Assignment Title: Audio Studio Design

Module: VEPT20012

Acoustic & Electronics

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Contents

Introduction

This Report aims to understand what is needed to build a studio. By seeing what acoustical issues there are, how to reduce them and why they are issues. While designing a studio with the knowledge gained from the research in acoustics; by choosing what kind of equipment and planning are necessary to build a studio.

1. Main Body

1.1 Room Modes

Standing Waves/ Room Modes.

Room Modes are the paths at which the sound can travel around the room, there are driven modes and resonant modes. Resonant modes are more interesting as there are the reason standing waves are created. The fundamental Axial mode can be identified by the fact that half of the wavelength can fit in the room between two parallel walls. An example being if the length of the room was 10m then the wavelength would be 20m. The reason why this creates a standing wave is because when the Fundamental Mode bounces back it makes an identical clone wave which then intertwines with the original wave and creates phase. (Newell, 2017) (Figure 0.9) (Figure 1.0) (Physicsclassroom, n.d) (Ballou, 2015) (Everest and Pohlmann, 2014)

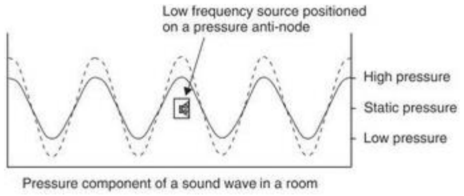


Figure 0.9 Standing Waves

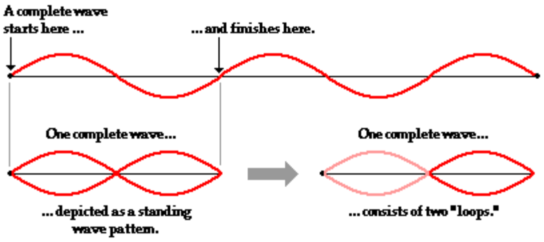
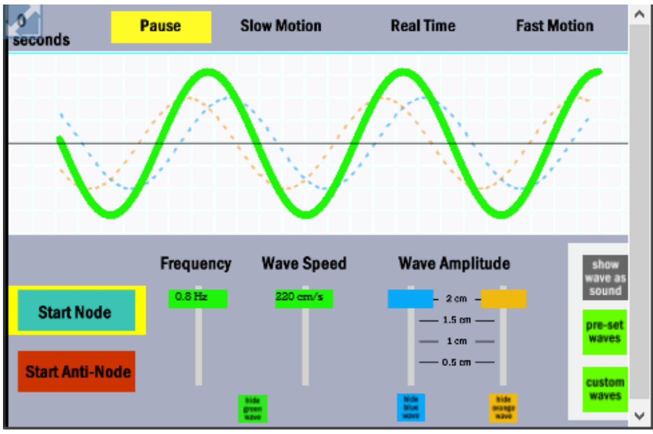


Figure 1.0 Half wavelength

With simple maths it is possible to find the fundamental frequency just by knowing the length of the room. By using the equation 344/2x(1/L). So, if the room's length was 10 meters. Then using the equation, 344/2x(1/10), the answer would be 17.2Hz. (Appendix 1)

Room Mode Issues.

Standing waves have points from the start to end of the wave, that seem to be standing still. These points are known as Nodes(a); then there are also other points that are placed at the maximum positive (Crest) and negative (Troughs) displacements which is the opposite of nodes, referred as Antinodes(b). Standing waves always consist of Nodes and Antinodes and they are always located at the same points. (Figure 1.1) (Physicsclassroom, n.d)



(a) Blue line: Nodes. (b) Red Line: Antinodes

Figure 1.1 Nodes and Antinodes.

What makes nodes and antinodes an issue is because they interfere with a room's response by adding and taking away frequencies. As Nodes are areas of cancellation and antinodes are reinforcement areas of a standing wave. By using a closed pipe of 2-ft long as an example. Firstly, it is best to find the fundamental resonant frequency of the pipe, which is $f^1$86Hz (344c/4ft = $f^1$86Hz) (Appendix 1). If someone were to stand in the centre of the pipe, it will be quieter compared to the ends of the pipe, As the node is in the centre of the pipe while the antinodes are at the ends. Which influences the sound to be inconsistent in volume. (Figure 1.2).

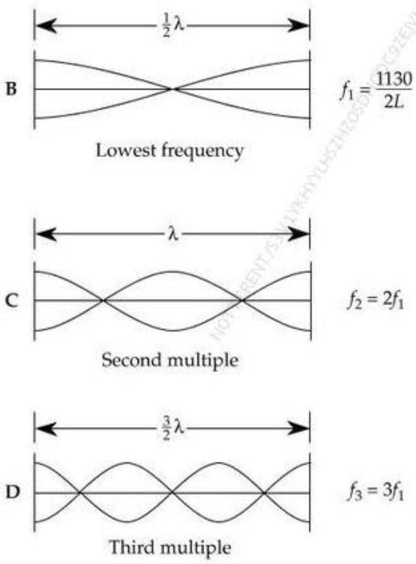
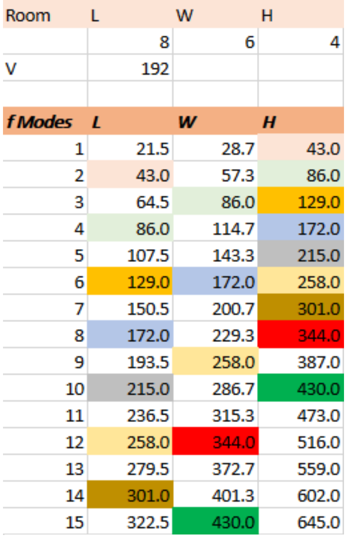


Figure 1.2 Fundamental F and multiples of F1

This equation and understanding can be applied to a room, but the main difference is that a room is three-dimensional, so the node and antinode problems are at the width, length and height as well. (Everest and Pohlmann, 2014).

The room dimensions are a major factor in to the modal response of a room. if a room's dimensions are multiples of each other, this will cause modes to be twice as bad. Here is a poor room dimension; **L, 8m. W, 6m. H, 4m**, the calculator shows that there a lot of multiples within the modes (Everest and Pohlmann, 2014) (Figure 1.3). Which means the low end of this room would have an uneven response.



Room	L	W	H
	8	6	4
V	192		
f Modes	***L***	***W***	***H***
1	21.5	28.7	43.0
2	43.0	57.3	86.0
3	64.5	86.0	129.0
4	86.0	114.7	172.0
5	107.5	143.3	215.0
6	129.0	172.0	258.0
7	150.5	200.7	301.0
8	172.0	229.3	344.0
9	193.5	258.0	387.0
10	215.0	286.7	430.0
11	236.5	315.3	473.0
12	258.0	344.0	516.0
13	279.5	372.7	559.0
14	301.0	401.3	602.0
15	322.5	430.0	645.0

Figure 1.3 Poor Room Dimensions

Room Mode Analysis.

There are three types of modes. Axial modes (a), that lies between two parallel surfaces.

Tangential modes (b), that lie between four surfaces and move parallel to the other two surfaces.

Oblique modes (c), which targets all six of the surfaces within a room and then travels back to the original point to then repeat itself. (Figure 1.4), (Newell, 2017), (Everest and Pohlmann, 2014).

