New Measurement Methods for Anechoic Chamber Characterization

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ABSTRACT

As a continuation of the work presented in 122nd AES Convention, this paper tries to study in depth the anechoic chambers qualification. The purpose of this paper is to find parameters that allow the characterization of this type of enclosures.

The proposal that becomes in this work is trying to obtain data of the anechoic chambers absorption by means of the transfer functions between pairs of microphones, or by means of the impulse response between pairs of microphones.

Based on the results of the transfer functions between pairs of microphones can be checked easily agreement of the inverse squared law, allowing to determine the chamber cut-off frequency. Making a band-pass filtering it could be confirmed the anechoic chambers qualification.

1. INTRODUCTION

As a continuation of the work presented in 122nd AES Convention [1], this paper tries to study in depth the anechoic chambers qualification. The purpose of this paper is to find, through different measurement methods, parameters that allow the characterization of this type of enclosures.

One of the main problems found in the characterization of anechoic chambers is the determination of the absorption coefficient, or the reverberation time, of the same ones. The traditional methods only try to verify the wellness of chamber as far as the agreement of the inverse squared law of within this type of enclosures. These methods are only based on the measurement of the sound pressure level inside the enclosure.

The proposal that becomes in this work is trying to obtain data of the anechoic chambers absorption by means of the transfer functions of between pairs of microphones, or by means of the analysis of the impulse response between pairs of microphones.

Based on the results of the transfer functions between pairs of microphones can be checked easily agreement of the inverse squared law, allowing to determine the chamber cut-off frequency. Making a band filtering it could be confirmed the anechoic chambers qualification.

Based on the results of impulse response measurements between pairs of microphones may be obtained EDT information and through Schroeder reverse integration it could be obtained information of the anechoic chambers reverberation time. Also, by filtering techniques of the impulse response, it is possible to obtain information of the absorption coefficient of the chamber.

The measurement methods proposed are based on the accomplishment of these measures in the zones where the agreement of the inverse squared law inside the chamber takes place, using different signal types (impulsive, broadband noise, MLS, etc.).

Also a method sets out to obtain the absorption coefficient making measurements between pairs of microphones in the proximities of the walls of the anechoic chamber, where the absorbent is placed. In this method, and through the assumption of the anechoic chamber behavior an LTI system can be found expressions for the absorption coefficient, if we consider that in the zone where the inverse squared law is agreed, the role of transfer is equivalent to an attenuation and a fixed delay, depending on the separation between microphones.

Both proposed methods are based on considering that, within certain margins, the anechoic chamber behaves like a LTI system, and therefore the expressions that allow that are tried to obtain the parameters are relatively simple.

The measurement system that is going away to use is based on the Brüel&Kjaer PULSE 7770 platform and the use of three microphones in simultaneous way. This platform allows the upset the data to Matlab, software which will make all the post-processing techniques.

The supposition of which the anechoic chamber behaves as a LTI system and the simultaneous use of multi-microphone measures allows to obtain a great amount of information that is not obtained by means of the use of traditional techniques of measurement until now in the qualification of anechoic chambers.

Let us think that the contributions of this work are of sufficient interest like being able to present conclusions that until the moment are not by the traditional methods.

2. ANECHOIC CHAMBER DESCRIPTION

Once placed the wedges, the inner dimensions of the chamber between the wedges are 5650mm×4320mm× 2850mm, what is equivalent to a free volume between wedges of 69.9m^3. If we compare it with the dimensions of the previous camera, of 38m^3, we see that the increment of volume is of 83%. The internal area of the surfaces limits of the chamber is 105.6m^2. As a datum, the diagonal of the chamber is 6670mm.

The material of the new wedges was decided to be rock wool with a density of 105 kg/m3 with a triangular wedge shape of 300mm of height and with a square base of 240mm×240mm and with a height of 100mm. The total the height of the wedge is 400mm. The base surface of each wedge is of 0.0576m^3 and the volume of the wedge is of 0.0144m^3. To avoid the deterioration of the wedges and to minimize as possible that was powder in suspension of the rock wool inside the chamber due to the degradation process it was opted to manufacture a case of porous cloth for each wedge. The color of the cloth is white in order of increasing the brightness inside the chamber.

