Sound field characterisation and absorption measurement of wideband absorbers

Soledad Torres-Guijarro
AtlanTTic - University of Vigo

Antonio Pena
University of Vigo

Alfonso Rodríguez-Molares
Defense University Center

Norberto Degara Quintela
Fraunhofer Institute for Integrated Circuits IIS

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Sound field characterisation and absorption measurement of wideband absorbers*

Soledad Torres-Guijarro[1], Antonio Pena[2], Alfonso Rodríguez-Molares[2], and Norberto Degara-Quintela[2]

[1] Laboratorio Oficial de Metroloxía de Galicia (LOMG), Parque Tecnolóxico de Galicia, 32901 San Cibrao das Viñas, Ourense, Spain
stores@lomg.net

[2] Universidade de Vigo, 36310 Vigo, Pontevedra, Spain
apena@gts.tsc.uvigo.es, amolares@gts.tsc.uvigo.es, norberto.degara@gmail.com

ABSTRACT

Wideband absorbers are a fundamental part of non-environment control rooms. They consist of huge angled hanging panels in conjunction with a multilayer wall or ceiling. Their absorption capacity is very noticeable, mostly in the low frequency range. In this contribution, the mechanisms of absorption of the wideband absorbers of the rear wall of the control room at the Universidad de Vigo will be studied. Conclusions will be drawn from the analysis of pressure, velocity volume and intensity measurements performed in the vicinity of the panels, and from the computation of the normal specific acoustic impedance and the normal absorption coefficient.

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1. INTRODUCTION

The non-environment design of control rooms was proposed around 1982 by Tom Hidley, where the goal was having an acoustical environment with the minimum of room sound. Sound radiates from the monitor loudspeakers with barely any sonic influence from the room. This basic principle allows a reflective floor and a diffuse reflecting front wall where the loudspeakers are flush mounted. Wideband absorbers cover the side walls, rear wall and ceiling, creating an almost hemi-anechoic space for the monitoring while keeping comfortable working conditions thanks to the reflecting front wall. This design is aimed to preserve the sound characteristics of the mixing and production studios when taking the product to other listening environments [1]. A detailed description of the wideband absorbers is given in Section 2.

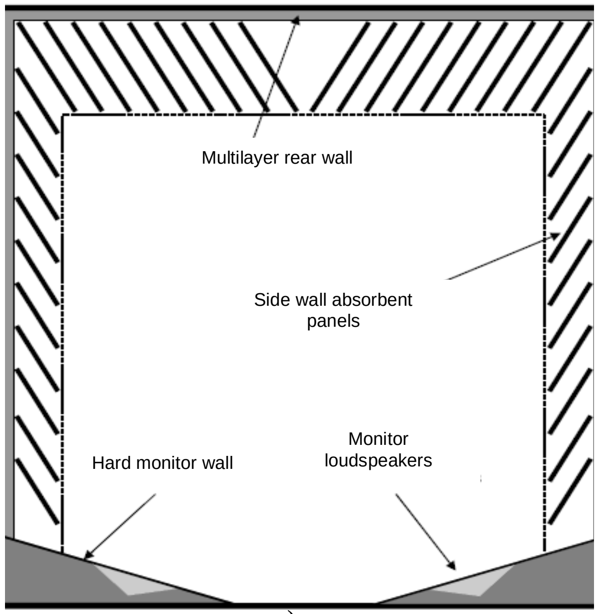
Although this wideband absorbing structure has been successfully used for over 30 years, mainly in control rooms, the fact is that few scientific studies have been done in order to demonstrate its behaviour. The most complete study was performed by Stuart Colam at the ISVR (Institute of Sound and Vibration Research, University of Southampton, UK). In his PhD thesis [2], Colam posed several hypotheses on the mechanisms of absorption of wideband absorbers. We have relied on his work to pose the hypotheses on the behaviour of the panels, presented in Section 3.

Our contribution is based on in situ measurements in the control room at the Universidad de Vigo. This control room was built by Philip Newell as a high definition listening laboratory, according to the non-environment principles, and its acoustical behaviour has been analysed in [3] [4]. A p-p intensity probe was placed in different orientations and positions around the panels, and was used to record the waveforms of sound pressure from both microphones. The measurement setup is detailed in Section 4.

