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STUDY OF SCATTERING PANEL PAIRS IN A VIRTUALLY ANECHOIC ENVIRONMENT.

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ABSTRACT.
In September 2006 a measurement campaign was run in Parma to study the AES recommendation document 4id-2001 on scattering panels' diffusion uniformity characterization. As allowed in the document appendix, the experiments were run on the floor of a large industrial shed to obtain a long enough anechoic time window and to study the first reflection from the panels themselves.
In these measurements two panels at the time were studied, following the recommendation that asks to maximize the surface under test, so to consider application realistic situations.
Some innovations were introduced: the use of the sine-sweep technique, a sonar mutuated visualization method gave new insights to the matter and permitted to enhance the time windowing of measurement data through an automated process.
The results on five types of panels are discussed together with an analysis of reflectivity data.

INTRODUCTION: THEORETICAL AND EXPERIMENTAL SET-UP

A campaign of scattering measurements continued the first one executed on single panels in the previous month of April and discussed at the AES convention in San Francisco [1].
The AES recommendation document 4id-2001 [2] (which is now being evaluated for becoming the ISO 17497 – 2 standard) and Cox and D'Antonio's [3, 4] previous papers on the matter were used as a reference to start the study.
This time mostly couples of panels were considered, to investigate the phenomena of uniform geometric diffusivity in more realistic situations (the first campaign's main purpose was to compare this type of analysis with a former study on single panels [5, 6]).

Experimental set-up.

As stated by the recommendation document, the anechoic conditions for studying the first reflection from the panels were obtained by setting the microphone array, the source and the panel itself on the floor of a very large industrial shed which is normally used for fairs and exhibitions. This was already demonstrated valid to obtain a clean first reflection signal, not corrupted by later reflections [1].

The receiver array had a semicircular shape as requested, it had a radius of 5 meters, centred at the panels' frontal face vertical axis base. The source was moved along a 10 meter semicircle centred as the smaller one.
On the basis of the results obtained in the previous experiment, it was decided to investigate 5 source positions for each double-panel assembly (-60°,-30°, 0°, 30° 60° incidence) and 3 for each single panel (the fast acquisition method specified by the AES recommendation, which asks to use –55°, 0°, 55° of incidence).

Since only 60 x 60 cm panels were considered, when the analysis took two panels at the time it created a surface roughly 120 cm wide per 60 cm high. Figure 1a shows the measurement setup with a panel under test (Type Galav2), 0° sound incidence, figure 1b shows two panels (Type Galav1)in one of the two possible configurations (the panels are asymmetrical and two configurations had to be studied).

The choice of using just 24 microphones was taken from the past research results, which showed little difference when employing 48 microphone positions.

Figure 1.

Acquisition process and protocol.

The measurement hardware was made by:

- 24 Bruel&Kjaer 4188 microphones with 2671 preamplifiers (phantom-powered);
- 3 8-channels Behringer AD-DA 8000 Converters;
- 1 RME Hammerfall DIGI9652 soundcard;
- 1 Turbosound TQ440 sound source.

The impulse responses were taken using the sine sweep technique [7]: a logarithmic sine sweep was generated using the Aurora Adobe Audition plug-ins (www.aurora-plugins.com).
In the past measurements this method was demonstrated to be quicker than the otherwise proposed MLS method (it does not need averaging on numerous measures) and good to reject the background noise from the nearby A1 highway (a constant Leq = 45 dB(A) had been measured in the shed on two minutes of observation).

A key factor from the past campaign was optimising the measurement protocol itself: this time it was decided to measure all of the panels with the same sound incidence angle within a short time period, comprising the empty take (to acquire h2 as will be explained shortly), this guaranteed a large correlation between the impulse responses.

Data processing.

