ABSORPTION AND DIFFUSION

Creating optimal acoustic spaces

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Photos courtesy Acoustics First

ACOUSTIC ISSUES IN A SPACE MANIFEST THEMSELVES IN MANY WAYS, AND FROM MANY DIFFERENT CAUSES. COVERING ALL THE POSSIBLE ITERATIONS OF SOUND PROBLEMS, THEIR SOURCES, AND THEIR SOLUTIONS WOULD BE BEYOND THE SCOPE OF THIS ARTICLE. HOWEVER, IT BECOMES MUCH MORE MANAGEABLE BY NARROWING THE FOCUS DOWN TO THOSE ISSUES WHICH ONE CAN MITIGATE WITH DIFFUSION AND ABSORPTION.

Materials to have in the toolkit

When approaching any task, it is necessary to understand the available tools. In this case, the tools at hand are materials for absorbing and diffusing sound. Knowing the strengths and limitations of these materials is paramount to effectively mitigating acoustic issues in a space and tuning that space for the best sound possible.

The broad overview of sound absorption and diffusion is this—absorbers reduce acoustic energy, and diffusers reflect energy in a way that contributes to a diffuse sound field. However, the devil is in the details, and not all these materials or constructions are created equal—and for good reason. Sound comprises a wide range of frequencies, and some of those frequencies have different properties and characteristics to their propagation. High frequencies are relatively easy to absorb and scatter due to their short wavelengths, while low frequencies are not so easy to absorb. Human hearing also plays a role in this, as it is more sensitive at some frequencies than at others.

Two types of absorption

Given, absorbers reduce acoustic energy. This is a vast oversimplification of how these materials work. Only by examining how they reduce energy does one understand why certain absorbers are suitable for certain tasks. There are two general types of absorbers by function: broadband absorbers and tuned absorbers. The practical difference in these two is "broadband absorbers" affect a wide range of frequencies, while 'tuned absorbers' focus on one particular range more than others.

Broadband absorbers

The general classification of 'broadband' is a bit of a misnomer. Broadband absorbers are usually constructed from materials classified as 'frictional absorbers'—which is related to how they reduce acoustic energy within a space. This is where high school physics classes become useful. The First Law of Thermodynamics states energy cannot be created or destroyed—merely converted from one form to another. What does this mean in acoustics?

Electrical current is converted into electromagnetism which moves a loudspeaker, which in turn, creates varying pressures through the air as it moves. This energy is propagated from air particle to air particle in all directions—lessening in intensity as it travels away from the source, because it is spreading that energy out in accordance with the inverse square law, which states with every doubling of distance away from the sound source, the sound will be four times less intense. That is, until it hits something. Now, in the case of a frictional absorber, that "something" is generally a lightweight, porous

Similar environments (above and on page 26) may use different methods to achieve the desired acoustic outcome. This large broadcast studio (iHeart NY, formerly ClearChannel) uses an array of absorbent fiberglass panels spaced around the room and an irregular ceiling design to tame the acoustics of the room.

material, which converts that acoustic energy into heat energy. As acoustic energy hits a porous surface, it tries to move the material, and the resistance to moving is what causes acoustic energy to be converted into heat.

The materials one generally finds in frictional absorbers are fiberglass tile or boards of different densities, felts and other fibrous materials, or foam. These materials all have different properties in density by weight, fiber length, thickness, binder materials, rigidity, and pore size. These variables affect the acoustic resistance of absorbers, and hence their effectiveness at different frequencies.

There is no frictional, broadband absorber which is "ruler-flat" in its frequency response throughout the entirety of the human hearing range. However, many of them are nominally effective through a wide range of frequencies—and mostly the higher frequencies. High frequency sounds are more effectively reduced by frictional absorbers than low frequency energy—this goes back to the laws of energy conservation. High frequencies oscillate over a shorter wavelength than low frequencies, and when travelling at the same speed as low frequencies, attempt to oscillate the fibers in frictional absorbers faster than low frequencies. Low frequencies retain more of that energy over the long travel of the wavelength than high frequencies—and penetrate deeper into those frictional absorbers due to this fact.

