Buenos Aires – 5 to 9 September, 2016
Acoustics for the 21st Century…

PROCEEDINGS of the 22nd International Congress on Acoustics

Challenges and Solutions in Acoustical Measurements and Design: Paper ICA2016-463

Analysis of acoustic devices used in homestudio

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Abstract

Homestudios are places installed in residential environment where is possible to produce music. The advance of technology contributed to the professionalization of these spaces, demanding larger efficiency mainly in acoustic performance in order to develop better phonographic materials in all steps of musical production. The objective of this work is to analyze acoustic devices installed in a chosen residential room for musical production activities: Helmholtz resonators for low frequency control, porous absorber for middle and high frequency controls, and acoustic diffusers to guarantee the homogeneous distribution of sound waves, promoting the adaptation of the chosen room to the ideal and technical recommendations for the control of internal acoustics phenomena in small rooms for musical activities. The methodology applied was prepared in these steps: documental search; architectural measurements; theoretical acoustic calculation in a spreadsheet; acoustic measurements of a residential room with a spectrum analyzer software based on Fast Fourrier Transform (FFT); proposal of construction of acoustic treatment devices and it's installation; financial viability analysis; and analysis of the influence of each of them in the space chosen for its application in arrangements and individually. The results showed that these acoustic control equipments attended to all of the necessary requisites for attenuation of the main prejudicial acoustic phenomena in the homestudio, although, it was found that the performance of the Helmholtz resonators were just guaranteed when applied together with other devices, mainly with diffractal diffusers, because of their capability to spread sound high pressure zones in the ambient.

Keywords: acoustic treatment, musical production, home studio.

Analysis of acoustic devices used in homestudio

1 Introduction

Professional music production rooms are built following acoustic rules to have maximum efficiency, but mostly for economic reasons, some of these places are commonly adapted in apartments and houses defined by a blue print that cannot be changed. In addition, musical technology offers a large variety of electronic musical instruments that can be used, so there is no need for acoustic isolation if the room is located in a quiet noise environment. In this way, for acoustic treatment, interventions in the room must be planned to guarantee homogeneous distribution and absorption of sound waves in large band of frequencies. When a sound source is reproduced in a room or other enclosed place, a series of acoustic phenomena occur due to the property of the sound is absorbed or reflected according to the characteristic of the material on the surface of each constituent wall of this space [1].

The listener perceives the sound in two ways: direct and reflected, called free sound field and the reverberant sound field - also called diffuse field [2]. Although acoustic isolation is not necessary in this specific situation (by using virtual musical instruments and the environment doesn't suffer with motor vehicles traffic), the study of the acoustic treatment in small rooms adapted for this use has to be refined, specially the comprehension of the actuation of resonant modes generated by low frequencies, which are capable to impair musical instruments recording and mask details in audio reproduction. To achieve this goal, is necessary to understand the acoustic phenomena in a room, also dominate diagnostic tools like theoretical calculation, computer simulation and acoustic measurements. This work adopted calculation and acoustic measurements to analyze the homestudio. After that, it is possible to manufacture acoustic devices and install them on places determined by those procedures. Lastly, to check if the performance of these devices worked, the acoustic measurement procedure is used again.

2 Homestudio characteristics

The room selected to be a homestudio is located in Maceió city, in the state of Alagoas, Brazil. This section will address physical and acoustic aspects in a theoretical and practical scope. The region where the room is located is characterized by having low traffic of motor vehicles. Background noise decibel meter measured in the region had an average of 44dB (A), being within the limit of residential places defined by NBR 10152/1987, where the acceptable range is 35-45dB (A) for living rooms [3].

2.1 Physical characteristics

The access is given by a glass door (wall 1). The material of the floor is ceramic tile and the walls and ceiling surfaces are made of painted smooth plaster. Table 1 shows the acoustic coefficients of the surface materials. The room has area 6,88m² and volume 16,80m³.