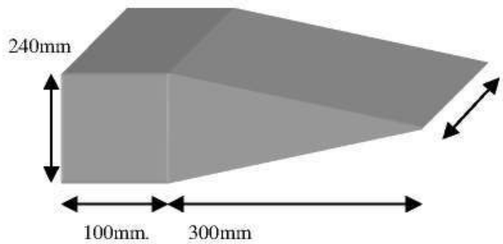

Figure 1 Wedge shape and dimensions

Finally it was decided that the material was the rock wool of 105kg/m^3 density and the triangular shaped wedge that it was commented previously. The advantage this wedge with a square base was that it could get placed in different geometrical shapes. The decision of the final wedges disposition was assumed according to increase the effective surface of absorption and that the coefficient of absorption was the higher as possible, in function of the measures of the same one that were carried out in the reverberant chamber of the Laboratorio of Sonido of the University. Once resolved the final disposition that they will have those whose, rotated 90º one with regarding the previous one, it was approached in previously commented problem of making a case of porous cloth (transparent to the sound) to avoid the deterioration of the absorbent material.

To be able to move inside the camera a square standing floor (tramex) 1000mm×1000mm of metallic grill 100mm×100mm, it was designed 500mm above the floor of the chamber and supported by height adjustable stands and supported to the walls.

To approach the topic of the internal and external connections of the chamber 4 oblique holes were designed in descent of 250mm of diameter each one. In the interior part of the chamber were prepared two connection boxes with 31 independent audio connectors (XLR, BNC and LEMO).

Figure 2 Actual chamber view with different measure arrangements

3. CHAMBER QUALIFICATION ACCORDING TO ISO 3745-1977

For the realization of the measurements a directive sound source was used, placed ½ meter away wall for four different directions (length, width and two diagonals) and for two opposite ways in each direction. The sound source was a coaxial loudspeaker Tannoy in order to avoid the high frequency directivity losses. The measurements have been carried out from distances to 25mm up to 4000mm/5000mm (if possible) from the sound source in each one of the four directions mentioned previously, data from which the SPL difference can settle down regarding the inverse squared law, that anyway will be inside the tolerances established down in the ISO 3745-1977 norm [2], and that they are presented in the following table.

Central frequency of 1/3 octave band (Hz)	Allowed deviation (dB)
≤ 630 Hz	± 1.5
De 800 a 5000 Hz	± 1.0
≥6300 Hz	± 1.5

Table 1 ISO 3745-1977 allowed deviations as function of frequency

3.1.1. One microphone SPL measurements with real time analyzer (RTA)

This study consists on the realization of numerous measures of SPL received along diverse longitudinal and diagonal directions defined in the chamber, in such a way that one can have a good idea of the acoustic chamber behavior in each one of these directions. In each direction measures were carried out in the two possible ways as well as to two source-microphone heights, corresponding in half and to a third of the chamber height [3] – [5].

As excitation signal a pink noise 1/3 octave band-pass filtered is used.

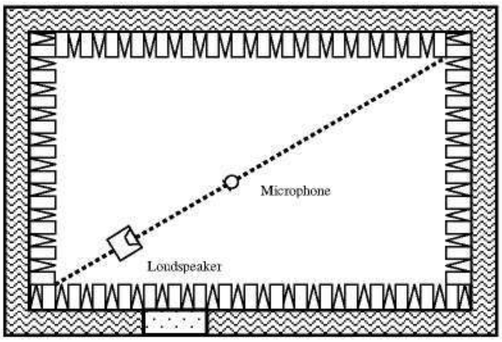

Figure 3 Example of sound source/microphone disposition

Some of the results of these measurements can be observed in the next figures.

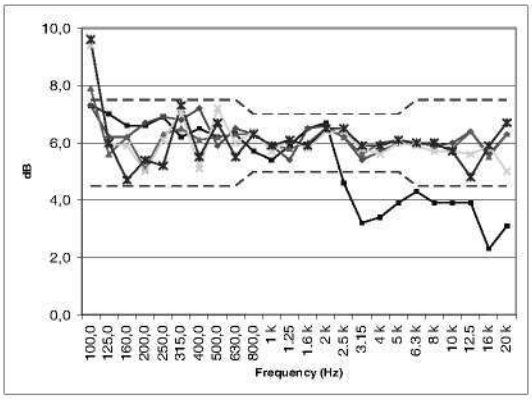

Figure 4 Inverse squared law deviation for distance couples from 200mm-400mm to 1000mm-2000mm in longitudinal direction

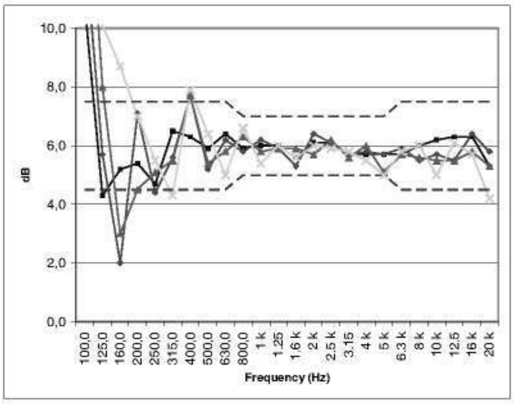

Figure 5 Inverse squared law deviation for distance couples from 1200mm-2400mm to 1800mm-3600mm in longitudinal direction

