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Prediction of the Random-Incidence Scattering Coefficient Using a FDTD Scheme

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Summary
This paper is focused on the evaluation of the scattering coefficient of sound diffusers which are based on the incoherency of diffusely reflected sound. A new approach for predicting the scattering coefficient is proposed; the method is based on a finite difference time domain (FDTD) scheme. Two established scattering coefficient measurement methods, proposed by Mommertz and Vorländer [1], are simulated; these correspond to measurements in a reverberant chamber, and free field. The results are also compared to those obtained in a previous paper [2], wherein it was demonstrated that FDTD schemes can be used to predict polar responses. These free field polar responses are used to find the correlation scattering coefficient, which in turn is used to validate the free field case. In modelling the reverberant chamber method, 2D simulations have been used to reduce computation time; hence it is necessary to derive a diffuse field formulation for a 2D reverberation chamber, which is presented. In this case, 1:5 scale experimental data is used for validation.
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1. Introduction

Sound scattering by a wall structure is an important factor affecting the sound quality of critical listening spaces. In recent years, significant efforts have been directed towards defining measurement techniques in order to characterize the performance of sound diffusers. The first standardized technique was published by the AES [3] and is based on free-field measurements of the reflected sound over a range of angles. For this purpose an impulse response must be obtained (using MLS, log-sweep sine chirp or another technique). A microphone is moved along a semi-circular arc (or over a hemisphere for full three dimensional evaluation), centred on the mid-point of the test sample, and appropriate time-domain windowing of the signal allows the elimination of the direct sound. Alternatively, near-field holography can be used to avoid the need for large anechoic environments which are required to ensure far field conditions [4]. Scale models offer a simpler solution to this physical problem - but the technique remains time consuming if several angles of incidence are considered, unless a system using multiple simultaneous microphone measurements is used. This technique is currently being considered by an ISO working group.

The parameter measured using this technique is known as the '*diffusion coefficient*', which is a measure of the uniformity of the reflected sound. It is useful when comparing the performance of different surfaces. The coefficient was formulated in order to facilitate the design of diffusers; however, attempts at interpretation of the polar distribution of scattered sound in a diffuse field are likely to prove problematic, since the details of the distribution (the lobes and nulls) are spatially smeared due to incoherent excitation.

In 1995, Mommertz and Vorländer [1] presented a completely different technique for the characterization of sound diffusers, based on the incoherency of diffusely reflected sound. Two alternative methods were introduced; the free field method, illustrating the concept of using coherence to split the reflected sound into its specular and scattered components, and a reverberant method which exploits this principle more efficiently to obtain a random incidence coefficient. In reference [5] the authors detailed these techniques, both based on the same principle.

Both of these methods provide the '*scattering coefficient*'; that is, a measure of the proportion of sound energy not reflected in a specular manner. Because this coefficient does not measure how the diffusely reflected sound is distributed, it does not measure the quality of the scattering. Consequently, it should not be used for evaluating diffuser quality. However, it is ideally suited for incorporating scattering into geometrical room acoustics models.

In the free field method, the complex reflection coefficient is split in its specular and diffuse components by coherently averaging the impulse responses while the test

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sample is rotated. From the complex specular reflection factor, the scattering coefficient can be obtained. The scattering coefficient generally depends on the angle of sound incidence. However, an angular average of the scattering coefficient derived using the Paris formula [6] can be used to estimate a random-incidence value, just like converting single-incidence absorption data to a random-incidence figure.

In the reverberant chamber method, a test sample is introduced and impulse responses for different sample orientations are obtained. Using synchronous averaging of these impulse responses, the diffuse reflected sound is eliminated and a virtual specular impulse response is obtained. From that impulse response, a pseudo-absorption coefficient can be obtained in an analogous way to the Sabine method. Finally, a random incidence scattering coefficient is obtained from this pseudo-absorption coefficient and the standard absorption coefficient. The method, now part of an ISO standard [7], draws heavily on the standard for measuring the random incidence absorption coefficient.

In prototyping diffuser devices, numerical methods may be used to model diffusion and scattering coefficients and to allow the rapid comparison of different scenarios. Significant efforts have been expended in the search for numerical methods to avoid the problems of measurements in the case of the AES standard. Cox, D'Antonio and other authors have performed a wide range of comparisons between predictions and measurements [8], and have demonstrated that amongst those prediction techniques tested, the Boundary Element Method (BEM) is the most accurate.

Concerning the ISO standard, several authors [9, 10, 11] have used different techniques to reproduce the Free Field method proposed by Mommertz and Vorländer, using the Paris formula [6] to average different incident angles and estimate the random incidence scattering coefficient. These methods imply the calculation of reflections from sources at several incident angles and thus, a very significant computational effort. However, in the published literature, no record is given of the prediction of the random incidence scattering coefficient directly by numerical simulation in the time domain; this task forms the main contribution of this paper.

