A New Understanding Of Diffusion

It's a far more complex concept than absorption is, and here's why.

By Jim DeGrandis
Acoustics First Corp.

The massive diffuser-testing rig at NWAA Labs in Elma WA is housed in a giant room that is larger than a football field.

In decades past, traditional barrel and pyramidal sound diffusers had their acoustical specifications presented with absorption coefficients as the only available acoustical data. This was handy for low-frequency control applications or targeting particular "bumps" in a room without adding too much absorption, which could make a room too dry.

Toward the end of the 20th century, more than one acoustical company began to use graphed polar plots of various diffusion devices to illustrate where sound was being redirected when it reflected off a device's surface. It could be "visualized" from that information.

However, the effects of diffusion could not be quantified as easily as absorption could be. By measuring the sound absorption of a particular device, expressed as an absorption coefficient, you can predict, with reasonable accuracy, the change in reverberation time from its addition to a room. By contrast, attempts at creating a useful equivalent for diffusion, in the form of a "diffusion coefficient" or "scattering coefficient," hit a practical roadblock—namely, that diffusion, being a multidimensional phenomenon, cannot be accurately expressed as a single number.

That limitation was reinforced recently at the ASA Concert Hall Research Group in Troy NY, where renowned acoustics guru Dr. Ning Xiang was making a presentation. He was discussing the equation for calculating how "diffuse" a sound field is, as well as the variables within that equation. Direction, phase and intensity—at every frequency—must be taken into account, measured and quantified before you can even begin this calculation. If you are quantifying how a device affects the development of diffusion in an environment, then you can see why a single-dimensional coefficient cannot completely describe its contribution. At best, it might yield some nominally helpful information for comparing one device to another.

Given the current state of technology, we can accurately measure and report the direction, intensity and phase offset of the acoustic energy reflected off a device; that information can be used in calculations of the development of a sound field and its diffusivity. Although this amount of information might seem daunting, consider the concept of absorption for a second. When W.C. Sabine first conceptualized a "number" for absorption, he was simply looking at how much acoustic energy a device removed from a space—that's it! Just one simple

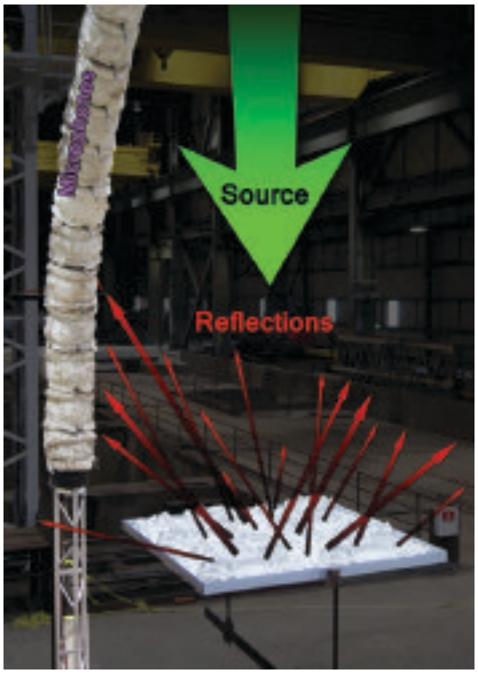
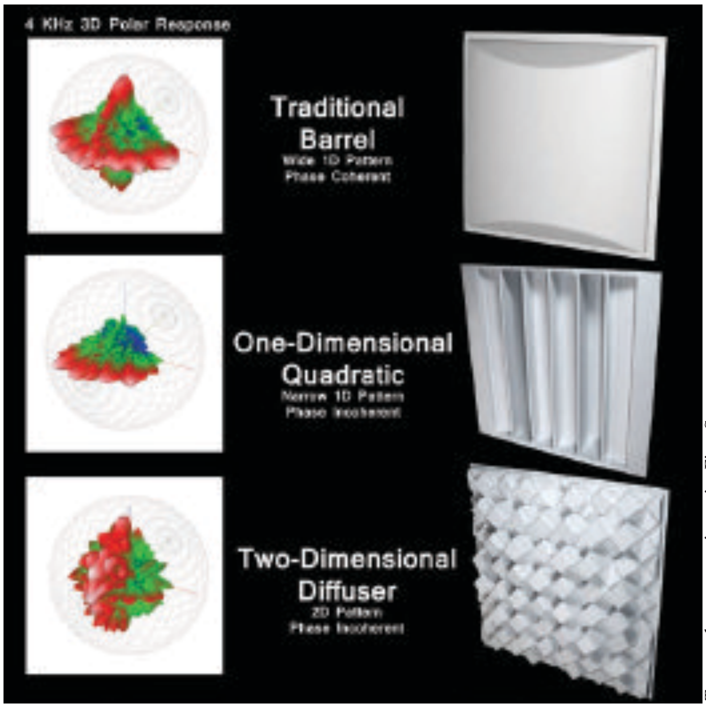


