Auditorium Acoustics 104

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When working with an acoustician in the design or renovation of a hall it is helpful for all to have an understanding of the basic concepts in auditorium acoustic design. You can't really design a hall just by knowing the basics of auditorium design. The acoustician maintains an arsenal of trade secrets and insider techniques, reserved to managing sound once it's been launched from the loudspeaker. But by understanding the basics, you can at least keep track of what and why various things are being done. You can explain things to fellow parishioners. Also, long before you even start, you have to find someone to help with the design work. Understanding auditorium design helps you interview candidates and recognize who is not able to answer straightforward questions. Finally understanding auditorium acoustics will help give you second thoughts when you find there is a problem with understanding sound from a loudspeaker. Your speaker was probably installed by perfectly competent sound contractor and is still working just fine. If it's loud enough to hear and you still can't understand it, then your problem isn't loud speakers, its acoustics.

Besides keeping the rain out, the next most important thing an auditorium must do is to provide a place where speech can be clearly understood. This means a good auditorium will have a good intelligibility rating. The set of minimum acoustic requirements that are met by a working auditorium starts with the direct sound from the speaker being loud enough, that means it replicates conversational sound levels. The background noise in the hall has to be fairly quiet. The hall acoustics should be fairly free from echoes and other types of late reflections. And finally, the hall acoustic is not very reverberant at all. Here we take a look at each of these factors as they apply to the three basic types of auditoriums that have evolved over the last century.

Reviewing the Basics of Auditorium Design

Auditorium design begins with the loudspeaker and how it plays sound into the hall. It ends with how the hall returns reflections of the sound back to the audience. The speakers should produce a sound level at about 65 dB,A everywhere in the seating area. It should have at least 20 dB of "head room" so that short lived bursts of sound up to 85 dB,A can be replicated without any hint of speaker or electronic distortion. Electronic distortion must be avoided. Distortion of the signal is one of the fastest ways to cause people to lose their understanding of the sound. In addition, the loudspeaker system should sound similar no matter where a person is seated. This is achieved when the speaker system is tested and confirmed to provide a fairly flat frequency response curve for every seat in the house.

The natural noise floor of the hall itself should be at least 20 to 30 dB quieter than the speaker level heard at the seats throughout the entire frequency range for speech. Generally the ambient noise levels for an empty good auditorium would be about 25 to 30 dB,A. This noise is the sound of the hall when everything is turned on, lights, air conditioning and even the sound system. The only thing that isn't happening is that someone isn't talking into the mic. Only a fairly good sound meter can measure sound levels this low. Then we open the doors and the audience moves into the hall. The background noise levels rise up to about 35 dB,A because of the breathing and other rustling that people naturally do. It is a well-established fact of human behavior that in a group, we collectively manage to make just a little more noise than the background noise level. That's why we act quietly in a library and noisily in a packed diner. (See Figure D)

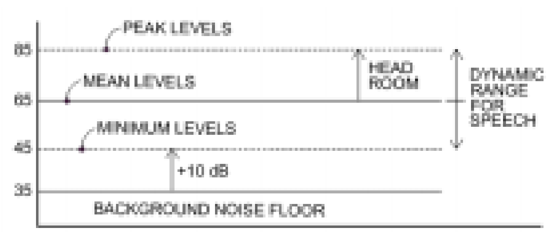

FIG-D
Noise levels, sound levels and head room.