This then leads the conversation to material thickness. With a frictional broadband absorber, the general rule is: the thicker it is, the better the low frequency absorption. As stated above, high frequencies absorb quickly and easily, but the low frequencies retain energy and penetrate deeper into the frictional material; therefore, the solution to low frequencies is "just make it thicker." When looking up absorption test results for a frictional absorber material, one will find many of them are tested repeatedly at different thicknesses. This is where one truly sees why they are called 'broadband' absorbers—go thick enough and they can absorb almost everything.

Why not just exclusively use broadband absorbers? If they are "thick enough," can they not absorb almost everything? Firstly, "thick enough" is a broad term, pardon the pun. When a situation calls for thicknesses up to 914 mm (36 in.) deep or more to absorb the lower frequencies, broadband absorbers start to become impractical. Second, it is very rare for a space design to entail absorption of "everything." Anechoic chambers which block outside sound and reflections do not make superb listening rooms—they are muffled and claustrophobic sounding. High frequencies will attenuate naturally, just by travelling through the air... and because they are also easily absorbed. An apparent low-frequency buildup remains due to the imbalance in the absorption rate of the various frequencies, resulting in a space with bass heavy environment.

Tuned absorbers

Bass frequencies are a relatively small segment of the human hearing range—but they can cause problems due to how they behave. Low frequencies are the principal culprits in peaks and nulls caused by room modes or resonances which exist in the room. A common mistake designers make is to add too much broadband absorption to try to absorb low frequencies. As stated before, the low frequencies will remain, and the room frequency response will become bass heavy with no high-end frequencies. This is where tuned absorbers come into play.

Tuned absorbers such as slot (or slat) resonators almost always focus on bass frequencies, or a specific subset of those frequencies. Almost all of them limit the absorption in the high frequencies to some degree, but there are a few that retain some of that absorption in order to tune the absorber to a wider frequency range. There are several different methods for creating tuned absorbers—some have a more focused approach than others. Resonant traps (*e.g.* slot resonators or so-called Helmholtz resonators) absorb sound through a resonant cavity in the material with one or more openings. The size, depth, orientation, and dampening of the cavities and openings adjust their effective frequency range. Some are very narrow band, focusing on a specific frequency, while others have a wider range that they can absorb.

Other tuned absorbers such as diaphragmatic low frequency absorbers or pistonic bass traps use a moving mass, either a limp mass or a membrane. These masses absorb energy by virtue of their ability to be moved. One must remember the physics—when acoustic energy impacts an object, that object has a response to that energy. If a surface has very high impedance or resistance to sound passage, like a painted concrete slab, acoustic energy reflects off—travelling back into the low impedance air from which it came. Now, by lowering the impedance a bit more—with a drywall surface for example—the high-energy, low frequencies do break the impedance threshold and impart some of their energy into the surface. But high frequencies will mostly still bounce off.

This church, located in Chester, Virginia, uses fiberglass absorbers around the room to lower the overall intensity of the sound and cut down the specular reflections from the large amount of wall space. They also added large barrel diffusers, which not only further break up the specular reflections, but function as bass traps due to their large resonant cavity filled with fiberglass batting.

Just changing materials and their means of mounting will produce different impedance values. In the case of a limp mass, like a mass loaded vinyl or a suspended sheet of plywood, the impedance relates to the size, weight, thickness, and density of the material, as they affect the ability of sound to try to "move" the mass. Since these materials are free hanging, one can calculate the impedance around them as negligibly different. By introducing a sealed cavity behind that material, another force comes into play: the impedance and resonance of the cavity behind the membrane. Where the limp mass absorber is tunable via size and weight, the membrane absorber with a sealed cavity has the ability to further focus the tuning on a specific frequency or range.

Yet another way to tune absorbers is to create composite materials. A designer does this simply by combining two or more materials to create an assembly that has a different set of performance characteristics. By laminating a flexible, yet impermeable, layer on or within a broadband absorber, one can adjust its low frequency response. Every time acoustic energy changes medium, the impedance mismatch at the boundary creates a conversion loss. This diminishes acoustic energy every time it needs to navigate through another material—creating laminates effectively tunes an absorber.