Both measurement techniques exploit certain time features of the scattered sound, and thus it is appropriate that a time domain technique should be used to simulate them. The Finite Difference Time Domain (FDTD) method is increasingly popular in acoustics. This technique was first introduced by Yee in 1966 [12] in order to study the scattering of electromagnetic waves. Meloney and Cummings [13] adapted the method to the field of Acoustics by using the conservation of momentum and continuity equations. The equations are transformed to central-difference equations obtaining update formulations for the sound pressure and particle velocity. The main strength of FDTD method relies on it being an extremely intuitive technique, so users can easily write and debug their own codes. The method can be used for room acoustics applications by employing Impedance Boundary Conditions [14]; that is by assuming a locally-reacting boundary whose acoustic impedance is independent of frequency. However, there remain issues concerning the modelling of absorbing surfaces which need resolving.

The object of this work is to produce a FDTD model for the direct prediction of the random-incidence scattering coefficient of sound diffusers, using a simulation of the measurements associated with the ISO standard. Results of simulations of the free field method will also be presented, to validate the numerical technique. Due to computational limitations, all the simulations carried out in this paper are in two rather than three dimensions, and this necessitates some thought concerning the nature of a two-dimensional reverberant sound field.

2. Free field method

The Mommertz and Vorländer method measures a series of impulse responses as the test sample is rotated. A linear average of all the time-domain impulse responses, one for each angle of incidence, is made. The averaging process removes incoherent reflections, and leaves only the coherent (and thus specular) component.

Before this is done, a reference measurement must be carried out. This is made in the free field, with a microphone placed on-axis to the source loudspeaker, at an equivalent distance to the total specular reflection path during measurements on a diffusing panel. It follows that the time arrival of this free-field reference measurement must be coincident with that of the reflected impulse during the panel measurement, so that the same time window can be used for both cases.

The post-processing involves taking a Fourier Transform of the two impulse responses from the averaged and reference measurements. The transform is taken over a selected portion of each impulse response, extracting the reflected sound only. These spectra are equalized by normalising with respect to the free-field measurement made with the source alone. At this point, the absorption coefficients (α_{spec} and α_{tot}) are calculated from the two normalized spectra. As the specular reflected energy is usually less than the total reflected energy, it will generally follow that $\alpha_{\text{spec}} > \alpha_{\text{tot}}$. Recalling the definition of the scattering coefficient s, and considering the fact that the specular reflected energy is a factor $(1 - s)$ of the total reflected energy, it can be shown that

$$s = 1 - \frac{E_{\text{spec}}}{E_{\text{tot}}} = \frac{\alpha_{\text{spec}} - \alpha_{\text{tot}}}{1 - \alpha_{\text{tot}}}, \qquad (1)$$

which should always be bounded between 0 and 1. It must be pointed out that edge reflections need to be windowed out to remove their effect on the scattering coefficient.

2.1. Numerical setup

The numerical scheme is designed as described in the free field method proposed by Mommertz and Vorländer [1, 5] to estimate the scattering coefficient (Figure 1). In order

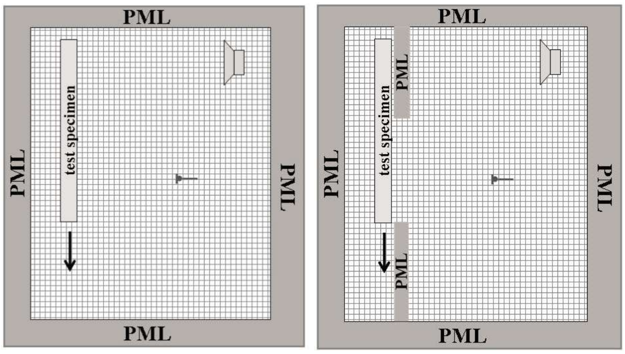

Figure 1. Numerical simulation of sound scattering following an adaptation of the Mommertz and Vorländer free field method. The test sample is translated 42 times in steps of 2 cm. Impulse responses are obtained for averaging and removal of the specular component. Absorbing terminations are numerically implemented using a PML. Scheme A (left): the test specimen is moved downwards in each simulation. Scheme B (right): A PML aperture is added to remove edge effects.

to reproduce anechoic boundary conditions in the FDTD model, a Perfectly Matched Layer (PML) [15] has been used at the boundaries to simulate free field conditions. The elements of the mesh have been chosen with an approximate size of 1 cm, and in order to operate with a Courant number as close to 1 as possible, the sampling frequency is in the region of 8.4 kHz [2]. For frequencies above 8.4 kHz, numerical dispersion will be significant enough to mask the energy reflected from the domain boundary.