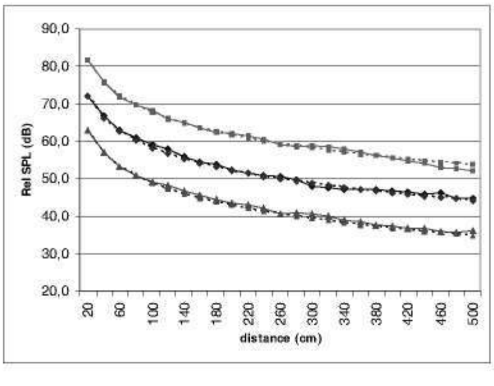

Figure 6 Theoretical and measured inverse squared law for 250Hz 1/1 octave band

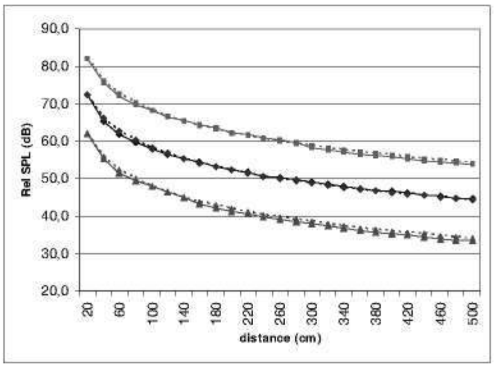

Figure 7 Theoretical and measured inverse squared law for 4kHz 1/1 octave band

Frecuencia Hz	20-40	40-80	60-120	80-160	100-200	120-240	140-280	160-320	180-360	200-400	220-440	240-480	260-520	280-560	300-600
12.5	0,5	0,3	2,7	-2,7	-8,7	-2,0	-3,4	2,3	-0,8	6,9	-3,6	-3,4	-5,5	-2,1	-4,5
16,0	-0,1	0,9	1,3	2,7	-2,8	3,5	-0,1	0,2	-1,4	3,0	-6,9	-7,3	-8,5	-5,3	-6,9
20,0	0,5	-2,5	4,8	7,7	1,5	3,7	3,1	1,2	0,7	-0,8	-5,9	-10,2	-9,7	-7,7	-6,1
25,0	3,4	2,8	1,4	1,8	4,4	6,1	3,0	3,4	-0,5	-1,0	-5,9	-6,2	-9,3	-7,9	-5,1
31.5	5,6	4,4	2,9	3,3	3,5	4,9	5,9	5,6	3,7	6,8	-2,2	-2,5	-6,5	-10,0	-7,8
40,0	6,5	6,5	3,3	2,2	2,0	2,5	4,3	5,1	6,4	9,8	9,4	6,5	3,2	-1,7	-4,4
50,0	7,3	8,8	6,9	5,0	3,2	2,8	3,0	4,3	5,3	7,8	9,9	9,2	10,1	4,5	-0,2
63,0	7,0	9,1	9,8	9,0	7,1	5,2	3,5	3,2	3,0	5,6	8,6	11,1	12,0	9,7	5,7
80,0	6,6	8,3	9,9	12,1	12,2	10,6	8,1	4,9	2,3	2,4	4,6	7,6	11,4	9,4	5,8
100,0	6,8	7,0	7,0	8,4	9,9	11,7	13,5	16,1	14,9	13,6	13,5	13,3	15,7	17,4	10,9
125,0	6,6	6,6	5,7	5,5	6,2	5,9	6,8	9,1	10,3	9,8	11,0	13,8	16,1	21,4	26,0
160,0	6,3	6,6	6,3	4,9	4,7	4,6	3,9	4,6	7,4	7,0	5,9	7,2	7,2	10,5	17,4
200,0	5,9	6,3	5,8	5,9	5,3	4,6	4,9	3,8	3,5	4,8	4,1	4,9	4,4	2,8	7,8
250,0	6,0	6,2	5,9	5,5	5,5	5,3	5,1	5,4	5,5	3,8	4,6	3,2	4,7	2,4	2,2
315,0	5,6	6,3	6,1	6,4	6,2	5,9	5,3	5,4	5,1	5,7	5,2	5,2	4,5	4,3	2,1
400,0	5,5	6,4	5,8	5,6	5,7	6,0	6,7	6,4	6,2	6,3	6,3	6,2	4,8	4,7	3,8
500,0	5,3	5,9	6,0	6,3	6,2	5,9	5,9	6,1	6,5	6,4	6,0	6,2	6,1	5,6	5,4
630,0	5,4	6,0	5,8	5,8	5,7	5,8	5,8	5,9	5,5	6,5	6,7	6,7	6,0	5,9	6,9
800,0	5,2	5,7	5,8	6,0	6,0	5,8	5,9	6,1	5,8	5,7	5,8	5,9	6,1	6,5	6,2
1 k	5,0	5,7	5,6	5,5	5,7	5,7	5,8	6,0	6,1	6,1	6,3	6,0	5,2	5,0	5,1
1.25 k	5,1	5,7	5,8	5,9	5,7	5,9	5,8	5,7	5,8	6,4	6,1	5,9	5,7	5,7	5,6
1.6 k	5,3	6,1	6,0	6,0	5,9	5,9	5,7	6,0	5,8	5,5	5,6	6,2	6,2	6,7	6,4
2 k	5,4	5,8	5,8	5,9	5,8	6,0	6,1	5,8	5,9	6,5	5,7	6,0	4,9	4,1	4,4
2.5 k	4,4	5,9	5,7	5,6	5,5	5,6	5,8	5,9	5,9	6,2	6,2	6,3	6,0	6,4	6,2
3.15 k	4,1	5,3	5,5	5,7	5,7	5,7	5,8	5,7	5,9	6,1	6,1	6,0	6,0	6,2	5,7
4 k	4,5	5,6	5,6	5,6	5,6	5,7	5,7	5,8	5,7	5,9	6,1	6,1	5,7	5,6	5,4
5 k	4,8	5,9	5,8	5,7	5,7	5,7	5,8	5,8	5,6	5,9	6,2	6,1	5,5	5,7	5,7
6.3 k	4,8	5,8	5,9	5,8	5,7	5,5	5,6	5,7	5,8	5,7	6,1	5,9	5,7	5,4	5,7
8 k	4,6	5,6	5,8	5,7	5,7	5,3	5,4	5,6	5,8	5,8	5,9	6,1	5,7	5,8	5,5
10 k	4,6	5,6	5,9	5,9	5,8	5,7	5,6	6,0	5,9	6,2	6,3	6,3	6,5	6,8	6,6
12.5 k	4,9	5,8	5,9	6,0	5,4	5,8	5,7	5,8	5,8	6,5	6,3	6,4	6,3	6,5	6,7
16 k	4,0	5,7	5,7	5,8	5,8	6,0	6,0	6,0	6,1	6,6	6,4	6,7	5,9	6,6	6,8
20 k	4,0	5,6	5,9	5,4	5,8	5,2	5,6	6,2	5,8	6,0	6,5	6,3	5,9	5,5	5,8