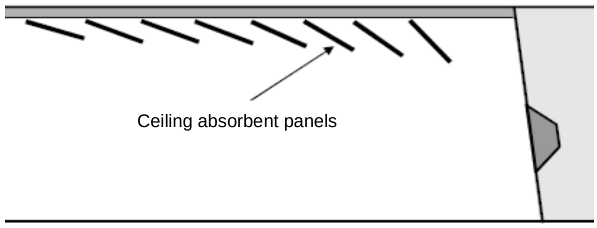
These waveforms are post-processed to compute volume-velocity and intensity, in order to analyse the sound field in the vicinity of the panels, characterise the panel arrangement and the rear wall in terms of its normal specific acoustic impedance and normal absorption coefficient, and verify some of the hypothesis on the mechanisms of absorption of the wideband absorbers posed by Colam. These results are presented in Section 5, and the conclusions that can be derived from them conclude this contribution in Section 6.

2. WIDEBAND ABSORBERS

The wideband absorbers consist of huge panels hung from chains in front of a multi-layer absorbent wall or ceiling, mounted in the manner similar to the shown in Figure 1.



a)



b)

Figure 1 Panel placement inside the control room; a) floor plan; b) cross section

The ceiling panels are inclined such that their leading edges point towards the loudspeakers, as shown in Figure 1, which was intended to provide the easiest access to the traps for the expanding waves leaving the loudspeakers. The lateral panels hang at an angle of 20º to the side wall. The rear panels, the object of this study, form an approximate angle of 40º to the rear wall. Their orientation is symmetrical regarding the longitudinal axis of the room, and their dimensions are 1 m wide and over 4 m height. They hang forming parallel channels with an approximate width of 12 cm between the outer cotton linings.

The construction of the panels can be seen in Figure 2: the core is nominally a 19 mm chipboard panel, but somewhat thinner plywood is also sometimes used. Stapled to the board is a damping deadsheet of 3,5 kg/m^2. Both sides of the panels are covered in 4 cm thick, cotton waste felt with a density of around 60 kg/m^3.

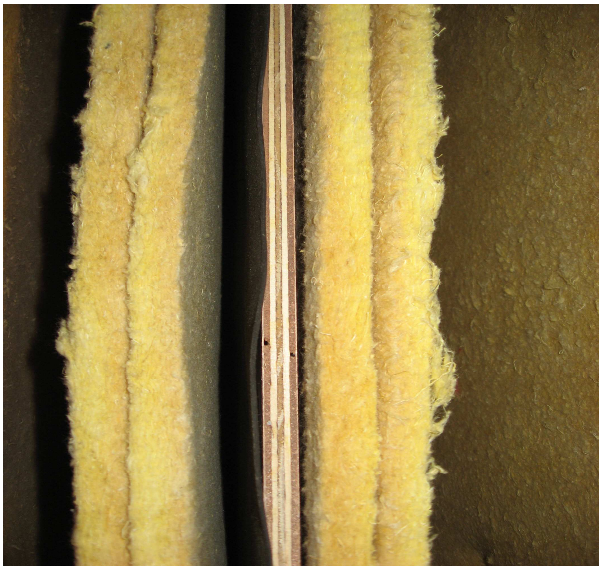


Figure 2 Panel construction

The walls and ceiling are constructed from a number of different layers. Figure 3 shows a cross Section of the rear wall, where the different layers can be seen. From bottom to top, behind the panels, there is a 2 cm layer of 60 Kg/m3 cotton waste felt, a 3,5 kg/m2 deadsheet, a 10 cm air space partially filled with 4 cm of cotton waste felt, 1,3 cm plasterboard, deadsheet, 1,3 cm plasterboard, 2 cm felt, 5-10 cm air space, and, finally, the concrete wall.

