The New Tool for the Acoustical Toolbox

Using Six Principles of Physics Simultaneously to Large Room Acoustics

Performance Space Acoustics is fraught with many myths, misinformation, and limitations. It is pure science, but its complexity makes it appear part of the mystical arts, brainwashing most into believing good acoustics is not possible or repeatable. What could be further from the truth? There are rules for acoustics. Follow them, and success is assured every time. Break any rule, and the results create an endless and costly cycle of experiments to correct the error. It doesn't have to be that way, but it is human nature for people to believe that the rules don't apply to them. The burning question is, which is greater, the laws of physics or human nature? The answer is simple. The laws of nature cannot be broken, and no amount of human cleverness can change that.

It has often been said and proven that acoustical problems come in layers. The most common and misunderstood layer has to do with excess bass. This layer is often misunderstood in acoustical measurements due to the sound-masking effects of bass energy. Most experts are not trained to spot the sound masking effect in an acoustical measurement on a graph or computer screen and, therefore, make misleading assumptions when recommending any acoustical treatment.

Just as acoustical problems come in layers, it is typical for acoustical treatments to be applied similarly. The first acoustical treatments usually never go beyond the initial layer. The first layer is most often brute force absorption. Most experts use this method because there isn't much else to work within the standard acoustical consultant's toolbox. When the only tool in the box only treats high-frequency sounds, the remaining low-frequency energy becomes louder, degrading speech and music intelligibility. Some experts experiment with diffusion, but they never go beyond using diffusion for nothing more than a spot treatment.

The good side of the brute force absorption approach is that it will eliminate the echo or excess reverberation, which is thought to be the significant problem people complain about. The downside to this approach is that it consistently degrades speech intelligibility and music – the very thing people want to be of high quality in a space where people gather in a large room. The application of sound absorption to a room has a tipping point. If there isn't enough absorption, people complain. On the flip side of this, the audience and audio techs constantly complain if there is too much absorption. When the audio techs complain, more money is spent on technology, which rarely improves an already correctly designed sound system.

From research and data, a well-managed room for an acoustical performance space, such as a concert and recital hall, is to have 20 to 24% of the total room surface absorptive. For a church, the total absorption is 30%. For an entertainment hall, the recommended absorption rate is 40%. What is most telling is the 30% tipping point for a performance space is based on an older building design that supports what science is just learning today.

This older building design employed vertical diffusers in a horizontal pattern. This system combines 6 principles of physics instead of two. As a result, it is possible to balance the acoustics of a room and avoid all the pitfalls associated with existing approaches to planning or solving problems for large room acoustics. To test if this approach works, live simulations were done. Live simulations were performed in dozens of churches (as access to performance spaces for doing experiments is limited), and every time, the results were immediate and

surpassed everyone's expectations in some of the most hostile acoustical spaces where people gather for music and speech. After doing field tests in many large spaces, permanent installations were implemented. In every instance, the results exceeded what the client had hoped for.

This method of sound management has its detractors. When people hear how good a performance space sounds, it silences anyone who has an aesthetic

objection. They are often the architects and Interior Designers who place aesthetics over function. Yet, from the many installations, only one client removed the acoustical system, only to have it replaced weeks later.

Another thing that was learned from the live simulations is that the performance of the properly treated rooms was very similar, but the sonic differences of the building materials became much more apparent, as in the difference of a room finished in drywall versus wood. The drywall space will have a dryer sound, while a room with lots of wood will have a softer sound. Yet, what is most telling is that both rooms will have similar overall, high-quality performance levels. Furthermore, when upgrading existing performance spaces of other room shapes, the overall performance dramatically improves as well. This is a universal solution for performance spaces.

Live simulations work, and the permanent installation performs even better, as live simulations have their limits. Computerized simulations do not even come close to the results. Computerized simulations work well with large, flat surfaces. When adding a system of diffusers, the equations have not been written yet to account for the complexity of the task at hand. While computerized predictability is impossible, real-world experiences, live simulations, and hundreds of examples give any facility the highest confidence in the results.

The notion of combining many properties of physics together is not what modern acoustics experts understand. A core of the audio and acoustical community has oversold the notion that acoustics is 100% predictable and truthful with computer simulations. What could be further from the truth? Currently, some of the better-known acoustical simulation programs are on their 5th and 6th generation software. They are getting better, but until the equations are developed that employ the following 6 principles of physics at the same time, computerized simulations are just dog and pony shows when it comes to performance space acoustics.