Table 2 Allowed deviations according to ISO 3745-1977 as function of frequency distance.

3.1.2. Multi-microphone measurements with fast Fourier transform analyzer (FFT)

With this method, the measurements realized in section before will be done again, in the same four directions and two ways per each one, but now with three microphones simultaneously and fixing couples of separation between sound source and microphones logarithmically spaced (always duplicating the distance between source and microphone 2 and between source and microphone 3). The arrangement could be observed in figure 8. All these measurements were done with a four channel FFT Analyzer Brüel&Kjaer model PULSE 7770 and three condenser Brüel&Kjaer microphones 4188. As excitation signal a broad band white noise is used (with different bandwidth or frequency span).

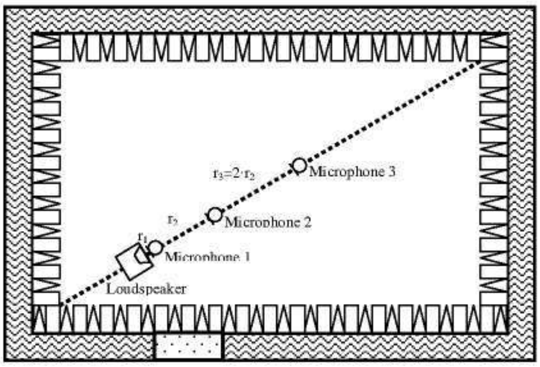

Figure 8 Example of sound source and three microphone (1, 2, 3) disposition

The use of a multichannel microphones measurement system is going to allow not obtain only the sound pressure level at every microphone, but also to obtain relations among the signals in pairs of microphones. It will be able to measure these relations using the transfer functions and the impulse responses that there provides the FFT analyzer.

The first microphone (mic1) will be in use for determining the anechoic response of the loudspeaker, with the high frequency limitations by placing the microphone in the near-field of the loudspeaker. Mic1 is placed at two fixed distances from the loudspeaker (50mm and 250mm). For our loudspeaker, the high frequency limitation of appears over 2 kHz, when it is placed at 50mm away and 10 kHz when it is placed at 250mm away.