As required by the AES document the single reflection can be obtained by subtracting the two impulse responses h_1-h_2, this rejects most of the direct wave and spurious reflections. The actual reflection (h_4) is then found by deconvolving the system response through division by the measurement system response (h_3) in the frequency domain:

$$h_4 = IFT\left[\frac{FT[h_1 - h_2]}{FT[h_3]}\right] \qquad \text{(Eq. 1)}$$

The first two impulse responses must be time windowed at the first reflection time position: the time window start was previously decided by visual inspection as required by the recommendation document.

At this point the H_4 (FFT(h_4)) absolute values where squared and summed strictly within each third octave and octave frequency band limits for each microphone, obtaining the required L_i (referring to the i-th microphone of N) .
Then these values were used to obtain the angular dependent (θ) diffusion uniformity coefficients (equation 2), the random incidence ones (average on all the investigated incidences) and to plot the diffusion polar graphs in dB scale.

$$d_\theta = \frac{\left(\sum_{i=1}^{N} 10^{L_i/10}\right)^2 - \sum_{i=1}^{N}\left(10^{L_i/10}\right)^2}{(N-1)\sum_{i=1}^{N}\left(10^{L_i/10}\right)^2} \quad \text{(Eq. 2)}$$

The diffusion uniformity coefficient is a qualitative parameter and it depends on the measurement geometry [5]: it gives a value of 1 to a panel which reflects the same amount of energy in all directions and 0 to a totally specular reflective panel.

The polar graphs show the direction distribution of the first reflection as in loudspeaker directivity polar graphs (figures 7 a,b).

DATA PROCESSING OPTIMIZATION – MOVING TIME WINDOW.

A 500 samples time window was considered as in the past experiments, to avoid any influence from the first room reflections (from objects hung at the ceiling of the shed).
The window's edges were smoothed through a raised cosine roll-on and roll-off and it started roughly 35 samples before the expected reflection arrival.
A few simple considerations permitted to note that the reflected wave arrival can be predicted through a simple geometrical model that sets two point sources at the panel border angles. Expecially for shoe-box shaped ones. Hence it is simple to predict the reflected and direct wave arrivals:

$$r_{reflected} = \sqrt{4r^2 + x^2} + \sqrt{r^2 + x^2 \pm 2rx \cdot \mathrm{sen}(\theta)} \quad \text{(Eq. 3)}$$

$$r_{direct} = r\sqrt{5 - 4\cos(\theta)} \quad \text{(Eq. 4)}$$

r is the receiver semicircle radius and the distance between the source and the semicircle
x is half the panel's width
θ is the angle of observation.

Superposing these theoretical curves with sonar-like measurement surface graphs of h_1-h_2 there is a perfect matching: figure 2 shows the superposition between measures and theoretical curves when sound is incising from 55 degrees, in this graph the window beginning is represented by the red lower line, and the window end by the magenta line on top.
In the past campaign the time window was quickly set by looking for the closest reflection and imposing the same beginning to all of the 24 tracks.
This study actually permits to make the reflection recognition automatic and to align the tracks to optimise the division with h_3 which can be windowed using the same concepts (length, beginning, etc.). The main advantage of the use of this method is in low energy retrieval, as expected by better centred windows.

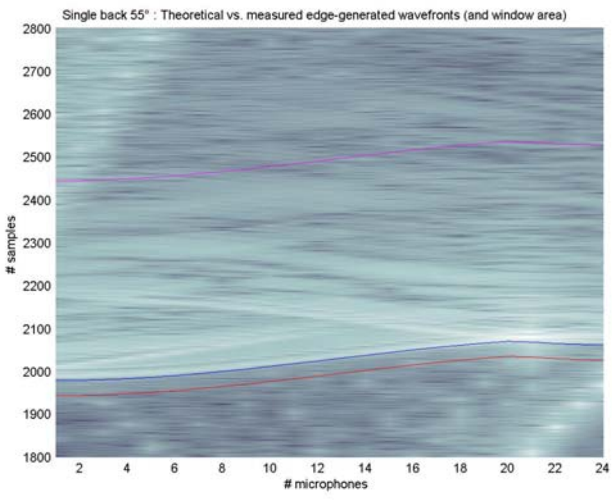

Figure 2.

