet underlay, in order to absorb sound energy which would otherwise reverberate directly off the brick surface.

The entry door to the studio will be replaced with an acoustic door built from steel *(Airborne noise vs. Structure-borne noise),* also layered with acoustic carpet underlay for the same reason as stated above for the dividing wall. Around the outside of this door will be installed door seals to insulate the room from the air outside *(DIY Seal Kit 2 – Double Door).*

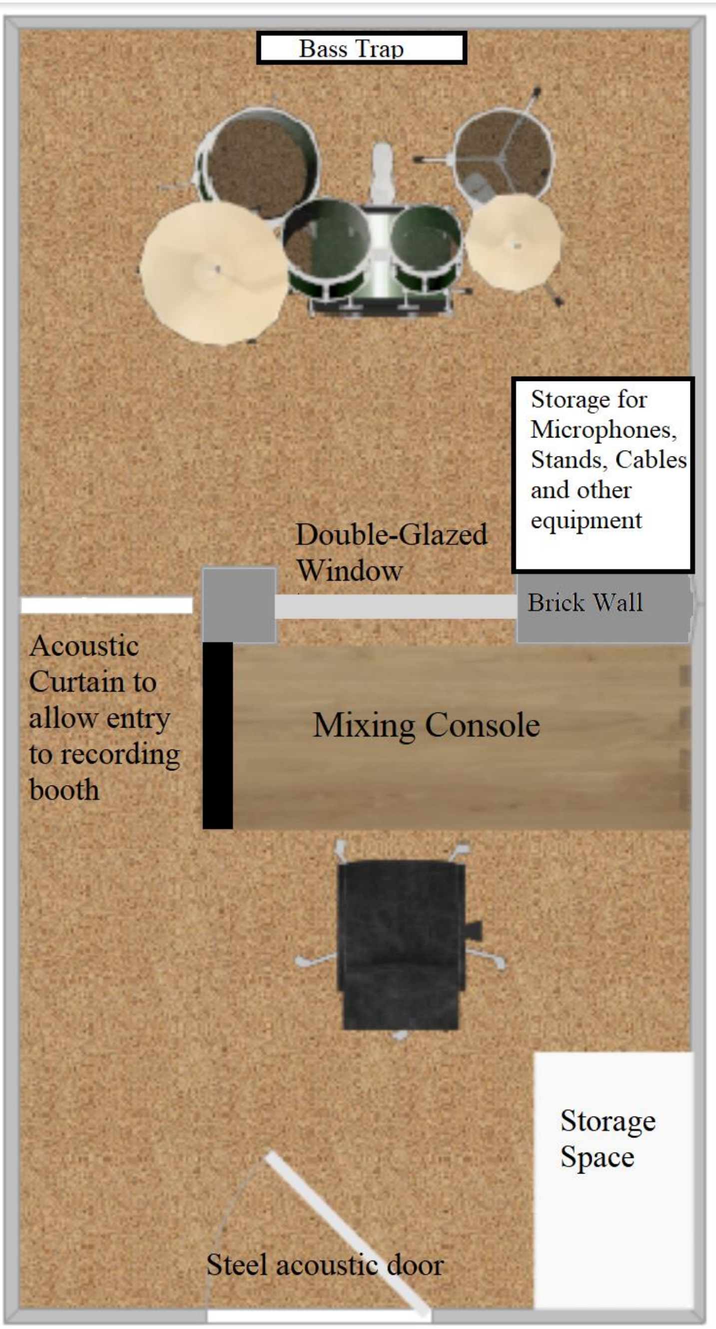
At this stage of the process, electric cabling will be installed beneath the floorboards, in a section of the floor with loose carpet and hollow crawlspace. This will act to futureproof the studio, as it will allow repairs or upgrades to take place in the future without significant difficulty.

As established above, this design combines suitable acoustic properties in a comfortable performing and mixing environment. It is essential for any studio to provide a warm atmosphere which stimulates creativity.

In the mixing room, 2 sets of 3 strong steel cables (wire rope) will be affixed securely to the ceiling. These will be contained within thick rubber tubing. Using counterweights and pulleys, monitor speakers will be hung from these, applying the same techniques demonstrated in weight and chain windows *(How Weight and Chain Windows Work).* A permanent winch system will be installed and used by the producer to raise and lower the speakers precisely to position them perfectly, so the stereo field is accurate. They will be positioned in an ideal position to avoid modes and well Isolated from the walls of the room *(How To Position Your Studio Monitors For Optimal Sounding Results)*This will decrease transmission of low-frequency waves into the surrounding rooms, as the surface area for structureborne energy transmission is significantly smaller than that on a standard speaker mount. In addition to providing acoustic benefits, this system will allow the speakers to be safely stored above the rest of the room when not in use as a studio, further reinforcing the multi-purpose functions of the room.

Ideally, a well isolated recording studio would include a floating studio design, meaning that the walls and floor would be elevated from the containing structure using elastic materials in order to decrease the amplitude of energy transmissions from the surrounding rooms. However, this approach to studio design is overly expensive and requires a specific room shape to achieve, and therefore is not suitable for this conversion project.

Diagram of the completed studio design



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