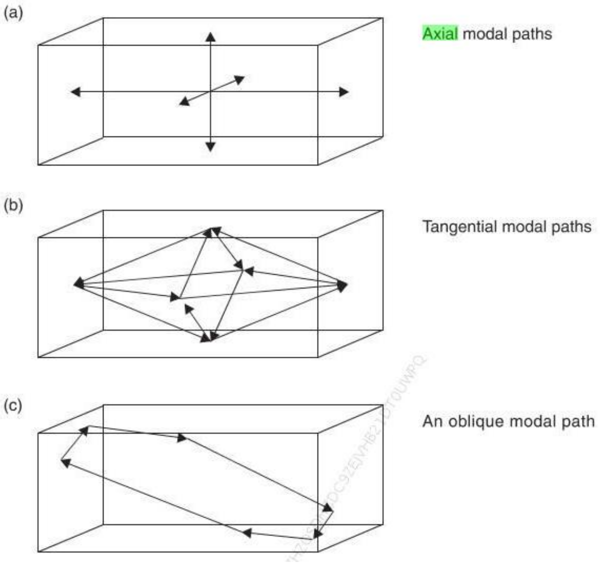


Figure 1.4 Three types of Modes

The issues these modes present is an infinite one. As noise is produced within a room, the space in the room and the walls will become excited which then causes a resonance of frequencies. The first resonance is the fundamental frequency which is followed by $2f^1$, $3f^1$, $4f^1$ and this continues indefinitely. This occurs in all three modal types. (Figure 1.5) (Everest and Pohlmann, 2014).

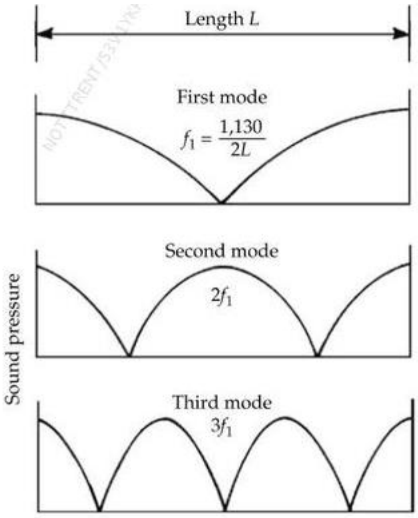


Figure 1.5 Developing Modes

With these equations, the fundamental frequency can be found for the Studio Build. (Appendix 1)

344/ (2*10.574) = 16.3Hz Axial Mode.

344/2*√ ((1/10.574)^{2}+(1/13.022)^{2}) = 20.9Hz Tangential Mode.

344/2*√ ((1/L)^{2}+(1/W)^{2}+(1/H)^{2}) = 54.7Hz Oblique Mode.

Room Mode Solution.

Room Ratios is a method to help reduce modes when designing a Studio. Room Ratios tend to be used early in planning. Because it determines the studio dimensions and helps manage the modes in the Studio. as Everest and Pohlmann (2014. pp.235-236) states that, if the room is small and has little space between each of the modes, the room will be dominated by modal resonances within the audio field. (Salford University, 2004)

The way the Room Ratios work is that the length and width will be multiplied by the height. Shown in (Figure 1.6). if the height was 2.5m then the ratio will multiply the height of 2.5m by L1.25, resulting in; a Length of 3.125m (Figure 1.7) the same is done for width, it will multiply W1.10 with 2.5m resulting in 2.75m. (Figure 1.6).

Ratio		
H	L	W
1	1.25	1.1

Figure 1.6 Room Ratio

Room	L	W	H
	3.125	2.75	2.5

Figure 1.7 Room Dimensions

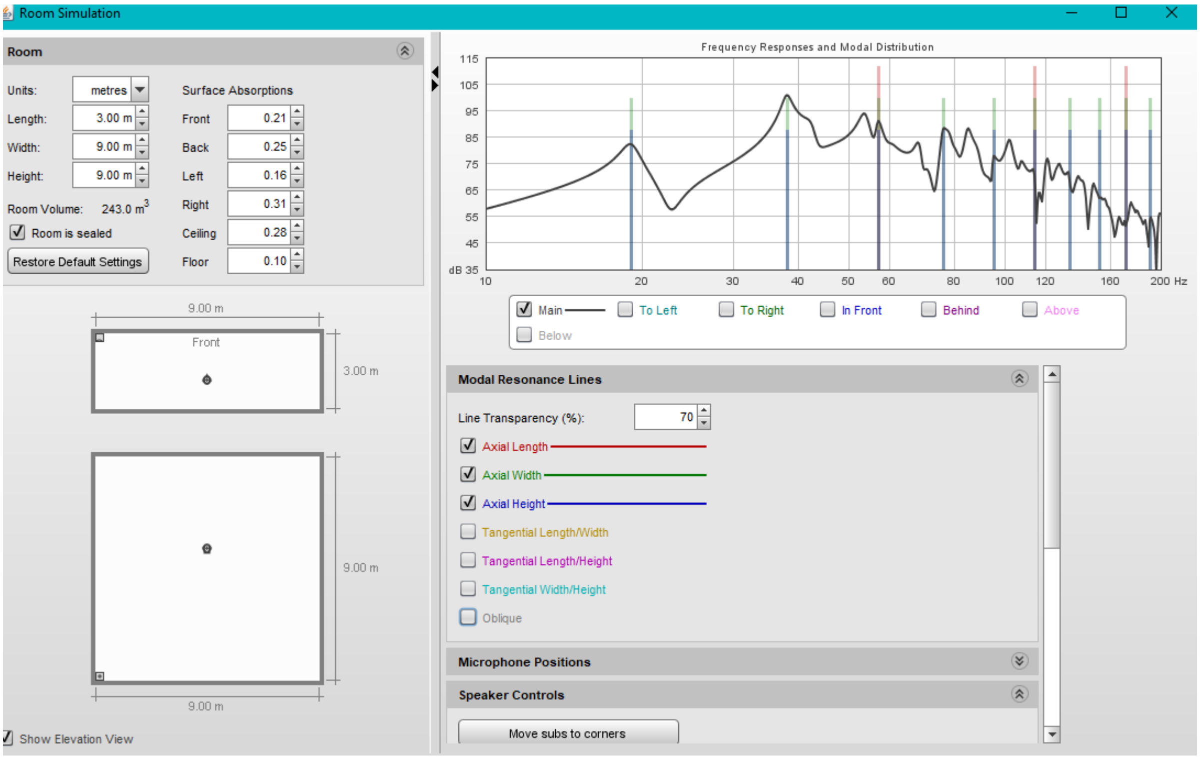
H:1, L:3, W:3 is a poor room ratio because the length and width are the same, thus the room dimensions are also the same. (Figure 1.8) What the duplicate room ratio and dimensions mean for the modal response is that each axial mode sits on top of each other (Figure 1.9), Which means the peaks in the frequency chart will be raised in level exponentially resulting in an uneven low-end resonance.