The other two microphones will arrange in a logarithmic form along each of the directions of measurement exposed before, so that the third microphone (mic3) always is to the double of distance from the loudspeaker that the second microphone (mic2). With this distances relation it will be able to obtain an idea of the accomplishment of the inverse squared law for distances up to 4000mm from the source.

The dispositio of the microphones and loudspeaker inside the anechoic chamber can be observed in the following figure.

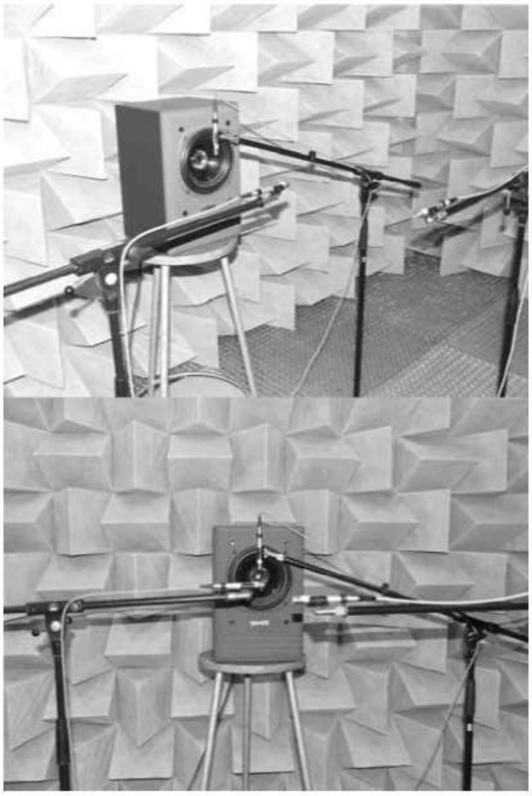

Figure 9 Loudspeaker and microphones disposition inside anechoic chamber

Since it has been commented previously, not only there are obtained sound pressure levels at every microphone, but also information of the loudspeaker response, both in time and in frequency domains.

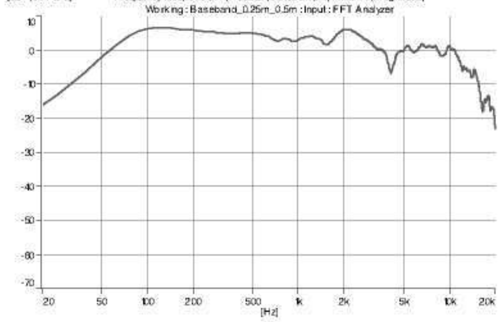

Figure 10 Loudspeaker frequency response as a transfer function between mic1 and power amplifier

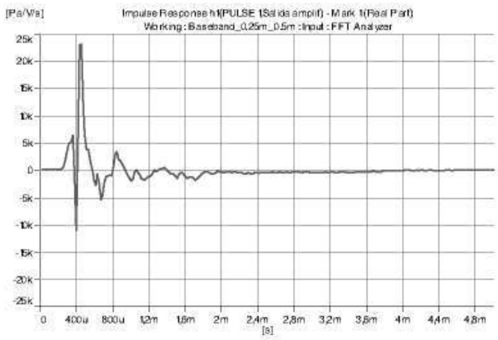

Figure 11 Loudspeaker impulse response as an inverse Fourier transform form transfer function in figure 10

Also, it could be measured the transfer functions between mic2 and mic3 with respect of the output of the power amplifier of that excites the loudspeaker for different source distances.

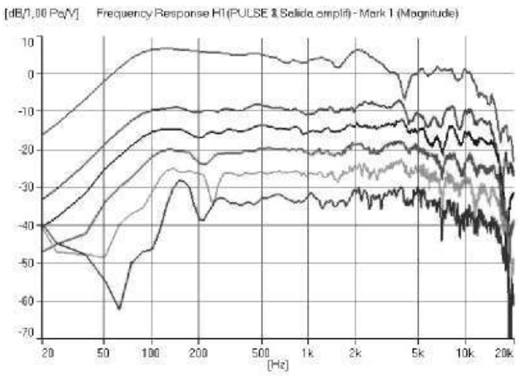

Figure 12 Loudspeaker frequency responses as transfer functions between mics and power amplifier for distances from 50mm up to 4000m

At figure 12 it is possible to observe the effect of the anechoic chamber on the low frequency response, due to the lack of accomplishment of the inverse squared law when the microphones are far away from the loudspeaker.

