Experimental Research Lab: Isolate Scattering and Calculate the Diffusion Coefficient

The objective of our research was to develop a standard measurement procedure that would allow researchers to conveniently evaluate the uniformity of scattering from a given topology from its polar responses in a reverberant space of a given size. This involves several considerations, including isolating the scattered sound from the direct sound and room reflections, determining a representative diffusion coefficient from the polar responses, evaluating the effects of not being in the far field, and evaluating the effects of using a periodic arrangement of a surface to cover a larger area.

$$h_4(t) = IFT\left\{\frac{FT[h_1(t) - h_2(t)]}{FT[h_3(t)]}\right\}$$

Let us first describe how to extract the scattered sound $h_4(t)$, from the direct sound and room reflections. The background scattered impulse responses without the sample present, $h_2(t)$, are subtracted from the impulse responses with the sample present, $h_1(t)$, thus isolating the scattered sound. The scattered sound is then windowed to further isolate the scattered sound. To remove the effect of any issues with the speaker and microphones, the transfer functions, $h_3(t)$, between the speaker and each microphone are measured by placing the speaker in the sample position and sequentially pointing it to each microphone. To accomplish this deconvolution, we simply divide by the Fourier Transforms (FT) of the isolated scattered impulse responses and the transfer functions and then calculate the Inverse Fourier Transforms (IFT) to return to the time domain. To effectively remove the narrow direct sound, the background scattering is subtracted with oversampling. This process is illustrated in Figure 1.

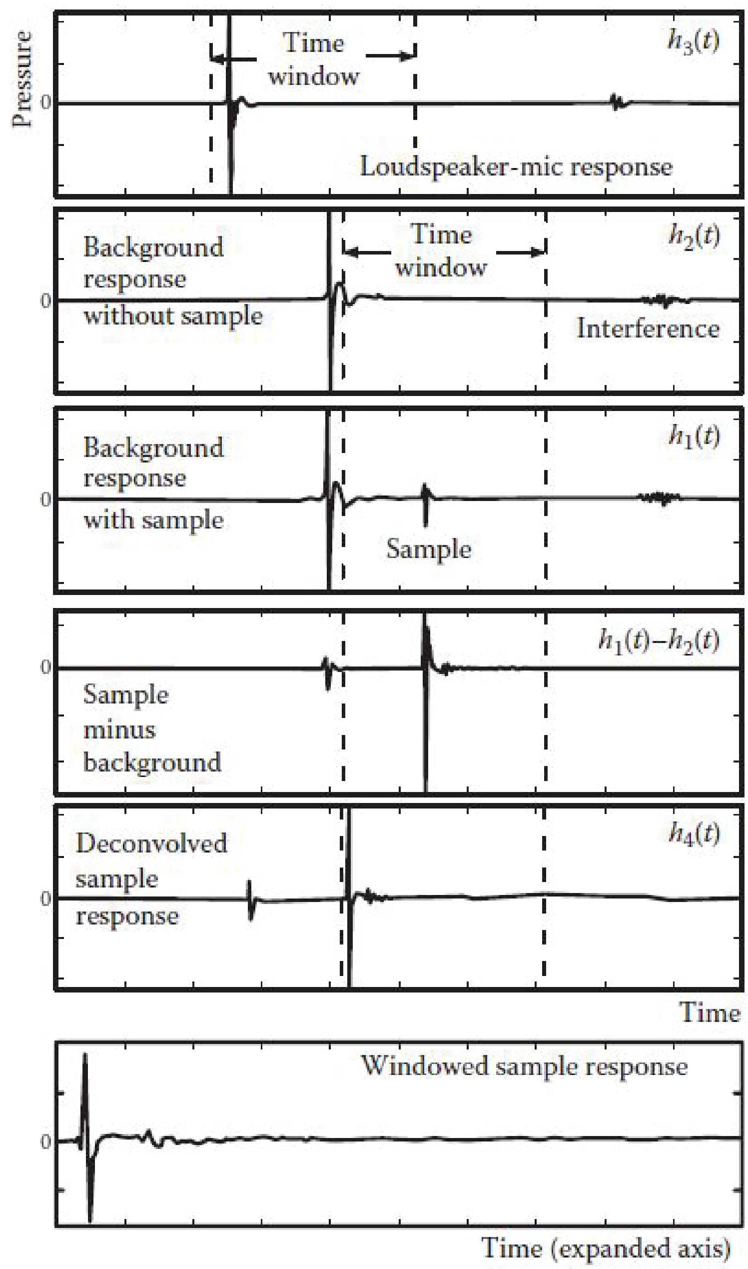

Figure 1. Process to extract the scattered sound for a given angle of incidence.