Room	L	W	H
	9	9	3

f Modes	*L*	*W*	*H*
1	19.1	19.1	57.3
2	38.2	38.2	114.7
3	57.3	57.3	172.0
4	76.4	76.4	229.3
5	95.6	95.6	286.7
6	114.7	114.7	344.0
7	133.8	133.8	401.3
8	152.9	152.9	458.7
9	172.0	172.0	516.0
10	191.1	191.1	573.3
11	210.2	210.2	630.7
12	229.3	229.3	688.0
13	248.4	248.4	745.3
14	267.6	267.6	802.7
15	286.7	286.7	860.0

Ratio		
H	L	W
1	3	3

Figure 1.8 H:1, L:3, W:3 Room Ratio & Axial Modes


Room Simulation

Room

Units: metres

Length: 3.00 m

Width: 9.00 m

Height: 9.00 m

Room Volume: 243.0 m^3

☑ Room is sealed

Surface Absorptions

Front 0.21

Back 0.25

Left 0.16

Right 0.31

Ceiling 0.28

Floor 0.10

☑ Main

☐ To Left

☐ To Right

☐ In Front

☐ Behind

☐ Above

☐ Below

Modal Resonance Lines

Line Transparency (%): 70

☑ Axial Length

☑ Axial Width

☑ Axial Height

☐ Tangential Length/Width

☐ Tangential Length/Height

☐ Tangential Width/Height

☐ Oblique

☑ Show Elevation View

Figure 1.9 H:1, L:3, W:3 Room EQ Wizard Modes doubling

Absorption is the solution to help with room modes and to flatten the response. There are different types of absorbers, such as Porous, Panel and Volume absorbers. It is known that porous absorbers are effective at the higher range of frequency whereas panel and volume absorbers are known to absorb the lower range of frequencies. (Newell, 2017)

As stated by Everest and Pohlmann, (2014. Pp.183) "*The Law of Conservation of Energy states that energy can neither be created nor destroyed. However, energy can be changed from one form to another.*" this means absorbers do not remove sound energy but rather converts it to an energy that is not harmful to the acoustics. With porous and fibrous absorbers, it is best to consider the distance between the wall and absorber, the best distance is at ¼ of the wavelength. This ¼ distance is where the particle velocity is at its peak. (Figure 2.0). (Everest and Pohlmann, 2014) (Newell, 2017). (ehomerecordingstudio, n.d)

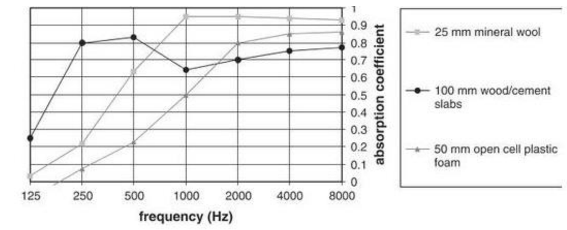


Figure 4.25: Porous absorber fixed directly to a solid wall.

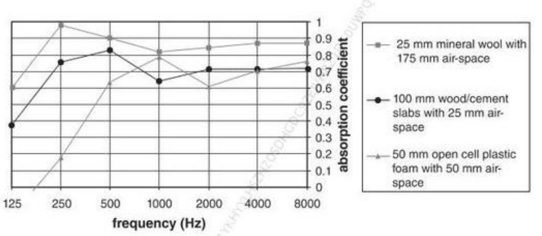


Figure 4.26: Porous absorbers with air space behind. Note the increased low-frequency absorption compared with Figure 4.25.

Figure 2.0 ¼ wavelength distance

In order to find the length of a ¼ wavelength, the equation 344mc/f is used to figure out the length of the wave, which is 30Hz = 11.4 m. The equation afterwards is f/4; 11.4m divide 4 = 2.8m. (Everest and Pohlmann, 2014). (Appendix 2)

The Room EQ can show the effects of applying absorption within the room. By looking at the frequency within Room EQ, the frequency is not flat, from 92.9 Hz and below the frequency is separated by peaks and dips. (Figure 2.1)

(Figure 2.2) shows the frequency being changed by the absorption. The Decibels are significantly reduced at the peaks, most noticeably at 26Hz, 32Hz and 42Hz by 10dB, this is the case with all the peaks through-out the frequency. The dips have also been reduced, most noticeably at 29.8Hz and 117.7Hz.

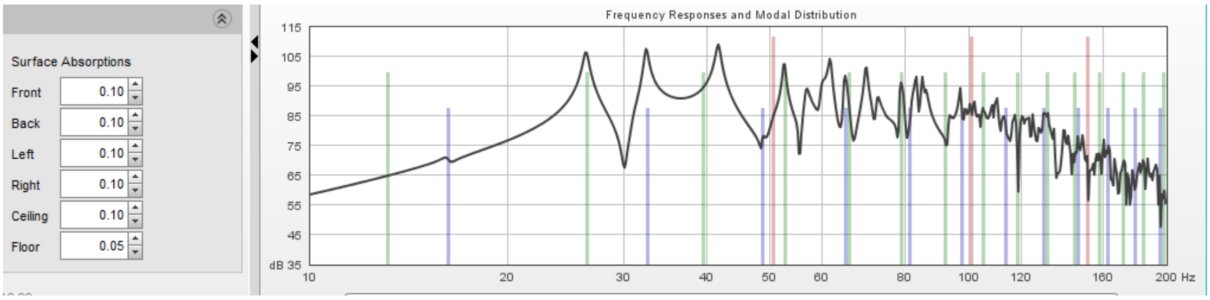

Surface Absorptions
Front 0.10
Back 0.10
Left 0.10
Right 0.10
Ceiling 0.10
Floor 0.05

Figure 2.1 The Room's Frequency bandwidth without absorption

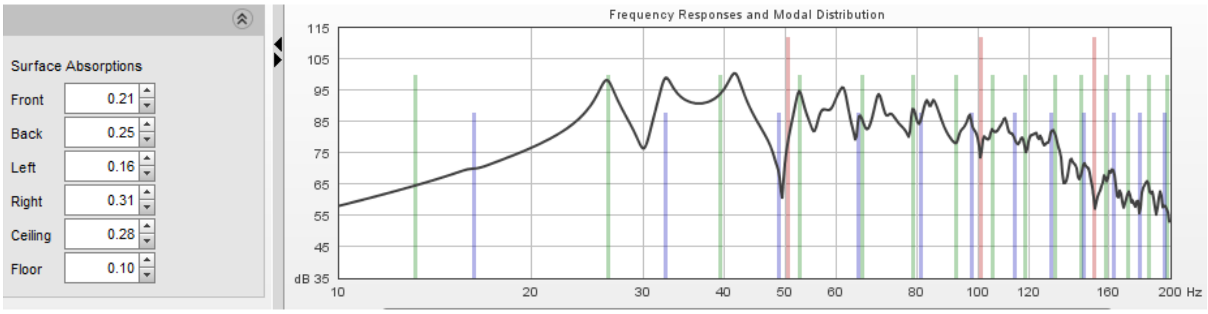
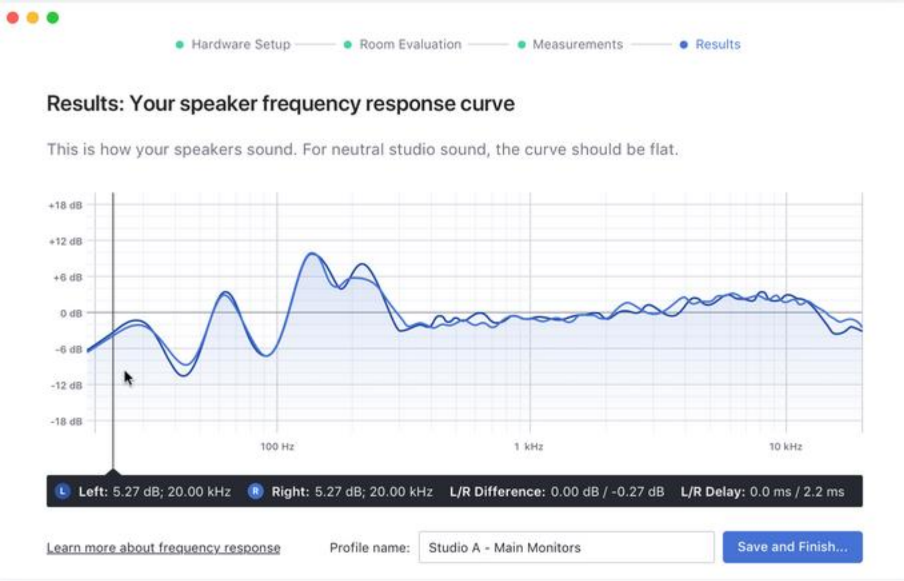

Surface Absorptions
Front 0.21
Back 0.25
Left 0.16
Right 0.31
Ceiling 0.28
Floor 0.10

Figure 2.2 The Room's Frequency bandwidth with Absorption

Sonarworks Reference four is frequency software that is built for loudspeakers and headphones, Reference is implemented in studios as it has the capability to measure the room's frequency response and corrects it to give the listener a flatter response.