Early reflections are very helpful but not necessary for achieving good intelligibility in a quiet hall. But many halls are quite perfect and that's when early reflections become a good little helper, especially for those of us who have begun to lose some hearing efficiency. A bright and clear sounding auditorium will be providing something like 30 separate early reflections, each arriving well within the first 1/40th second following the initial impact of the direct signal. Some of these will be strong and some will be weak but the overall summed power of all the early reflections should be in the range of 60 dB,A to provide good speech reinforcement. (See Figure C & E)

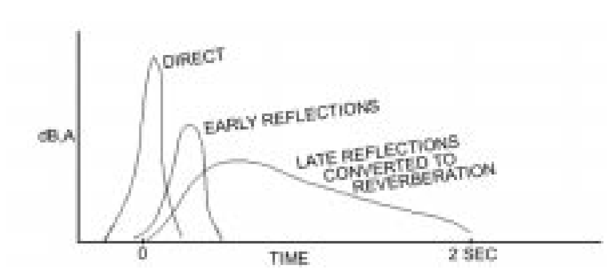

FIG-C
Sound level vs time for an acoustic event. Both direct and early reflections help with understanding.

The next group of reflections is to be avoided. They are those that arrive at the listener's ear within a time delay following the direct signal between 1/40th second and ¼ second. These reflections should be relatively indistinct and quiet, about 15 dB below the speech signal range. The late reflections and echoes are the most problematic part on auditorium acoustics. Some designers simple eliminate all late reflections by absorbing them. Other more tricky designers like to cover the surfaces of the hall with sound scattering devices to disburse late reflections, breaking them up into a plethora of fairly quiet reflections that do not obscure the perception and understanding of speech.

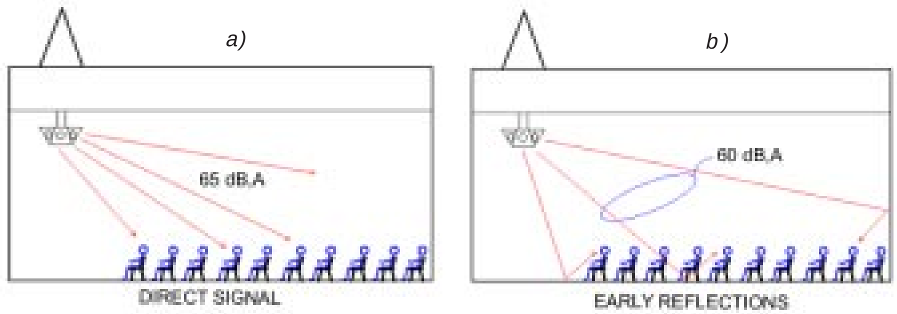

FIG-E
a) Direct signals leave the speakers and impact the audience.
b) Indirect signals are those that bounce off nearby surfaces into the audience.

Following this should be a low level rise and fall of reverberation, again in the range of about 15 dB below the direct and early reflected signals. The overall reverberation should fall away and become inaudible within 1 second following the initial direct signal. (See Figure F & G)

Starting in about 1985 a new concept was being introduced (by SynAudCon) to a few of the top sound contractors in the country. Sound installations were soon going to be judged by a new set of performance criteria, the intelligibility spec and contractors had to bone up to be able to do jobs that would meet this new, higher level of performance. . Prior to this, sound systems only had to meet loudness specifications. Now, loudness was not enough, understandability was the final judge of a system. This was a major step forward in the evolution towards good sound. The only problem was that providing good loudspeakers was no longer good enough. Bad hall acoustics could easily ruin any good sound system. The top sound contractors in the country had to learn about acoustics. Intelligibility meters soon become available and have become more affordable over time. Nearly any good sound system was required to achieve a score of 80 to 85% in every seat in the house when measured with intelligibility test equipment.

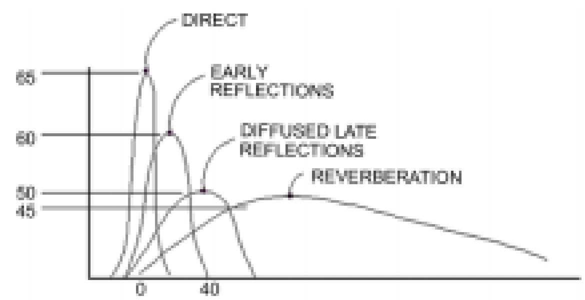

FIG-F
Late reflections, echoes and reverberations obscure understanding the direct plus early reflections.