	AREA	Acoustic absorption coefficients - Frequencies						NRC
	(S)	α 125Hz	α 250Hz	α 500Hz	α 1kHz	α 2kHz	α 4kHz	(α)
Wall 1								
Painted Smooth plaster	5,28m²	0,02	0,02	0,02	0,02	0,03	0,06	0,02
Glass door	1,75m²	0,1	0,1	0,04	0,04	0,02	0,02	0,05
Air – door hole	0,06m²	1	1	1	1	1	1	1
Wall 2								
Painted Smooth plaster	7,09m²	0,02	0,02	0,02	0,02	0,03	0,06	0,02
Wall 3								
Painted Smooth plaster	6,41m²	0,02	0,02	0,02	0,02	0,03	0,06	0,02
Wall 4								
Painted Smooth plaster	5,46m²	0,02	0,02	0,02	0,02	0,03	0,06	0,02
Slab								
Painted Smooth plaster	6,83m²	0,02	0,02	0,02	0,02	0,03	0,06	0,02
Floor								
Tile	6,88m²	0,01	0,01	0,01	0,02	0,02	0,02	0,01
Sum of the areas = 39,78m² / VOLUME = 16,8m³								

Table 1: surface materials, acoustic absorption coefficients of the chosen room.

Figure 1 shows the blue print and dimensions of the chosen room.

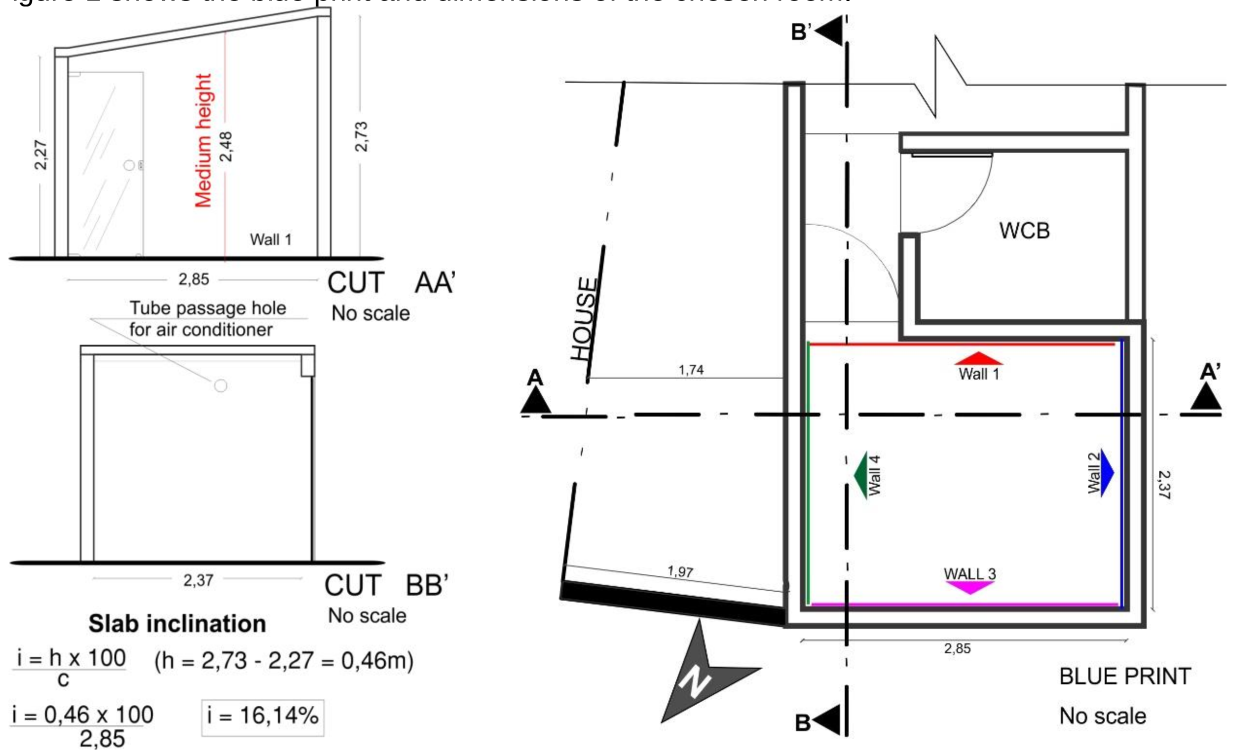


Figure 1: Room dimensions

According to the American Society for Testing and Materials [4], the NRC (Noise Reduction Coefficient) is a single value based on the arithmetic average of four coefficients of sound absorption at 250, 500, 1000 and 2,000 Hz.

