Church & Worship
TECHNOLOGY

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BIG Church Acoustics

Finding a Happy Medium Between Technology and Building

All too often, a church is built like a civic auditorium--big space and many seats--yet in the case of a large church, the building is expected to perform like a church. An auditorium is made for "auditing", or listening. A church is made for auditing and singing, therein lies the important difference. Most acoustic design projects, and churches are no exception, start with a budget and a vision. By the time the building committee is finished with a fully functional church, it will have allocated about 10 percent of the total building budget to the acoustics, and that does not include the sound system, wiring, the audio room or the sound equipment. The hope is, after all is said and done, that the church will actually sound like a church.

Reverb Design Brings Bad News

The basic acoustic definition of an acoustic project always begins with its "Reverb Time". Reverb time is the time it takes for a loud sound to completely die out in a room. You can pop a balloon and measure the reverb time with a stopwatch. For a church, the recommended reverb time (T) in seconds depends on the type of service (S) and the volume (V) of the room.

1) T = S (Log V - 1.0)

For a large modern auditorium type church, the service factor S = 0.20 sounds very well for speech. For a large traditional Catholic church, the service factor would be S = 0.45, giving a more reverberant, old world church type of sound. The reverb time (T) tells us how long sound should linger and remain audible with the congregation being two-thirds full. It is based on data from hundreds of churches around the world. A handy reference on this subject is found in many acoustic books, one of which is Acoustic Design and Noise Control (1977, Michael Rettinger).

In our giant church example, we have a 10,000-seat auditorium style church. We allow 10 square feet of floor space per person for comfortable traffic and seating. Smaller churches need an additional 2,000 to 3,000 square feet for pulpit and choir areas. About 6 square feet is needed to comfortably seat each. A 10,000-seat church certainly will occupy about 100,000 square feet of floor space. It might well be a rectangle, 400 feet wide and 250 feet deep with a raised platform against the middle of one long wall. The ceiling in these spaces will be about 40 feet high which puts the volume of our room at 4 million cubic feet. The "recommended" reverb time now can be estimated.

1a) T = 0.20 (Log 4,000,000 - 1.0)
= 1.12 seconds

When we make a noise in a big church the sound remains captured within the volume (V) of the room until it either dies out or escapes from the room through an open space. In either case it disappears as it were escaping through an open window area (A). The reverb time (T) depends on the ratio of room volume to window area (A).

2) T = 0.049 V/A

This is called the Sabine equation, named after a great acoustic pioneer in the 1800s. However, in our case, we already know what the reverb time should be (1a) and the volume (V) of our room. What we would like to know is how many square feet of open windows do we have to cut into the walls to make this big room sound good. We rearrange the Sabine equation.

3) A = 0.049 V/T

Now we have something to work with because what we want to know about is expressed in terms of what we already know about, room volume and reverb time.

3a) A = 0.049 x 4,000,000 / 1.12
= 175,000 square feet of open window

For a hall of 4 million cubic feet to sound great, the room has to have about 175,000 square feet of open window space. Sounds like the building could get a little drafty. Let's look at the walls. The perimeter distance around the hall is (250 + 400 + 250 + 400) 1,300 feet and the walls are 40 feet tall. We have 52,000 square feet of wall space. Even if we blow out all the walls and hold up the roof with a few columns (like the Parthenon) we are short of open space by 123,000 square feet. We can remove the roof and gain another 100,000 of open space and now have a total of 152,000 square feet of open space, no walls or ceiling either and still 23,000 square feet shy.

No, the equations aren't wrong. We are simply running into the acoustic reality of large spaces. We need to stop thinking of our giant church as something slightly larger than a normal church. We have to start thinking of it as something slightly smaller than a normal astrodome.

Intelligibility Design Means Quality Sound

Let's accept that big rooms are essentially untamable with respect to reverb time. Fortunately, there is more to acoustics than reverb time. We know that we can't understand each other if we stand in opposite corners of a big empty gym and yell. If we get close together and whisper, we can certainly understand each other. In either case, the loudness of the voice reaching our ears remains the same. The big difference is the loudness of the reverberation. If we whisper, the reverberation is quiet. If we yell, the reverberation is loud. It is very important to understand that in both cases, the reverberation time (T) remains the same.

In a church setting, "wall of sound" would be built into the front wall of the church, hidden of course behind some architectural grill system.