The concept of diffusion

After covering a range of different materials that remove acoustic energy from a space, one must now consider materials that take the energy in a space and redistribute it. Firstly, one must more closely examine the concept of diffusion. In physics, a completely diffuse field is defined as one where energy travels equally in all directions (isotropic) and has uniform sound pressure.

'Diffusers' contribute to diffusion in a space through the redistribution of acoustic energy. The mechanics of how they do this can vary greatly—

from reflective geometric shapes, slots, blocks, organic profiles, and mathematically calculated structures.

Geometric diffusers

The large geometric shapes are relatively straight forward. Barrels, pyramids, wedges, hemispheres, and basically any other set of large facets, faces, and curves can redirect or reflect sound. These shapes contribute to diffusion through spatial redirection. Flat plates and planes can even work in some environments, arranged in a way that breaks up parallel reflections in a room. These larger shapes are simple in their function—they just scatter energy. Here is how they work.

A room's acoustic field is affected by every element within it—it is a system of materials and elements installed in a certain way. As sound travels through the space, some surfaces will absorb sound, while others will reflect it. If those surfaces are large and flat, the wave will stay mostly intact and continue as a cohesive and contiguous sound wave. That mirror-like reflection is referred to as 'specular,' which means it travels together in the same direction, and in phase—this is opposite of diffusion. By adding differing surfaces to the space, larger reflections brake up and redirect spatially, interacting with other surfaces which will absorb or reflect them and subdivide them even further. As sound then takes varying paths throughout the space, it will travel different distances—and with sound travelling at a constant speed, distance equals time. The shift in time balances out sound pressure, and the shift in direction breaks up the sound wave, making it more isotropic and hence more diffuse.

Mathematic diffusers

Another class of diffusers is the 'mathematic diffuser.' While the geometric diffusers are mostly large redirectors utilizing other elements in the space to develop diffusion over a wide range of frequencies, mathematic diffusers are more focused and efficient in their approach. Mathematic diffusers are optimized and tuned to affect different frequencies in different ways. One way is by using temporal offset. One must remember: distance equals time. A sound can cancel itself out by interacting with itself, offset by a one-half wavelength. Here is how it works.

Sound travels as waves of positive and negative pressure. The frequency of those oscillations is the frequency of the sound. The orientation of pressure is noted as its 'phase.' By inverting the phase, in effect flipping the time during which the positive and negative pressures are aligned, the negative

This smaller broadcast studio (88.7 WBWV–Beckley, West Virginia) uses a room completely covered in acoustic wedge foam, with diffusers placed to the rear at ear-level to spread some of the energy around the room—and keep it from sounding claustrophobic.

pressure will "cancel out" the positive pressure. This is exactly what certain mathematic diffusers do. By forcing the wave to travel into a cavity that is a quarter of its wavelength, it then must come back out—travelling another quarter wavelength for a total of one-half wavelength—it exits the cavity 180 degrees out of phase with itself. This process is very frequency dependent, which is why one will see many diffusers that have arrays of wells or blocks at different heights or depths, which correspond to different frequencies.

Blocks and wells have evolved with more complex computing into other optimized shapes, which target frequency bands using a matrix of bicubic interpolation—which has the added benefits of enhanced spatial redirection and smoother frequency transitions. Some other variations use grating or targeted diffraction, which occurs as acoustic waves bend around certain shapes and expand outward. These shapes can be slots, rings, edges, perforations, corners, and peaks—and their orientation, size, and structure have a different impact on acoustic energy. The benefit is diffracted energy that disperses and dissipates over many different surfaces across a device. This lowers the reflection intensity as these diffracted "sources" are not specular in nature.

As noted above, mathematic diffusers are designed to affect different frequencies in different ways. Some wavelengths are too long for a certain size diffuser, limiting its impact on those frequencies. These diffusers are most often optimized for mid to high frequencies as low frequencies are difficult to diffuse. As with frictional absorbers, diffusers need to be gigantic to affect low frequencies. If a wavelength at 20 Hz is over 17 m (56 ft), the quarter-wavelength design would still need to be over 4.2 m (14 ft) deep. A diffuser would be impractical at that size.