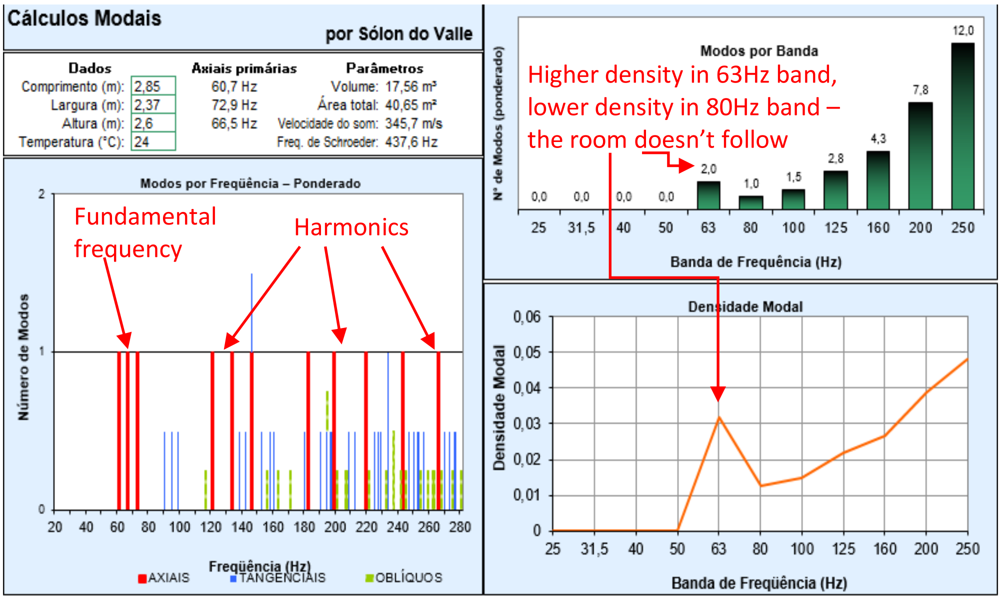
2.2 Acoustic phenomena in the room

All the methodology employed to develop the acoustic devices followed some rules. First of all, to be selected, the room should:

- Be small, with short dimensions, preferably cubic;
- Have high reverberation time, provided by low acoustic absorption coefficient materials;
- Not meet the Bonello Criteria.

2.2.1 Standing waves and resonant modes

Oscar Bonello developed a method to establish a recommendable dimensional pattern for rooms to minimize the interference of standing waves, called Bonello Criteria, based on the concept of modal density. Modes are created by a room dimension coinciding with particular frequency's distance of travel [5]. Modal density graphic basically must have the raise of the number of modes with the frequency [6]. Figure 2 shows the modal density graphic of the chosen room and evidence that it doesn't obey the Bonello Criteria.



Source: adapted from Valle, 2006

Figure 2: Modal density graphics of the chosen room.

It's important to clarify that the large number of frequencies found are harmonics resultant from the fundamental frequencies originated from each of the three dimensions of the room and its combinations depending of the configuration of any mode – axial, tangential or oblique.

2.2.2 Reverberation time (theoretical procedure)

Sabine equation was applied to get the reverberation time of the empty room and for the acoustic treatment strategy.