PANEL STUDY RESULTS.

Panel backs (reference flat panel).

As the flat reflecting surface widens, the reflection coefficient decreases as expected, since it resembles more to the ideal 'acoustical mirror'. This panel is to be used as a reference to be compared with the following ones.

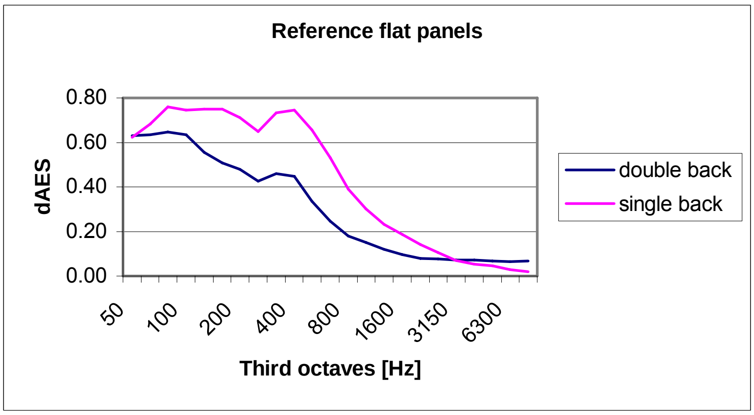

Figure 3.

Perforated panels.

In this case just one perforated 560 x 960 mm panel was measured in two configurations: standing and laying on its side. It had a 1,33% of perforation with a design resonant frequency of about 120 Hz.

The study on this panel start to confirm that there is correlation between the panel's width and the first maximum frequency (where the sound diffraction is at its most and the panel acts like a point source) and the depth and the second maximum frequency, further analysis on different panels will give complete confirmation of this theory.

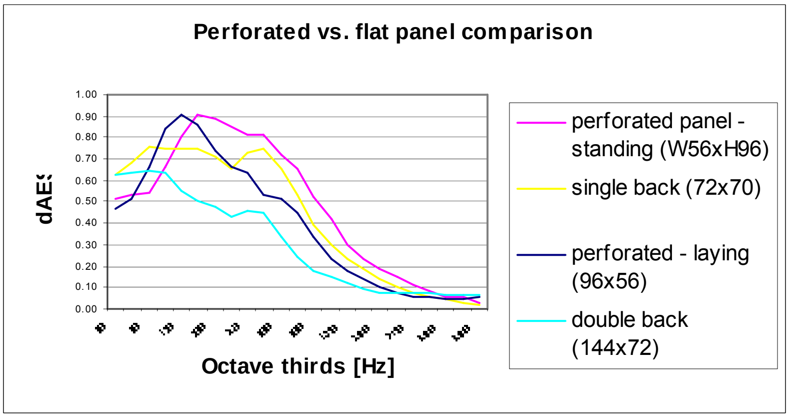

Figure 4.

Galav panels.

The last pairs to be discussed are two diffusor panels developed in Parma in 1999, and named Galav1 and Galav2. Since they are not symmetrical respect to their front face vertical axis, two possible combinations were studied for each panel type and were denominated a and b.

The results are quite similar for both combinations at high frequencies but oscillate at low and mid frequencies.

Galav1 partially behaves like a QRD7® having a strong diffusion localized at the panel depth related frequency (400 Hz – see figure 5). It is actually the galav2 panel which strikes with a quite high and uniform diffusion across the spectrum, expecially in the a disposition.

Comparison between 4 panel couple types.

Figure 5 shows the comparison between the four panel pairs under investigation: the Galav2 pair in disposition (a) has the best result in terms of uniformity of diffusion on the emi-space in front of it.

