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Auditorium Acoustics 102

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Reflections Make All the Difference

An auditorium is a place where people come to "audit", it's a place to listen. It won't matter if the auditorium is big and beautiful, warm and comfortable, if the people can't understand what is being said in the auditorium, it just isn't doing the right job.

In the previous article on auditorium acoustics, we considered that quietness is more than an important factor, it is the prerequisite for good listening. There are a number of ways that noise intrudes into the auditorium. The quiet of an auditorium is degraded when outside noise gets inside, soundproofing helps. The quiet is also degraded by internal noise sources, quiet air conditioning helps. The quiet is affected when sound from the loudspeaker reverberates too long, sound absorption helps. Whenever the auditorium isn't quiet, people begin to not understand what is being said. This time we consider reflections, not all but some reflections are helpful in improving our ability to hear clearly, to understand sound.

Much of the sound we hear in an auditorium is reflected sound

Imagine the bird's eye view from the elevated vantage point of the central speaker cluster. The loudspeaker illuminates its entire view but only a tiny fraction, 1/5th of 1% of the sound actually hits the target, the ears of the people below, the "direct sound". The rest of the sound, over 99.8% of it, the "indirect sound", misses the ears and continues on, crashing into the walls, floor and carpet, the people, coats, and chairs, the roof and its beams, the walls, windows and doors. Every time some part of the indirect sound hits a surface, it is reflected. How the surfaces of the hall reflect the indirect sound determines how the room sounds, its voice. What happens to the reflections of the indirect sound is what makes all the difference between the sound of Carnegie Hall and a high school gym. (Figure-1).

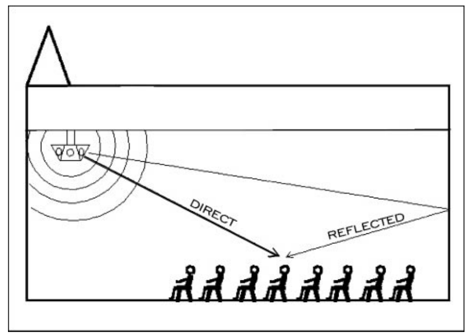

FIG-1
Reflections make all the difference between a good and bad hall.

The amount of indirect sound that is reflected depends on the acoustic nature of the reflecting surface. Hard surfaces such as a concrete floor, reflects all the sound. Softer surfaces such as a carpeted floor, absorbs the treble range of frequencies and reflects the bass range. Other surfaces work nearly in an opposite manner. A glass window will reflect the treble range sound and let the bass leak right out of the hall. The window is neither heavy enough nor strong enough to resist being pushed out and pulled in by the powerful pressures of a bass range sound wave. The indirect sound remains in the hall reflecting off of one surface after another, remaining audible to the listeners until it finally disappears, having been absorbed and leaked out of the room.

Some reflections are good, others not so good

There are three types of reflections that people hear in an auditorium: Early reflections, late reflections and reverberation. Early reflections are good, late reflections are generally bad and reverberation varies between good to bad. The "voice of the hall" depends on the nature of the sequence of reflections heard by the people in the audience.

Early reflections help us understand speech

Imagine standing in the quiet of a desert sand dune trying to talk to someone, our voice seems to just fade away over even the shortest of distances. At 25 feet, we have to nearly yell to be understood. The same thing happens outside after a fresh snowfall. This type of acoustic space is one without reflections, "anechoic". However, stand out on a huge blacktop area and talk with someone and you'll hear them much better. The hard surface of the asphalt created one reflection that the sand and snow didn't create and this makes a huge difference, the sound is louder.

Let's move our conversation into a quiet office. Even at a distance of 25' it is very easy to talk to each other. Not only did the floor provide a reflection but the ceiling did, the walls did, so did glass windows, lamp shades, doors and the desk top all act to bounce sound, providing dozens of reflections that end up helping us to hear better. The more early reflections there are, the better a person can hear.

There are two ways to make sound "louder". The ordinary way is to make it physically louder. Cup your hands and yell, makes it louder. The other way is to add as many reflections as you can. Cup your hand over your ear makes it louder, or talk in an office. Not all reflections help hearing but those that do help people understand what they are hearing are called "early reflections". Adding early reflections raises the apparent loudness of the direct sound in a comfortable, natural way, much more agreeable than turning up the volume.

Echoes can be fun but they also ruin the understanding of speech

Early reflections are those that bounce off nearby objects. But when the object is located some distance away, the situation changes, you can hear the reflection off of it and we call this acoustic event an "echo". An echo can be great fun at times but when it's time to pay attention to someone talking, it also makes listening very difficult. The echo is a good example of a "late reflection" because it is a reflection that can be distinguished as being separate from the direct signal.