The following step consists in calculating the relative transfer functions between microphone couples for different distances among these and the loudspeaker. This measurement allows to eliminate the loudspeaker response and therefore it will not be influenced the measurement by the fact that the loudspeaker frequency response would be not flat.

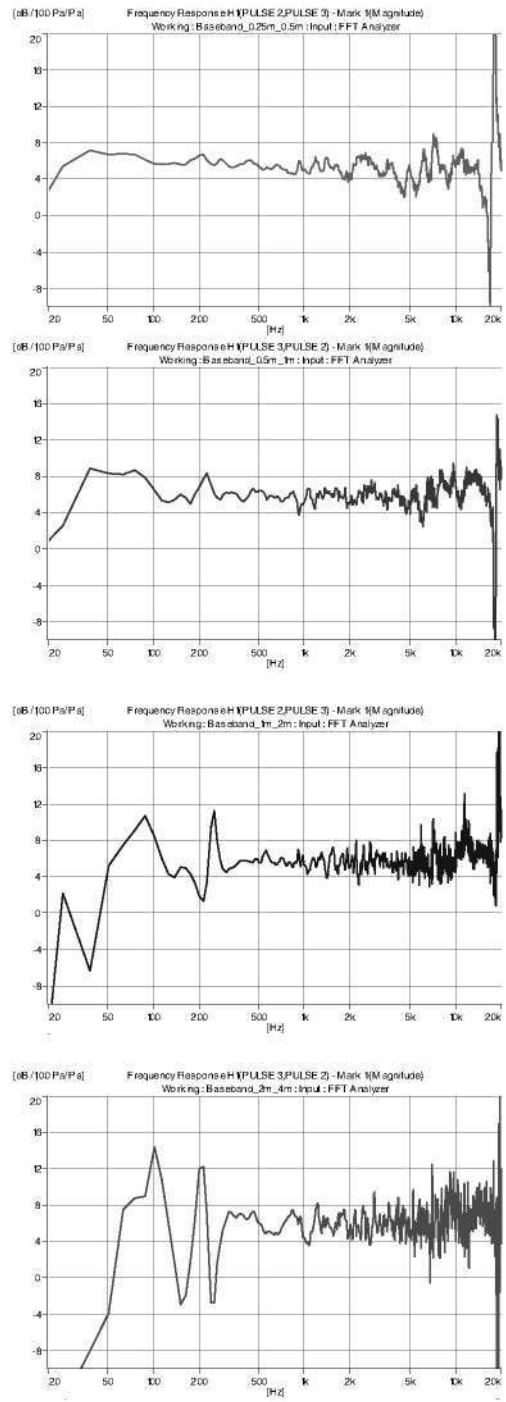

Figure 13 Transfer function between mic2 and mic3 for couples of distances from 250mm-500mm to 2000mm-4000mm from loudspeaker

From these measures, which are obtained easily by the FFT analyzer, it could be verified the accomplishment of the inverse squared law, calculating the average level in bands of 1/3 of octave (theoretically, between mic2 and mic3 always there would be a level difference of 6dB, assuming free field condition inside the chamber). The results can observe at figures 14 and 15.

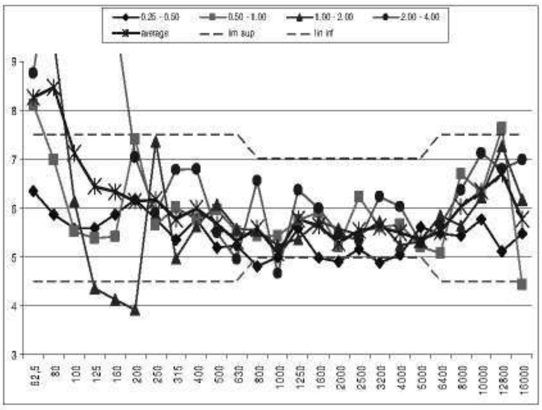

Figure 14 Inverse squared law deviation for distance couples from 250mm-500mm to 2000mm-4000mm in longitudinal direction. Mic1 is placed 50mm away from loudspeaker

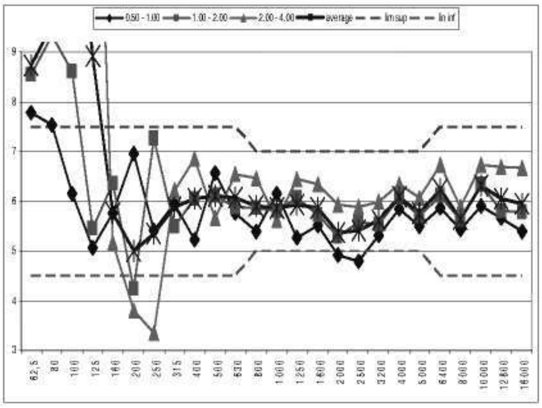

Figure 15 Inverse squared law deviation for distance couples from 500mm-1000mm to 2000mm-4000mm in longitudinal direction. Mic1 is placed 250mm away from loudspeaker