Excitation is introduced by a point source placed at the right hand side of the integration area (Figure 1). Sound propagates towards the diffuser, and is (potentially) scattered in all directions on reflection. Time domain signals are recorded at the receiver position. We have considered 10 angles of incidence; large angles (> 50°) have not been considered, since this would require the definition of integration areas with aspect ratio very different to the original, proposed for normal incidence. For each source position (incidence angle) a receiver is placed in the direction of specular reflection. This implies the use of 10 receivers; one for each source position.

Instead of using time windowing to separate incident and reflected sound, a reference calculation without test specimen is made; then the reflected sound is obtained by simply subtracting that reference condition from impulse responses measured with the test specimen in-place. This is equivalent, and much simpler, when compared to using the Total Field to Scattering Field formulation [16].

As commented previously, only 2D simulations are considered in this paper. This means that the exact procedure laid down in the ISO standard, in particular the rotation of the test specimen, cannot be reproduced. Instead, in this paper the test specimen is translated from side to side. This departure is anticipated by several authors [11, 17] who state that for panels which diffuse strongly in only one plane (say a cylinder or a 1D Schroeder diffuser) it may be more appropriate to translate the surface, rather than rotating it around an orthogonal axis.

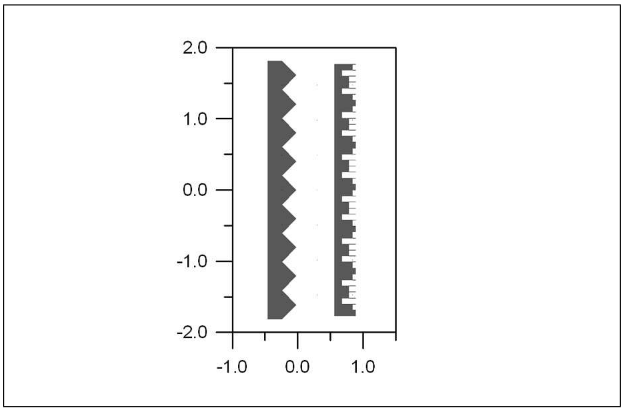

Figure 2. Illustration of the two diffusers which were tested.

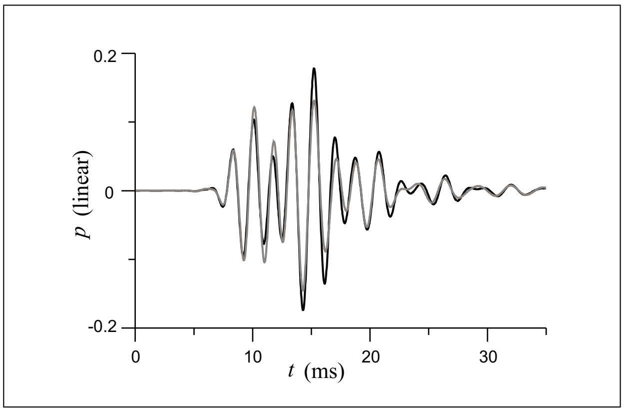

Figure 3. Band limited (500 Hz octave band) reflected pulses for one particular position of the sample (black line) and that averaged for many sample positions (gray line). The diffusing sample was the set of triangles.

In order to validate the FDTD scheme, several surfaces have been simulated. After the simulation, and for the sake of brevity, we have chosen two examples sufficiently representative to cover the range of possible cases. Specifically, the selected cases are:
1. six periods of a Quadratic Residue (QR) diffuser of 7 wells with a maximum depth of 20cm (design frequency 500 Hz), and 3.6m total width.
2. a set of 9 triangles with angle 45° and a 1cm-wide flat section between each period, metricconverterProductID2. A0.2 m depth, and 3.66m total width.

Both samples are illustrated in Figure 2.

2.2. Results

Figure 3 illustrates band limited reflected pulses for one particular position of the sample, and also those averaged for many sample positions. The test sample is translated 42 times in steps of 2 cm. This number has been chosen after some preliminary trials. It is the minimum number of movements that produces a significant reduction of the signal after averaging. It can be observed that the initial part of the reflections are very similar. These are the specular