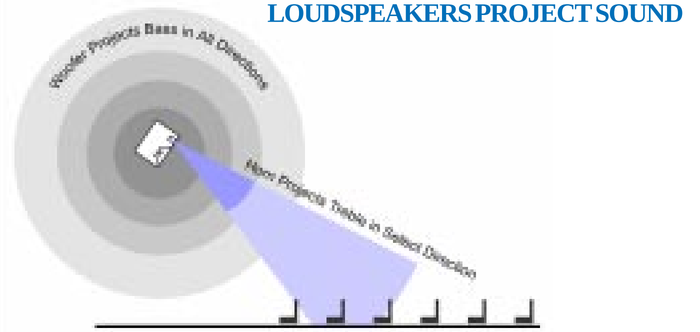
This illustrates how we deal with communication in reverberant spaces, we improve the signal to noise ratio. The signal is the direct sound from the speaker. The noise is the loudness of the reverberation. We like the signal set at some reasonable level, not too loud and not too quiet. The only thing we have to work with is the loudness of the reverberation. Acoustic design based on intelligibility has been around for over 30 years and has been taught to acoustic designers, sound contractors and architects during the last 10 years. The best acoustic design includes an intelligibility specification in addition to a reverb time specification.

The Conundrum of Loudspeakers

The modern loudspeaker usually has two speakers mounted in the front of a big box. One speaker has a rectangular shape, the other circular. The rectangular one is a horn that plays treble range sound. The round one is a woofer that plays the bass range. The two speakers crossover at about 400 Hz, that's a fairly high pitch, close to A440 the orchestra tune up note. Together, and in a good box, the system usually sounds just great.

Horns are made to project their sound right into the congregation, like a megaphone. This works because the wavelengths in the treble range are shorter than the length of the horn. Horns work like a flashlight, you can shine the beam where you want, but not so with the woofer. It acts like a bare light bulb, emitting waves out in all directions. And that's our problem. The treble horn is good, it's a megaphone that projects sound only into the congregation. The bass woofer is bad, it projects sound into the congregation and everywhere else as well (see Loudspeakers Project Sound).

LOUDSPEAKERS PROJECT SOUND



The treble range horn of the loudspeaker projects most of its sound directly toward the congregation, however the bass range woofer projects most of its sound away from the congregation.

The musical range of sound is divided. Half the notes are in the bass range and half the notes are in the treble range sounds. If we listen carefully to sound in most any church, separate the bass from the treble, we will find that the garbled part of the sound is almost always in the bass range.

If your church has garbled bass and you are getting desperate to do something about it, start by turning down the bass volume a little. Since you can't understand the bass anyway, no need for it to be loud. Quiet garbled bass is better than loud garbled bass. The bass part of the voice ends up being just a constant murmur over which the treble part of the voice stands out. The female voice is much easier for the congregation to understand. It usually does not generate as much bass as the male voice and it usually is richer in the treble range. The female voice generally produces a better signal to noise ratio and is easier to understand.

It is not unusual for a church to become frustrated with their sound system because of it's lack of understandability and decide to buy a new speaker. Computer modeling is used to predict how well the speaker system will perform. These programs produce great looking printouts and some of them even "auralize" or create sound that is supposed to mimic how your church is going to sound. The shortfall of these programs is that they are all "ray tracing" programs. They work very well in the treble range because treble can be aimed. They work very poorly for bass range because bass cannot be aimed. Changing speakers is mostly an exercise in changing the treble part of sound. The problem sound, garbled bass, usually remains the same.

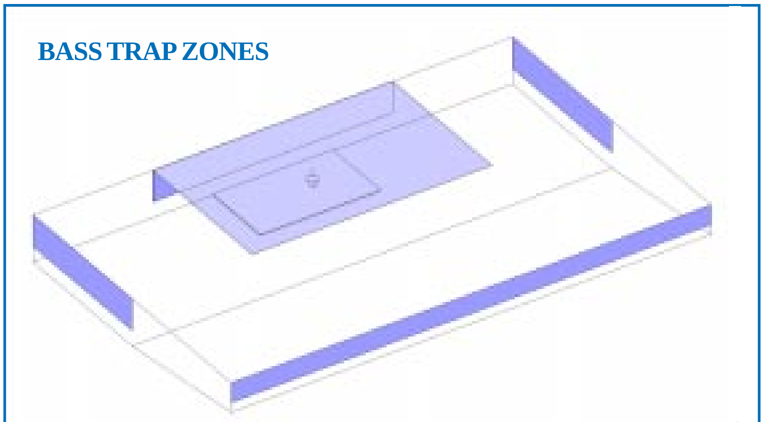
There are three different ways to remove bass garble from the hall. All reduce the amount of bass that feeds the reverberation buildup. We can move the bass speakers closer to the audience and turn the volume down. We can leave the volume alone and absorb any bass that isn't going directly towards the congregation. We might even try to combine some of these effects.