It is possible to observe that the curve that represents the average value of the deviation supports inside the limits allowed by ISO 3745-1977, from the 160 Hz 1/3 octave band. This result agrees totally with the obtained one for the methods described in [1]. The advantage that supposes the method is the velocity of making the measurement for every microphone position. The FFT analyzer B&K 7770 allows to connect up to 4 microphones simultaneously, with what it is possible to obtain an analysis of the anechoic chamber in a short time, always minor that the used in the traditional methods.

These measurements have been realized for different analysis frequency span of the FFT analyzer, in order to obtain more detailed information of different parts of the spectrum. In all the cases there has been configured a 1600 points FFT analysis and Hanning windowing. It Two frequency span have been used: 3.2kHz and 20kHz.

In the same way, it is possible to work with the temporal information of the microphones obtained from inverse transforms of the previous transfer functions of, so from mic/ampl as from couples of microphones.

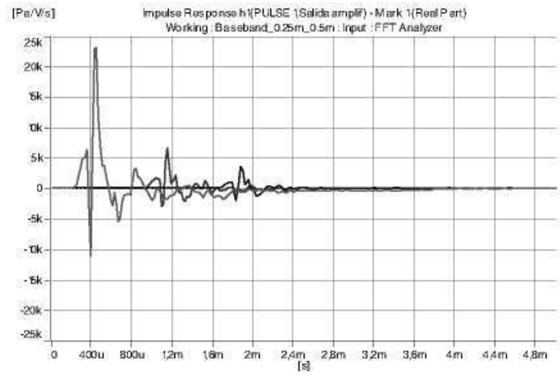

Figure 16 Loudspeaker impulse response from mic1 (50mm), mic2 (250mm) and mic3 (500mm)

At figure 16 it is possible to observe the attenuation that suffers the loudspeaker impulse response depending on the distance inside the anechoic chamber. Figure 17 shows the loudspeaker impulse responses for the microphones placed at 500mm, 1000mm, 2000mm and 4000mm. In the last case, the effect of the opposite wall reflection is observed (signal that comes with 2 ms delayed with respect of the loudspeaker direct signal). In this response the characteristics of the loudspeaker (the first part of the impulse response) are mixed with the characteristics of the room. Therefore, to try obtaining information from the anechoic chamber is necessary to eliminate the information from the loudspeaker.

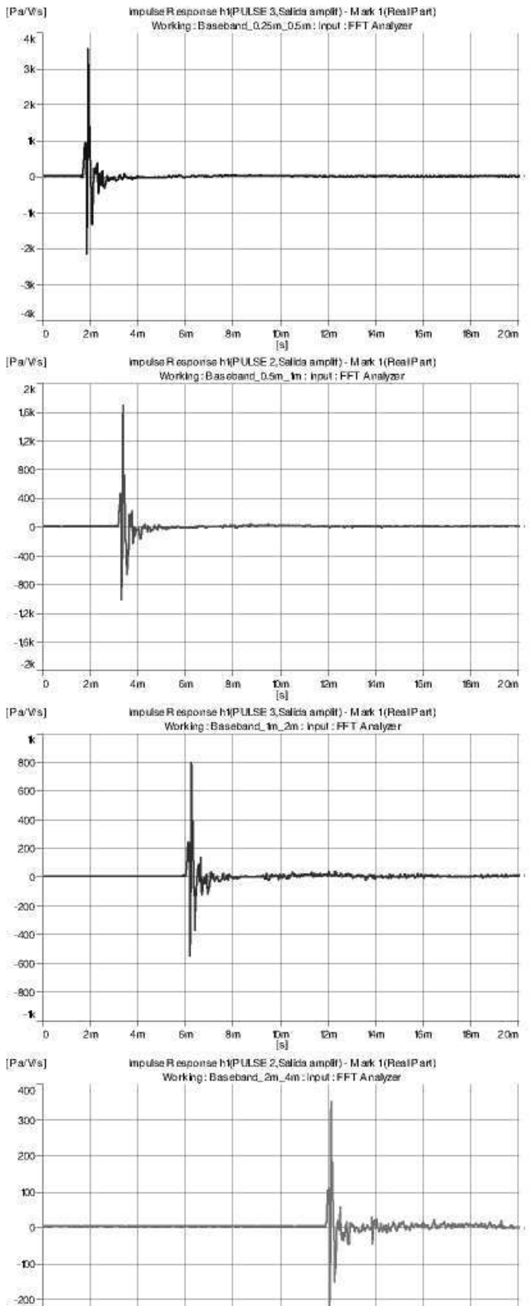

Figure 17 Loudspeaker impulse responses from mics at 500mm, 1000mm, 2000mm and 4000mm