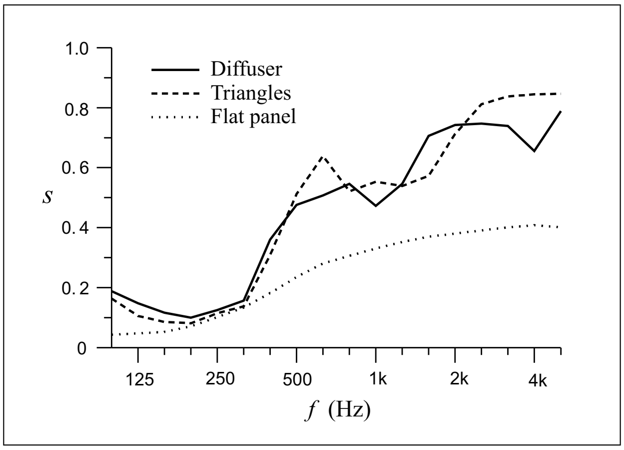

Figure 4. Scattering coefficient vs. frequency for two diffusing surfaces considered and a flat panel, obtained using an adapted Mommertz and Vorländer free-field method: Scheme A (see Figure 1).

components of the reflection, and remain unaltered as the sample is moved. In contrast, later in time the pulses start to differ, and depend on the particular sample position. By averaging the reflected pressure, the scattered component is removed and only the specular energy remains.

Following scheme A (Figure 1), the results shown in Figure 4 were obtained. For reference, results for a flat surface are displayed and these show a non-zero scattering coefficient. This outcome is due to the edge effects which occur due to the adoption of specimen translation, rather than rotation. Scheme B (Figure 1) is proposed to remove these effects. This 'hiding' of the edge of the sample has also been suggested by others looking at the ISO measurement approach using rotation [18].

The results for scheme B are illustrated in Figure 5. Notice that the scattering coefficient for the diffuser does not approach zero at low frequency, but hovers around 0.2. This can be attributed to an effect of the proximity of the microphones to the sample. In our reproduction of the Mommertz and Vorländer method, microphones are not in the far field at low frequencies. This shortcoming has been tolerated in the interests of constraining computation time.

For validation purposes, the scattering coefficient is shown together with the correlation scattering coefficient [19]. The correlation coefficient has been obtained from simulations carried out in reference [2], where the diffusion coefficient was modelled using the AES standard in a FDTD scheme, and by using

$$s_c = 1 - \frac{\left|\sum_{i=1}^{n} p_1(\vartheta_i)\, p_2^*(\vartheta_i)\right|}{\sum_{i=1}^{n} |p_1(\vartheta_i)|^2 \cdot \sum_{i=1}^{n} |p_1(\vartheta_i)|^2}, \qquad (2)$$

where p_1 is the sound pressure reflected from the test specimen, p_2 is the sound pressure reflected from a flat panel, * denotes complex conjugatation, θ_i is the receiver angle of the ith measurement position and n is the number of measurement positions.

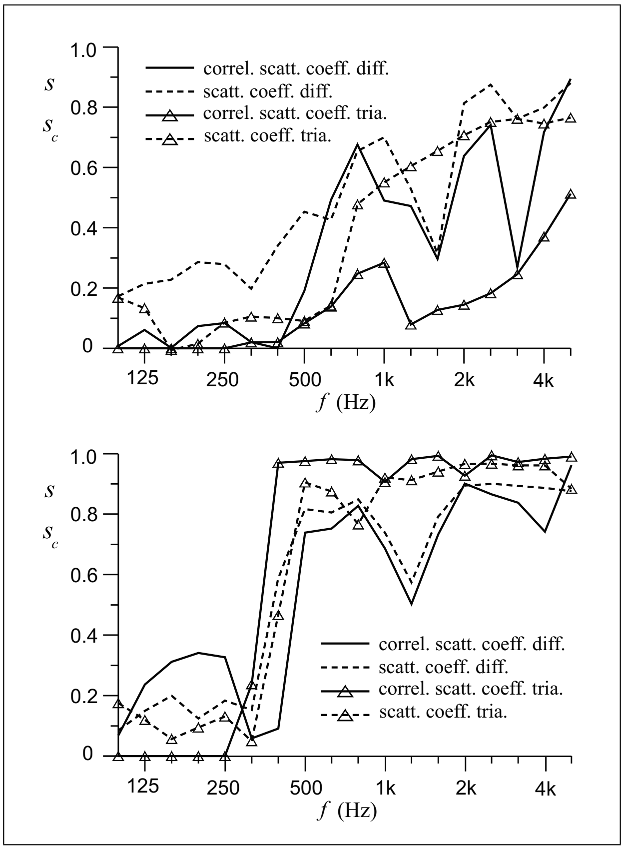

Figure 5. Scattering coefficient and correlation scattering coefficient for two diffusing surfaces vs. frequency, obtained using an adapted Mommertz and Vorländer free field method: Scheme B (see Figure 1). Normal incidence (upper plot), angle of incidence 45° (lower plot).