Stand next to a large building with a large field of grass stretching out and away from the building, with no other buildings of structures nearby. (Figure-2). Clap your hands and you hear what you expect, the clap of your hands. Step away from the building two big steps, clap and again everything sounds normal enough. Step again away two more big steps, now you're 12 feet from the building wall, clap and things still sound normal. Take 4 more big steps away from the building, now you are 25 feet from the side of the building. Clap and things still sound normal.

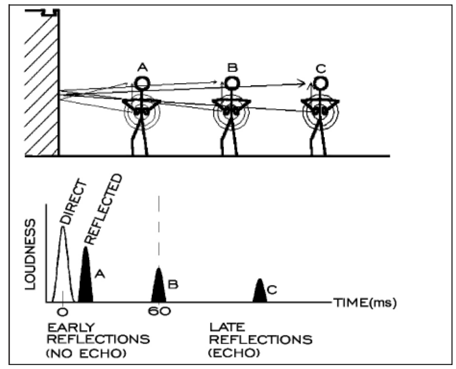

FIG-2
Echoes can not be detected if you stand close to a wall.

Take 4 more steps away from the side of the building and clap. Now, something is different. This time you heard the echo of your clap off the side of the building. You are 37 feet from the side of the building and you heard an echo. At 25 feet you did not hear an echo but by all reason, the sound of your clap did reach you and you must have heard it. Early reflections are reflects that you can't actually detect. Echoes are reflections you can detect, they are "late reflections".

Sound travels just over 1100 feet per second. Echoes off a wall 25 feet away travel a round trip distance of 50 feet, taking 55 thousandths of a second to arrive (55 ms or milliseconds) back to where you are standing. Direct sound from your handclap travels but a short distance from your hands to your ears. It arrived at your ears some 3 ms after being created by your hands. The reflection of your handclap off the side of the building 25 feet away arrived at your ears about 55 – 3 = 52 ms after you first heard the direct signal. Even with this amount of time delay, 1/19th second, you couldn't hear the reflection as a separate sound.

However, at 37 feet distance, the round trip for sound was 74 feet, taking about 65 ms for a round trip. This time the reflection followed the direct signal with a time delay of about 65 – 3 = 62 ms and it could easily be heard as a separate signal. Generally, people can just begin to detect echoes if they arrive about 60 ms after the direct signal arrives, about 1/16th second. All early reflections, those that arrive at the ear within the first 60 ms, improve the loudness of the perceived sound. It is very healthy to receive as many as 20 to 40 early reflections. When it comes to early reflections, it's one of the few situations in life when more is better. A good, clear and bright sounding auditorium provides ample opportunity for many early reflections to reach each seat in the hall.

Late reflections ruin listening to speech

Late reflections are those reflections that are distinguishable as separate acoustic events from the direct signal. Echoes are late reflections. Multiple reflections, strings of echoes are late reflections. There can be just a few late reflections or many late reflections. Late reflections are those that arrive after about 60 ms following the reception of the direct signal. They can stretch out up to around 250 ms (¼ seconds) or so. If you concentrate you might be able to identify where some of them come from. When too many are coming, there is no hope to separate them out in terms of direction or timing but you still hear them as being separate from the sound of the direct signal. (Figure-3).

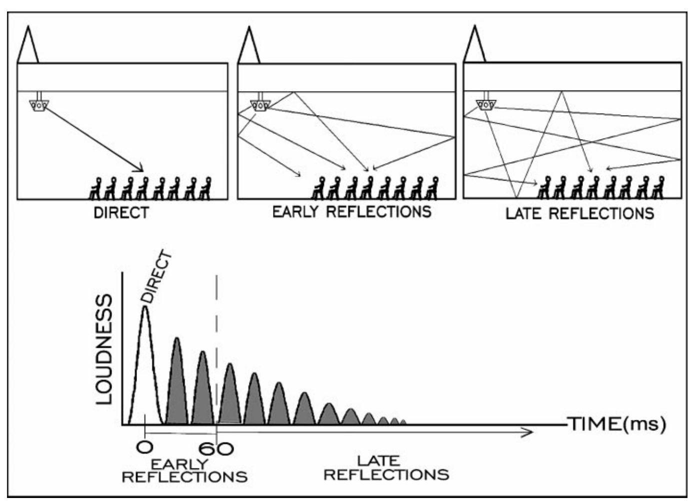

FIG-3
Three types of sound: direct from the speaker, early reflections, and late reflections.

In order to understand speech, it is important to hear the start, the sound and the ending of each syllable. Each syllable contains both loudness and tonal variations that add emphasis and can even meaning to the ultimate word. To understand speech, we must be able to hear and understand the rapid changing sonic variations within the syllables of speech. When people are speaking, they produce about 4 complete sonic events per second and frequently interspersed with short quiet moments. We can imagine a model for speaking that generates a sequence of sounds each lasting 1/8th second followed by 1/8th second silence.