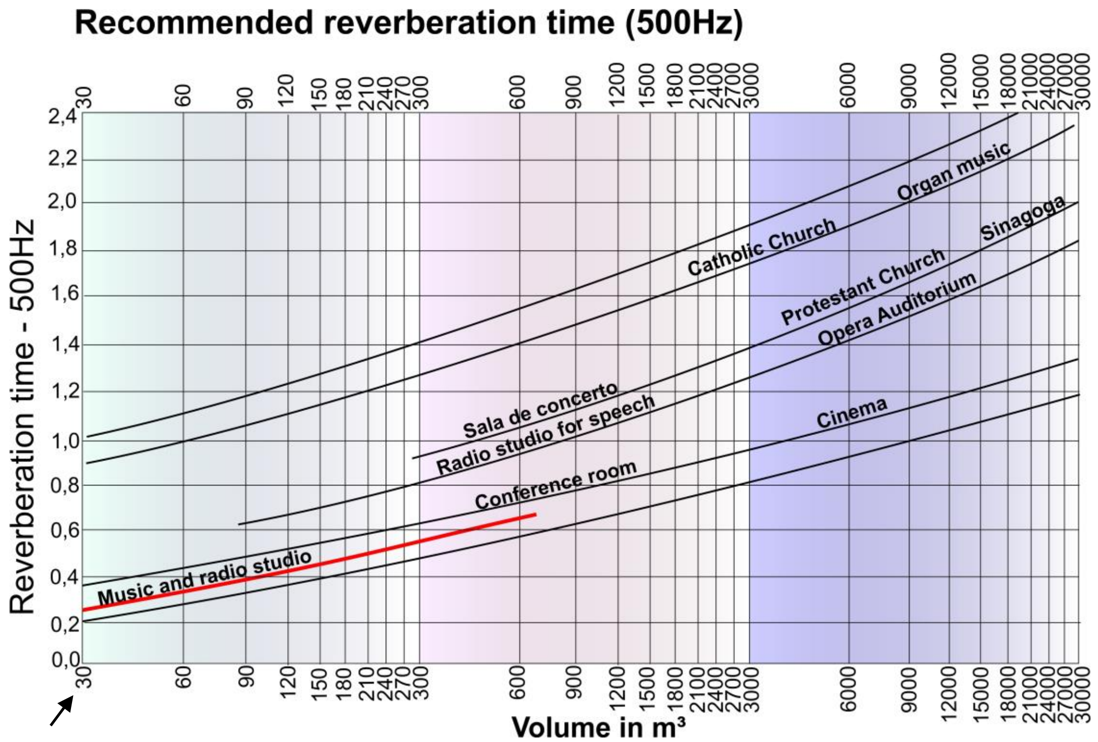
$$RT60 = \frac{0{,}161\,x\,V}{\sum S\alpha} \tag{1}$$

where $0{,}161$ is a constant; V is room's volume; $\sum S\alpha$ is the sum of the multiplication of surfaces areas by the acoustic absorption coefficient (α).

RT60 – Sabine (before treatment)						
Frequency (Hz)	125	250	500	1000	2000	4000
RT60 (s)	**2,879**	**2,879**	**3,242**	**2,995**	**2,294**	**1,281**

Table 2: Reverberation time before treatment

The recommended reverberation time chart [7], in figure 3, connects reverberation time with the volume of the room for each type of activity.



Source: Carvalho, 2006

Figure 3: Recommended reverberation time (500Hz).

This chart consider that a minimum volume of 30m³. The chosen room has 16,88m³. By approach, it's possible to consider the RT60 of 0,2 seconds for 500Hz. Sabine equation is used again to previews application of acoustic devices: Helmholtz resonators, diffractal diffusers and porous absorbers. After that, acoustic measurement procedure is adopted to compare both methods.

RT60 – Sabine (after treatment preview)						
Frequency (Hz)	125	250	500	1000	2000	4000
RT60 (s)	**0,535**	**0,421**	**0,277**	**0,305**	**0,303**	**0,294**

Table 3: RT60 preview after acoustic treatment.

2.2.3 Reverberation time and acoustic measurement procedure for the empty room

This work selected a freeware software of acoustic measurement called Room EQ Wizard (REW). It's a non-linear dynamic acoustic analyzer using TDS (time delay spectrometry) technique [8]. This software is based on Fast Fourrier Transform (FFT). The instruments used to make an acoustic measurement were an omnidirectional microphone, a pair of reference speakers and an audio card. The software generates a signal that "sweeps" gradually from 20Hz to 20 kHz (human's audition length) called "sweep signal" [8]. Then, it has several analysis tools, like RT60 and decay diagrams that shows the performance of peaks and valleys of the acoustic response in function of time.