There is considerable similarity between the correlation scattering coefficient and the scattering coefficient in the case of the QR diffuser. However, the same is not true for results obtained with the set of triangles, in which the correlation scattering coefficient tends to overestimate the efficiency of the surface in scattering sound. In the derivation of the correlation scattering coefficient undertaken by Mommertz, there are several assumptions regarding decorrelated terms. It may be the case that this decorrelation does not occur in the case of the triangles because the scattered polar responses are distinctly different from those which might be expected for a random, rough surface. The correlation coefficient measures the differences between the polar responses for a test and reference flat surface, whereas the ISO coefficient measures the invariance of the pressure when a surface is moved, and these are not necessarily the same thing. It is suggested that the differences in the results are most likely to arise from the different coefficient definitions, rather than deficiencies in the numerical approach. The difference between the scattering coefficient and the correlation scattering coefficient has already been pointed out by different authors (see for instance [20]).

These preliminary results suggest that FDTD schemes may be used to model diffuser measurements made to the

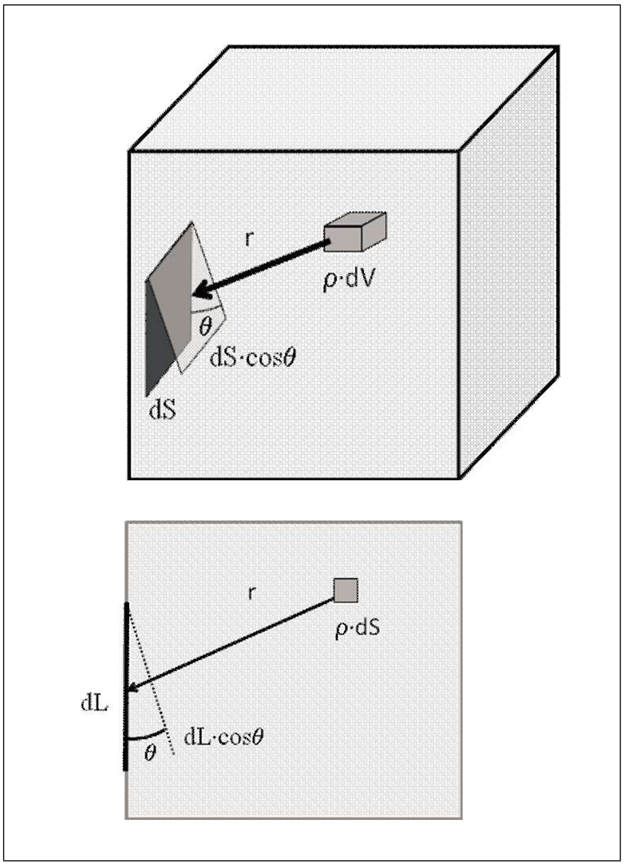

Figure 6. Schema of the energetic interaction between the sound energy inside the room and the boundaries. On top 3D case, and on bottom 2D case.

ISO standard. It appears that the incoherence of diffusely reflected sound is suitably reproduced in the numerical model. In next section, we will summarize a methodology for the application of the FDTD method for simulation of the ISO standard in the reverberant field. Here, we will also perform an experimental validation of the simulations.

3. Reverberation chamber method (ISO/DIS 17497-1)

The basic idea behind measuring scattering coefficients in a reverberation room is the same as described for the free field method in section 2. A circular test sample is introduced into a reverberant chamber, and impulse responses for different sample orientations are obtained. The initial parts of the reflections are highly correlated; these are the specular components of the reflection and remain unaltered as the sample is rotated. The latter parts of the impulse response, which are due to scattering from the surface, depend strongly on the specific orientation. Using synchronous averaging of these impulse responses, the diffuse reflected sound is cancelled out and a virtual impulse response containing only the specular energy is obtained. The averaged impulse response is time-reverse integrated to derive a corresponding reverberation time, and a pseudo-absorption coefficient can be obtained in an analogous way to the Sabine method. Finally, a scattering coefficient is obtained from this pseudo-absorption coefficient and the more familiar energy absorption coefficient.

Along with other numerical methods, the FDTD method is not currently viable as a modelling approach to simulate a full 3D room up to high frequencies. Usually numerical tools such as Near-to-Far-Field Transformation [21], or symmetry properties, are exploited to reduce the huge computational cost. Some authors are currently working to overcome this problem by means of graphic processing units in which FDTD codes are extremely efficient (see for instance [22]). However, even when using these approaches, a solution for 3D scattering of a sound diffuser remains impractical at present. It is therefore necessary to implement simulations in 2D, where one must note that the basic physics of the problem must be addressed as well as the modelling geometry. For instance, room volume is replaced by room area, and absorption area is replaced by absorption length. Moreover, wave theory applied to a 2D space also shows significant differences; modal density is lower because oblique modes do not exist. Thus in the 2D case, the limit frequency above which the field is mostly diffuse is higher than in the 3D case.