The limitation this software has is that it can only correct the listening position, it will not reduce room modes and other acoustical anomalies. So, it is not something to be considered when trying to reduce modes, but is viable after the studio is built, as it will only make the response flatter. This software also effects headphones by accurately making their frequency response flatter. This is the main takeaway from Reference four since headphones lack acoustical interface. (Sam Inglis, 2018) (Sonarworks, N.D) (Figure 2.3)



Results: Your speaker frequency response curve

This is how your speakers sound. For neutral studio sound, the curve should be flat.

Left: 5.27 dB; 20.00 kHz Right: 5.27 dB; 20.00 kHz L/R Difference: 0.00 dB / -0.27 dB L/R Delay: 0.0 ms / 2.2 ms

Learn more about frequency response Profile name: Studio A - Main Monitors

Figure 2.3 Results shown after Frequency Calculation

Diffusion is the practice of trying to distribute the sound source equally through-out the room, while trying to keep the directional sound as well. It is difficult to achieve complete diffusion within rooms, and generally hard to achieve good diffusion in the lower spectrum of the frequency bandwidth, due to modal present within. (Everest and Pohlmann, 2014). What a diffuser does to achieve an even audio field is reflect the waveform back in to multiple weaker phase waveforms (Figure 2.4), not to be confused with Specular reflectors (Figure 2.5), as these kinds of reflectors only reflect the waveform back in a single-phase waveform, in fact most reflective surfaces are typically Specular reflectors. (Lenz, N.d).

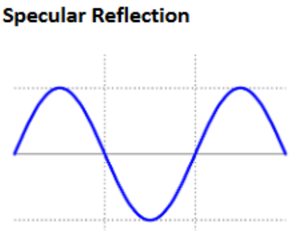


Figure 2.5 Specular Single-Phase Wave

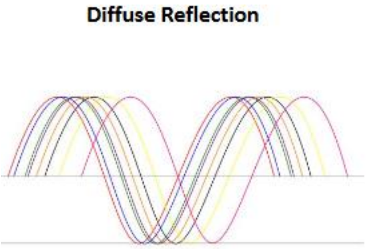


Figure 2.4 Diffusion Multi-Phase Wave

1.2 Room Design

Room Ratios/ Dimensions.

Using the Room Ratio Sheet provided by Salford University, there are multiple ratios to choose from. Listed in three different sections; 50m3, 100m3 and 200m3. For this proposal 200m3 section (Figure 2.8) will be used for the studio, because it has more choices. Because Salford states (Salford University, 2004) that the white areas show the uneven worst ratios and the black areas show the best ratios.

By analysing each 50m3, 100m3 and 200m3 graphs, it shows that 50m3 (Figure 2.6) and 100m3 (Figure 2.7) having larger black spots, but fewer. Also, the black spots are not as spread out compared to the 200m3 (Figure 2.8) thus making it not as good as a choice since there are less options for a room.

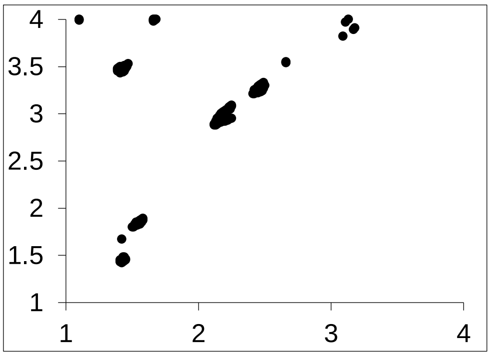


Figure 2.6 50m3

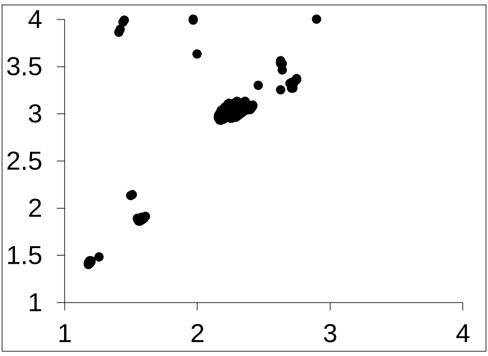


Figure 2.7 100m3

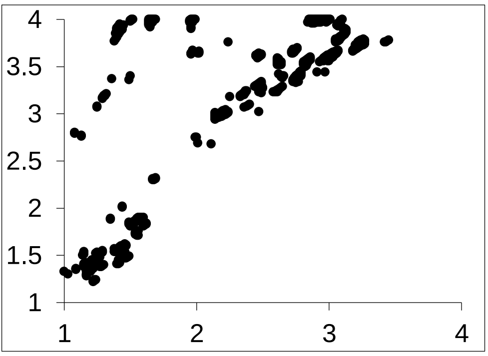


Figure 2.8 200m3

It is time to decide on what Room Ratio to pick from. To find a suitable Room Ratio, the Room Modes Calculator will used with the Room EQ Wizard.

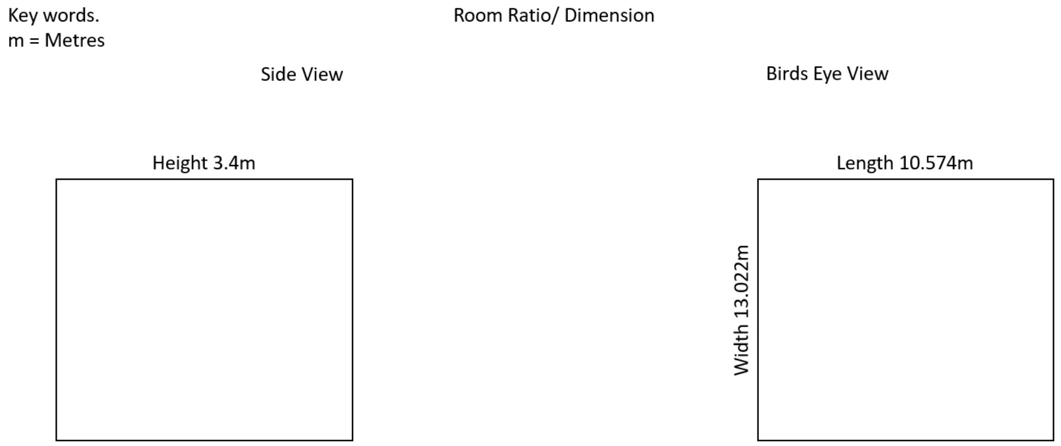


Figure 2.9 Room Ratio/ Dimension. Studio Build (Appendix 3)

The Room Ratio that will be used for the Studio is, ***H: 1 L: 3.11 W: 3.83.*** A height of 3.4m, which provides a length of 10.574m and a width of 13.022m (Figure 2.9). This was chosen as the results in Room Modes Calculator, show that the modes are not affecting each other. (Everest and Pohlmann, 2014). (Figure 3.0) (Figure 3.1)

The Room Ratio/ Dimensions were also decided with Room EQ Wizard, as by looking at the graph provided, (Figure 3.1) it shows that from 50Hz to 200Hz the frequency dips and peaks are closer together, and the Axial modes are too. Which results in a flatter low-end response because of the lack of huge dips and peaks.