The panels and the wall are hidden behind an acoustically transparent fabric, which was partially removed for these measurements (see Figure 4) to give access to the channel where the intensity probe was located

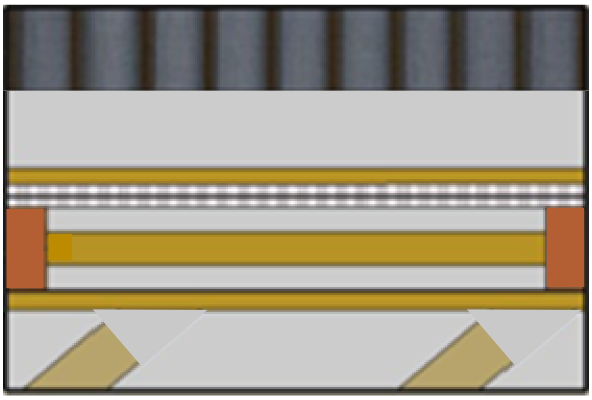


Figure 3 Cross section of rear wall

Figure 4 Fabric wall partially removed to show rear panels

3. HYPOTHESES ON THE MECHANISMS OF ABSORPTION

The main mechanism of absorption that may be involved in the behaviour of these wideband absorbers, given their geometry and construction, can be summarised in the following [2]:

a) Dissipation of low frequency sound energy through panel absorption. Previous measurements with accelerometers placed on the panels [5] concluded that flexural vibration of the panel has a minimal contribution on the power absorption (perhaps only 0.1% of the incident energy being absorbed), thus this hypothesis will not be further investigated.

b) Absorption solely due to the porous absorbent. It should be noticed that the wall behind the panels and both sides for each panel are covered by 4 cm of cotton waste felt. Although this represents a large amount of porous absorbent placed within a proportionally small volume, it is not expected that a 4 cm thick absorber provides high absorption at frequencies below several hundreds of hertz. This point is proven through absorption measurements of the felt using a Kundt´s tube [2]. The case of oblique incidence may pose a doubt in this conclusion, and will be analysed later.

c) Filtering of the sound as it propagates from the front loudspeakers down the length of the room, encountering a periodic array of panels on each lateral wall. As the present work focuses on the panels placed in front of the rear wall, this effect will not be analysed here.

d) Absorption due to ¼ wavelength resonances in the channels between panels. Adjacent panels and the multi-layer wall form closed end channels. At odd integer multiples of ¼ wavelength, the reflected sound from the wall will be in anti-phase with the incident sound at the opening (or mouth) of the channel. The acoustic impedance at this point and at these frequencies, will be purely real, and a maximum in the absorption will occur. Our measurements will show the relevance of this effect on the rear wall absorbers, where the sound is close to normal incidence.

e) Attenuation of sound as it travels down the channels between panels, which effectively act as lined ducts. This effect is similar to the attenuation suffered by sound as it propagates along an air conditioning circuit lined with absorbent material. Below the cut-on frequency of the tube, where only plane waves can propagate, the attenuation of sound is poor, as the particle velocity normal to the duct boundary is not significant. The cut-on frequency equals the frequency of the first "transversal mode" and is determined by the smallest transversal dimension of the channel; in our case it is over 500 Hz. The effect of this transversal resonance will be analysed in Section 5.

f) Panels acting as waveguides, forcing the sound to be incident on the multilayer wall at a particular angle. The waveguide effect of the panels was proven in [6] and is also corroborated in our analysis. On the other hand, the multilayer wall by itself provides a significant absorption, particularly at low frequencies. This point is verified in a set of measurements performed at different construction stages of a non-environment control room (see Appendix 1 in [1]). The combined effect of panels plus multilayer wall is more difficult to model, and would involve the study of the felt absorption under oblique incidence. Another related absorption mechanism is the "horn effect": the inclined panels act like reversed horns, with the high particle velocity at the mouth of the openings giving rise to high pressure at the throat, were the panels almost touch the wall. The phase differences of the wavefront on each side of the panels, due to their waveguide effect, lead to high particle velocities through the porous material between the panel and the wall, increasing the losses in the path through the fibrous material and giving rise to considerable absorption.