In next subsection, a diffuse sound field theory is developed for a 2D closed space in order to provide an expression of the reverberation time in 2D, equivalent to Sabine's formula, which will be used to evaluate the scattering coefficient with the Mommertz and Vorländer reverberant chamber technique.

3.1. Reverberation time in 2D

In a closed enclosure, both reverberation and sound diffusion are closely related to each other. In a reverberant chamber, the laws of reverberation can be formulated in a simple way because diffuse sound field theory can be assumed.

Figure 6 shows a sound ray interacting with a wall in the 3D case (for reference), and also the 2D case. The energy density is represented by ρ. In 3D, a differential amount of sound energy in the room is represented by $\rho\,\mathrm{d}V$. Thus in 2D, it becomes $\rho\,\mathrm{d}S$, where ρ must now represent energy 'density' in units of J/m^2. In order to derive an equation for reverberation time, an energy balance equation must be established, based on the energy provided to the room by a source and losses absorbed by the walls. As a first step the energy incident onto a wall will be obtained. Suppose a ray makes an angle θ to the wall normal and has energy $\rho \cdot \mathrm{d}S$, such that a length element $\mathrm{d}L$ is illuminated by the ray (Figure 6).

The incident energy $\mathrm{d}E_{\mathrm{dS\,d}l}$ of a differential quantity of surface energy $\mathrm{d}S$ on a particular boundary element $\mathrm{d}L$ is

$$\mathrm{d}E_{\mathrm{d}S\,\mathrm{d}l} = \rho\,\mathrm{d}S\frac{\mathrm{d}L\cos\left(\theta\right)}{2\pi r}. \tag{3}$$

In order to consider the whole sound energy in the 2D room, equation (3) must be integrated over the whole space. The total energy arriving at $\mathrm{d}L$ in a time $\mathrm{d}t$ is that contained inside a semicircle of radius $c \cdot \mathrm{d}t$. By integrating over the variable r the whole sound energy inside the semicircle is considered. Approximating $\mathrm{d}S = r\,\mathrm{d}r\,\mathrm{d}\theta$ and assuming homogeneity and isotropy of the sound field (a hypothesis of the diffuse-field model), the total energy received over time $\mathrm{d}t$ is

$$dE_{\mathrm{d}S\,\mathrm{d}t} = \int_0^{cdt}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} r\,\rho \frac{\mathrm{d}L\cos(\theta)}{2\pi r}\,\mathrm{d}\theta\,\mathrm{d}r. \qquad (4)$$

After integrating, the total energy incident onto the wall element $\mathrm{d}L$ is

$$\mathrm{d}E_{\mathrm{d}S\mathrm{d}t} = \frac{1}{\pi}\rho c\,\mathrm{d}t\,\mathrm{d}L. \qquad (5)$$

Considering the energy balance in the room we get [6]

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = \frac{1}{S}\left(W - \frac{1}{\pi}\rho c L\alpha\right). \qquad (6)$$

Equation (6) is a first order partial differential equation and the stationary solution (ρ_s) is obtained when the energy density is assumed to be constant, and its first time derivative is null,

$$\rho_s = \frac{\pi W}{cL\alpha}. \qquad (7)$$

By solving equation (6) with $W = 0$ and using (7) as an initial condition, we get the transient solution

$$\rho(t) = \rho_s\,\mathrm{e}^{-cL\alpha/(\pi S)t} = \frac{\pi W}{cL\alpha}\mathrm{e}^{-cL\alpha/(\pi S)t}. \qquad (8)$$

Thus, equation (8) represents the energy decay in the room from the stationary state. The 60 dB decay time can be derived,

$$t_r = \frac{\pi}{4}\frac{0.162S}{L\alpha}. \qquad (9)$$

Here t_r is the reverberation time, S is the area of the 2D room, L is the perimeter of the room, and α is the mean absorption coefficient of the room walls. This equation is equivalent to Sabine's expression for reverberation time in a 3D space. Reducing a volumetric room in 3D to a "flat" room in 2D results in a modifying factor of $\pi/4 \cong 0.79$ for the reverberation time, coupled with the reduction by one dimension of the space terms involved in the equation: the volume V and the surface of the walls S are transformed to the surface S and the length of the walls L (see Table I).

3.2. Numerical model

The simulation scheme in the case shown in Figure 7 is similar to that described in section 3.1, with the exception of the use of rigid terminations of the (reverberant) integration area. For simplicity, walls are parallel and additional diffusers are not included as recommended in the ISO 354 standard [23]. A number of energy level decays were checked for linearity, and the results for different receiver positions were similar. Consequently, it can be assumed that the 2D room is sufficiently diffuse in the frequency band of interest. Here, edge effects are removed using a 'hard' window (scheme B) meaning that a flat, rigid test specimen gives a true scattering coefficient of zero.