Illustration by the author.

The devices are excited from above with a sound source, which reflects off the diffusers and which is measured by the microphones along the arc.



Test results courtesy Acoustics First Corp.

From the measurement, 3D polar responses and phase information are extracted at all frequencies. These figures show the response of three very different surfaces at 4kHz, detailing the direction and intensity of those reflections.

function: energy in versus energy out. Measure the energy before, add stuff and measure the energy after—done! No direction…no phase…no problem.

To say diffusion is more complex is a massive understatement. Absorption was initially experimented with and explained by using seat cushions—a fairly simple and pretty easy-to-explain object—but diffusion is like trying to explain air, wind, haze or fog. To wit, diffusion is really an environmental concept. An environment, not a device, is diffuse. Sure, a device that is specifically designed to contribute to the development of diffusion is called a diffuser, but *the diffuser itself* is not diffuse. It uses many different mechanisms to affect an environment, which is why the single-dimensional coefficient falls apart.

Flat panels with holes can break up intensity using absorption or diffraction; geometric diffusers can be effective spatial redirectors, diffractors or absorbers; mathematic diffusers can play with diffraction, phase offset, spatial redirection or absorption—the list goes on. Also note that all of these affect the propagation of different frequencies in different ways (and to varying degrees). Some might absorb at low frequencies, diffract in the midrange and become very specular at high frequencies, whereas others might have characteristics that have a vastly different effect on the direction that the reflections travel, thereby changing the room's acoustic performance considerably.

The Diffraction & Diffusion research group (E33.05 P) at ASTM International has been working on the details of how to measure and report all the acoustic characteristics of an object by taking hemispheric impulse-response measurements around a device. This process involves exciting the device under test with a loudspeaker and then using an array of microphones to capture and extract the reflected energy from the device. This gives a starting point for the analysis by providing an impulse response at every microphone position around the device. Having that impulse-response measurement, you can extract polar responses for directional intensity, and phase information, at all measurable frequencies and at every sample location. This gives a multidimensional dataset on how that device affects acoustic energy, and, in turn, how the device contributes to that system.

This method allows the impulse-response measurements to be retained for future analysis of the data, as new uses for this information are developed. Although polar responses are an obvious output, some have taken the first steps toward creating metrics for the visualization and comparison of phase shift, directivity-pattern analysis, performance in geometric room models and even using the impulse responses to inform simulations in the time domain. By leaving the raw measurements intact, the test goes far beyond just the paper report; instead, it's a snapshot of how that device interacts with sound.

Measuring and reporting all the characteristics of a device finally provides enough information to model and simulate that device's effect on the environment. Your acoustic environment is a system, and all the components of that system interact with other elements as sound propagates and the sound field develops. If you don't know the exact direction that sound is going to travel after encountering a device, or know its effect on the phase and intensity of that sound (at whatever frequency), you cannot accurately model, simulate or calculate its role in that system—you simply don't have enough information. This measurement information is also very useful in developing simulations to predict the performance of new designs and their characteristics, and it helps answer questions about the placement and use of these designs in different environments, as well as their contributions to those systems.

By utilizing these spatial measurements, some time and equally abundant computing power, we have a new understanding of the essential contributions of a sound diffuser, and we can more effectively design and use them.