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Auditorium Acoustics 101

By Arthur Noxon

The Quieter, the Better

Let's start with the basics. The architect designs a great looking and comfortable auditorium. The sound contractor installs a great looking sound system. The people attend the grand opening and are impressed with what they see, but they have gathered for more than a dazzling display of architecture, lighting, electronics, carpets, glass, surface textures and paint. They have come to be in an auditorium, a place to hear and, moreover, a place to listen to and learn from the lecture or, as the case may be, the sermon. The outer beauty of an auditorium is recognized by how it looks, but the inner more lasting beauty of the auditorium is truly known by how it sounds. And with this we mark the beginning of our journey into auditorium acoustics.

Lots of sound, but little is heard

A sound wave starts at the loud speaker, which is suspended high overhead in the front of the hall. Seated way below, are the many people who came to hear that sound. The greater the size of the audience, the farther from the speaker they have to sit. An audience of 1,000 people would occupy about 8,000 square feet of floor space. A member of that audience typically might be seated some 50 feet away from the loudspeaker. The sound wave emitted by the loudspeaker spreads out in the shape of an expanding quarter sphere. By the time this wave reaches the audience, it has expanded out to a radius of about 50 feet. It has spread out over a quarter sphere surface area of 7,850 square feet or about 1.13 million square inches.

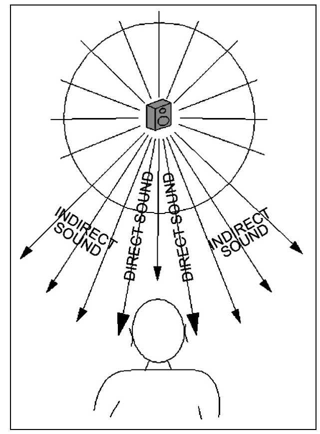

FIG-1
The people listen to 1/10th of 1% of the sound emitted by the speaker.

Each ear of a person collects about one square inch of sound, funneling it down into the eardrum. A person in the audience of an auditorium collects about two square inches of the sound wave, that's just about 0.00017 percent of the total sound emitted by the central cluster loud speaker. This tiny fraction of sound is called the "direct sound" because it goes directly from the loud speaker to the listeners' ears. (Figure-1).

If 1,000 people are in the audience, their combined ears collect only 0.17 percent of the direct sound emitted by the loud speaker. The rest of the sound, the other 99.83 percent of the sound, is called the "indirect sound". What happens to all this indirect sound is what auditorium acoustics is all about. If the indirect sound is neglected or mishandled, the auditorium will sound bad, and if it is well handled, the auditorium will sound good.

To recap, auditorium design or renovation can be understood to involve three consecutive areas of expertise. The architect designs a building that is attractive, comfortable and allows people to see what is going on. The sound contractor supplies a sound system to the auditorium that makes a direct sound loud enough so people can hear what is going on. However, nearly all of the sound generated by the sound equipment misses its intended target, the ears of the people. Picking up and handling the stray sound is the responsibility of the acoustical engineer. How it is collected and processed makes all the difference between a good- and a bad-sounding auditorium.

Noise blocks our ability to hear

The auditorium is meant for understanding speech. It should be kept quiet so the people can hear and understand what is being said. Speech heard in the auditorium should be comfortably loud and crystal clear. Noise destroys sonic clarity. We have all seen photos taken in a fog. The general clatter in a hall from air conditioning to feet shuffling through the aisles can create a continuous din, a noise floor that seems to white out, haze over and block out the detain in an otherwise perfectly fine presentation. We have also seen photos taken on a clear day but blurred by a moving camera. Similarly, noise such as echo and reverberation can act as a blurring agent that makes it difficult to even make out what sound is actually there. These are the two kinds of noise. The fairly continuous din of extraneous noise is called "background" noise. The echo and reverberation of sound emitted from the loudspeaker is called "acoustic" noise. (Figure-2).

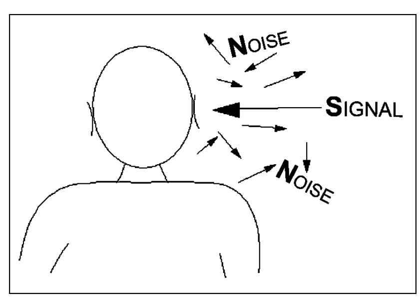

FIG-2
Noise blocks our ability to hear the signal.

The ability to hear and understand depends on the “signal to noise” ratio. We want as much direct signal as is comfortable to receive and as little noise as possible. It would seem that if the noise is a little too loud then simply turning up the volume of the direct signal, the loudspeaker, should solve the problem. This doesn’t work very well. Loud sound is uncomfortable. Loud sound does improve the fairly constant background noise to signal ratio. Loud sound does not improve the acoustic noise to signal ratio because the loudness of the acoustic noise depends directly on the loudness of the loudspeaker.