With the aim of verifying the hypotheses d), e) and f), we have measured the sound field in front, between and behind the panels with a p-p intensity probe. The pressure waveforms from both microphones are post-processed to compute volume-velocity and intensity, in order to analyse the sound field in the vicinity of the panels. Also, their absorption is characterised in terms of the normal specific acoustic impedance and normal absorption coefficient measured at the entrance of the channels. The measurement procedure is described in the following.

4. MEASUREMENT SETUP

The channel between the 4th and 5th panels of the rear wall, shown in Figure 4, was selected for the measurements, in the belief that its behaviour will closely resemble that of the rest of the channels of the same wall. It is located in front of the left loudspeaker, at roughly 1/3 distance from the left wall and 2/3 to the right wall.

We have studied the sound field through measurements at points 1 to 7 of Figure 5. Points 1 to 4 lie equally spaced in the middle of the channel, and are intended to show the waveguide effect of the panels. Points 5 and 6 are close to the gap between the left panel and the rear wall, and are intended to study the "horn effect". Point 7 lies in the middle of the mouth of the channel, 10 cm in front of it, and is used to compute normal specific acoustic impedance and normal absorption coefficient. All 7 points were measured at two different heights, as shown in Figure 5: height "a" (79 cm from the floor) and height "b" (30,5 cm from the floor). Henceforth, the measurement points will be identified as 1a-1b to 7a-7b.