Auditorium Acoustic Design

Today's auditorium is generally quite different than those built early in the last century. Both types use loudspeakers but that's where the similarity ends. We will consider both types here and the transition auditoriums built within the last few decades. We start with the traditional auditorium, made out of heavy rock blocks or pour in place concrete walls with ceilings made out of wood or concrete beams. We end up simplifying construction to reduce costs. Today, concrete block or tilt-up concrete walls are used to outline the space and roofs are made out of corrugated metal supported by exposed metal trusses. The shell of today's auditorium is built not much different from an industrial space.

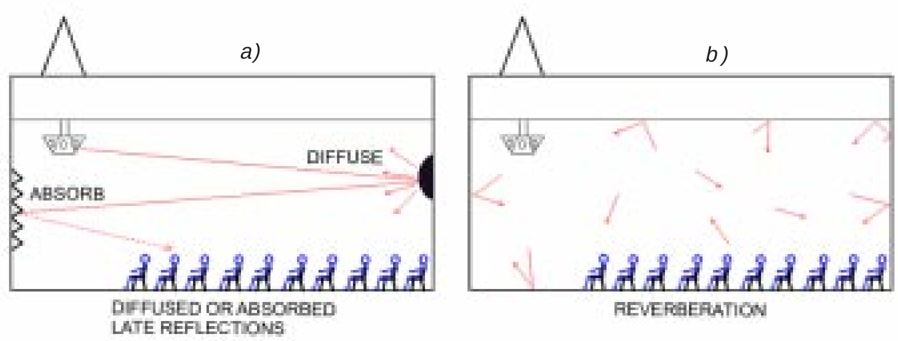

FIG-G
a) Diffuse late reflections to raise reverberation level.
Absorb late reflections to reduce reverberation level.
b) Reverberation is residual sound that has lost all sense of direction.

Fundamentally the old world auditorium is a "what you see is what you get" type of building. The interior surfaces of the building are what manage the sound. The seating, the height and the interior architecture all work in unison to produce the required intelligible acoustic condition for reasonable listening. The reflecting surfaces of the hall provides for some early reflections but not much. The sheer volume of the hall helps to avoid generating late reflections and the multifaceted ceiling and upper wall surfaces further act to diffuse the late reflections. The audience provides the acoustic materials that act to control the reverb time.

Architects are flocking to the new design trend in auditorium design and it's very different from the classical auditorium. These new spaces are large concrete boxes that have been decked out with sculpted wooden, plastic, metal, sheetrock and sometimes even glass panels. The hall is full of big, curved panels that are suspended off the walls and again high overhead. The new look and sound in auditorium, church and music hall design is one of acoustic clouds, lots of acoustic clouds hanging in midair, below a completely blacked out high bay ceiling. Although efficient to build and outfit, to the traditionalist, these halls, sporting their marching arrays of flying sound panels seem a little strained, possibly too technical, if not somewhat contrived. The acoustic clouds however are intended to adjust the signal to noise ratio in a direct and effective way. They provide for early reflections, diffuse and weaken the late reflections and regulate the reverb level and decay rate. The audience provides some acoustic absorption and the rest is located way up out of sight, behind the acoustic clouds.

In between these two styles we find built in the recent past, large sweeping rooms with padded seats and carpet, topped off with the largest expanse of an acoustic tile ceiling one could ever imagine. This type of hall is also a large concrete box but its interior surface has been built out to create a very dead hall. Its design seems directly opposite to that of the classic concrete and marble auditorium. There are no early reflections designed into the space, certainly no late reflections and as well, no reverberation. The only heard sound in the hall is the direct sound from the loudspeakers. Built on the supposition that if reverberation is bad for speech, then an acoustically dead space must be good for speech. These spaces are so big and so dead that the audience suffers from sensory depravation. Distributed sound systems have to be installed in the acoustic ceiling in an effort to help inject life back into the space. One thing is for sure about these spaces. Because they are so acoustically dead, they work great for making TV shows.