Table I. Comparison of the Sabine equation and the equivalent reverberation equation in 2D. τ_r: Reverberation time, α: Absorption coefficient ISO standard 354 [23].

	2D	3D
t_r	$t_r = \frac{\pi}{4}\frac{0.162S}{L\alpha}$	$t_r = \frac{0.162V}{S\alpha}$
α	$\alpha = \frac{\pi}{4}55.3\frac{S}{L}\left(\frac{1}{c_2T_2} - \frac{1}{c_1T_1}\right)$	$\alpha = 55.3\frac{V}{S}\left(\frac{1}{c_2T_2} - \frac{1}{c_1T_1}\right)$

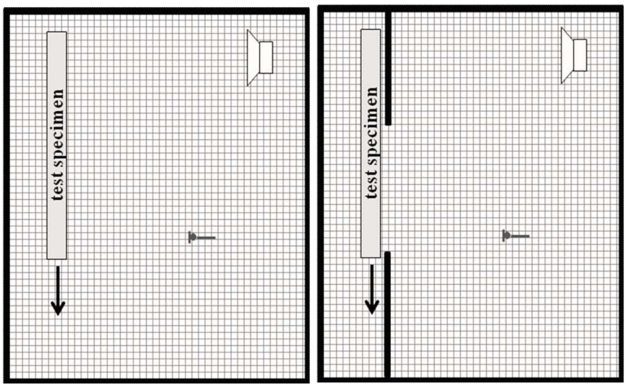

Figure 7. Numerical simulation scheme for sound diffusers following the ISO method in a reverberant chamber. The test sample is translated 42 times in steps of 2 cm. Impulse responses are obtained for averaging and removal of the specular component at 10 receiver positions randomly distributed across the room. The position of the receivers and the sources in the figure is schematic. Walls are perfectly reflecting surfaces. The room is 8.5 m long by 5.1 m wide. The test specimen is moved downwards in each simulation. Scheme A (left): No window is defined. Scheme B (right): A rigid window is included to remove edge effects.

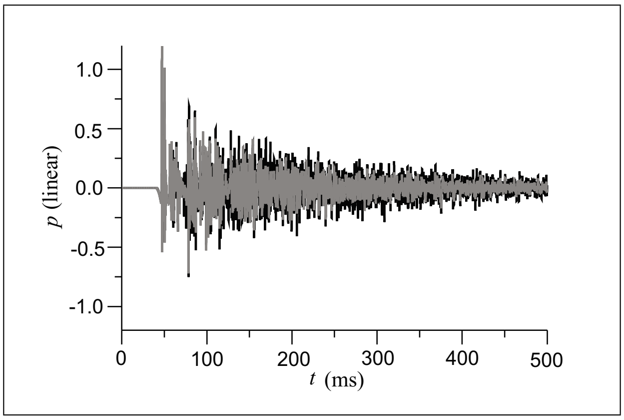

Figure 8. Impulse response of the reverberant room. Black trace: a single impulse response. Gray trace: Average of several impulse responses after translations of the test specimen.

3.3. Results

In Figure 8 the impulse response of a single simulation is compared to the impulse response obtained after averaging several simulations with different positions of the test specimen. The test sample is translated 42 times in steps of 2 cm. This number has been chosen after some preliminary trials. It is the minimum number of movements that produces a significant reduction in the reverberation. It can