Also there is a context factor. People expect to hear a conversational style lecture at conversational sound levels (60 dB-A), a quiet voice at quiet voice levels (40 dB-A) and a raised voice at a raised voice level (70 dB-A). Cranking up the sound throws the presentation off, whereby the loudness is out of context with the lecturer’s action—it’s simply not natural.

For good intelligibility, there will be at least 20 dB between the quietest parts of the desirable signal and the background noise—since the more quiet parts of speech are easily in the 40 dB-A range and less. Background noise levels in a good auditorium will be as low as 20 dB-A. Also, there should be at least 10 dB between the signal and the acoustic background noise.

Background noise

Background noise is all the sounds one hears when the lecturer is not saying something. There are three types of background noise. Just sit and listen in most any meeting space and you can distinguish operational system noise, intruding outside noise and self-generated audience noise. In order to achieve a strong signal to background noise, the background noise has to be reduced to as quiet as possible.

The operating system includes all things that operate in order to accommodate the occupancy of the auditorium. Here we have the noise from systems that handle electricity, water and air in the building. They include the hum of lighting ballasts, the hiss and hum of the sound system, overhead circulation fan motor hum, video projector fans, air-conditioning noise and water pipes, both fresh water and wastewater. (Figure-3). Other systems sounds include the more intermittent operation of a dishwasher, garbage disposal, refrigerators, space heaters, toilet, faucet shut-off, watering, water hammer and thermal expansion and utility devices such as the copy machine, coke machine and cold water drinking fountain. The air-conditioning system is usually a strong contributor of noise, piping turbulent air and fan noise into the room through every air supply and return opening.

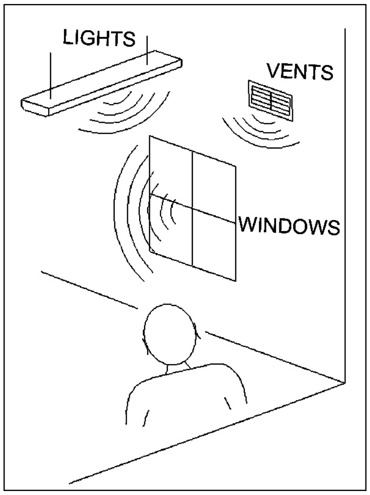

FIG-3
The noise floor is created by many different sources.

Intruding outside noise is conducted into the auditorium through the windows, doors, room and walls of the building. Traffic noise penetrates inside, in from the street and down from overhead planes. Parking-lot noise—driving, starting, door slamming and sidewalk conversations—contribute to intruding noise. Rain and wind can cause noise by hammering and scraping on the building. Outdoor stationary equipment such as heat exchangers and sprinklers cause noise. Even HVAC units mounted on the rooftop generate noise that can come in through the roof and upper windows, let alone shake the structural beams of the building. Activities in other parts of the building get into the auditorium by passing directly through the walls but also by simply traveling in the air, down corridors, under doors and through air-conditioning ductwork, room to room.

Self-generated audience noise also raises the noise within the auditorium. Here we have the rustle of paper, books, coats and clothes, shoe scuffing, candy wrappers, kids talking and parents hushing, coughing and sneezing, baby shouts, whining and eventually crying. Noise is generated even when people breathe and when they make little noises of agreement and appreciation and whisper to each other. To illustrate, a person trying to stand absolutely still, breathing as shallowly as possible still generates enough noise to register 20 dB-A at a distance of 10 feet.

There is a symbiotic effect of background noise. Some noise begets more noise. The quiet of a library provides testimony to this effect. It starts quiet and stays quiet all day. When the background noise is at a raised level, people feel that they too can make a little noise and no one will notice. But multiple this by 1,000 people and we have a significant increase in people-generated noise. This then results in a further raised noise floor and, once again, it seems easy for people to make just a little more noise. This spiraling effect can create a very noisy auditorium, full of disruption and inattention. An auditorium whose background noise level starts in the low 20 dB-A range stays quiet when the audience arrives.

Acoustic noise, echoes and reverberation

Sound expands away from the loud speaker. Most of what is created is not directly heard but goes past the audience and begins reflecting around the hall. If a reflection is strong and we know where it comes from, it is called an echo. If we hear many reflections at one time from seemingly no special direction, it is called reverberation.

Generally, any echo is bad. In addition, and to put it simply, loud reverberation is bad. But quiet reverberation can be interesting, if it is in limited doses. Both reverberation and echoes degrade the perception of timing in the material being presented. Strong echoes are disorienting to the timing aspect of speech or music, like trying to be coordinated in a disco strobe dance floor. It is not unusual for echoes to bother the performer more than anyone else in the auditorium. Echoes usually bounce off the back wall of the auditorium and because the person on stage is farthest from the back wall, the echo for the performer is the most delayed. And it is most important that the performer does not suffer disorientation due to echoes. We cannot forget Pavarotti walking off the stage of a large hall filled with people because the echo was so strong that he couldn't sing—but certainly, as we understand acoustics, we can understand and forgive.