Also, the fundamental frequency is found to be lower in this room compared to a smaller one, as shown in, (Figure 3.1) the fundamental mode is at 13.2Hz in the selected room while as shown in, (Figure 3.2), the fundamental frequency is higher in the smaller room, which starts at 38.8Hz. (Everest and Pohlmann, 2014).

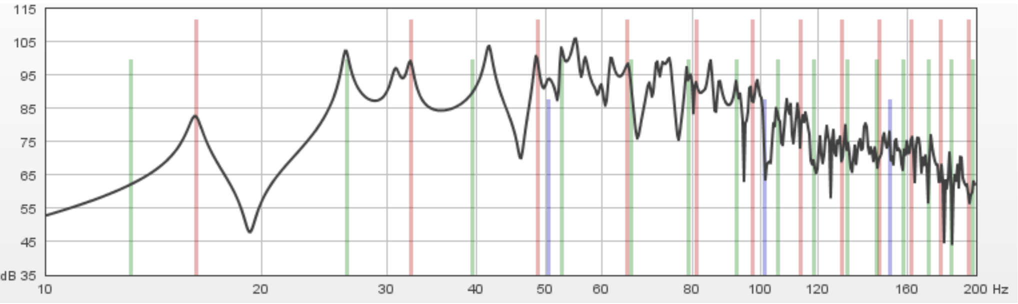
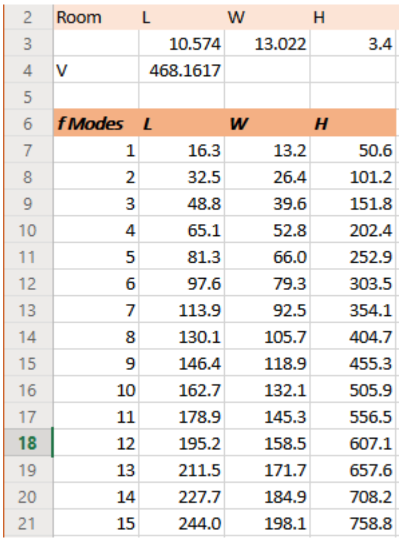


Figure 3.1 Chosen Room Dimension's Frequency Graph. Modal Response



2	Room	L	W	H
3		10.574	13.022	3.4
4	V	468.1617		
5				
6	***f Modes***	***L***	***W***	***H***
7	1	16.3	13.2	50.6
8	2	32.5	26.4	101.2
9	3	48.8	39.6	151.8
10	4	65.1	52.8	202.4
11	5	81.3	66.0	252.9
12	6	97.6	79.3	303.5
13	7	113.9	92.5	354.1
14	8	130.1	105.7	404.7
15	9	146.4	118.9	455.3
16	10	162.7	132.1	505.9
17	11	178.9	145.3	556.5
18	12	195.2	158.5	607.1
19	13	211.5	171.7	657.6
20	14	227.7	184.9	708.2
21	15	244.0	198.1	758.8

Figure 3.0 Frequency Modes

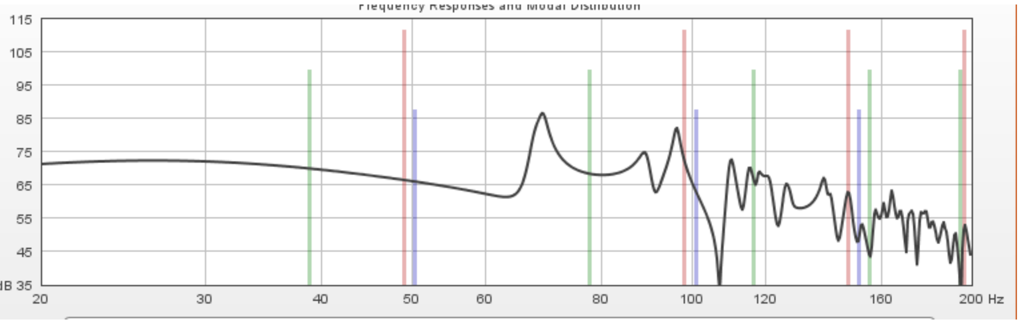
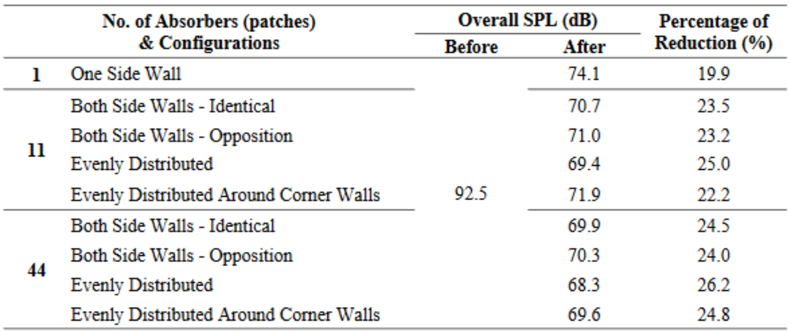


Figure 3.2 Smaller Room Dimension's Frequency Graph.

Acoustics/ Diffusion.

First thing to consider is what kind of absorbers to use. The first absorber used within the studio build will be porous, which is carpet. as carpet is an effective porous absorber as it has an effective absorption at mid and high frequencies. It also reduces reflections from the ceiling. (Everest and Pohlmann, 2014).

When dealing with the walls, it is best to consider how to distribute the absorbers. (Figure 3.3) shows the results when placing absorbers. It shows that using 44 absorbers on the walls result in better reduction in SPL, because the sound cannot bounce around the room without being weaken when reflected or completely transformed to heat. This can be compared to the results of the One Side Wall Absorber, with the weakest results, it does not halt the sound source reflecting off surfaces. The results that is best is the Evenly Distributed Absorption, as it has reduced SPL of 26.2 dB, making it the viable option for the studio build. (iopscience,2017) (ehomerecordingstudio, n.d)



No. of Absorbers (patches) & Configurations		Overall SPL (dB)		Percentage of Reduction (%)
		Before	After	
1	One Side Wall	92.5	74.1	19.9
11	Both Side Walls - Identical		70.7	23.5
	Both Side Walls - Opposition		71.0	23.2
	Evenly Distributed		69.4	25.0
	Evenly Distributed Around Corner Walls		71.9	22.2
44	Both Side Walls - Identical		69.9	24.5
	Both Side Walls - Opposition		70.3	24.0
	Evenly Distributed		68.3	26.2
	Evenly Distributed Around Corner Walls		69.6	24.8

Figure 3.3 Results of absorber placement

Before any absorber placement is done though, it is good to take this absorber placement by stages. Firstly, the Trihedral corners (Red Dots), then Dihedral corners (Blue Dots) and lastly The Walls (White surfaces). (Figure 3.4). (ehomerecordingstudio, n.d)

Because it is simpler to treat the room's heavily influenced areas first, as trihedral corners have 3 sets of parallel walls join, thus having an absorber here subdues the rooms modes from all 3 dimensions. Dihedral is next because it deals with 2 dimensions/ room modes and the walls are last as they deal with one. (ehomerecordingstudio, n.d)

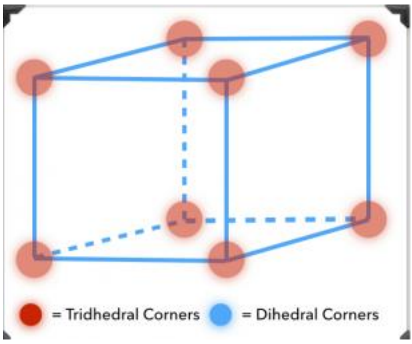


Figure 3.4 Stages of Absorber placement

Before applying absorbers, it is crucial to figure out the peak particle velocity. Using the equation. 344mc/f then f/4. The answer is 5.2m (Appendix 2). (Everest and Pohlmann, 2014). This is the 16.2Hz fundamental ¼ wavelength, this covers half of the length of the room, this mode cannot be heard, so it can be ignored. the first audible mode is 32.5Hz, and the ¼ wavelength is 2.6m.