Regardless of which option we choose, what makes all the difference in the quality of sound in the church is to reduce the loudness of the reverberant bass in the room. The problems can be split into three categories: distributed bass, projected bass and absorbed bass.

1) Distributed Bass

The use of distributed speakers is the standard recommendation when it comes to setting up acoustics in a large, reverberant space. We see this in airport terminals, with their speakers every 40 feet. Sound contractors and architects know all about distributed speakers. But we are not talking about the standard distributed sound system. Our distributed speaker system is only for bass.

A good distributed sound system will have many speakers. Close to the audience and set at a low volume. A poor distributed sound system will have few speakers, as far apart and as loud as possible. A good system for us will see woofers as close as 10 feet above the heads of the listeners and no more than 15 feet apart. Even though the speakers will be all around overhead, our ear/brain will take its directional cues from the central cluster speakers and we will think all the sound is coming from the central cluster.



Because loudspeakers project their bass equally in all directions, bass traps have to be located in 5 specific areas to reduce the loudness of bass reverberation and improve the intelligibility.

Here is what the overall picture looks like. We have one big central speaker cluster hanging down from the ceiling up front and sprinkled overhead throughout the seating area are many small hanging woofers. It will take about 250 woofers to cover the entire seating area of 10,000 people. The distributed woofer system will be on a staggered time delay pattern, set up so the treble sound from the central cluster reaches each listener first followed by sound from the overhead woofers arriving within 20 milliseconds. Once the architect gets over the initial shock of having to deal with many small overhead objects, the creative juices will begin to flow. A distributed

DO YOU HAVE A BASS TRAP?

Figuring out if your church needs an acoustic make-over before you add technology means finding the places where sound is the least favorable during the service--during any kind of service. One of the biggest problems to a sound system is a bass trap. Since sound starts with the central speaker cluster that typically hangs down from the ceiling above the speaker's platform, a church has to absorb as much of the bass wave as possible except that which is heading into the seating area. However, sound gets weaker as it moves away from the sound source. Here are some typical hot spots for you to investigate when working with your acoustician.

A) The ceiling. The fraction of bass sound that heads up from the speaker or down towards the floor accomplished little more than to just bounce back and forth between the floor and ceiling, creating reverberant garble. We locate bass traps on the ceiling above the speaker out to one-third the width of the room and out from the front wall no more than one-half the length of the hall. This takes the up/down bass bounce out of the room and reduces bass garble.

B) The side walls. Another large fraction of bass sound expands out from the speaker sideways, impacting the walls to either side of the speaker. This sound continues to bounce back and forth between the side walls, creating reverberant garble. Here we cover the upper two-thirds of the front half of each side wall with bass traps. The lower part in the front and all of the back half of the wall is left alone. This takes the side to side bass bounce out of the room and reduces bass garble.

C) The back wall. Another segment of sounds expands out from the cluster, over the heads of the congregation and slams into the back wall. This starts a front to back bouncing of the bass that leads to more garbled bass. The entire upper two-thirds of the back wall is fit with bass traps, leaving the lower one-third of the wall alone. This helps remove the front to back bass bounce out of the room and reduce bass garble.

D) The front wall. Another fraction of bass expands from the speaker towards the front wall where it begins its own sequence of bounces between the front and back of the room, resulting in more bass garble. We cover the upper two-thirds of the central one-half of the front wall with bass traps to help knock down the amount of bass garble in the room. Everybody's eyes face this big wall and the architect's touch here is critical.