The data are further post-processed to provide frequency responses, polar responses, and finally, diffusion coefficients, as shown in Figure 2 for a reference reflector on the left and a diffusor on the right. The 2D boundary measurement geometry with the loudspeaker at -60^{a}, with respect to the normal, is shown in Figure 2a at the top of Figure 2. Also shown are the 37 receiving microphones and a scattering sample at the origin of the mic and speaker semicircles. In Figure 2b, the impulse response for a microphone at 0ª is shown, with the scattered data outlined in a box, corresponding to the time window in Figure 1. The scattered data are windowed for all angles of observation and concatenated in Figure 2c. A Fourier Transform is then applied to each of the impulse responses to get the frequency responses, Figure 2d. The visible polar response of the reflector in the left panel at high frequency is narrow and directed in the specular direction of +60ª, as would be expected, whereas the corresponding polar response for the diffusor is uniform. The polar responses can then be further processed to give a diffusion coefficient, which is plotted versus frequency to obtain the diffusion response, Figure 2e. As the frequency increases, one can see a drop in the diffusion coefficient of the reflector, as the width of the panel becomes increasingly large compared to the wavelength, providing specular reflection.

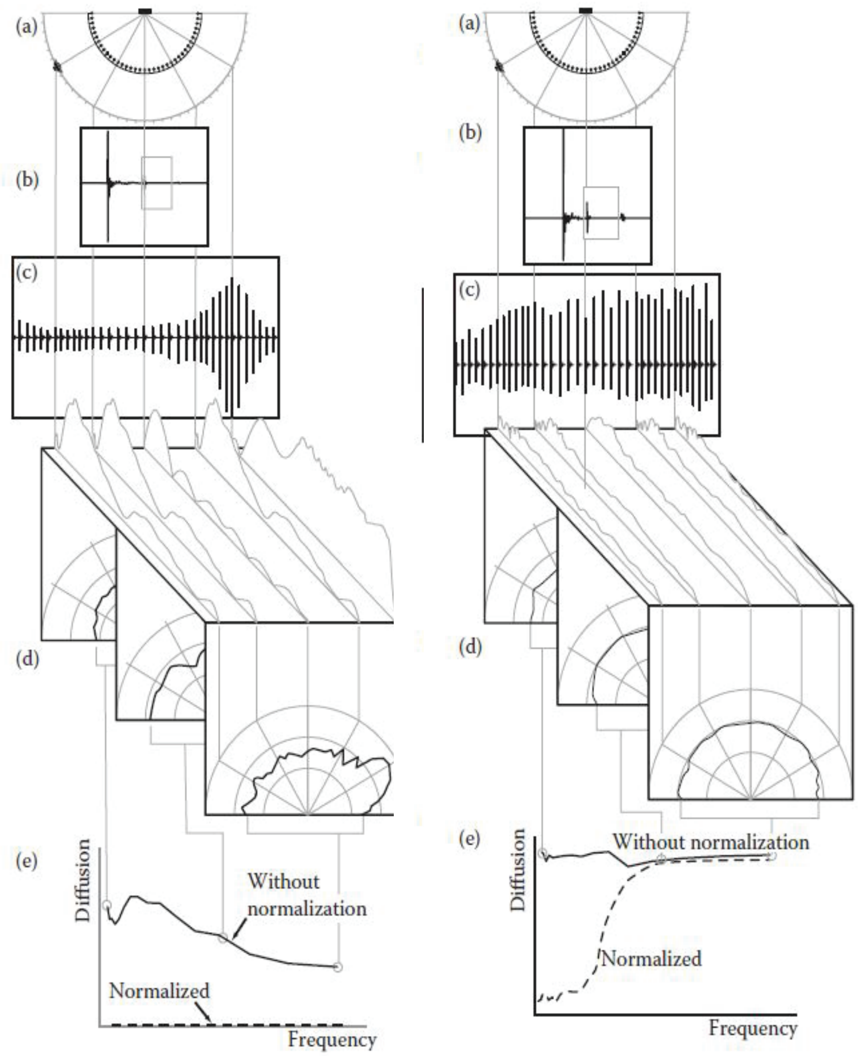

Figure 2. Calculation of the diffusion coefficient of a flat panel of equal surface area (left) and the sample under test (right), without and with normalization.