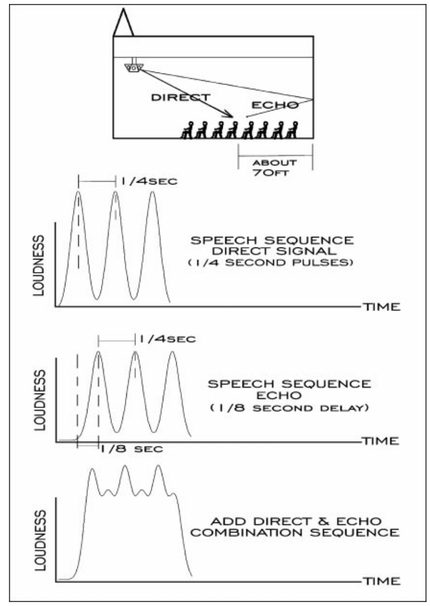

FIG-4
Echoes backfill the quiet between syllables.

Anything that backfills the 1/8th second quiet times between syllables is noise and tends to mask or block out the understanding of the signal. (Figure-4). Late reflections easily backfill those quiet 1/8th second periods, causing separated speech syllables to seem to slur together. The excessive presence of late reflections makes the difference between a room that yodels and a room that gargles.

Late reflections are best converted into early reflections when ever possible because this helps with the understanding of the direct sound. There are two other ways to get rid of late reflections (including echoes): Absorption or diffusion. If late reflections are absorbed, they are removed from the sonic space entirely and the overall loudness of the subsequent reverberation is markedly reduced. If late reflections are diffused, scattered about, they are not removed from the sonic space and the reverberation remains loud.

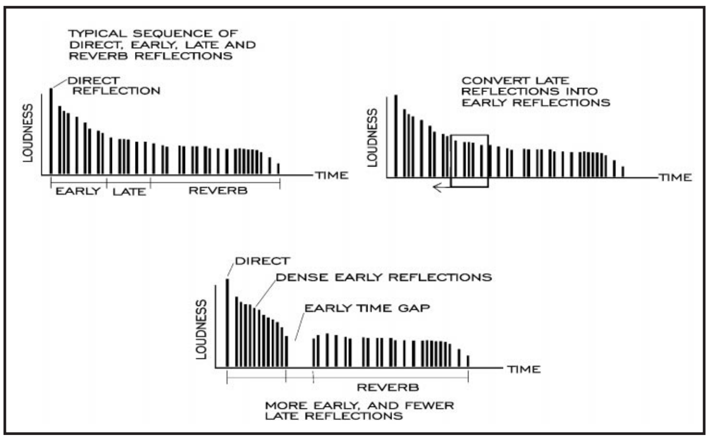

FIG-5
Late reflections are eliminated to improve understandability of a hall.

It is important to rearrange the late reflections in designing or revoicing an auditorium. A good sounding speech hall has an "early time gap" in the sequence of ongoing reflections, a unique absence of late reflections. It sports a strong direct signal, accompanied by a distinct and flush group of early reflections. This is immediately followed by a distinct absence of late reflections (the early time gap) and after about ¼ second of relative quiet, the backfill of reverberation is noted. (Figure-5).

Reverberation

This type of sound is no longer made up of a distinct set of reflections. Reverberation is a different kind of sound, it feels different, seems to roll. It comes from everywhere and nowhere all at the same time. It is fairly quiet and creates the feeling of largeness. It is the kind of sound that begins to be felt starting about ¼ second after the direct signal passes by and lasts out some 2 to more 5 seconds. It is the rounds of sound in the room that slowly dies out and it is the very last thing we hear of a sound before the hall finally falls silent. (Figure-6).

Reverberation is not a series of echoes, like late reflections are, it is much more chaotic than that. There is no measurable or detectable direction for sound of reverberation. There is no distinct time sequences for the sounds that make up reverberation. There are some curious features however within a reverberant field. In a large hall comprised of distinctly different spaces, each open to another, the reverberation of each separate space can be heard in addition to the reverberation of the main central room. Sometimes reverberation seems to be raining down from a great dome overhead. When seated under a balcony, reverberation seems to come from the high volume part of the hall out in front. Reverberation can come from somewhere but it is an overflow of chaotic sound being stored in a reverberant space. It is not a "reflection" of a sound wave.