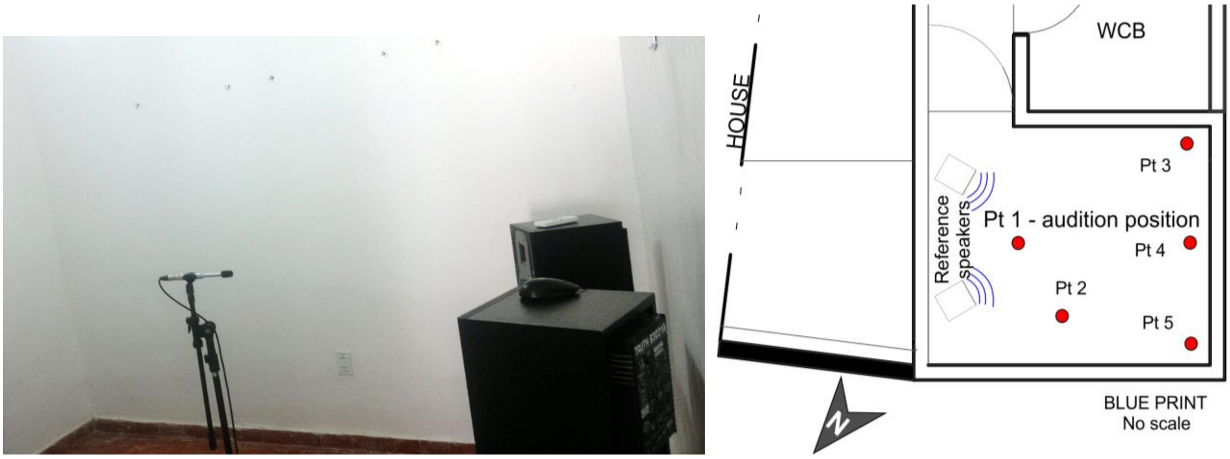
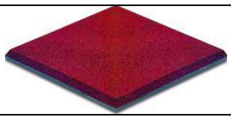


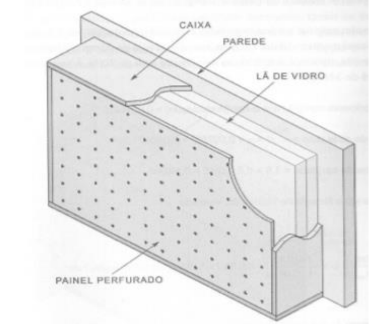
Figure 4: Points measured in the room.

5 points were measured to diagnose the acoustic phenomena that occur in the studied space. Point 1 acoustic response shows 2 peaks: 61,7Hz and 153Hz. Both frequencies were found on other points measurements and will guide the tuning of some acoustic devices (section 2.3).

2.3 Acoustic devices chosen for treatment

The devices characteristics are showed in table 4.

MATERIAL / PHOTO	NAME / DESCRIPTION				
	**POROUS ABSORBER** – composed by synthetic foam. Dimensions: 0,625m x 0,625m and 50mm of thickness.				
Acoustic absorption coefficients (α) octave bands – Porous absorber.					
125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
0,19	**0,42**	**1,07**	**1,09**	**1,08**	**0,92**



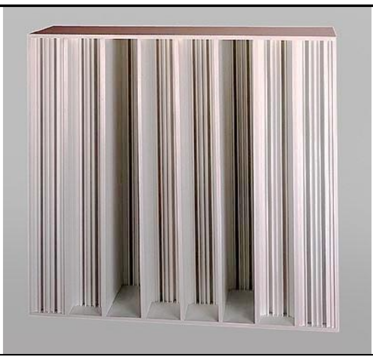
HELMHOLTZ RESONATOR (perforated panel) – its basically a hollow box with one of the faces perforated. The Resonance Frequency is given by:

$$RF \cong \frac{c}{2\pi} \times \sqrt{\frac{S}{L \times V}} \qquad (2)$$

where c is sound velocity; S is the area of the perforation; L is the drilling pipe lenght; V is the internal box volume [9]. 2 devices were installed in the room tuned in 61,7Hz and 153,5Hz.