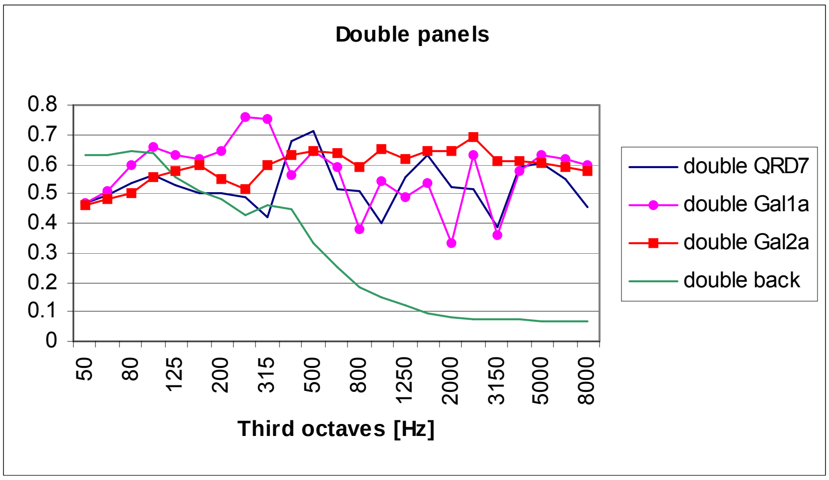

Figure 5.

It is also notable that galav1 has a design frequency which is lower than the QRD7® under test, and is well diffusing as low as at about 250 Hz.

FIRST REFLECTION FROM A PERFORATED PANEL.

The experimental setup is meant to study the first reflection geometry in the emi-space in front of the panel itself, this permitted to study the perforated panel first reflection in depth.
The analysis of the single impulse responses at the microphones showed a strong vibration within the reflection pattern (figure 6a), recorded in front of the panel when sound was incising laterally. This led to study the relative frequency responses (figure 6b).
It was remarkable the fact that the phenomenon was univocally shifting in frequency depending on the angle of observation (the microphone of reception), it was localized only in a specific sector of the emi-space and presented a discontinuity at about -45°.

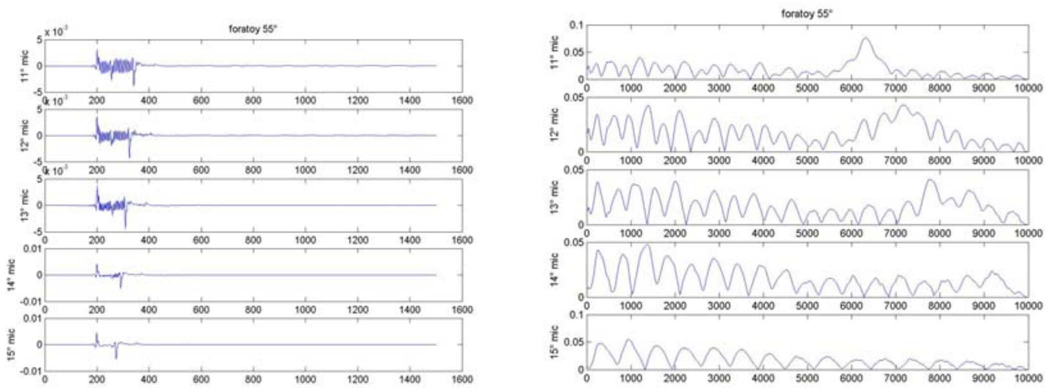

figure 6 a,b.

These results lead to think about the behaviour of loudspeaker arrays when fed on a delay line; the panel was hence modelled as a matrix of monopole sources [8], positioned in space and with the same radius as the panel holes, it was studied their contribute at each point on the observation semicircle. Each omni-directional source was considered emitting sound on the moment the incising sound illuminated it.
Equation 5 shows the equation describing the model.

