Auditorium Acoustics 103

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Speakers Make Sound, Acoustics Clean It Up

Intelligibility is the single most important service that an auditorium can provide. Without intelligibility, an auditorium is functionally little more than a gymnasium after the basketball hoops have been folded out of the way and the chairs have been carted out, unfolded and set up.

In either acoustic space, sound will be emitted from a pretty good sound system. In both cases, the same tiny percent of the sound actually gets to travel directly from the speaker into the ears of the listeners. And in both cases, the rest of the sound, about 99.9% of the total sound produced by the speakers, overshoots the listeners' ears and ends up crashing into the rest of the interior of the building. It crashes into the people and their clothes, the chairs, floor, walls and windows, the draperies, doorways, ceiling, light fixture and so on.

The only sonic difference between a gymnasium and an auditorium is completely accounted for by considering only one thing, what happens to the sound that misses the ears of the people. And so, by studying the part of the sound wave that actually misses the listeners we become more able to understand the difference between gyms and auditoriums.

Auditorium Acoustics is About Reflections, Not Loudspeakers

It is no surprise that people tend to focus on what they hear rather than on what they are not hearing. Some might be seated in the auditorium, they could be the building committee who commissioned the auditorium, the architect who designed the auditorium or the sound contractor who hung loudspeakers. But the acoustician, the person brought in to voice the space, is much more concerned about the sound they didn't hear, the sound that passed them by. That's the sound that remains trapped in the room, circulating, to be heard again and again. Acoustics is not about the 1/10th of 1% of the sound from the loudspeaker that is directly heard by the people. Acoustics is about the other 99-9/10ths % of the sound, intercepting it and turning it into a sound that is fit to be heard.

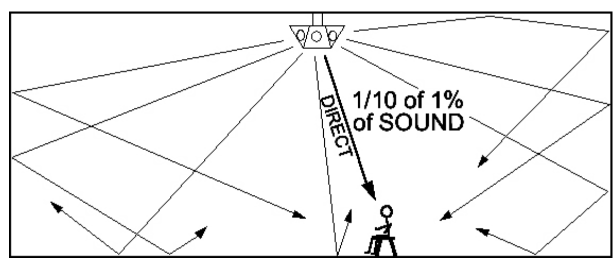

FIG-1
Direct sound is 1/10 of 1% of the all the sound.

If you are in a gymnasium, the direct sound, 0.1 % of what the loudspeaker produces, is providing important information, it's what we want to hear. (Figure-1). The rest of the sound, all 99.9% of it, turns into noise and that's why we can't understand sound very well in a gymnasium. A gym usually has a poor signal to noise ratio (SNR) A good signal to noise ratio is important to keep in mind when trying to change a gym into an auditorium or more likely, trying to keep an auditorium from sounding like a gym. All too often, the building committee will think that acoustics means trying to absorb all the sound that misses the audience. That approach does knock down the noise but it's like throwing the baby out with the bath water. Rooms that are too dead are almost as bad as rooms that are too live.

Acoustics isn't about sensory depravation, it's about getting good sound. And we get it by working hard to corral, train and manage those errant reflections, 99.9% of the sound emitted from the loudspeaker. Auditorium acoustics is about getting the best use out of all the sound that missed the people on its first pass.

Intelligibility Means a Good Signal to Noise Ratio

In order to really understand speech, we need to have the noise level of sound about 15 dB quieter than the sonic signal we hear and are trying to understand. That means a signal to noise ratio of 15 dB. It is just barely possible to understand speech if the noise level is just as loud as the sonic signal strength, a 0 dB SNR. Understanding is poor with a 5 dB SNR, OK with a 10 dB SNR, good with a 15 dB SNR and excellent with a 20 dB SNR.

Note: When people have hearing aids or otherwise have their hearing challenged they require about an extra 5 dB SNR to get the same intelligibility rating as those with undamaged hearing. The ADA (American Disabilities Act) has recently adopted a new ruling, that all people have a right to be able to understand what is being said. That generally means that facilities in which communication is an essential feature, now have the added responsibility to improve their speech SNR by about 5 dB. The expense can even be taken as a tax deduction.