Acoustic absorption coefficients (α) octave bands – Helmholtz resonator.

125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
0,98	**0,97**	**0,95**	**0,52**	**0,32**	**0,28**



DIFFRACTAL DIFFUSER – This device can be made of wood, plastic, or any rigid material and provides the scattering of sound waves. Its construction follows the quadratic residue formula applied twice.

$$\mathrm{L} = \mathrm{W} \times n^2|p| \qquad (3)$$

Where L is section depth; W is width of section; $n^2|p|$ “is the rest of the division” of n (number of sections of the diffuser) for $|p|$ (module prime) is a prime number correspondig to the number of sections of the diffuser [6].

Acoustic absorption coefficients (α) octave bands – diffractal diffuser.

125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
0,23	**0,24**	**0,35**	**0,23**	**0,2**	**0,2**

Table 4: List and characteristics of chosen acoustic devices.

The devices were positioned in the room following this scheme:

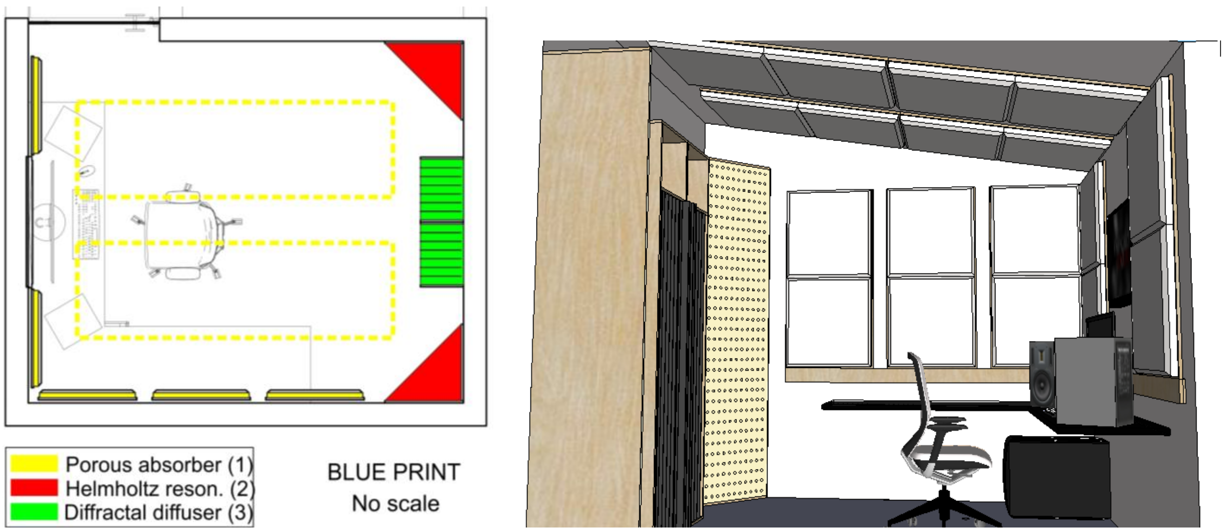
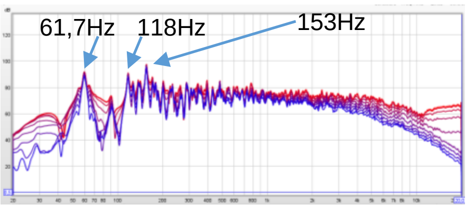
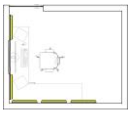
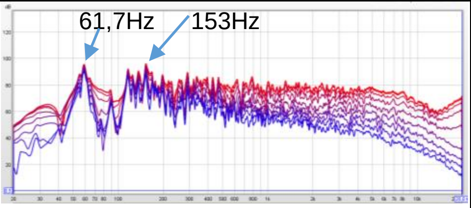
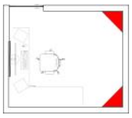
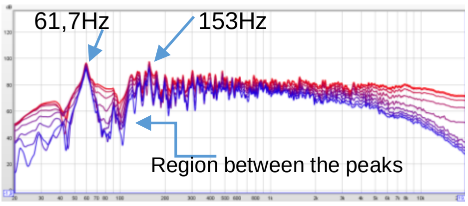
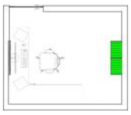
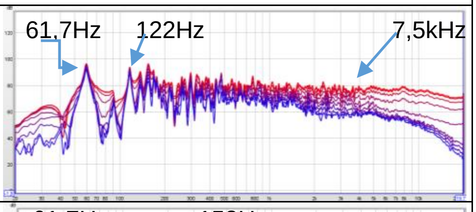
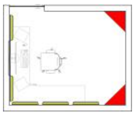
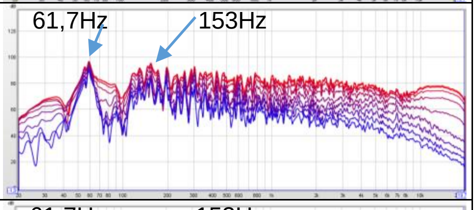
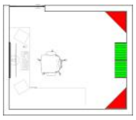
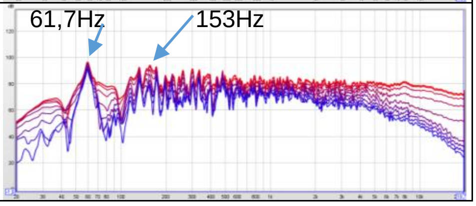