Where diffusers come into play

Imagine a room that has four parallel walls, a parallel ceiling and floor, and no other materials. Any sound energy will remain mostly intact as it bounces off each of these surfaces. These intact reflections are essentially echoes—continuing to the next surface and reflecting off again. While an echo can enhance one's experience at, say, the Grand Canyon, it will be problematic inside a room, as there is little delay in echo. Echoes in this hypothetical room play on top of the next source sound and echo from other surfaces in regular, but rapid, succession—think hundreds of times a second. These overlapping echoes create artifacts or unwanted sound or noise through wave interference, which manifest themselves as flutter, ringing, comb filtering, and other unpleasant anomalies.

Diffusers break those contiguous waves down into thousands of lower intensity reflections, many of them travelling different paths, and with various degrees of phase shift. The large, intact echoes disappear as the energy is dispersed throughout the space uniformly, removing the harsh artifacts. Again, like absorbers, there are geometric diffusers and mathematic tuned diffusers. Breaking up large, flat surface reflections can be accomplished with those geometric diffusers and for more refined control of specific frequency ranges one can turn to the mathematic diffusers. Both types are designed with different diffusion patterns, so directing the energy where it needs to go is as simple as choosing the right diffuser and installing it in the right place.

Putting it all together

Here is a quick summary before moving into some treatment cases in familiar spaces.

- Absorbers are generally broadband or tuned.
- Broadband covers a wide range of frequencies and generally gets better the thicker it is, but there are practical limits.

- Tuned absorbers are usually implemented to improve bass absorption performance.
- "Too much," "not enough," and "wrong type" of absorption can be bad.
- Diffusers have several different types and configurations.
- Geometric diffusers are used to break up large, flat, surface reflections.
- Mathematic diffusers are more frequency specific.
- Diffusers have different reflection patterns.
- Diffusers are generally limited to mid and high frequencies, again due to practical limitations.

The following are several examples of different treatment options and related considerations designers commonly consider to assess acoustical issues in certain space.

Offices or small rooms

In smaller spaces, primary acoustic problems are caused by smaller dimensions and parallel surfaces. Those flat surfaces near sound sources and the listener are of immediate concern. A designer's primary objectives should be to increase comfort, intelligibility, and clarity. Just image a conference call, speakerphone, zoom, or other type of auditory information exchange. Those "small room problems" will be amplified and retransmitted in such a space. Secondary concerns are the energy build-up and tuning the space to sound less like a little box. For reference, assume this room is not a critical listening space (*i.e.* a recording studio or meeting room, and is more like a home office or living space).

Broadband absorption should be immediately implemented to tame the parallel surface reflections which are the prime contributors to the flutter, ringing, and other artifacts in the space. The bonus is that by deploying broadband absorption, it will also reduce the overall buildup of energy in the room. These treatments do not need to be thick (*e.g.* up to 51 mm [2 in.] thick fiberglass or foam panels), but should be dispersed relatively evenly throughout the space, as sound could be generated from different sources, or received in different locations. Carpets or area rugs can also be effective to help control reflections between the ceiling and floor.

These steps will address the main issues of the space and can be implemented using a variety of ceiling and wall treatments for the desired effect. Diffusion may be attained through other furnishings in the space—bookshelves, tables, chairs, or by adding some mathematic diffusers to assist in the development.

Critical listening room

A critical listening environment, like a recording/broadcast studio or a mixing/mastering room, requires a very different approach than the previous example. Begin by analyzing the differences between a critical listening space and a normal office space. Assume the spaces are roughly the same size and construction.

The critical listening space is more deliberate in its function than other rooms, such as offices spaces. This room is laid out with a purpose. A user may still be at a desk, but now they are mixing music in this space—so the speakers are the primary sources of sound in this environment, and the listening location(s) will be generally static. When treating a room like this, start by determining the locations of the sound sources and the listener and address any issues that would interfere with the sound travelling to the listener's ears.