What happens if you were to combine the following 6 principles of acoustics at the same time?

1. Phase
    - 1.1. Phase Gradience
    - 1.2. Phase Coherence
2. Phase cancellation
3. Wave Confusion
4. Distance
5. Absorption

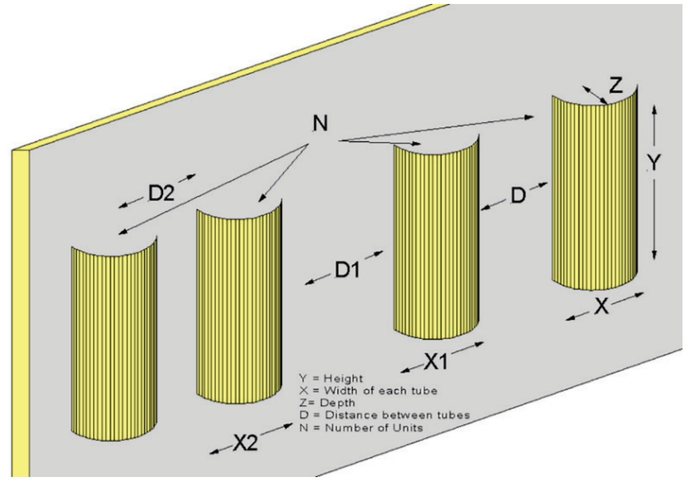
1. **Phase**
    - 1.1. The manipulation of in-phase and out-of-phase reflections.
    - 1.2. **Phase Gradience**
    - 1.3. The "in" phase reflections are set up in a pattern to either add or subtract sound energy.
    - 1.4. **Phase Coherence**
    - 1.5. The "out" of phase reflections are set up in a pattern to be canceled or reduced when colliding with the in-phase reflection.
2. **Phase cancellation**
    - 2.1. When two reflections of the same frequency interfere with each other out of phase, they cancel.
    - 2.2. The cancellation amount depends on how many degrees they are out of phase.
        - 2.2.1. At 180 degrees, the two reflections are canceled out 100%.
        - 2.2.2. At 90 degrees, they cancel out 3dB.
        - 2.2.3. At 135 degrees, they cancel out 6dB.
    - 2.3. The cancellation of sound has the same effect as absorption without the massive panels that would be needed otherwise.
        - 2.3.1. For example, it is easier to cancel 100% of 100 Hertz than to make eleven-foot-thick panels covering all the walls to absorb 20dB of energy.

2.4. In a typical installation, a generic pattern reduces sound energy from 80 to 1500 Hertz 10dB.
2.5. In some rooms that need passive equalization, a diffuser system can reduce specific frequencies up to 40 dB.
2.6. By changing the distance, sizes, and groupings of the half-round diffusers, you can equalize the frequency response of the room.

3. **Wave Confusion**
   3.1. By scattering sound waves at the point of impacting a surface and forcing the reflections into random patterns, the longer wavelengths cannot combine and sum together to form standing waves or excess buildup.
   3.2. This prevents bass energy from building up on walls and following walls into the corners of the room.
   3.3. This prevents the need for bass traps.
4. **Distance**
   4.1. Outdoor sound decays at a rate of 6dB per doubling of distance. Therefore, air can be used to absorb sound if you can mimic the effects of the outdoor sound indoors.
   4.2. Indoors, all surfaces act as sound amplifiers.
   4.3. Therefore, the decay rate over distance is reduced by the amount of energy reflected off the walls.
   4.4. At the same time, the amount of sound energy impacting the walls as the sound arrives at the wall can also reduce the amount of reflection.
   4.5. By combining sound attenuation methods with random sound scattering, the signal-to-noise ratio increases, and the path of the remaining sound reflections becomes longer. This gives the air a greater opportunity to absorb the lows and preserve the important high-frequency sounds needed for clear speech and music.
5. **Absorption**
   5.1. Absorption is the conversion of kinetic energy into heat by vibrating fibers on a surface plain.
   5.2. The panel's thickness and the incidence angle determine the range of frequencies the panels can absorb.
   5.3. Absorption complements diffusion.