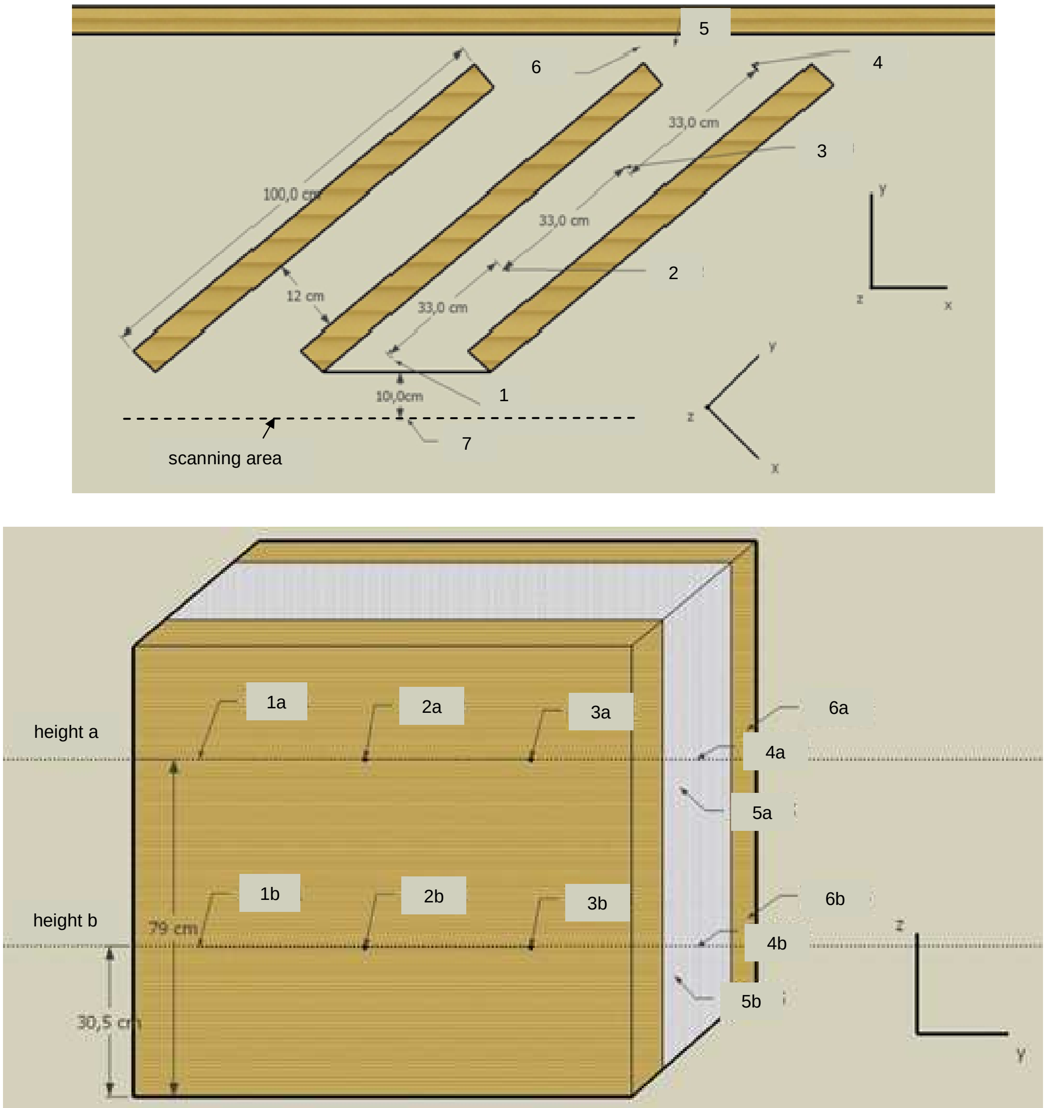


Figure 5 Measurement points in the channel between panels: horizontal plane and elevation

We also defined an area of 1 m^2 at 10 cm from the fabric covering the panels, to perform a scanning intensity measurement in order to obtain a spatial average of the normal absorption coefficient of the set of panels + multilayer wall. This area was marked on the fabric with tape, as seen in Figure 4.

The measurement instrument employed was a face to face p-p intensity probe whose pressure signals can be independently recorded. The probe is positioned in each measurement point in three orthogonal directions, with the aid of the adjustable arm seen in Figure 6. The probe orientations are represented as x-y-z axes in Figure 5. Note that there are two possible x-y axes in the horizontal plane to facilitate the interpretation of the results: one with the y axis parallel to the panels, for the measurements in the channel, and another with the y axis perpendicular to the rear wall, for the measurements at points 5, 6 and 7, and the scanning area.

Figure 6 Probe mounted on an adjustable arm

The excitation signal used was pink noise radiated from the central loudspeaker, adjusting its SPL to 85 dBC measured at the sweet spot at the height of the monitors, what reasonably represents the normal working conditions of the room. The distance from this source to the closest measurement point is over 5 m, therefore we can suppose that the waves that reach the panels are plane, and their direction of arrival is normal to the rear wall. We also used stationary tones of frequencies the centres of 1/3 octave bands. The interest of this excitation is to analyse the active/passive intensity balance and conclude the corresponding character of the sound field in different locations and frequencies.

The chosen microphone separation in the intensity probe was 50 mm, the larger available, to enlarge the lower measuring frequency limit as much as possible. The enabled frequency range with this separator is 20 to 1250 Hz.

5. RESULTS

The pressure signals from both microphones of the intensity probe are first used to compute the volume-velocity and the sound intensity at each point and frequency. The analysis of these variables can shed light on the character of the sound field around the panels.

5.1. Waveguide effect

The waveguide effect can be confirmed by the intensity plots obtained from intensity values in octave bands measured inside the channel. Figure 7 shows, as an example, the intensity plot for points 1a to 6a in the 63 Hz octave band. Each vector in the plot represents the projection of the intensity vector in the horizontal plane, and is obtained by vector combination of the intensity measurements in the x and y directions. It can be seen how the sound gradually changes its direction from normal incidence to the wall to parallel to the panels. The vertical component (not shown here) is noticeably smaller than the horizontal one. Similar results can be found in all the measurement range. The behaviour of the sound power flux in the proximity of the wall will be analysed in Section 5.3.