E) The floor. Some bass also reaches the congregation area. Although people absorb treble, they don't absorb bass. The seating area is a good place for bass traps. Mounting them under the seat is a good idea. If we have bench seats, the bottom and back surfaces of the seat act like a big sound funnel, compressing bass right into the corner, a perfect spot to build-in a corner loaded bass trap. Bass absorption in the seats even further reduces the amount of bass garble in the room.

lighting system, piggyback on the woofers, might be used instead of those high power streetlights we see in churches today. The distributed bass option is effective but is visually challenging.

2) Projected Bass

Bass can be projected, but it's not easy. It takes a lot of speakers. The Grateful Dead pioneered the "wall of sound" to project powerful bass into the audience without bothering the neighbors by their outdoor concert. They stacked speaker box upon box, easily 30 feet high and 50 feet wide, a solid wall of speakers, one stage left and the other, stage right. It looked and sounded impressive, toed in to crossfire into the audience. Behind the wall of speakers, there was almost no sound. And they set up the stage always with it's back towards the noise sensitive nearby town.

In a church setting, "wall of sound" would be built into the front wall of the church, hidden of course behind some architectural grill system. Feedback is not a problem because of the low sound levels anywhere on stage. Time delay is set on the cluster so that it just leads the plane wave off the front wall. Bass traps are only needed behind the audience, on the back wall. The projected bass option uses a lot of speakers and also is visually compromising.

3) Absorbed Bass

The last option is to simply absorb the bass wave when and where it is found going in any direction but the listener's. We need to use bass traps to get the job done. These are different from the more commonly available sound panels, which only absorb in the treble range. They have to absorb bass sound waves between 80 Hz up through 400 Hz. Bass flows past most objects with ease. Working together, the architect and acoustic consultant can specify acoustic transparent grills that look great.

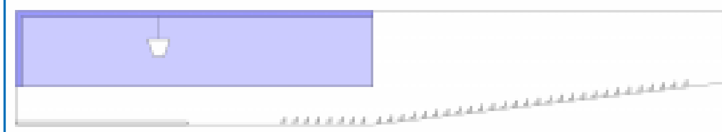
The next thing is to figure out where the bass traps go. Sound starts with the central speaker cluster that typically hangs down from the ceiling above the speaker's platform. We want to absorb as much of the bass wave as possible except that which is heading into the seating area. Sound gets weaker as it moves away from the sound source. The closer we place our bass traps to the speaker, the more sound power our bass traps can absorb. A trap 50 feet away from a speaker will absorb one-twenty-fifth of what it would absorb at 10 feet. Hanging baffle-type bass traps can work, but they are so visually distracting, it usually is better if the bass traps are located on the ceiling and walls (see Bass Trap Zones).

What is very interesting about the absorbed bass option is that it can also help to quiet down the room. It can provide "two for the price of one" acoustic conditioning. Most every room needs a reasonable amount of full bandwidth acoustical treatment in order to sound any better than an empty gym. Our church is no exception. Bass traps can be built to include treble range absorption at little additional cost. The acoustic material in the room now will not only develop bass range intelligibility but also serve a second purpose, to improve the acoustics of the room as a whole.

Something to Sing About

As we review what we have created with the absorbed bass option we discover that we have a large room that contains two separate acoustic systems. One system guides the sound from the speaker cluster to the congregation, delivering clear speech. The other system acts to contain the sound of congregational singing, holding it close to the congregation, making for a lively singing environment. Look at the ceiling directly above the congregation and the walls directly to the either side, front or back (see Multipurpose Acoustics). They are all sound reflective. The design allows bouncing back and forth of sounds generated by congregational singing. It does not allow bouncing for the sounds of speech generated by the central speaker. We have designed an acoustic space that seems to change its sonic nature on cue but really it is just a space that reacts differently, depending on where the sound comes from.

MULTIPURPOSE ACOUSTICS



The loudspeaker sounds best if it plays into a quiet space. The congregation sounds best when it sings in a reverberant space. Intelligibility-based acoustic design creates a space that facilitates both aspects of worship under one roof.

People hear best in an acoustically quiet space and sing best in a reverberant, lively space. These acoustic properties seem to be at odds with each other, and often are. But we now know that we can have a church where both the pastor and the music minister can be happy at the same time. The pastor needs to get a message to the congregation. The music minister needs to engage and involve the congregation with song. Designing a church with a good central cluster and bass traps located on the first reflecting surfaces creates a space that sounds auditorium but sings like a church.

❖ *About the Author*

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