Doing this for the width gives the distance of 3.2m, and the height distance is 1.7m. (Everest and Pohlmann, 2014) (ehomerecordingstudio, n.d). (Figure 3.5) (Figure 3.6) (Appendix 2)

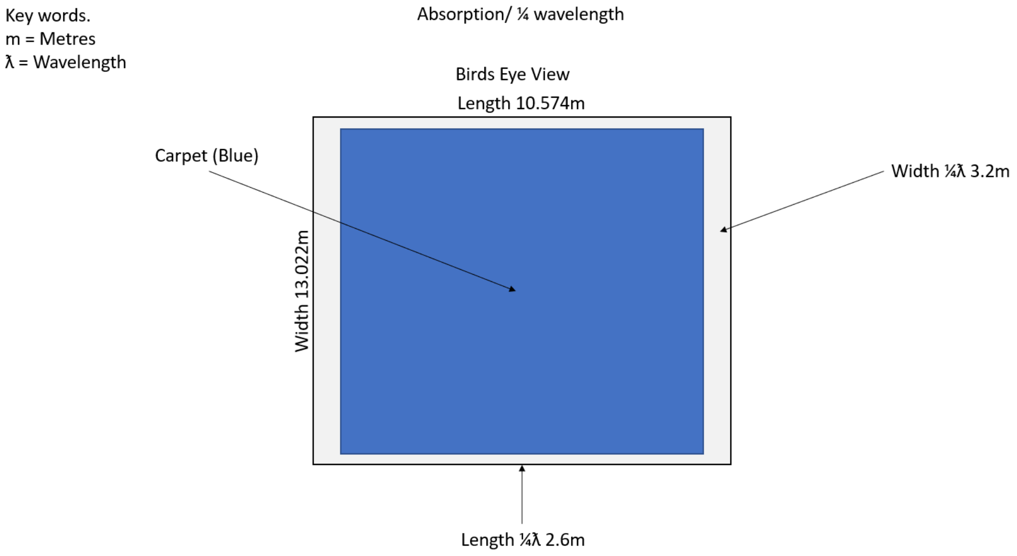


Figure 3.5 Absorption/ ¼ Wavelength Length & Width. Studio Build. (Appendix 3)

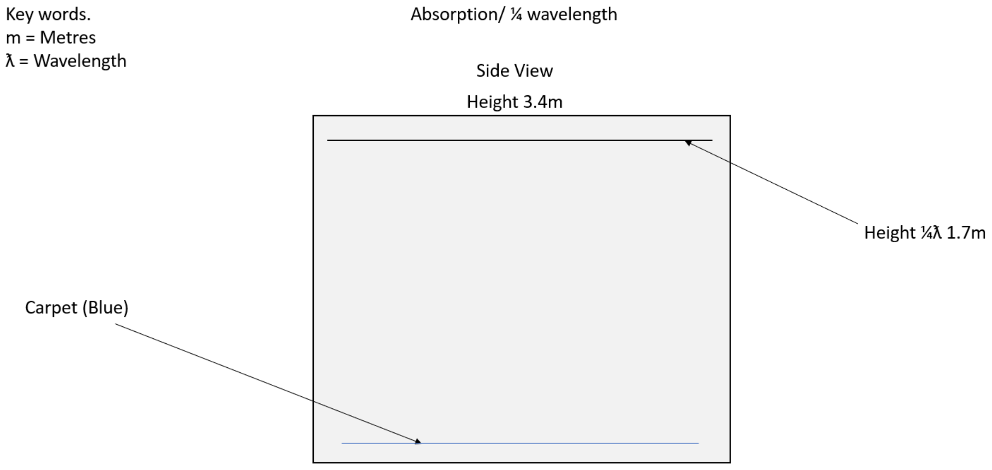


Figure 3.6 Absorption/ ¼ Wavelength Height. Studio Build. (Appendix 3)

Absorber Choice.

The RPG Modex Corner Bass Trap will be used, Because of its unique design, it optimises the absorption efficiency by having a damped membrane absorber inside itself. Which converts the high sound pressure fluctuations located at wall and corners into absorption. (Figure 3.7) (Figure 3.8) (Rpgeurope, n.d). The bass traps will be stacked up in each corner. (Figure 4.2)

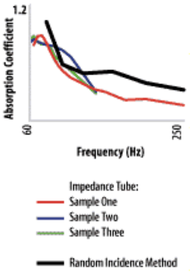


Figure 3.8 Absorption Coefficient of RPG Modex Corner

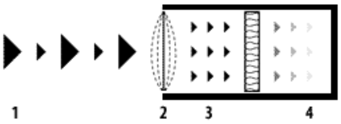


Figure 3.7 RPG Modex Corner Diagram

The RPG Profoam will be used, because this absorber was designed to have the foam distant from the wall, so it accommodates ¼ wavelength. The absorption coefficient is useful for the mid and higher frequencies (Figure 3.9). This will placed evenly disributed around the room. (Rpgeurope, n.d) (Figure 4.3)

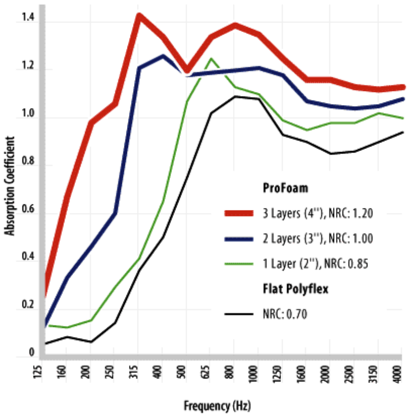


Figure 3.9 Profoam Coefficient

RPG Formedffusor 600x600 will be used as the ceiling absorber and the diffuser. This size offers flexibility. Also, this Diffuser does absorption of low-mid frequencies, noticeably at 250Hz to 500Hz (Figure 4.0) and offers a wide-angle diffusion, noticeably at 500Hz to 1kHz (Figure 4.1). (Rpgeurope. N.d) (Figure 4.2)