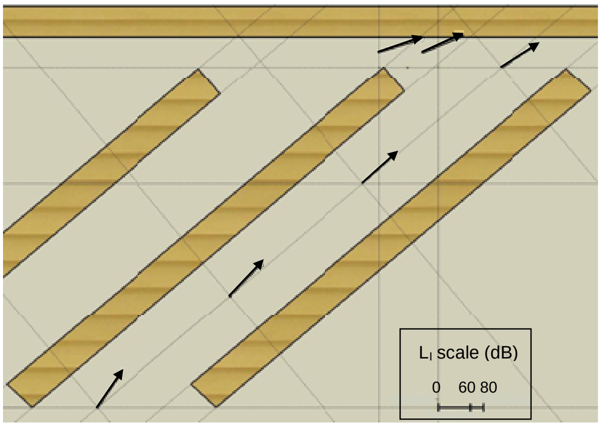


Figure 7 Intensity plot, horizontal plane, height “a”, 63 Hz octave band

Our results show that the mean intensity in the direction normal to the panels is small. This can be due to the waveguide effect, which produces a very small volume-velocity in the transverse direction, but it can also be argued that there might be hidden effects such as stationary waves or reactive field, that would not show up in a mean intensity representation, but would produce some energy flux in the transverse direction. The former will be analysed in next section. The presence of a reactive field was studied through:

- the active/reactive intensity balance using steady-state tones as the excitation, and
- the pressure-intensity index (δ_{pI}), computed as the difference between pressure and intensity levels; that is the indicator used by the intensity probes to detect reactive fields that would lead to a inaccurate intensity measurement.

The results of this study, that will be detailed elsewhere, show that a reactive field in the transverse direction can be identified at certain points and frequencies, but they are isolated cases.

5.2. Transverse stationary waves

The presence of a transverse stationary wave is evident when the volume-velocity in the three measuring directions is compared. Figure 8 shows the three components measured in third octave bands at point 2b, as an example. The y component, parallel to the panels, is clearly dominant in all the frequency range, except for the 400-700 range, where the x component has a noticeable rise. This rise can be related to the presence of a transversal standing wave.

The distance between the panels, measured board to board, equals half a wavelength at a frequency of 555 Hz at this measuring point. The maximum volume-velocity in the x direction takes place in the 500 Hz 1/3th octave band, with the curve showing a low Q resonance around this frequency. The effect of this stationary wave will also be seen in the absorption coefficient, below.

Similar behaviours can be found in the rest of the measurement points inside the channel between two panels.

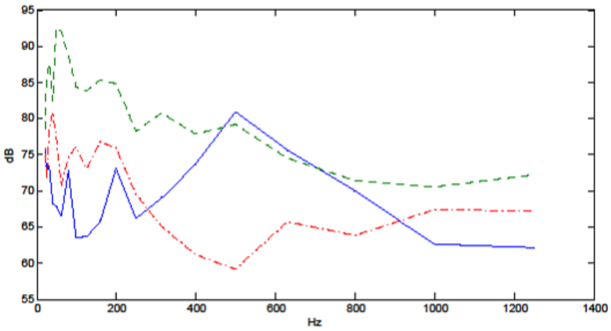


Figure 8 Volume-velocity spectra at point 2b in the three axes: – x, - - y; - • - z

5.3. “Horn effect”

The existence of a “horn effect” in the area between the rear part of the panels and the back wall has been studied through intensity, pressure and volume-velocity measurements at points 5 and 6. Intensity vector plots show a net energy flux from point 6 to point 5 at 63 Hz (both heights, see Figure 7 for an example) and 125 Hz (height “a”). Pressure results are very similar for all frequencies. The velocity component in the x axis direction at those points is bigger at some frequencies and smaller at others, compared to the y components, but no consistent tendencies could be found. Thus, the only evidence of the existence of the horn effect seems to come from the intensity results at low frequencies.

In an attempt to maximise the impact of the “horn effect” on the absorption, the gap between the end of the panel and the wall was filled with cotton felt. Measurements at points 5 and 6 were repeated, and the results with and without the filling compared. No general tendencies, such as a clear decrease of the velocity in certain frequency range, could be appreciated. We also compared the absorption coefficient with and without gap filling, calculated by the method described in Section 5.4 (see the results below), but again no significant differences could be found. Thais might be due to the fact that, if the "horn effect" contributes to the overall absorption, its contribution may be small, and hence may be masked by stronger effects.

5.4. Normal absorption coefficient

In order to characterise the set of rear wall + panels, we have estimated the normal absorption coefficient from the measurements at point 7 and the scanning area defined in Section 4.