The Classic Auditorium

This is the type of auditorium that was widely built during the WPA years to help bring relief to the grips of the great depression in the early 1930's. The features of this hall are well documented in older architectural and acoustic design books. It is tall, a little longer than wide and has balcony seats running on the two sidewalls and the back wall. The ceiling has a deeply coffered design and the sidewalls are lined with pillars or rounded pilasters. This hall uses a central speaker cluster elevated high over the proscenium of the raised stage.

This hall is a classic example of minimalist design. It employs an elevated, central speaker position to provide fairly uniform sound levels to every seat in the audience. The room is a high volume hall, with ceilings 40 to 50 feet high over the main floor. From the viewpoint of the speaker cluster, the main floor, two sidewalls and rear wall is nearly completely absorptive when the hall is fully occupied. The only remaining surface that the speakers can see is the ceiling and it appears to be a very diffusive surface acting to scatter sound in all directions. (See Figure H)

It is instructive to run through the basic acoustic calculations for the large classic auditorium design. Here are some basic ratios. Each seated person occupies about 7 square feet of floor space and provides about 3 square feet of sound absorptive surface. A hall that is 200 feet wide and 300 feet long will provide about 7,000 seats on the main floor. The rear balcony section will be about 50 feet deep and provide about 1250 seats. The sidewall balconies will be about 30' deep and provide 1000 seats each. The total seating of the hall is 9250 seats. Occupied hall calculations are based on the hall being 2/3rds full, just over 6000 people.

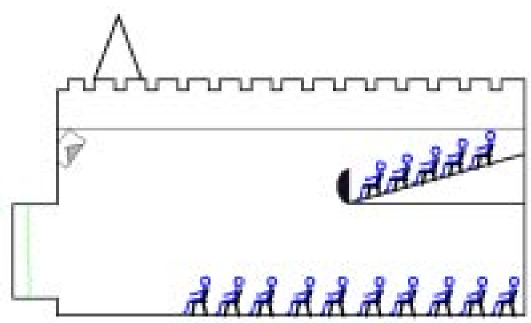

FIG-H
Classic auditorium design. Elevated central speaker, balconies, coffered ceiling and stage curtain.

The audience provides about 18,500 square feet of absorption distributed over the floor, side and back walls. The hall has a volume of 3 million cubic feet. Empty it will have a reverb time of about 7 seconds. This means in all its complexity, it has a physical acoustic surface equivalent of about 21,400 square feet. The hall has a floor and ceiling surface area of 60,000 sqft, surface area each. The walls have a surface area of 50,000 sqft. The average absorption coefficient of the surface of the hall is already about 12.5%, including atmospheric absorption effects.

When the audience arrives, they bring into the hall their additional component of sound absorption, bringing the total absorption up to about 40,000 square feet. The reverb time for the hall will now be about 3 ¾ seconds, far from the "required 1 second". To be able to meet the desirable 1 second reverb time it would take a total of 150,000 square feet of absorption in the hall. This means that nearly 100% of the 170,000 square feet of total surface area of the hall would have to be covered with sound absorption. This was not possible in the early days of marble surfaced halls. But auditorium designers didn't stop trying. They invented "acoustical plaster", a surface that looked hard but wasn't. There were numerous formulas for this material but over time the art of acoustic plaster, the formulations and the skilled people who applied it by hand have all disappeared. Still, the hall acoustics could not come close to accommodating a 1 second reverb time.