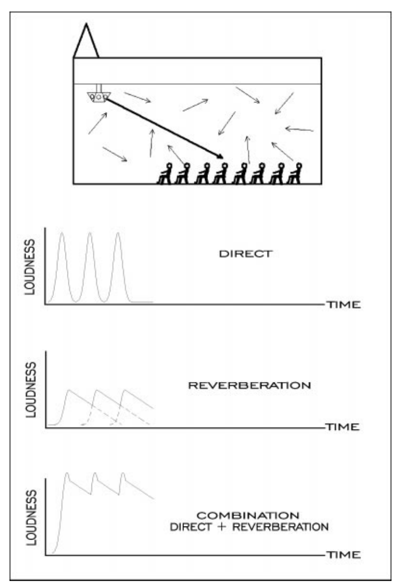

FIG-6
Reverb backfills the quiet between syllables.

Reverberation is a general din of noise that takes a long time to die out compared to the rapid sequences of speech sounds. Two people are close together and talking in a bare gym. They understand each other. Then they start backing away from each other and keep talking. At some point, maybe about 30 feet apart, they can no longer really understand each other. The loudness of the reverberation is the same anywhere in the room. The rate of reverb dying out in the room remains the same everywhere in the room. What happens as the talkers separate is that the direct sound becomes weaker because of the increased distance until it is finally too weak compared to the reverb noise level and understanding is lost.

Early Reflections help with listening

Of all the types of reflections only one, early reflections, actually add to the direct signal to create a louder, more clearly understood sound. Early reflections have to arrive at the listener within the first 60 ms following the direct signal. The distance from the loudspeaker to the surface providing an early reflection and then back down to the listener can not be more than 50 feet longer than the direct distance between the loudspeaker and the listener.

Sound spreads out from the loudspeaker and some of it might miss the congregational seating area and hit the sidewall. If the sidewall is close enough to a group of listeners that the reflection washing over them off the sidewall arrives within 50 ms of the direct signal, this wall reflection aids in hearing what is being said. It is easier to hear an early reflection coming in from an area in front of us, above us or to the side of us than if the reflection comes in from behind us due to the way our ears are shaped.

Ceilings and sidewalls can be shaped or they can be fit with objects that create early reflections landing in the seating area. Balcony facings, and balcony ceilings can provide substantial early reflections. Pillars (especially big, hollow fake ones) can be placed in special locations along the sidewalls to cause early reflections. They are also good for catching upper rear wall reflections and side scattering them. Softly rounded soffits placed high on the sidewalls provide a second set of early reflections. The open space above the soffits can be used for uplighting. (Figure-7).

Another form of early reflections is often seen in auditoriums and music halls, it is the suspended acoustical cloud. These flying wings seem to loom overhead and to some greatly compromise the visual integrity of a “traditional” space. The problem is however that the traditional space doesn’t acoustically work very well. At any rate, suspended acoustic clouds are positioned and shaped to intercept upward bound sound and rescatter it back down into the audience area, all within the early reflection time period.

Finally, early reflections can be faked (simulated) by adding a distributed sound system. These speakers are played at a fairly low sound level, about 5 dB below the strength of the direct signal and each speaker is on a specific time delay so that the “early reflection” arrives within 50 ms after the direct signal. Line source or customized planar loudspeakers are best for this application. The more common two-way box speaker is much more apt to be spotted by the listening ear. The line or planar speakers project sound more evenly over greater distances, they essentially feel more like a reflection.

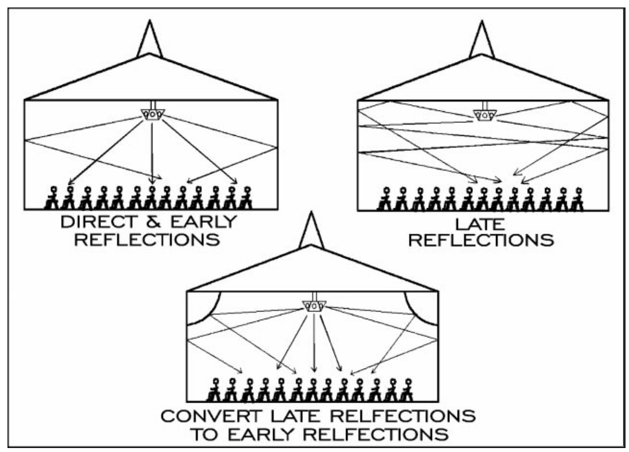

FIG-7
Hall design includes objects that scatter late reflections.

Conclusion

Early reflections are the single most overlooked opportunity for developing good sounding speech in today’s auditoriums and sanctuaries, live theaters, lecture halls and even classrooms. These most desirable reflections can be mechanically induced by appropriate positioning and shaping of sound reflecting surfaces. They can be electronically emulated using a time delayed distributed sound system. Good sounding auditoriums don’t misuse their sound systems to create overly loud sounds. They use sound systems to generate a comfortable loudness for the direct sound and then compliment this with a bevy of early reflections, immediately followed by a distinct absence of late reflections and finally backfilled with a groundswell of distant sounding reverberation. Early reflections can’t be distinguished from the direct sound and that’s why they are the only reflections that actually add to clarity of speech.