In order to appreciate how so much time, effort and money can be spent getting good acoustics in the auditorium, it helps to understand something about “signals” and “noise”.

Intelligibility means having a Good Signal

A good signal is usually thought of as coming from a good loud speaker, arriving loud and clear. Generally people prefer the sound of speech to be about the loudness of natural speech, about 65 dB,A on the average. The sound contractor has to hang and align the loudspeaker so it delivers sufficient Direct Sound into the congregation or audience. The audio tech has to properly set the loudness level and the EQ so the speaker is not too lour or quiet, too dark or bright. However, there is more to a good signal than simply adjusting the direct sound from the speaker.

A good signal includes early reflections. Early reflections help people listen to and understand speech. Any reflection that arrives at the listener’s ear within the first 1/16th second following the arrival of the direct sound is considered part of the “direct signal” as far as listening to speech in concerned. The ear/brain system cannot separate the direct sound from any of the early reflections. They merge together and become one sound. One of the big challenges in the design of large auditoriums is to create early reflections. It is not so easy to position sound reflecting surfaces near enough to so many people and still have a nice open architectural space to look at. (Figure-2).

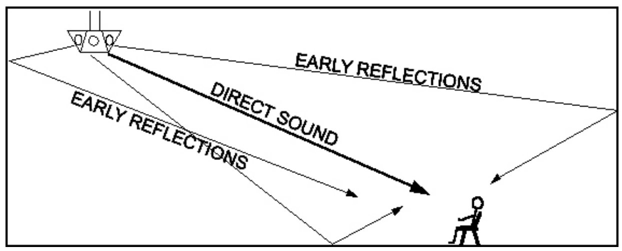

FIG-2
Early reflections help with understanding.

Noise Ruins Intelligibility

Noise degrades the quality of listening in any room, from the auditorium or sanctuary to the fellowship hall, meeting rooms, daycare and even the gym. As long as the signal from the loudspeaker is loud enough to hear, the only thing that can ruin understanding what is being said is too much noise. The louder noise becomes, the less we understand of the signal.

There are different types of noise and each one of them must be reduced to an acceptable level below the level of the signal. But the acceptable level for noise can be quieter than one might expect. Noise is additive, the strength of two noises is louder than each of them separately. For example, if we have 3 types of noise, all equally quiet, then the sum effect of all three at once is to create an overall noise level that is 5 dB louder than any one of the individual noises. When dealing with multiple noise sources, each has to be reduced to at least 5 dB below the tolerable noise floor so that when all three are going on at the same time, the accumulated level does not exceed the tolerance limit.

The “noise” part of signal to noise means any sound you hear before or after the “signal”. There are three kinds of noise. One is the fairly steady environmental noise, as from the air conditioning system, light ballasts, the din of freeway noise coming through a door, window or even a fresh air intake vent. The second type of noise is intermittent. It is a baby’s cry, some whispering nearby, coughing, the rustle of feet and clothes and so on. The third type of noise is transitory. It is the echoes and reverberation of sound due to the acoustics of the hall.

Noise is any sound that is not wanted or not helpful in hearing what we want to hear. If a noise is emitted or enters an acoustically dead room it doesn’t last long in the room, it dies out quickly. However, in a reverberant hall, noise ends up being reflected again and again and we continue to hear the same noise over and over again. These multiple reflections effectively amplify the original noise, making it louder than it originally was. Having to hear a noise once is usually more than enough. Noise can be acoustically amplified as much as 10 times (+10 dB) over what the original noise sounded like, that makes it seem twice as loud.

Echoes and Late Reflections Interfere with Understanding of Speech

Late reflections are those reflections that are too strong and arrive just at the wrong time, when our listening/understanding process is most vulnerable to interruption. This sensitive time period begins just after the end of the early reflection time period. It is a time period when our understanding of what we hear is very susceptible to being easily confused. And it is perfectly natural. One of the most notorious of these late reflections is the echo. Designing an auditorium is to a significant degree a process of creating an acoustic space that eliminates late reflections, especially echoes, for all listeners. (Figure-3).