The floor, sidewalls and rear wall present 100,000 sqft of surface area that intercept the sound from the speakers. With the sound absorption of the people added to the natural absorption of the hall surfaces, these 3 surfaces present about 31,000 sqft of absorption facing the loudspeaker. This means that 31% of the incident sound is absorbed during the first reflection. Sound reflecting off these 3 surfaces is reduced in strength by about 2 dB. If we assume that the sound reflects back across the room, traveling an average of 225 feet and taking about 1/5 second. Sound is further attenuated by the natural surface absorption of about 10% upon this reflection. As a result, by the time sound makes one round trip in the hall from the proceneum wall into the audience and back, it has been attenuated down to 62% of it's original strength, about -2.5 dB all in one round trip time period of 1/10th second. After one second, there will be 20 such round trips and the overall sound will have dropped by about 25 dB in strength. The hall will have a reverb time of about 2.4 seconds. Adding stage curtains that show even when pulled back will drop the reverb time to about 1.8 seconds. This is a reasonable reverb time for a large hall.

But there is more than "reverb time" to hall acoustics. There are the good early reflections and the bad late reflections. The early reflections need to be cultivated. The late reflections need to be weeded out. The balcony facing is sculpted to provide early reflections back down to the main floor. The back wall of the balcony and ceiling is sculpted to provide early reflections into the balcony seats. (See Figure A)

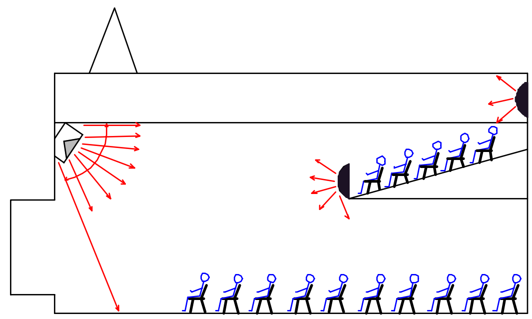

FIG-A
Classic auditorium is shaped to enhance presence of early reflections.

The late reflections are mainly dealt with by combining two features. It begins with having a heavily coffered ceiling. Any sound that is heading upwards eventually hits the coffered ceiling, only to be splintered into a cascade of tiny and off angled reflections. The second factor is the height of the ceiling. A 70' ceiling with a loudspeaker mounted some 35' off the floor starts splashing sound back onto the main floor at about 40 ms after the direct signal has passed through the audience. The coffering of the ceiling breaks this reflection up into dozens of low-level reflections with a variety of additional time delays. The high coffered ceiling acts to diffuse and randomize the only possible late reflections in the hall. Other sounds that are traveling upward that went over the heads of the balcony seating continues upwards after the wall bounce and are also intercepted by the deeply coffered ceiling scattering grid ceiling. The low level of time-delayed backfill continues until it is overwhelmed with the rise and decay of the reverberant part of the hall sound. (See Figure B)

The classic auditorium of the early 1900's was almost, nearly a perfectly balanced system of people, space, speakers and surfaces. It was a symphony in sound and architecture.

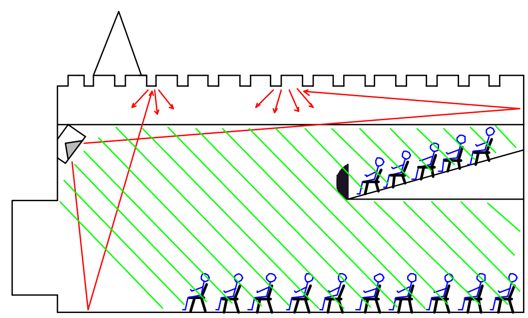

FIG-B
Classic auditorium is shaped to convert harmful late reflections into helpful early reflections and reverberation.

Oldies but Goodies, Gone Forever

The old auditoriums, built in the early part of the last century could be designed and built to sound pretty good. They were giant, expensive hand built civic halls. But over the wear and tear of time, they began to look run down, worn out and shabby. After WWII, a new product took the architectural and building world by storm, acoustic ceiling tiles. During the same time a new form of civic pride dictated "off with the old and on with the new" and this kind of new meant concrete block walls and acoustic tile ceilings, and a whole new way to build auditoriums. The era of fine sounding old traditional civic auditoriums ended in a bang, sounded by the wrecking ball.