The computation procedure to derive the absorption coefficient from the pressure signals from the microphones is as follows. First, the normal specific acoustic impedance, $z=p/u$ (*p*: acoustic pressure, *u*: volume-velocity), is computed using one of the two following frequency domain methods:

Direct method: The frequency domain estimation of the normal specific acoustic impedance is computed by dividing the pressure and velocity spectra ($Z=P/U$). Both spectra are estimated from the short time Fourier transform (STFT) of *p* and *u*, which are averaged before division. *p* is the average of the signals from the microphones, ½ $(p_1+ p_2)$, and *u* can be estimated as:

$$u \approx \frac{-1}{\rho d} \int (p_2 - p_1) dt \qquad (1)$$

where ρ is the air density and *d* the distance between the microphones.

This estimation procedure is considerably noisy, but is the only one possible from the scanning.

Indirect method: This alternative method is more robust to noise in the velocity estimation, but is only applicable for stationary measurements that provide steady estimations of the auto-spectra and cross-spectrum of *p1* and *p2*. The impedance is obtained as [7]:

$$\frac{z}{\rho c} = i\left(\frac{kd}{2}\right)\frac{G_{11} + G_{22} + 2\,\mathrm{Re}(G_{12})}{G_{11} - G_{22} - 2i\,\mathrm{Im}(G_{12})} \qquad (2)$$

where G_{11}, G_{22} and G_{12} are the auto-spectra and cross-spectrum of the pressure signals; *c* is speed of sound speed in air and *k* the wavenumber.

The normal absorption coefficient is next computed from the normal specific acoustic impedance as:

$$\alpha = \frac{4\rho c r}{(r+\rho c)^2 + x^2} \qquad (3)$$

where $z=r+ix$.

Figure 9 shows the normal absorption coefficient measured at point 7b. The continuous line represents the result without gap filling; the discontinuous line is the absorption with gap filling.

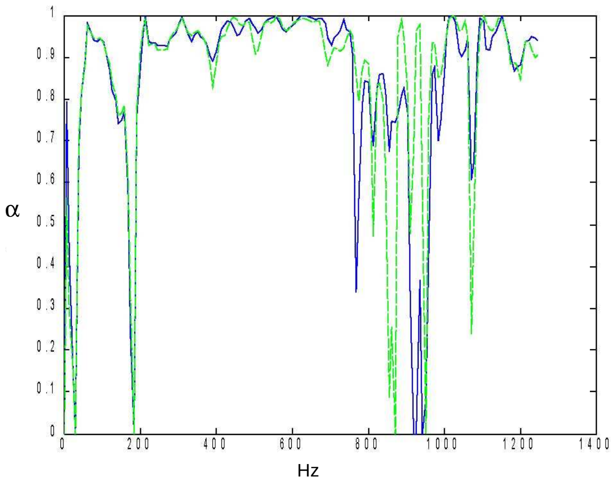


Figure 9 Normal absorption coefficient at point 7b; --: without gap filling; - -: with gap filling

The main effects that can be identified here are:

- maximum absorption at $f_{\lambda/4}$ and $\cdot 3f_{\lambda/4}$, that are the first and second resonances of an open-closed tube. Given the dimensions of the panels, and supposing an effective panel width (channel length) of 1,25 times the real width (as measured in phisical models in [2]), these two frequencies should theoretically be around 70 and 210 Hz, close to the two first maxima in the curve. The high absorption values around $f_{\lambda/4}$ may hide the contribution of the horn effect that was initially proven at 63-125 Hz.

- minimum absorption at $f_{\lambda/2}$, that can be identified as being responsible for the dip between the two maxima.

- high absorption from $3f_{\lambda/4}$ onwards, except for a "hole" around the transversal resonance, which is expected around 900 Hz in this measurement setting. It should be noted that the distance between the panels is now smaller, as they had to be separated a little to accommodate the probe and measure points 1 to 6, but they are back to their nominal distance here.

- from 1 KHz onwards, the mean absorption for the cotton-felt covering the panels and the rear wall is around 0.9, in accordance with the measurements in [2].