Reverberation is the ongoing part of sound in a large hall that gradually decays away, a totally chaotic lingering presence of a previous direct sound, a sonic afterglow, a remembrance. Loud reverberation upsets the timing of sequential sonic events by blurring everything together. It is especially detrimental to speech and music in small hard-surfaced rooms. However, it can also be great personal fun, as in singing in the shower, but, in this case, the singer and the listener are one and there are no concerns for improving the communication.

Quiet reverberation can contribute to the feeling that a larger-than-life experience is taking place. It adds a dramatic flair of importance to speech. It is an essential accompanist to acoustic music sources as orchestra, ensemble, choir and organ. Reverberation generally ruins the presentation of modern electronic bands.

There are three aspects of reverberation to be understood. Onset time delay is the time between the direct signal is heard and the reverberation begins to be heard. The second is how loud the reverberation becomes. The third is how long the reverberation lasts or can be heard; the "reverb time" is officially the number of seconds it takes for sound to die down a full 60 dB. Reverberation in an auditorium that is used for speech, lectures and talks should have one-third second onset time delay, be at least 10 dB-A quieter than the direct signal and have a reverb time die out within 1.25 seconds.

If reverberation builds up too quickly it competes with the clear perception of the sequence of sounds that make up speech. A short reverberation onset time will fill the essential quiet moment that exists between and delineates sequential sonic events. The introduction of each new sound is blurred by the upwelling presence of the old sound. Speaking more slowly can help this situation, but forced slow speaking is a stopgap measure at best. Acoustically slurred speech is very difficult to understand. The time delay for the onset of reverberation should be about one-third of a second. Background noise is best if kept at least 20dB below the sound levels of speech. People speak at a rate of about three separate sounds per second. Some languages speak more slowly and others more quickly; auditorium acoustics have to be designed for the kind of speech that takes place in them.

The loudness of the reverberation is important, at least 10 dB-A below the level of direct speech will create reasonably clear speech. (Figure-4). A reverb level of 10 dB-A below the direct signal is very desirable. The loudness of the reverb changes the feeling of the auditorium. A warm, cozy, personal chatauqua style auditorium will have a large difference between direct and reverb levels, as much as 18 dB-A. A cold, impersonal, more political rally sounding auditorium will have a lower difference, possible as little as 5 dB-A.

Finally the length of time the reverberation remains audible is to be adjusted. Generally large rooms for speech are allowed reverb times of 1.5 seconds. Smaller auditoriums and more intimate sounding rooms should have reverb times as low as 0.9 seconds. The personal, conversational chatauqua style auditorium, growing popular in the world of broadcast TV church worship, will have reverb times as low as 0.7 seconds.

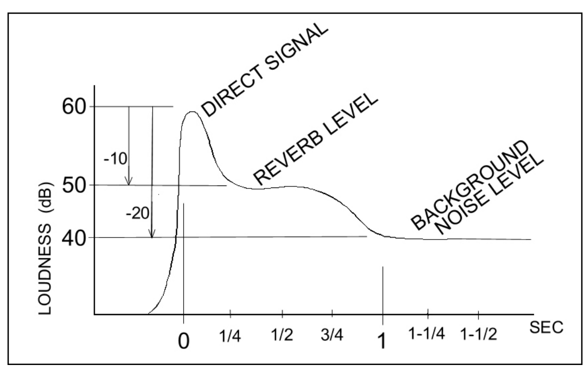

FIG-4
A good signal to reverb noise ratio is 10 dB, a good signal to background noise is 20dB

These three reverb factors are generally the same for auditoriums used for speech, plays and modern music. More traditional music tends to sound better with longer reverb onset delay times, louder reverb levels and longer reverb decay times. Some auditoriums are built to support a varied venue, from speech and plays to operas and symphonies. They have adjustable acoustics: reflecting and absorbing panels that are moved, exposed or hidden to independently adjust the three factors of reverberation.

An old saying: Look before you leap

The auditorium is a purpose-built hall, built for audition, listening. Before it can be designed, the architect has to understand what the large hall is to be used for. Before the sound contractor can specify the sound system, the purpose of the hall must be understood. Before the acoustical engineer can bring a voice to the auditorium, the feeling and style of presentations intended for the hall has to be understood. Voicing the auditorium means deciding what to do with 99 percent of the sound, generated by the loudspeakers but not directly heard by the audience. A bright and beautiful looking auditorium will attract people. But the quiet, good-sounding auditorium will keep them coming back.