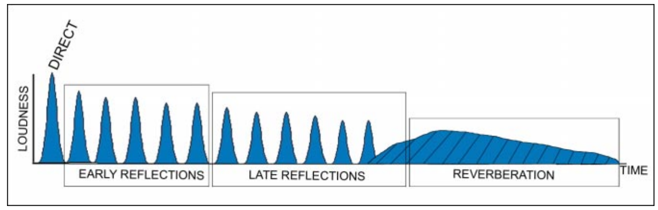

FIG-3
Late reflections and echoes intefere with understanding.

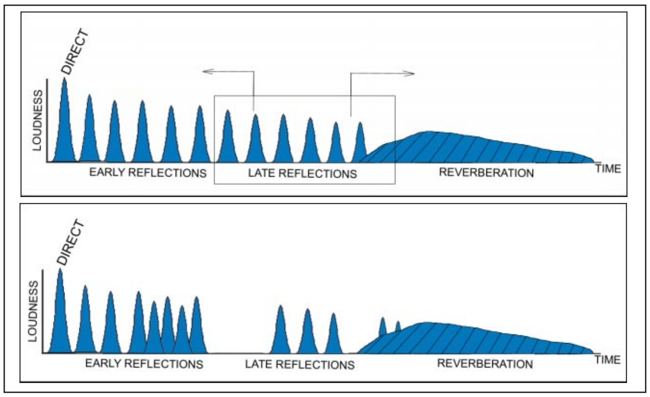

FIG-4
Scattering into early reflection and reverberation times.

Good acoustic design manages to eliminate or at least temper the late reflections. Late reflections can be moved forward in time into the early reflection time period, by repositioning the reflecting surface. (Figure-4). They can also be shifted backwards in time into the reverberation time period. Late reflections can be simply eliminated by absorbing them. (Figure-5). They can also be splintered into numerous small reflections by diffusing them.

Regardless of how the late reflections are managed, it is essential to reduce their strength to have an intelligible space. The resulting moment of relative quiet, the early time gap, is a quiet interlude that provides for the understanding of what is being said. It is a lull in the wash of sound over the audience and every good listening environment. The early time gap exists between 1/16th and 1/4th second following the direct sound. The acoustic signature of a gymnasium won't have it while the acoustic signature of a good auditorium will have it, and it usually cost quite a bit to get it.

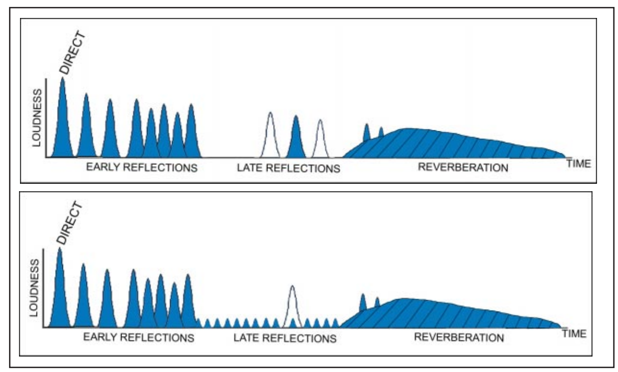

FIG-5
Absorb and diffuse late reflections.

Reverberation, a Little goes a Long Way

Reverberation is the upwelling and dying out of chaotic sound. Unlike reflections, which are organized sound waves with a measurable direction and strength, the sound of reverberation has no direction, only its loudness can be measured. Reverberance is sound coming and going in all directions at one time. It is a unique type of sound and remains generally agreeable for people as long as it isn't too loud or last too long.

Too much reverberation will blur words together. But there are two kinds of "too much reverberation". Reverberation can be too loud or reverberation can last too long. In a properly designed room, the reverberation is set to the proper loudness and it is set to last the proper amount of time. A bare gym is a great place to get to know about reverberation. Talk loudly and the reverberation is loud, talk softly and the reverberation is quiet. (Figure-6). In either case, the reverberation dies out at the same rate, the same number of dB per second. A very reverberant gym will have a reverb decay rate of the about 12 dB per second. A loud shout or balloon pop can be heard lingering for about 5 seconds.