- the effect of the gap filling is not clear.

Figure 10 shows the result of computing the normal absorption for the scanning. The result has been smoothed with a 3 points median filter in order to reduce the spurious points, produced by the estimation of *z* through the direct method.

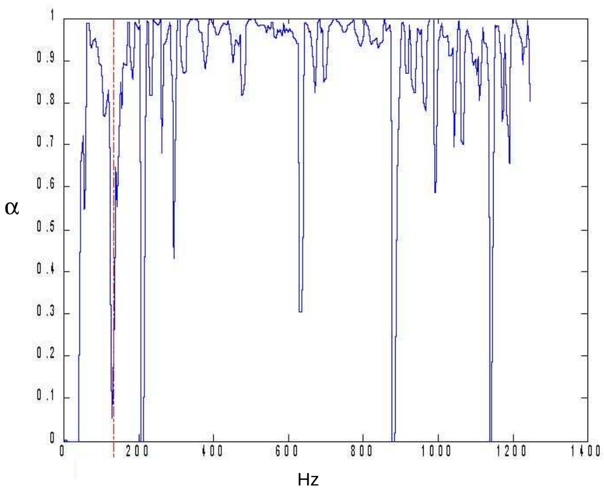


Figure 10 Normal absorption coefficient for the scanning

The main difference with the results of point 7 seems to be the disappearance of the transverse resonance effect, probably due to the spatial averaging. Note that the scanning covered four channels between panels in the horizontal dimension, and around 1 m in the vertical dimension.

5.5. Predictive model

A simple model can be derived from the above results to help the designer to predict the absorption of panels, of arbitrary width *L*, when mounted in front of the multilayer rear wall. The restrictions to this model are that the panels should hang at an approximate angle of 40º to the rear wall, and that *L* is long enough enable the waveguide effect to take place. Under these conditions, the normal absorption of the rear wall will resemble Figure 11, where the important characteristics of the curve are related to *L*.

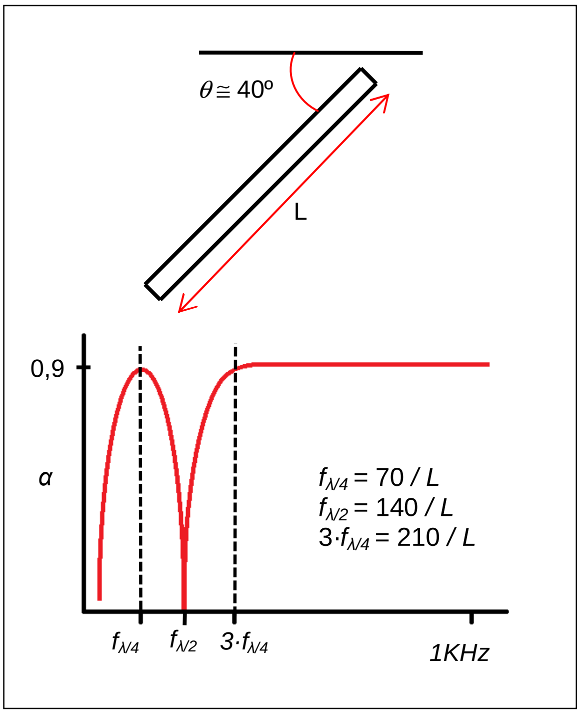


Figure 11 Predictive model for the absorption of the rear panels

6. CONCLUSIONS

The acoustic behaviour of the wideband absorbers of the rear wall in the control room at the Universidad de Vigo have been studied through pressure, velocity and intensity measurements. The existence of the following phenomena regarding the sound field around the panels has been proved:

- a waveguide effect, in the longitudinal dimension of the channel between the panels
- a stationary wave, in the transverse dimension

The existence of the "horn effect" at low frequencies (63, 125 Hz) can be supposed in view of the intensity plots, but the analysis of the other acoustic variables does not confirm this.

The normal absorption coefficient of the set of panels + rear wall has also been measured and modelled, the results showing a strong correlation with the $\lambda/4$ effect of a open-closed tube.

7. ACKNOWLEDGEMENTS

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