What is unique is the concept of using the flat spaces between the half-round diffusers to create an interference pattern with the in-phase reflection off the flat portion of the wall. Where the wave pattern intersects with the out-of-phase reflection off the half-round diffusers, the sound is attenuated according to the degrees the reflections are out of phase.

When you combine the first five items, you create a diffusion system. When you add absorption, you can balance the acoustics to satisfy both speech and music equally as well. This is a balance easily achieved with this method and is repeatable in any room shape.



As said earlier, room shape has a bigger impact on performance spaces than previously realized. With the current methods of managing large room acoustics, acoustical experts are always looking to solve one problem at a time. This is because they work with a limited toolbox. With this new method of managing sound with live simulations, problems can be fixed the moment they are identified. Furthermore, you can play with the acoustical system to discover different ways to make the acoustical system even better. You can even create an echo and then get rid of it in real-time. While there is an upfront cost for doing live simulations, you can test a room dozens of times in a day, whereas complex computer simulations can take days or even weeks to get meaningful results.

This combination of acoustical principles makes it easier to understand why rectangle-shaped rooms are so much better than any other room shape. As it turns out, when a reflection of sound comes from the side walls, it helps to synchronize the sound with the movement of the person speaking. When the lip movement and sound match up properly in the mid and high frequencies, it offers the highest level of speech communication. When there is no wall that is perpendicular to a person's ear nearby, speech cannot be supported in the same way.

In a fan-shaped room, there are no side walls to support synchronized speech. Instead, the direct sound goes past where a person is sitting, and the reflection off the back walls competes with the direct sound. Most of that reflected sound is in the mid and bass range. Excessive low-frequency energy will overpower the highs, which must travel further and naturally decay over distance. That reflected sound is also delayed. That delay is enough to degrade speech intelligibility even though you can't hear it.

What most people do in fan-shaped rooms to remedy this problem is that they will add more absorption. As they add more absorption to the room, speech, and music intelligibility decreases, yet it fools people into thinking that what is heard is more articulate. By implementing this new alternative method of managing sound, you can increase the signal-to-noise ratio of the back walls, making them disappear, which drastically improves intelligibility.

It seems that side wall reflections support speech, both audibly and visually. When the side walls are absent in other room designs, the sound system must be louder than necessary for reasonable sound quality. But wait, what about the back wall in a rectangular room? Isn't that the same thing? No. All walls act as amplifiers. Since the side wall reflections are ahead of the listener, it supports the direct sound and are synchronized. Any remaining sound energy will have decayed enough that it is not audible as a backwall reflection.

A critical detail that must be included is the signal-to-noise ratio in a room. When the signal-to-noise ratio is less than 9dB, everyone must speak louder, and for musicians they must perform louder just to hear themselves. When the signal-to-noise ratio is above 15dB, people can hear themselves loud enough that they don't have to play or speak as loud. In a typical room that is treated with this method of sound management, the signal-to-noise ratio is often between 20 to 25 dB. At that level, musicians stop playing excessively loud and play 10 to 15dB quieter without compromising the quality of the performances. When musicians can hear each other, they will automatically play quieter. It is no secret that people learn to play better with quality instruments. It is also true that musicians learn faster in a room with a high signal-to-noise ratio.

The support for rectangle performance spaces is ubiquitous in concert halls, classrooms, and rehearsal spaces. Two of the most famous concert halls, The Boston Symphony Hall in the United States and La Scala in Italy are the best-known performance spaces where the shell of these spaces is a rectangle. Another sign of a great performance space is the amount of diffusion in the room. The more the room is diffused, the better the room performs. This is what is learned when working with a diffusion system that can be simulated in real time.

As long as people keep defying the laws of nature, acoustical problems will persist. Man's cleverness will never defy the laws of physics. When given a choice between " science" and aesthetics, science always wins, despite man's determination to challenge physics. The human will to try to circumvent "the science" is a fruitless endeavor. That said, when people are given these choices, it is amazing how making the right acoustical decision changes how people think, and it becomes a productive endeavor to make the acoustical system more aesthetically pleasing rather than having another failed experiment.

Finally, it needs to be made clear that this new combination of these six principles of physics is not new at all. It comes from an ancient text written 3500 years ago. Who would have thought that such a primeval writing could solve modern day acoustical issues.