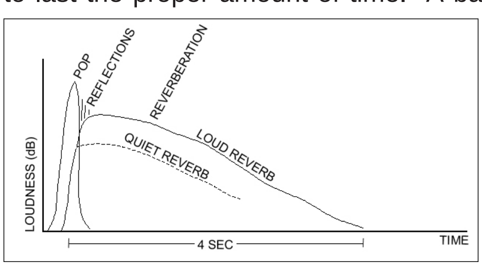

FIG-6
Loud or quiet reverb both decay at the same rate.

Let's imagine two people in a large, shiny surfaced, quiet and otherwise very empty gymnasium. If they get together and raise a ruckus, then suddenly stop, it will take about 5 seconds for the reverberation to completely die out. This is called the "reverb time" or RT-60. It is the time it takes for the loudness of sound to diminish by 60 dB. On the average this is just about exactly the time it takes for a loud sound to die out and become inaudible. Pop a balloon and use a stop watch to measure how long you can hear the noise lingering and you will measure the RT-60 of the gym. A gym with a 5 second RT-60 has a decay rate of 12 dB per second.

The loudness of reverberation depends on how much sound is being dumped into the hall. Actually that isn't quite true. We take the total amount of energy dumped into the hall, subtract the amount absorbed during reflections and what ever is left over is what fills the hall and becomes reverberation. The rate of decay of the reverberation does not depend on how loud the reverberation is. Reverberation dies out at the same rate, dB/second, regardless of how loud or quiet the sound happens to be. Adding acoustical material to the hall does change the rate of energy decay in the hall, the more acoustics the shorter the decay time. (Figure-7).

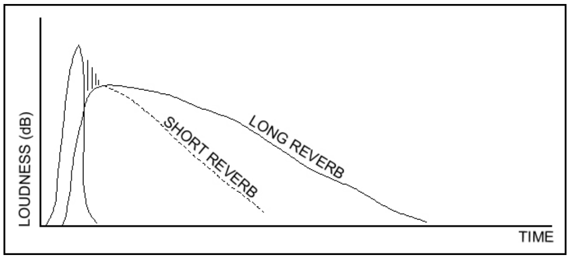

FIG-7
Sound dies out faster with a short reverb.

The total energy stored in the reverberant condition of a hall is equal to the how loud it is times the volume of the hall. A large hall stores more energy than a small hall. A hall with loud reverberation is holding more energy than if it has quiet reverberation. Reverberation energy is stored in the volume, in the air of the hall. Reverberant energy is removed by friction between the waves and the walls of the hall, not much different than an ocean wave the beach.

Reverberation is stored in the volume of the hall and absorbed on the surface of the hall. How long it takes for sound to die out of a hall depends on the ratio of volume to surface area and of course the roughness or acoustical friction provided by the walls, floor and ceiling of the hall. Once the architectural surfaces and furnishings have contributed their percentage of acoustical friction the reverberation time is usually still way to long. At this point acoustic materials have to be introduced to make up the difference. And where these materials end up being located puts the finishing touches on the "voice" of the hall.

Voicing the Auditorium

The voice of the auditorium is a complicated sound. It starts with sound from the loudspeaker. This sound along with early reflections wash over the audience and provide the direct signal that contains all the elements necessary for communication. Competing with the audience reception of this signal is noise. Crowd noise and air conditioning noise combine with echoes, late reflections and reverberation to create an overall hubbub of background noise. This semi continuous background noise masks out important parts of the direct signal and effectively blocks understanding of the message.

Developing the voice of the auditorium starts with determining how much acoustic material needs to be added to the hall in order to produce the correct reverb time for good listening. Reflectors are added to enhance the presence of early reflections. Some late reflections are absorbed using acoustic materials specified for reverb control. Others are simply splintered with diffusion, converting a few big ones to many little ones. Still others are kept intact but back scattered forwards in time into the early reflection period or backwards in time out into the reverb period.

The voice of the auditorium ends up being nothing more or less than the sculpted sequence of sonic reflections. The acoustician, working with a sonic chisel, starts with a blank concrete box and carves it into an auditorium. Even though the reflection sequence has to be technically different for each and every seat in the house, a good auditorium design will deliver a fairly similar sound pattern to nearly every seat in the house.