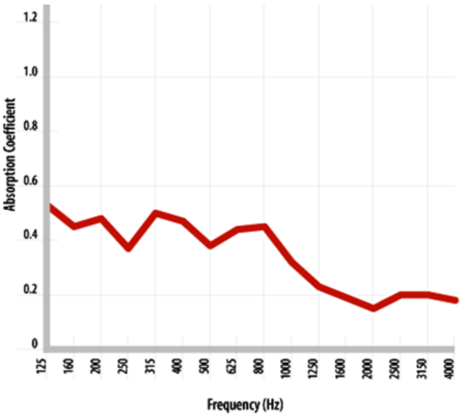


Figure 4.0 Formedffusor Absorption

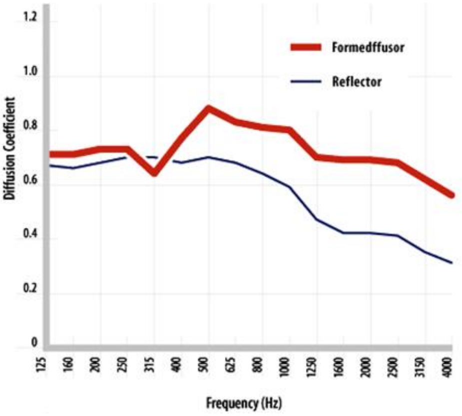


Figure 4.1 Formedffusor Diffusion

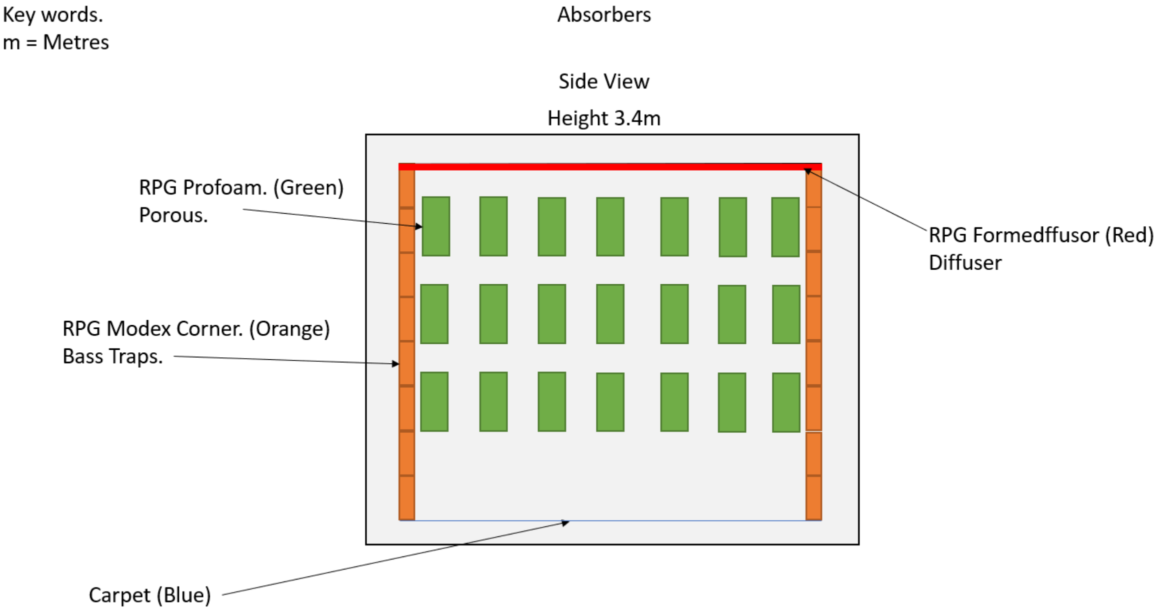


Figure 4.2 Absorber placement Side view. Studio Build (Appendix 3)

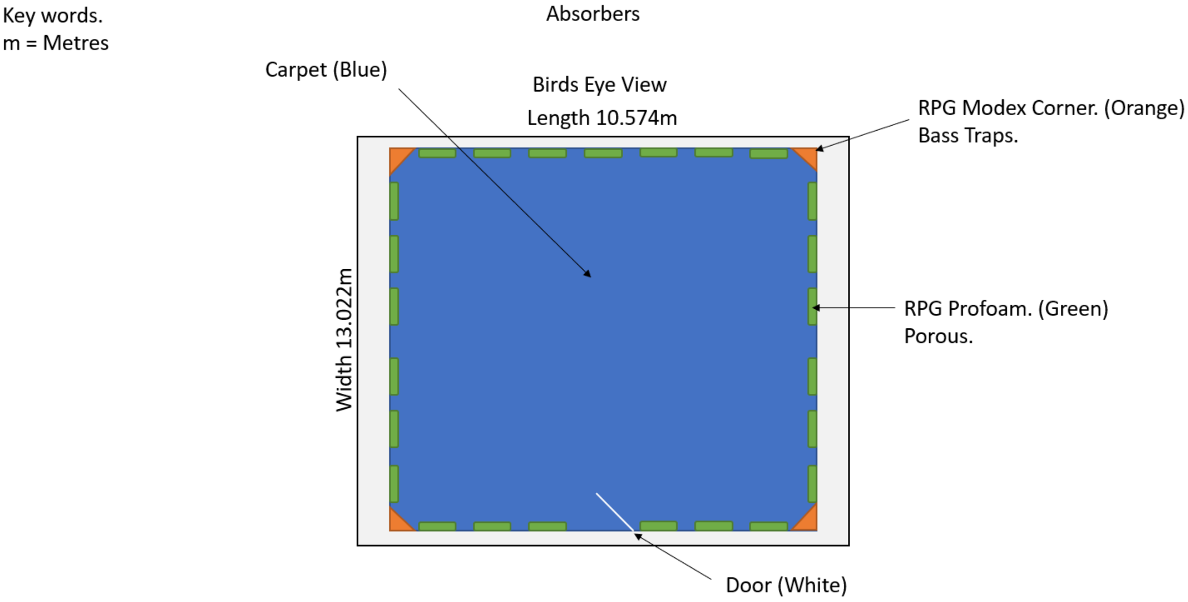
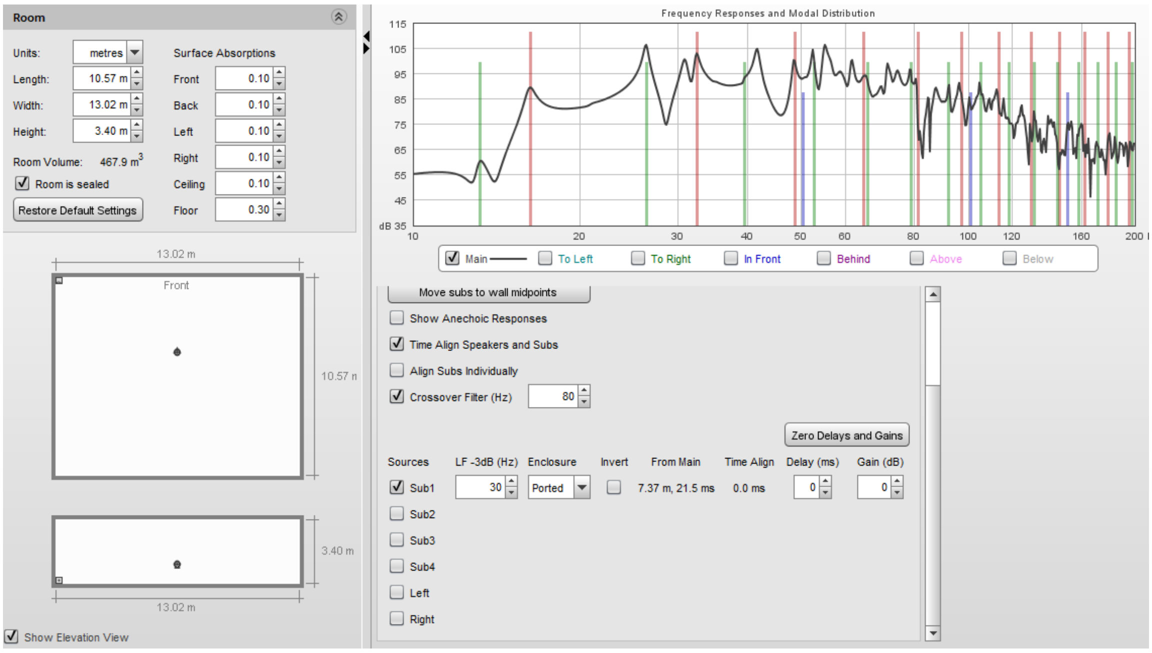


Figure 4.3 Absorber placement Birds eye view. Studio Build (Appendix 3)

1.3 Listening Position/ Speaker Position

To tackle the listening position, a strategy is needed. A place to avoid is the centre of the room, as the centre will have reinforced reflections, meaning the response will be disturbed by certain frequencies being too loud. Even after the room has been acoustical treated the centre will still suffer from reflections. (Owsinski, 2013)

But reflections at the quarter and three-quarter points are non-existent compared so they are viable placements. Professionals will place their loudspeakers at points between the quarter, middle or three-quarter points. Many agree on a point at 38% in the room. Which for the Studio Build is 4.02m. This was found using Room EQ, as moving the listening point in the room gives the percentages of positioning in the room. (Figure 4.4). (Owsinski, 2013).