Figure 5: Position of the devices in the room.

2.4 Analysis of acoustic response of the room provided by devices arrangements

The design of acoustic devices should provide mobility if homestudio were eventually moved to another room. It also enabled the study of combination of them in arrangements.

Arran-gement	Description/ Behavior after installation	Decay graphic
EMPTY ROOM	The red line represents the instantaneous accoustic response of the room. The sequential lines in shades from purple to blue represent the decay, the time that the frequency persists in the room after the sweep signal impulse. The decay is set from 0 seconds (red) to 160 miliseconds (blue). The goal is to detach red line from blue line and decrease peaks and increase valleys on it.	
1 	**Device 1** – porous absorber. 18 pieces of this foam glued in pairs on 9 MDF plates 15mm thick, hanged on the Wall supported by 8mm metal hooks. The devices were fixed on the slab and on walls 4 and 3. It's response is initiated at 200Hz.	
2 	**Device 2** – 2 Helmholtz resonators positioned at the corners of the room. The resonator tuned in 61,7Hz is allocated on the vertex of walls 1 and 2 and the resonator tuned in 153,5Hz, of walls 2 and 3. It promotes light decay in mids and highs because of its shape that "breaks the sharp edges" of the corners. However, it had Little influence in frequencies they were designed to work.	
3 	**Device 3** – Diffractal diffuser. 2 units placed on center of Wall 2 in front of the reference speakers. Scatter behavior is from 185Hz to 6880Hz. These devices influenced on acoustic response of the room in a wider range of frequencies: 122Hz to 7,5kHz.	
4 	**Device 1 + Device 2:** It's posible to notice an "activation" behavior of the resonators promoted by the porous absorbers. The performance in 153Hz was reached. 61,7Hz had a light response. It shows that the resonance mode in this frequency is too strong in the room.	
5 	**Device 2 + Device 3:** The resonance in 61,7 Hz is still persistant, although 153Hz loses it's force when used together with these two devices.	

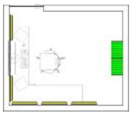
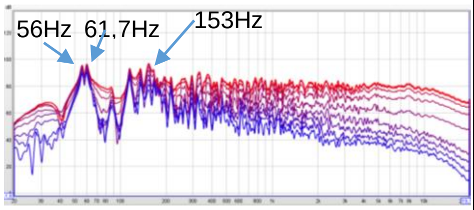
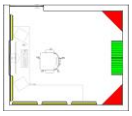
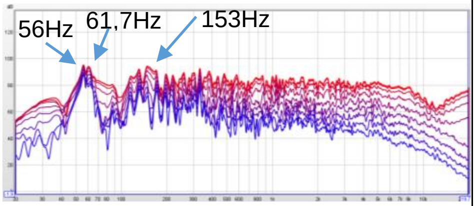
6 	**Device 1 + Device 3:** This graphic representsthe situation of most homestudios: lots of foam providing absorption only on highs and parcial diffusion. This constructive configuration completely ignores resonant modes so these reinforcements, if not contained, generate losses both on the audio and health of the user (irritation, dizziness, drowsiness, and others [10]).	
7 	**Device 1 + Device 2 + Device 3:** Now, there's a clear evolution of the room's acoustic response, specially at lower area. The decay in the peaks of 61,7Hz and 153Hz were of 16dB and 25dB respectively. It shows that the acoustic response of a room, to be reached a large band of frequencies, specially lows, has to be fullfilled by different tuned devices.	