First reflection points are a primary concern as they will smear the source content as it interacts with those secondary sound paths due to the reflection points. One should map those locations and treat them as

A SUMMARY OF DEFINITIONS

Absorption: The removal of acoustic energy from an environment.
Diffuse Field: An environment where energy travels equally in all directions (isotropic) and has uniform sound pressure.
First Reflection Points: Surfaces that cause a specular, first-order reflections between the source sound (loudspeaker) and the listener.
Frictional Absorber: A porous material that converts acoustic energy into heat.
Geometric Diffusers: Materials with different shaped surfaces to reflect sound spatially.
Mathematic Diffusers: Devices which use calculated structures to affect specific wavelengths of sound using phase offset, diffraction, or other means.
Tuned Absorber: Devices which are constructed to remove energy from specific frequency ranges—usually bass frequencies. **CS**

appropriate with broadband absorbers which are thicker than in the previous example due to the wider frequency range and higher sound pressure levels experienced in these environments. Depending on the space and speaker configuration, a designer will examine the first reflections on the side walls between the speakers and the listener, on the ceiling in the first reflection zone, and on the front wall behind the speakers and on the rear wall. While this sounds similar to the previous example, the designer must be more deliberate with the placement of these thicker absorbers, as their function is less about broad control of parallel reflections and more about making sure a clear source sound gets to the listeners ears.

Second, bass control is a priority in a critical listening space. Music rooms, movie theaters, and other critical listening spaces can have a great deal of bass content. Where it was an option in the previous example, controlling the bass here will be essential. The room will likely have tuned traps in the corners as well as some composite tuned absorbers for areas outside of the first reflection points. To get an idea of the correct frequency ranges, a designer should calculate or measure the room modes, and select the tuned treatments accordingly.

Finally, all of this absorption may have cleaned up the modes and reflections, but it may also have left the space a little "dry" sounding. This is a common problem that occurs is these critical listening spaces. One should add diffusers to the back wall, rear upper side walls, and rear ceiling to redistribute some of the remaining energy back into the room. While it may seem a bit counter intuitive, having that energy back in the room is a good thing, and balances the sound field while reducing listener fatigue.

Larger communal spaces

The label "larger communal spaces" covers a wide range, and could be an article in its own right, but this article will take a broad, generic

ADDITIONAL **INFORMATION**

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Key Takeaways

Acoustic issues as to the richness and functionality of sound in a space manifest themselves in many ways, and from many different causes. When approaching any task, it is necessary to understand the available tools. In this case, the tools at hand are materials for absorbing and diffusing sound. Knowing the strengths and limitations of these materials is paramount to effectively mitigating acoustic issues in a space and tuning that space for the best sound possible.

MasterFormat No.

09 84 00—Acoustic Room Components
09 84 33—Sound-Absorbing Wall Units

UniFormat No.

C2010.30—Acoustic Wall Treatment

Keywords
Division 09
Acoustics
Absorption
Broadband Absorption
Diffusion
Geometric Diffusion
Mathematical Diffusion

approach towards them. Broadband absorbers can be used to reduce overall noise here. These noises could be people talking, coughing, laughing, eating, and other sounds of basic living. In spaces where many people congregate, a designer should look to reduce reverb time to help improve intelligibility for announcements, reduce the cacophony caused by numerous, simultaneous conversations (a.k.a. the "cocktail party effect"), and increase safety. In reverberant spaces, people have a tendency to speak louder in response to their own lack of clarity. These spaces become increasingly uncomfortable, and it becomes harder to hear safety announcements, alarms, warnings, direction and the space just seems awash in noise. Like the office, spread out the absorption to address the many sources and receivers of sound. Focus treatments on the speech range of frequencies, as these are the main sources of noise in these spaces. Use diffusers if the space has large flat surfaces—geometric diffusers generally work well in these environments. If there is a bit of a bass buildup, analyze it to add some tuned absorbers to the space.

The difference between treating a problem and tuning a space

The acoustics toolkit is not only used to fix problems, but also to optimize the sound in the space. Use absorption for overall intensity and first reflections, tuned absorbers for specific bass problems or buildup, and diffusers to control specular reflections or to round out the uniformity of the sound field. Again, different spaces have different requirements—and different problems have different solutions at different frequencies. In a world where the reflections within a space define its feel and functionality, learning the strengths and limitations of the tools available is the key to picking the right tool for the job. Obtain the specific test data for specified materials and learn their performance profiles. Analyze the problems in the space and approach the problem with broad strokes, treat the larger problems first, then tune the space with targeted treatments for specific anomalies, and finally tie it all together and smooth it out. **CS**