It has been shown that the autocorrelation of the polar responses provides significant advantages over other statistical techniques. The autocorrelation measures the scattered energy's spatial similarity with receiver angle. A surface that reflects sound uniformly to all receivers will produce high values in the spatial autocorrelation function. Conversely, surfaces that concentrate reflected energy in one direction will give low values. For a given angle of incidence, the diffusion coefficient, d_ψ, can be simplified to a single equation, shown below, where L_i is a set of sound pressure levels in decibels in a polar response, n is the number of receivers, and ψ is the angle of incidence. The circular autocorrelation function is calculated for each angle of incidence, d_ψ, and then averaged for all angles of incidence.

$$d_\psi = \frac{\left(\sum_{i=1}^{n} 10^{L_i/10}\right)^2 - \sum_{i=1}^{n}\left(10^{L_i/10}\right)^2}{(n-1)\sum_{i=1}^{n}\left(10^{L_i/10}\right)^2}$$

At low frequency, edge diffraction causes the diffusion coefficient to increase with decreasing frequency, because the sample acts as a point source reflecting the same energy in all directions. While there is a clear physical explanation for this effect, it does lead to confusion and so a normalized diffusion coefficient was introduced. The result of normalization is shown in Figure 2e. This gives a more intuitive response, with surfaces producing little diffusion at low frequency. It also more clearly illustrates the frequency where the diffuse reflection begins. The normalized diffusion coefficient formula, d_n, specified in ISO 17497-2 is shown, where d_d and d_r are the diffusion coefficients calculated for the test sample and a reference flat surface of the same overall size, respectively.

$$d_n = \frac{d_d - d_r}{1 - d_r}$$

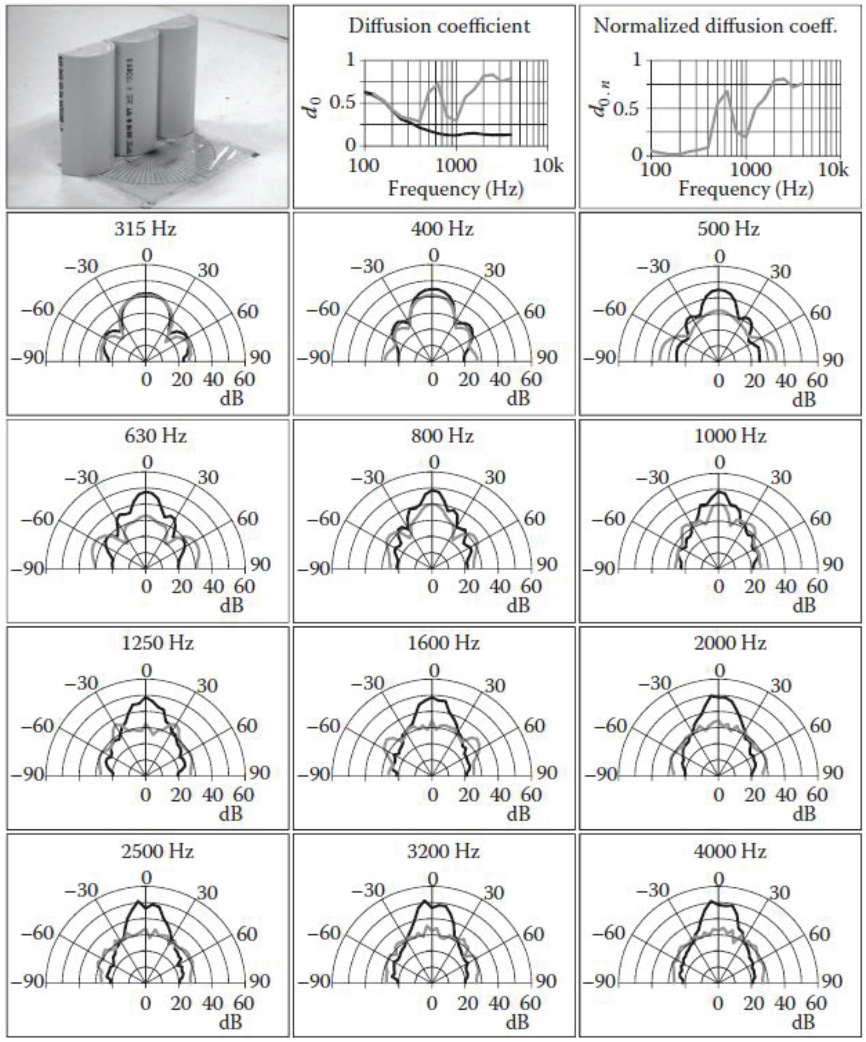

Figure 3. Presentation format specified by ISO 17497-2 for the diffusing surface (gray) and the reference reflector (black) at normal incidence.

The presentation format specified in ISO 17497-2 is shown in Figure 3. In the top row, a photo of three periods of a semicylinder sample, the diffusion coefficient for the sample (gray), a reference reflector (black), and the normalized diffusion coefficient (gray) are shown. Below that the polar responses for the sample (gray) and the reference reflector (black) are compared at various third-octave frequencies from 315 Hz to 4,000 Hz, for normal incidence.

In the next post, we will evaluate the effects of the measurement not being in the far field and the effects of using a periodic arrangement of a diffusing surface to cover a larger area.

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