Table 5: Position of the devices in the room.

The RT60 of the room before and after the acoustic treatment were registered too. The reduction of the reverberation time is showed in table 6.

RT60	**Low frequencies** (third octave bands)									
	20	**25**	**31,5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**
Before acoustic treatment (s)						2,6	1,97	2,53	2,83	2,45
After acoustic treatment (s)						**1,34**	**1,01**	**0,56**	**0,71**	**0,44**
RT60	**Mid frequencies** (third octave bands)									
	200	**250**	**315**	**400**	**500**	**630**	**800**	**1k**	**1,25k**	**1,6k**
Before acoustic treatment (s)	2,74	2,93	2,20	2,45	2,18	1,96	1,61	1,48	1,46	1,45
After acoustic treatment (s)	**0,41**	**0,41**	**0,44**	**0,34**	**0,31**	**0,31**	**0,34**	**0,28**	**0,29**	**0,29**
RT60	**High frequencies** (third octave bands)									
	2k	**2,5k**	**3,15k**	**4k**	**5k**	**6,3k**	**8k**	**10k**	**12,5k**	**16k**
Before acoustic treatment (s)	1,39	1,43	1,45	1,31	1,45	1,49	1,39	1,22		
After acoustic treatment (s)	**0,26**	**0,23**	**0,22**	**0,21**	**0,21**	**0,20**	**0,19**	**0,17**		
Reduction of 67,21% (Lows)	$= 100 - \frac{\sum before \times 100}{\sum after} = 100 - \frac{4{,}06 \times 100}{12{,}38}$									
Reduction of 83,29% (Mids)	$= 100 - \frac{\sum before \times 100}{\sum after} = 100 - \frac{3{,}42 \times 100}{20{,}46}$									
Reduction of 84,82% (Highs)	$= 100 - \frac{\sum before \times 100}{\sum after} = 100 - \frac{1{,}69 \times 100}{11{,}13}$									

Table 6: RT60 before and after acoustic treatment

The values of theoretical end practical procedures were close too. The homestudio doesn't reach the 0,2 seconds RT60 in 500Hz, but it shows that the reverberation phenomenon in the room is controlled and balanced frequency by frequency.

RT60 **TR = 0,161 x V / Σ S x α** - Sabine formula and measurement method						
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**
SABINE (s)	0,535	0,421	0,277	0,305	0,303	0,294
Measurement (s)	**0,71**	**0,41**	**0,31**	**0,28**	**0,26**	**0,21**

Table 7: RT60 obtained with Sabine calculation and acoustic measurement method.

3 Conclusions

The performance of the acoustic devices installed in the homestudio attenuated frequencies which were designed to act on. Diffractal diffusers were able to reach a wider frequency range than the expected (185Hz to 6880Hz range) – they acted from 122Hz to 7,5kHz. Porous absorbers worked well from 150Hz to 20kHz. Meanwhile, the operation of Helmholtz resonators has drawn attention in the analysis. It was expected that these devices functioned as common as absorbers, reducing the curve decay even if they were installed alone – without the other devices – in the room. However the graphics showed that the resonators don't work like common absorbers. The operating principle of this device is to resonate on the peaks of resonant modes of the room to eliminate phase cancellations that promote valleys in the acoustic response of the room, leaving the homestudio with a more homogeneous and balanced sound distribution, mainly when they're functioning in conjunction with diffractal diffusers and porous absorbers.

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