$$p = \frac{\rho_0 kc(4\pi a^2 \hat{u})}{4\pi \cdot r} \sum_i \sum_j e^{-jkx_{i,j}} e^{-jky_{i,j}} \qquad \text{(Eq. 5)}$$

where:

a = source radius (hole radius)
u = superficial velocity module = 0.1 m/sec
r = reception array distance = 5 m
i = i-th source matrix column
j = j-th source matrix row
$x_{i,j}$ = distance between illuminating source and monopoles (panel's holes)
$y_{i,j}$ = distance between monopoles and receiving semicircular array

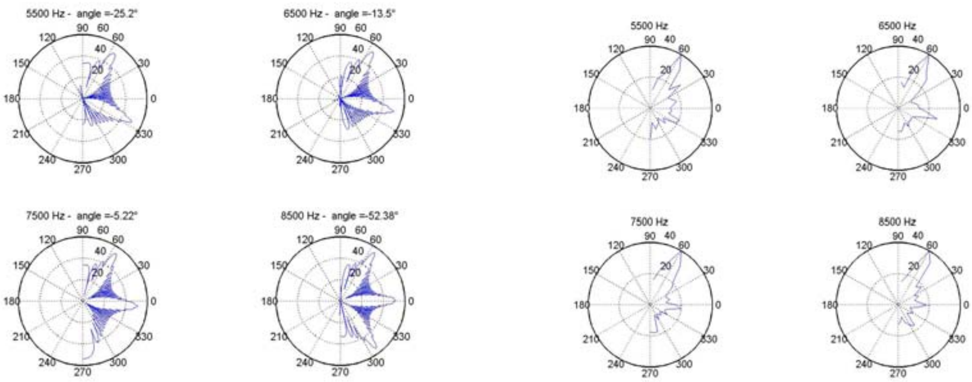

Figure 7 a, b

The model results in figure 7a give a perfect match with the measurements results.
They also correlate well with the polar plots obtained filtering in twelfth octave bands the measured pseudo-intensity spectrum values in figure 7b (note that the measurements have a poor resolution respect to the mathematical model, the graphs are plotted at the maxima frequencies). These results confirm the existence of a natural re-irradiation phenomenon in non specular direction.

CONCLUSIONS.

The present study permitted to ameliorate again the acquisition protocols of the measurements run in pseudo-anechoic environments. It confirmed the galav2 panel superiority in diffusion uniformity, even when arranged in pairs. The perforated panel measurements gave some interesting results which will be investigated in more depth.
Next investigations will continue to study the large database of measurements data and carry on new similar experiments.

References:

[1] Lorenzo Rizzi, Angelo Farina, Paolo Galaverna, Paolo Martignon, Andrea Rosati, Lorenzo Conti, Surface scattering uniformity measurement in reflection free environments, 121st AES Convention, San Francisco, 5-8 October 2006 , Convention Paper 6922
[2] AES-4id-2001, AES information document for room acoustics and sound reinforcement systems - Characterization and measurement of surface scattering uniformity.
[3] Peter D'Antonio, Trevor Cox, Two decades of sound diffusor design and development. Part 1 and 2, JAES Volume **46, No. 11-12** pp 955-976; 1075-1091 November-December 1998
[4] Peter D'Antonio, The Directional Scattering Coefficient: Experimental Determination, JAES Volume **40, No. 12** pp. 997-1017, December 1992.
[5] Angelo Farina, Michele Zanolin, Elisa Crema, Measurement of sound scattering properties of diffusive panels through the Wave Field Synthesis approach, 108th AES Convention, Paris 18-22 February 2000.
[6] Angelo Farina, Measurement of the surface scattering coefficient: comparison of the Mommertz/Vorländer approach with the new Wave Field Synthesis method, International Symposium on Surface Diffusion in Room Acoustics - Liverpool (GB) 16 April 2000.
[7] Angelo Farina, Simultaneous Measurement of Impulse response and distortion with swept sine technique, 108th AES Convention, JAES (Abstracts) volume **48 p 350**, April 2000, preprint 5093
[8] L. Kinsler, A. Frey, A. Coppens, J. Sanders, Fundamentals of Acoustics, John Wiley & sons, 4th edition.