Room

Units: metres
Length: 10.57 m
Width: 13.02 m
Height: 3.40 m
Room Volume: 467.9 m³
☑ Room is sealed

Surface Absorptions
Front 0.10
Back 0.10
Left 0.10
Right 0.10
Ceiling 0.10
Floor 0.30

☑ Show Elevation View

☑ Main ☐ To Left ☐ To Right ☐ In Front ☐ Behind ☐ Above ☐ Below

☐ Show Anechoic Responses
☑ Time Align Speakers and Subs
☐ Align Subs Individually
☑ Crossover Filter (Hz) 80

Sources	LF -3dB (Hz)	Enclosure	Invert	From Main	Time Align	Delay (ms)	Gain (dB)
☑ Sub1	30	Ported	☐	7.37 m, 21.5 ms	0.0 ms	0	0
☐ Sub2							
☐ Sub3							
☐ Sub4							
☐ Left							
☐ Right							

Figure 4.4 Listening Position 38%. Studio Build

This results in the frequency being flatter. The main changes from the original position are the raise in volume at 20Hz, as the original had a big dip at that point. The issue with this new position is that there is a dip in frequencies at 80Hz to 84Hz.

The loudspeaker configuration used within the Studio Build will be a 5.1-Channel Surround-sound system, as Surround-sound offers much more creative options for mixing, such as panning, level balancing and audio importance (i.e. the audio that goes in the centre and closer to the listener, so it cuts through the mix, like solos and vocals). (White, 2002)

The Surround-sound system comes with the consideration of other systems, more than usual. As the mix may sound strange and unbalanced in a stereo setup. Also, if the playback system was also a 5.1 system, a small different can make a big difference in the mix since there is more to consider with placement and what kind of speakers. (White, 2002)

A surround-sound set up needs to have each speaker balanced to produce the same SPL, this is done so it will not confuse the listener and make it so it can be used for mixing. (ITU, 2012)

The configuration L/C/R and LS/RS surround-sound system will be used within the studio build. (Figure 4.5), as the other configuration has two more speakers which is not necessary. The speakers will be placed at a height of 1.2m, with a slop downwards at 15 degrees on the LS and RS speakers. The Centre speaker are at 0^{o}, The Left and Right speakers are at 60^{o} and the LS and RS are at 120^{o}. (Figure 4.6)

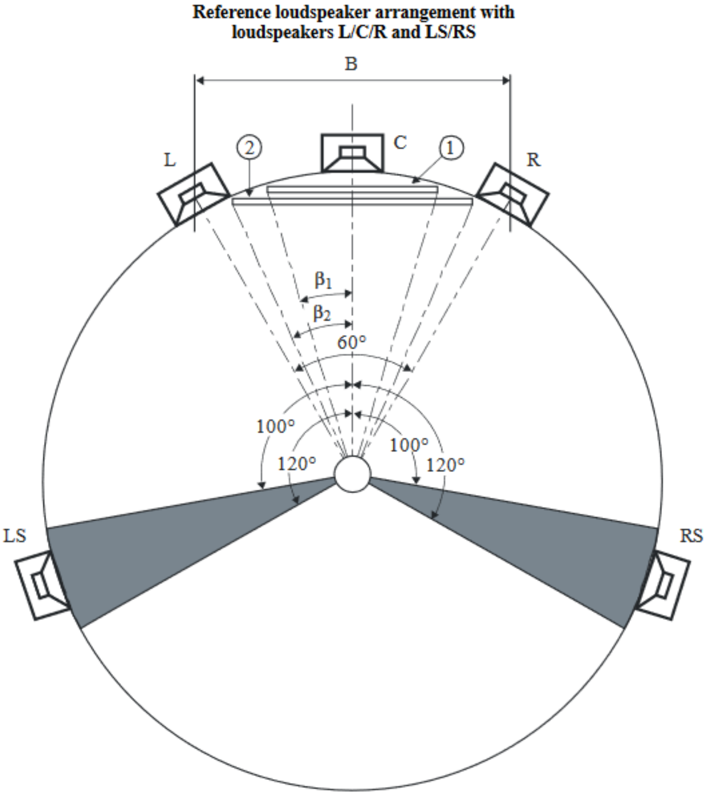


Figure 4.5 Stereo Surround-sound configuration

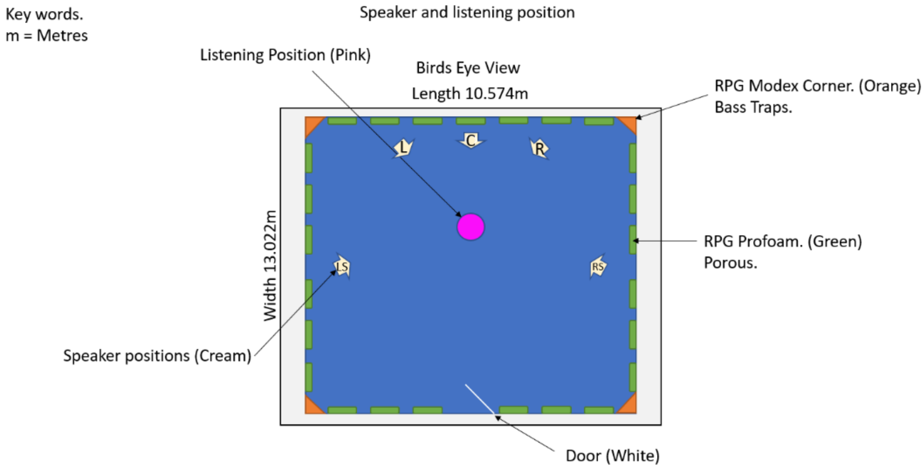


Figure 4.6 Surround Sound System. Studio Build. (Appendix 3)

Conclusion

Through-out the report, is it clear that acoustics is complex; with many factors involved. The main goal with acoustics is to subdue Room Modes, each aspect works together. Learning these aspects are imperative to build studios without help, it can also be a very creative process.

The findings that are important are the mathematics and room modes. As the Mathematics can be the hardest to understand, and these are important to properly build a studio. Room Modes are also important as these are the main issues rooms suffer with.

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Appendix

1. Calculation for Axial modes, the equation is: 344/(2*L)
   Calculation for Tangential modes is: $344/2*\sqrt{((1/L)^2+(1/W)^2)}$
   Calculation for Oblique modes: $344/2*\sqrt{((1/L)^2+(1/W)^2+(1/H)^2)}$.
   These Calculation are used to find the fundamental frequency for each mode. To way this calculation works for the Tangential modes, as Length and Width are added in to calculation. While the Oblique works because it adds the Length, Width and Height together to find the Fundamental.
2. 344/f then f/4. This calculation is used to find the quarter wavelength; To find the optimal distance to place a porous absorber to get the absorption to hit the peak particle velocity. (Everest and Pohlmann).
3. Studio Build File. NOTHING IS TO EXACT SIZE.