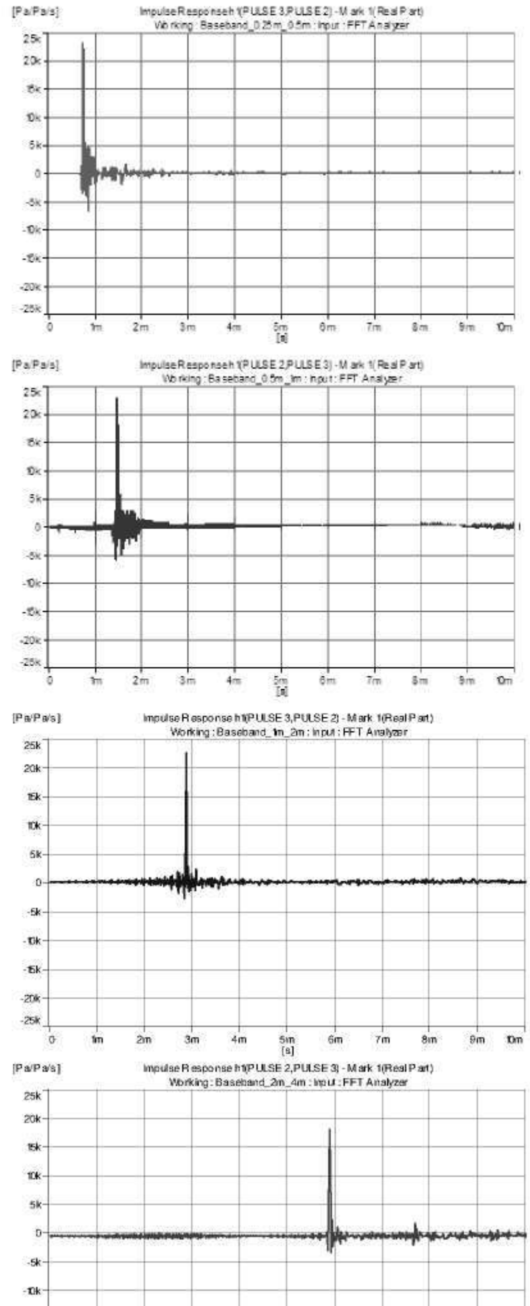

Figure 18 Anechoic chamber impulse responses couples from 250mm-500mm to 2000mm-4000mm

To do this, it will be calculated the impulse response between the microphones mic2 and mic3 for the same pairs of distances that in case of the transfer functions.

The information so obtained corresponds only to the anechoic chamber characteristics.

From the information of the impulse responses between pairs of microphones, it is possible to try to get information of the reverberation time in the anechoic chamber and later to obtain the information of the absorption coefficient of the chamber, in order determine its real cut-off frequency.

The problem appears in the own nature of the anechoic chamber, which produces impulse responses of very short duration and with a quick energy decay of the. The method that one has proposed is a backward Schroeder integration [6] - [8] realize from the impulse response between pairs of microphones separated always a double distance. This method supposes a band-pass filtering of the impulse response.

Up to the moment the obtained results are not too encouraging, though it will continue investigated in this way.

4. CONCLUSIONS AND FUTURE WORKS

The conclusions that can be obtained of the anechoic chamber characterization are the following ones:

- The verification of the inverse squared law (free field conditions) completing is a complicated process by the great quantity of measurements that should be carried out and for the lack of exhaustive information that the anechoic chambers owners provide.
- In employment of methods of having multichannel measurements by means of FFT analysis and obtained data post processing allow to become independent of the sound source characteristics that we are using (it usually presents radiation problems in low frequency and of directivity leakage in high frequency).
- The facility and rapidity of the inverse squared law (free field conditions) checking by means of the multichannel method, it does is preferable to the traditional methods.

As for the future works:

- We will continue working with the transfer functions based on cross spectrum among microphones trying to estimate the chamber absorption coefficient carrying out measurements nearest to the absorbent walls.
- Under the supposition of the behavior of the anechoic chamber like a LTI system when behaves as free field, it will allow to simulate the intermediate distances as an attenuation and a delay, allowing to estimate the absorption coefficient of the chamber walls.

5. ACKNOWLEDGEMENTS

We would like to thank the work carried out by Oscar Villarejo-Villanueva and Teresa Haro-Marino during their Bachelor Degree Thesis.

6. REFERENCES

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