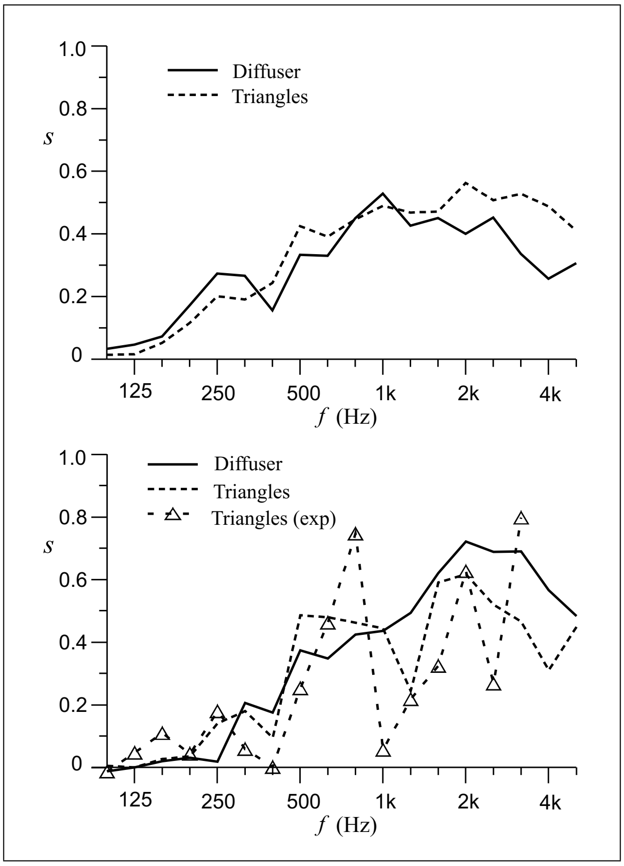

Figure 9. Random-indicence scattering coefficient of a QR diffuser and a set of triangles, evaluated with the reverberant chamber method. On top: Scheme A. Bottom: Scheme B, including a plot corresponding to experimental data.

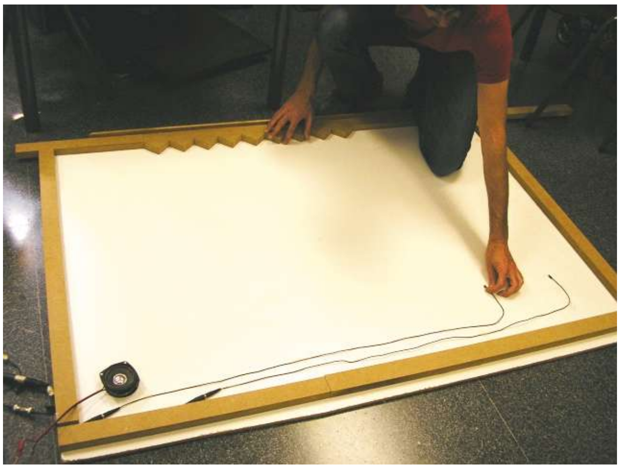

Figure 10. 1:5 scale reverberant chamber (2D) used for the measurement of the scattering coefficient of a set of nine triangles.

be observed that the decay is slightly faster in the averaged case, due to the removal of the diffusely reflected sound.

Figure 9 illustrates the results obtained following the above method. In the case of scheme A, results for the two specimens are similar, with the set of triangles giving higher performance at higher frequency. This is in contradiction with the results obtained in a previous paper by some of the authors [2]. However, in that paper only the (AES) diffusion coefficient was obtained, and the new result is useful in demonstrating a difference between Scattering and Diffusion Coefficients. The triangles have side angles of 45° degrees and for many source positions are effective in redirecting (in a specular manner) rather than dispersing sound; indeed for a source normal to the surface, energy is reflected straight back to the source and is not dispersed at all.

For case B, a distinct dip in the scattering coefficient is seen between 1 and 2 kHz for triangles; an effect seen also for the free field case for both types of coefficients (Figure 5). This dip is absent from case A in the reverberant simulation, presumably since the scattering from the moving edge masks the dip. The dip is also seen in the experimental data (Figure 10), suggesting that case B, where the edges are hidden, is a more appropriate model.

The fact that the scattering coefficient does not reach 1 at high frequencies, as generally observed in experimental measurements, can be attributed to two causes. Firstly, the numerical phase error in the FDTD model is larger for high frequencies, where larger values of the scattering coefficient are expected. Therefore, numerical noise can mask the decorrelation between signals. This is due to the fact that the numerical 'noise' is deterministic, and it is not attenuated by the averaging process. Secondly, at high frequencies the energy decays become less linear, suggesting insufficiently-diffuse behaviour; the use of decay portions differing from ISO 354 (i.e. not from −5 to −35 dB) does not resolve the problem, and diffusing surfaces and non-parallel walls are proposed for future models.

Verification measurements for the reverberant FDTD model were made in a reverberant 2D environment, as shown in Figure 10. The scale was 1:5, and the set of nine triangles was employed as the test sample. The depth of the 2D environment was 1 cm, which corresponds to a depth of 5 cm in actual size, implying a first axial resonance in this dimension of approximately 3400 Hz. Results in Figure 9 are plotted for frequencies below that limit. Measurements were made using sample translation rather than rotation, as per the model.

4. Conclusions

There is a need for an efficient and effective way to estimate the random incidence scattering coefficient for use in computer models. As the measurement process is based on impulse response measurement, it makes sense to try and use time domain models to obtain broadband coefficients. To this end, this paper has explored whether Finite Difference Time Domain (FDTD) schemes can be an effective approach.

The free field simulations have shown reasonable results in comparison to the correlation coefficient for a Quadratic Residue (QR) diffuser, and seem to indicate that the FDTD approach is possible. The reverberation chamber simulations are encouraging but need further work, and proposals for increasing model diffuse behaviour at higher frequency have been made.

Acknowledgements

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